The International Loran Association

PROCEEDINGS OF THE
TWENTY-SIXTH ANNUAL TECHNICAL SYMPOSIUM

OCTOBER 5 - 9, 1997

OTTAWA, CANADA

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RAMADA HOTEL AND SUITES
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Proceedings of the 26th Annual Convention And Technical Symposium

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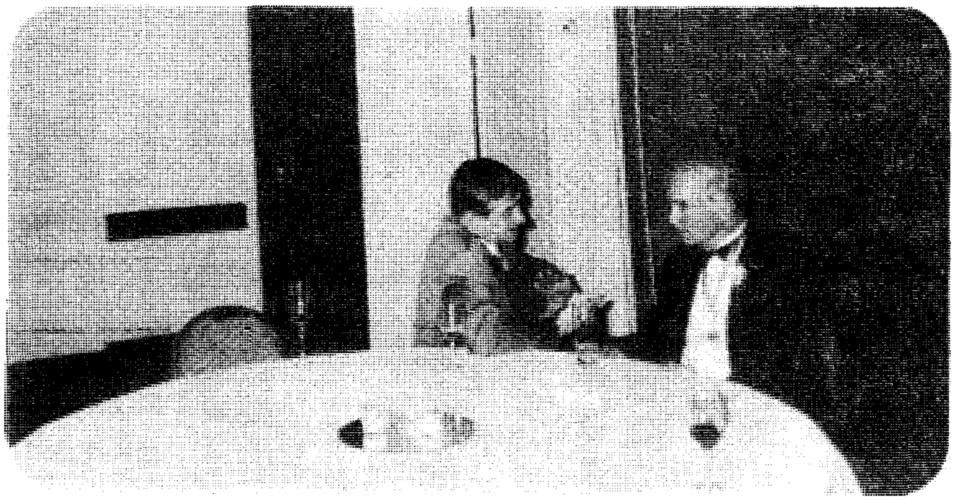
A year in advance...



At the conclusion of the 1996 International Loran Association Convention and Technical Symposium in San Diego, Bob Lilley, general chairman, talks with David Waters, Canadian Coast Guard, to assure him that convention chairmanship is "....really easy, and a lot of fun...". With a bit of concern over the meaning of the word "easy, " David's response was that the 1997 Ottawa meeting would be well-organized, informative and useful for the participants and attendees alike. He and 1997 convention chairman John Butler and the people of the Canadian Coast Guard made good on this promise.

Thanks to Chairman John Butler, the Canadian Coast Guard and to David and Jeanette Waters for your hard work organizing the successful 26th Annual International Loran Association Convention and Technical Symposium!

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Foreword

The International Loran Association is a professional organization of individuals who have an interest in loran radionavigation and who wish to foster, preserve and advance the loran art and science.

The ILA strongly advocates the use of Loran-C in conjunction with other systems of navigation to produce a safe and reliable positioning, navigation and timing service for marine, land and aviation users.

The logo for the ILA is adapted from the organization's predecessor, the Wild Goose Association, which was named for that tireless and accurate long-distance navigator, the Canada Goose. The organization was created in 1972 and its membership represents many interests including those of engineers, scientists, planners, promoters, designers, manufacturers and users of loran positioning, navigation and timing equipment throughout the world.

The rapid expansion and use of Loran-C and the development of the Global Positioning System (GPS) has created the need to address the interoperability of the two systems. As representatives of the ILA, members are assisting government agencies to recognize the necessity for compatible operation of satellite systems and Loran-C, worldwide, to achieve a truly robust positioning, timing and navigation service.

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Chairman: William J. Brogdon, Jr.
ILA President

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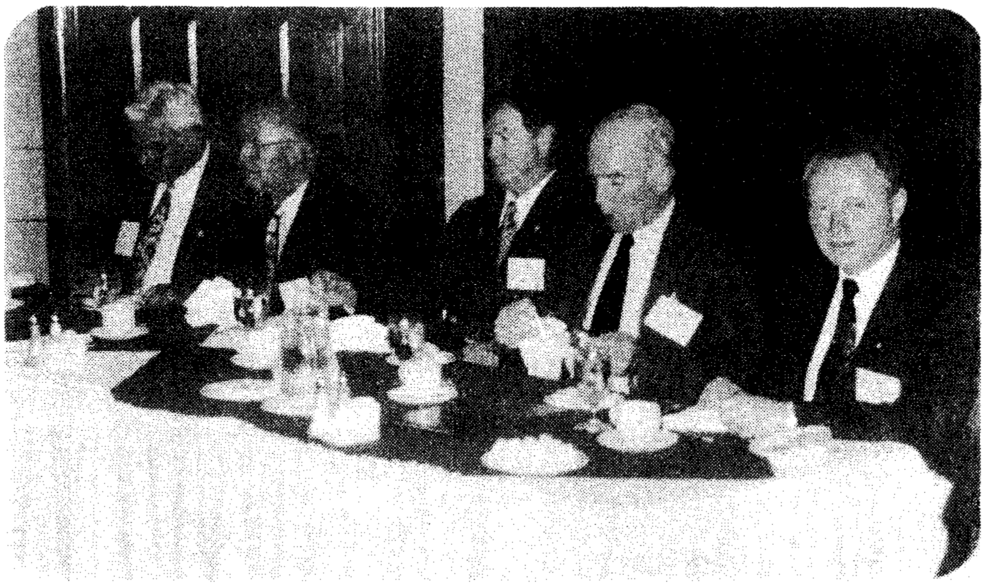
Luncheon Address

The United States Department of Transportation Loran-C Study

Robert Hawley, Program Manager
Booz-Allen and Hamilton, Inc.



At the luncheon head-table from the left: convention technical chairman Bill Roland, speaker Bob Hawley, ILA President Bill Brogdon, board member Bob Lilley and convention chairman John Butler

THE UNITED STATES DEPARTMENT OF TRANSPORTATION LORAN-C STUDY

PRESENTED TO THE

INTERNATIONAL LORAN ASSOCIATION

6 OCTOBER 1997

SOURCE OF THE STUDY REQUIREMENT

- 1996 US COAST GUARD AUTHORIZATION ACT DIRECTS THE DEPARTMENT OF TRANSPORTATION TO PREPARE A PLAN "DEFINING THE FUTURE USE OF AND FUNDING FOR OPERATIONS, MAINTENANCE, AND UPGRADES OF THE LORAN-C RADIONAVIGATION SYSTEM".

TASKING TO BOOZ·ALLEN FROM THE US DEPARTMENT OF TRANSPORTATION

To carry out this requirement, the DOT issued a contract to Booz·Allen and Hamilton, Inc., calling for a five step development process:

Task 1 Data Collection

- Government Provided Data (plus ILA contributions)
  - Previous Studies (technical + C/B)
- Establish a LORAN-C Functional Baseline
  - What capabilities does LORAN provide?
  - Who are the users - type and numbers?
  - What exactly are they using?
  - What alternatives are currently/potentially (when) available?

BOOZ·ALLEN TASKING (CONT.)

Task 2 Convene and Facilitate a LORAN-C Meeting

- Purpose:
  - To provide the user community the opportunity to ensure that we have a full understanding of the full spectrum of LORAN-C issues
  - To afford the user community the opportunity to present their views and supporting data on LORAN-C
  - To provide a venue for dialogue between the user community, government officials and Booz·Allen

BOOZ·ALLEN TASKING (CONT.)

Task 3 Conduct a Cost/Benefit Study

- Benefits:
  - By user community
  - Safety assessment
  - Equivalent level of service
  - Economic life
  - New/Potential uses

- Costs:
  - Users (retrofit, training)
  - Providers (refurbishment, operation, maintenance, replacement)

BOOZ·ALLEN TASKING (CONT.)

Task 4 Develop a Transition and Funding Plan

- When can equivalent level of service be expected to be achieved?
  - For which users (type and number)
- Comparison of cost/benefit results with attainment of equivalent level of service
- What technical, regulatory and managerial issues would need to be addressed to alter the current plan?
- Funding required, sources of funds, and potential impact to other programs

BOOZ·ALLEN TASKING (CONCLUSION)

Task 5 Prepare a Report to Congress on LORAN-C

- Technology and User Analysis
- Status of the Integration of Satellite- and Ground-Based Radionavigation Services
- Plan for Transitioning from LORAN-C to Satellite-based services
- Plan for Continued Funding for LORAN-C Services
  - Budget Constraints
  - Cost Recovery

TASK STATUS

- Data collection for Task 1 complete; report is in development
- Users Conference held 8-9 September; summary due 10 November
- CBA preliminary analysis (what do we measure and how do we measure it ?) underway.

KEY AREAS OF ANALYSIS

- What unique capabilities does Loran-C offer?
- What capabilities does LORAN provide that are technically superior or more cost effective than alternatives?
- What role can/should Loran-C play in a satellite-based system?

AREAS OF ANALYSIS (CONT.)

- What are the estimated costs for Loran-C retention options ?
- When can we expect to achieve full Loran-C service equivalency from a space-based system ?

TASK COMPLETION SCHEDULE

- Call for data through 12/15/97
- CBA due 1/6/98
- Transition and Funding Plan due 2/9/98
- Report to Congress (final) due 3/27/98

Introduction, Questions and Answers

In his introduction of Mr. Hawley, ILA President Bill Brogdon noted that Mr. Hawley comes to us with over twenty years with the U. S. Air Force as a pilot and air traffic controller, and with the FAA as editor of the terminal instrument procedures manual. . His navigation experience includes work with the Microwave Landing System, Loran-C non-precision approaches and the automatic blink system requirements development. Since 1987 he has worked as an aviation consultant, and currently manages the Booz-Allen and Hamilton Global Air Traffic Management System consulting business, including support for the U.S. FAA, DOD, EC EUROCONTROL, Russian Federation and China.

ILA members were active in the Booz-Allen and Hamilton Loran-C user meeting in September, 1997, at which user communities were identified. Many were surprised at the extent of use of loran by the timing community.

The Booz-Allen study emphasizes benefit-cost analyses. According to Mr. Hawley, in order for Loran to succeed, these analyses must show a beneficial ratio, and the FRP policy on year 2000 must be undone. These are separate items. The benefit-cost study content will not be affected by DOT policy or FAA. Benefits and costs will be done only for the U. S.

A lively question and answer session followed:

Q: Will you try to quantify the effect on such areas as Canada or on the decisions made by the rest of the world as a result of a U. S. decision? If we lose loran in the US, a potential market for products will disappear, since other countries will also abandon the system.

A: That goes beyond the question we've been asked by DOT; we're concentrating on the U. S. provider costs and benefits for users who use the U. S. system. These users could be Canadians, for example. Because of the direct link between the US and Canadian systems, we will address the likely turnoff of the Canadian stations resulting from the US decision and the impact on Canadian users. We will use data provided by the Canadians.

A: (in answer to a question on receivers) A joint GPS/Loran-C receiver available in three years will be "way too late." The "train is moving 500 miles per hour" and will be gone by that time.

Q: GPS may be shown to meet "all the individual requirements" but what of the overall requirement for positioning and timing service?

Comment from the floor: The price-tag for failure is increasing. We are doing more with radio positioning systems.

Response: There is concern that we may be watering down the requirements, settling for less than in previous times. (Single-thread systems, for example.)

Q: If Loran were available at no cost, would the government perceive a negative benefit because it would dilute GPS benefits?

A: No. If we have $250 million in costs, we need at least $250,000,001 in benefits in order to show a desirable CBA ratio. This is independent of GPS benefits.

Q: How about separating Alaska from the lower 48, since costs per user are different in the two areas?

A: The USCG is providing data which will allow us to study that.

Q: How good a job have the commercial fishing interests done in providing data?

A: Mediocre after a lot of work by us. They have no collective body and are widespread. We will try to obtain good data samples and will extrapolate.

By the way, from our own user meeting in September, we recognize that timing may turn out to be the key to understanding the benefits.

Comment from the floor: I am concerned that we may be making "the big mistake." Some time ago NASA shuffled all the money it could, from other programs including those supporting expendable launch vehicles, to the Shuttle program. The Shuttle became our only way into space. After the Challenger explosion, this single thread broke, and our weather and intelligence satellites and even GPS programs all were delayed while expendable launch vehicles were resurrected or launches bought from other countries. I am afraid we are making that big mistake again.

Response: The GPS program still feels the effects of those delays.

Q: Will your report go top-down, with policy perspectives, or will you be incrementally comparing loran cost/benefit ratios with VOR, DME, etc., etc.?

A: Given the scope of this study we cannot hope to do a cross comparison with all other systems. We will look at, "Who are the users? What do they use the system for? What benefits accrue and how much are they worth? Then, if it is cost-beneficial to run loran, how should we fund it?" User fees are probably not the way to do it. For the amount of money needed, the cost of collecting fees from users would be too high."

Comment from the floor: The U. S. Federal Radionavigation Plan says we need two systems; one strong argument made in the FRP over the past three issues is that electronic chart display systems (ECDIS) are said to require two inputs.

Q: If the benefit/cost ratio is greater than 1, will loran continue to operate?

A: Maybe.

Q: You seem to present a biased assumption -- we must compare a loran benefit/cost ratio including system costs, with a GPS environment where the system is offered "free".

A: GPS as a service is assumed.

Concluding remarks by Mr. Hawley: In conclusion, we need data; not anecdotal data, but hard data on users, uses, costs and benefits. I believe that a cost/benefit analysis is the key to the success of our study; policy interpretations will be attached by DOT or others, not by us.

Personally, I am sympathetic. I am a loran user; a pilot and a boater. The study will, of course be independent of that. We deal with costs and benefits only.

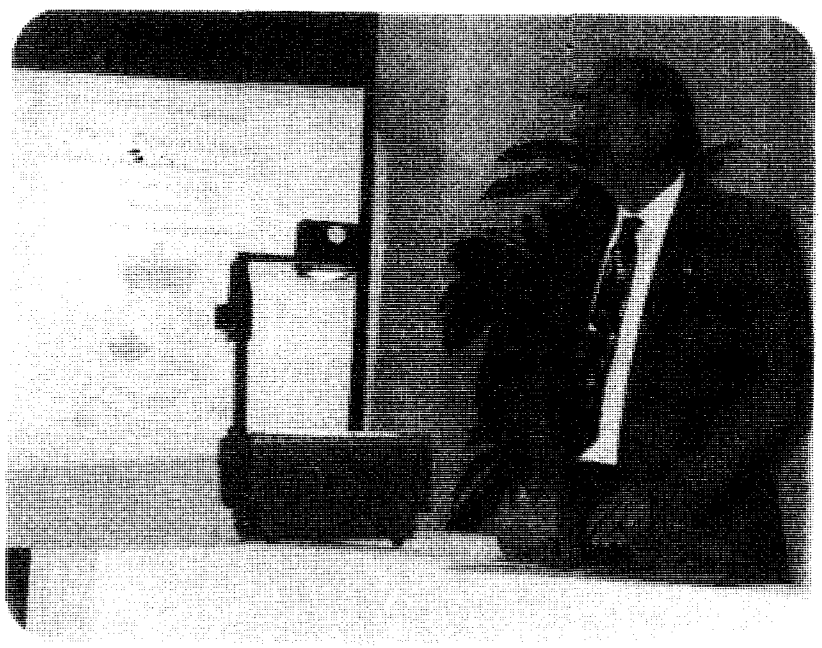
Luncheon Address

Loran-C in Canada: Past – Present – Future

Gary K. Running, Director General
Marine Navigation Services
Canadian Coast Guard

Unfortunately, notes on Mr. Running's introduction and Q&A were not available for printing.

From left: Norway's Terje Jorgensen, speaker Gary Running, ILA President Bill Brogdon, convention chairman John Butler and technical chairman Bill Roland prepare for Gary's luncheon address with a good meal.



Canadian Coast Guard's Gary Running at work.

Luncheon Address

Loran-C in Canada: Past – Present – Future

Gary K. Running, Director General
Marine Navigation Services
Canadian Coast Guard

Canada's first experience with Loran-C came in 1965 when the US Department of Defense was interested in installing a string of Loran-C stations to provide extensive coverage over their eastern waters and the North Atlantic. The US funded the construction, maintenance and operation of the Cape Race, Newfoundland, station which formed a part of two different Loran-C chains: the North Atlantic Loran-C chain, with master at Angissoq (Greenland), and secondaries at Sandur (Iceland) and Cape Race; and the US East Coast Chain, with master at Carolina Beach (NC) and secondaries at Nantucket (Mass), Jupiter (Fl), Dana (Indiana), and Cape Race. The coverage from these two chains was solely for the benefit of the US military, since the public made little or no use of the Loran-C system at that time. I think the US subs were trying to find out where they were. A typical receiver cost in the order of $20,000 and was not user-friendly.

At the time that the Cape Race station was built, Canada already had an existing system of some 7 Loran-A stations and 15 Decca Navigator stations, providing extensive, but not complete, radionavigation coverage over both coasts. By 1977, the US had completed a study which advocated adoption of the Loran-C system as the radionavigation system to provide coverage over their coastal confluence zone. We were immediately interested in joining their system in order to reduce the proliferation of different radionavigation systems, and perhaps save a few bucks in the process, by closing the 22 Loran-A and Decca stations.

One of the first things we did was to conduct some sea trials off the Canadian east coast during a time when bad weather was prevalent. These "dirty weather trials," as they came to be known, gave us a better insight into signal propagation and receiver performance during adverse weather conditions. (A little advice here -- if you get a chance to go on a trip like this, go out of your way to avoid it.)

We really got our feet wet in the Loran-C world when we joined the USCG in providing Loran-C coverage over the entire west coast, including Alaskan waters. We filled a hole in coverage by building a station at Williams Lake, B.C. The US Coast Guard very kindly provided us with the station electronics free of charge. Williams Lake became master to stations in George (Washington State) and Shoal Cove, Alaska. The chain, called the Canadian West Coast chain, with an assigned rate of 5990, was commissioned in early 1978. The following year, we closed our two Loran-A stations (Spring Island and Grey Point) on the west coast.

It wasn't too long after this chain came on air that the discovery was made that the southern end of the intended coverage area was not receiving strong enough signals from the most northerly station, Shoal Cove. It turns out that the Shoal Cove signals were being seriously attenuated by the mountainous shoreline along the path from Shoal Cove to the southern end of Vancouver Island. To fix this hole in coverage, it was necessary to build another station in British Columbia. This is how the station at Port Hardy, located at the northern end of Vancouver Island, came to be. The US Coast Guard again kindly provided both the electronic equipment and the antenna. This station was commissioned in the summer of 1980 and became the Zulu secondary of the Canadian west coast chain.

The Port Hardy station was very unique in one sense. It was the first Loran-C station, both in the USA and in Canada, that ran in an unattended mode. The Williams Lake station was continuously manned, since it was the control station for the Canadian west coast chain. It was just a matter of installing suitable remote monitor and control equipment at Williams Lake. If there was an emergency situation at Port Hardy that could not be rectified remotely from Williams Lake, technical staff were on call in the Port Hardy area to rectify the problem. The operation proved quite successful, paving the way for future destaffing at other stations.

Slide #2

In the early 1980's there was considerable interest in oil exploration in the Canadian Arctic with drilling taking place both on drill ships and on man-made islands in the Beaufort Sea. We became interested in the safety aspects of transporting oil out of the Arctic, and if it ever became necessary to install a radionavigation system, we wanted to know how far a Loran-C signal will propagate across permafrost. With this objective, we installed a triad of portable mini-transmitters in the Beaufort Sea area and made signal measurements at the limited number of airports and roads in the area. It was confirmed -- Loran-C does not like permafrost. The signal attenuation was severe. Before too long, the need for a navigation service subsided since the oil companies made no attempt to move oil out of the Beaufort Sea.

Shortly after the west coast expansion was complete, planning was underway for a reconfiguration of existing coverage that would result in complete Loran-C coverage along Canada's east coast. This was accomplished in two stages. The first stage occurred in 1980 when the existing US East Coast Chain was changed into that what we have today: Caribou (Maine) being the master to secondary stations at Cape Race and Nantucket (Mass). It was called the Canadian East Coast Chain and had

an assigned rate of 9930. The second stage involved the construction of a new station at Fox Harbour, in southern Labrador, at the end of 1983. Subsequently, the North Atlantic Chain (Angissoq (Greenland) - Sandur (Iceland) - Cape Race (Nfld)) was reconfigured into the Labrador Sea Chain, Rate 7930, with Fox Harbour as master to Angissoq and Cape Race. As well, the Fox Harbour station was dual rated, becoming a third secondary on the Canadian East Coast Chain.

Slide #3

The introduction of any new radionavigation system always brings with it a certain amount of reluctance or resistance to change, no matter how well you think you have done your job. Well, Loran-C on the east coast was not different. User complaints were received relating to poor signals or difficulty in using the system. It became necessary to form a technical team that would meet with fishermen to discuss their problems, inspect their receiver installations, sometimes sail with them, and generally give them some hands-on experience. In the end, two primers were produced, one dealing with proper receiver installation, and the other with receiver operation. Once the users became familiar and comfortable with the system, the complaints stopped. (Gary's aside - Frank Ling & Ed Matthews).

From the time of the first installation at Williams Lake, we began to slowly turn off our Loran-A and Decca Navigator stations. By 1986, the last of the 22 stations was decommissioned.

By the 1991-92 timeframe, plans were being carried out to refurbish the Cape Race station. The buildings, antenna and equipment were then more than 25 years old. The plan called for a new transmitter building, new solid state transmitter, new standby diesel plants and a shortened, re-guyed antenna. Construction began in 1992, and by early 1993, a brand new transmitter building was sitting beside the old transmitter building, along side the base of the huge 1350 foot transmit antenna. The electronic installation team was ready to commence installation of the new electronic equipment the following morning, when the antenna suddenly collapsed. One part of a guy insulator assembly failed, and the resulting collapse totally wiped out one end of the old transmitter building, including its contents. The new transmitter building managed to escape with only minor damage. Luckily no one was injured.

If you thought government employees can't move fast, you're wrong. Within about six months the mess was cleared up, new antenna anchors were constructed, a new antenna was designed, tendered, built, delivered and erected, the electronics installed and the station placed back in service.

By the early 1990's, it became apparent that changes were coming relating to the operation of the Angissoq, Greenland, station. With the completion of the GPS satellite system by the US, the US military no longer had a need to support the operation of the Angissoq station and that funding for it would cease by the end of 1994. The European nations that were in the midst of expanding Loran-C coverage over western European and eastern North Atlantic waters also had no requirement for Angissoq coverage. If the Angissoq station was too close, then the Labrador Sea Chain, of which Angissoq was a part, would cease to exist. Rather than Canada paying for the entire cost of operating the Angissoq station (which at that time was in the order of $3M US annually), it was felt to be more cost-effective to build a small, low power station in central Newfoundland, creating a new chain that would replace essential lost coverage in the waters off eastern Newfoundland. Thus, in December 1994, a new station at Comfort Cove, Newfoundland, was completed.

Slide #4

Also, in the early 1990's, the US federal Aviation Administration became interested in Loran-C and wanted to see complete coverage across the interior of continental USA. They ended up funding the construction of two new Loran-C chains, comprised of four new stations that were linked to existing stations where possible. This is how the Williams Lake station became dual-rated, tied to the Havre/Montana, Gillette/Wyoming, and Beaudette/Minnesota stations to form the North Central US chain, rate 8290. The FAA consented to fund the increased costs at Williams Lake that were incurred as a result of the dual rating.

It is interesting to note that one can now travel from Victoria, British Columbia (in western Canada) to St. John's, Newfoundland (in eastern Canada) and be in continuous Loran-C coverage the entire time. This may not mean much to a mariner, but I am sure it is a great benefit to private aviators in Canada.

I spoke earlier of our newest station at Comfort Cove, Newfoundland. The design of the Comfort Cove station was quite different from that of the normal station, which typically consists of a good sized transmitter building, a transmitter capable of outputting anywhere from 400 to 800 kilowatts of power, and a transmit antenna that is anywhere from 625 to 720 feet in height. This station was designed for unattended operation, meaning you don't need much space for staff cooking facilities, locker rooms, storage facilities, etc. The required output power was only 185 KW, so we were able to get away with a small transmitter, (16 Half Cycle Generators, versus the normal 32 or 56 Half Cycle Generators), and a smaller back-up diesel generator set which again resulted in a smaller transmitter building. Finally, the antenna was only 450 feet high, which means the wind and ice loading was decreased, translating into smaller antenna legs and guy cables. In all, the savings in construction costs were considerable.

The new chain was called the Newfoundland East Coast Chain, with master at Comfort Cove, and secondaries at Fox Harbour and Cape Race. It has an assigned rate of 7270.

Slide #5
(shows current Loran C coverage in Canada)

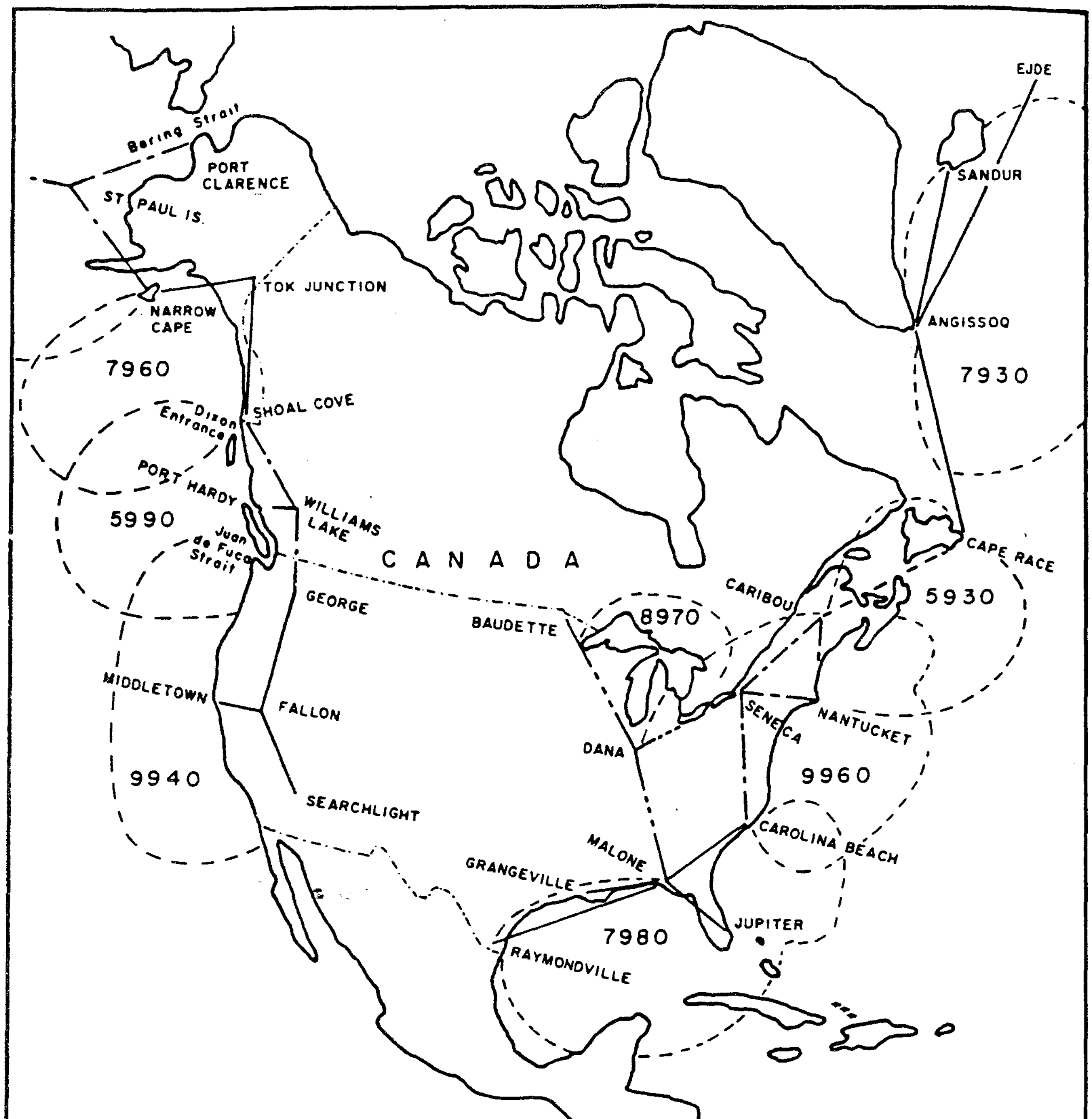
So - we have briefly covered Loran C - past and present in Canada. Let's now very briefly look to the future. Just as Loran A and Decca gave way to Loran C, over time, Loran C will give way to GPS/DGPS.

I would like to reinforce what our Commissioner (David Watters) said in his opening address. But first let met say that the potential termination of any service where people have given their all is not a matter upon which to be lightly embarked. Nor should it be. The planned termination of Loran C is just such a matter. You should know that of all the Loran C users in Canada, namely: marine recreational, fishing and commercial, aviation, surface and scientific, it is the marine commercial user who has had the largest say to date in the future of Loran C. This is because the Marine Services Fee (which includes a portion of the cost of Loran C in Canada as well as a portion of the conventional marine aids system and a portion of VTS) is paid only by commercial marine clients. There is no direct charge for pleasure boaters, fishers, civil aviation, surface or scientific users. Through our Marine Advisory Board, commercial users tell us there is no need to continue Loran, particularly if they are going to pay for it.

Be assured that we will not cease Loran C operations without extensive consultations with our total client base and we are now putting plans in place to just that. Further, as the Commissioner pointed out on Monday, we have had a long and mutually beneficial Loran C partnership with the USCG and any re-visiting by them of their Loran C termination date may give us pause to re-visit ours. However, subject to consultation with our total client base, our current plans call for the closure of Loran C in Canada in 2001.

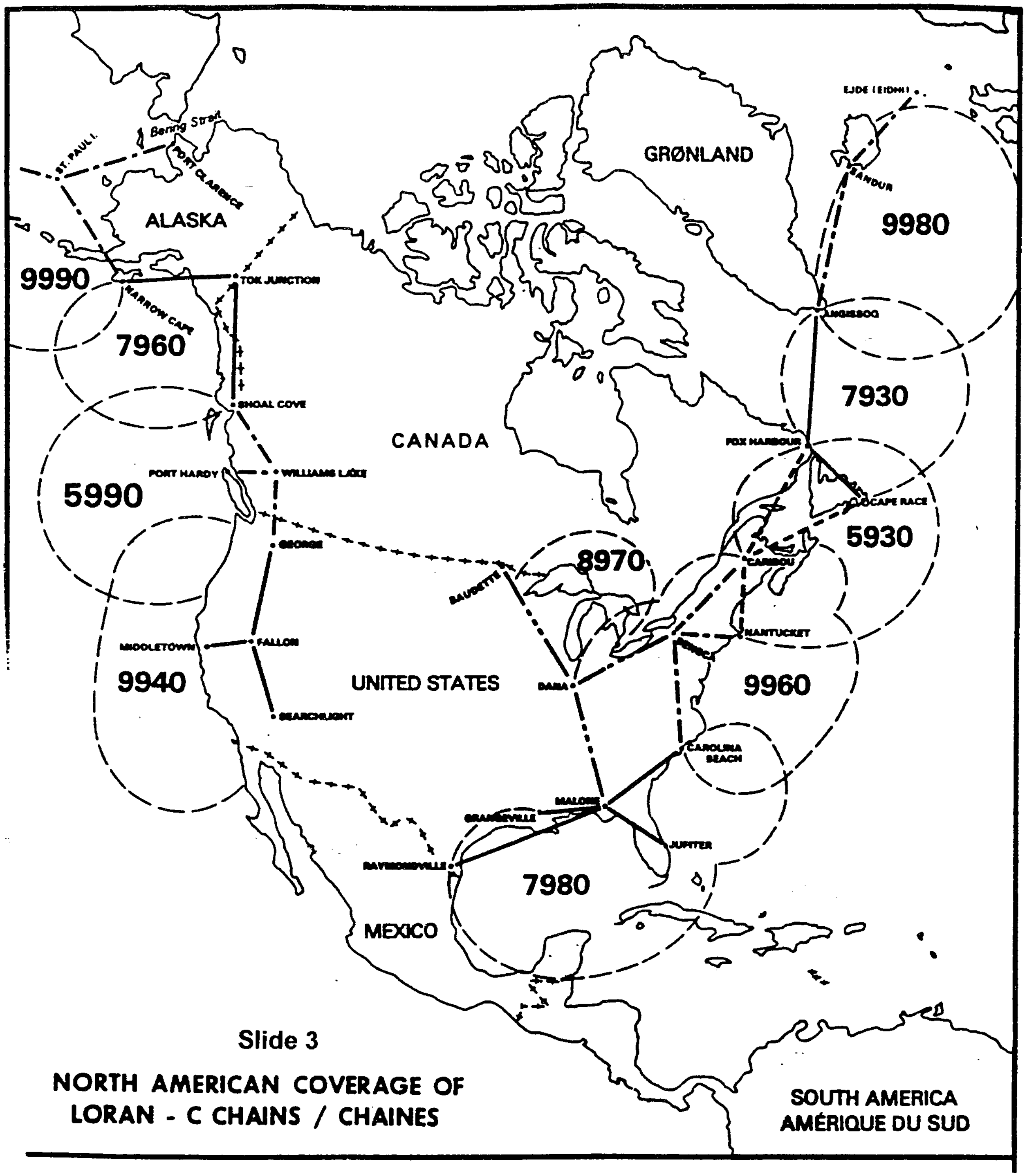
That concludes my brief look at Loran C in Canada -- Past, Present and Future. I would be happy to try and answer any questions you may have.

PC Docs 32999 v4



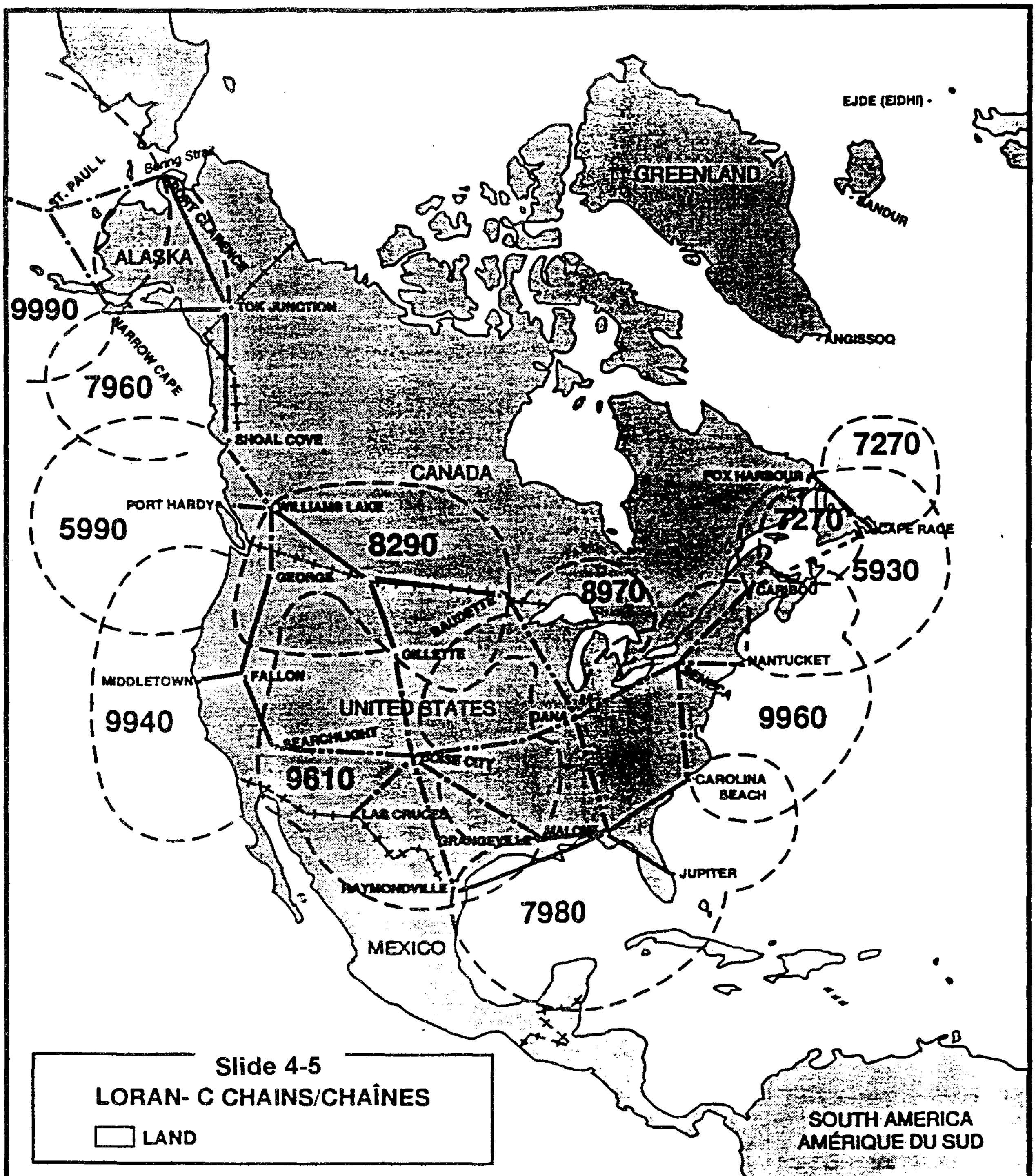
Slide 2

NORTH AMERICAN COVERAGE OF
LORAN-C CHAINS/CHAINES



Slide 3

NORTH AMERICAN COVERAGE OF LORAN - C CHAINS / CHAINES



Slide 4-5

LORAN- C CHAINS/CHAÎNES

Atlantic English/Map - 1

Commentary: Omega Transmissions Stop

John M. Beukers, October 3, 1997

Mr. Beukers was unable to attend the meeting; however, he submitted these observations on the termination of the Omega Navigation System. ILA members are invited to consider this action as evidence that the threat of termination of Loran-C is indeed a real one.

After more than a quarter of a century of service to air, sea and land users worldwide, the international Omega radionavigation system went off the air on September 30, 1997. (This was the date announced in the 1994 Federal Radionavigation Plan, a change from the 1992 Plan, which called for operations until 2005.) Operators at the eight stations located around the world simultaneously turned off the transmitters in what is described by some observers as "premature", "tragic" and an "irreversible mistake." While some users have already converted to the replacement technology, GPS, others have yet to do so and some cannot for technical limitations of GPS. (Omega signals could be received under water and in other places invisible to satellites.) Hardest hit are the weather predictors and modelers who relied upon Omega, particularly in the southern hemisphere, to obtain meteorological data from 300,000 balloon borne radiosondes launched annually.

In a communication from one of the two major radiosonde manufactures, Vaisala of Finland, the last Omega launch is described:

"This morning we assembled for a final radiosonde launch using Omega at Vaisala plant. Some 40+ persons were present at the launch 05:30 AM local time. Good data until the end of transmissions.

Veijo Antikainen had checked the archives and identified our first one: 14th September 1971 at 15:52 local time.

Transition to GPS and Loran-C based systems has gone perhaps a bit better than expected a year ago, although few users have developed the real observation routine yet. A lot of work is still ahead, and the final impact of this change remains to be seen."

Omega was the brainchild of the late Jack Pierce who had received wide acclaim for his work on low frequency aids to navigation. The Omega system became operational in the northern hemisphere in the early 1970's and fully operational in the southern hemisphere after the completion of the Australian station in 1982. The system cost the United States $5 million annually.

Comment: The 1994 Federal Radionavigation Plan and the 1996 issue, yet to be distributed in hard copy, provide dates for the termination of *all* terrestrial radionavigation systems. Omega is the first to go and suggests that DOT is serious in carrying out the published termination plans. Total reliance upon any radionavigation system is unwise and unsafe particularly when this is a vulnerable space system whose weak signals are susceptible to interference and jamming.

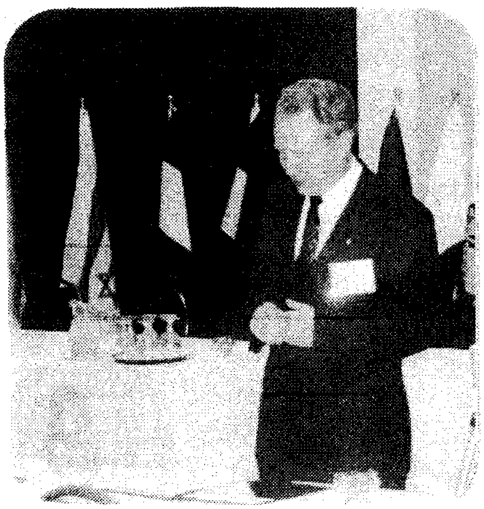
DOT needs to revisit this GPS sole-means policy and determine a suitable mix of systems for the 21st century ***with a transition policy based upon time-proven performance of new technologies rather than fixed arbitrary dates***. We need this change to be published in the 1998 FRP.

For reasons of economy, the weather observers are converting to Loran-C where there is coverage because the GPS radiosonde is more expensive and cannot be afforded by many of the world's meteorological services.

Session 1: Opening and Keynote Address

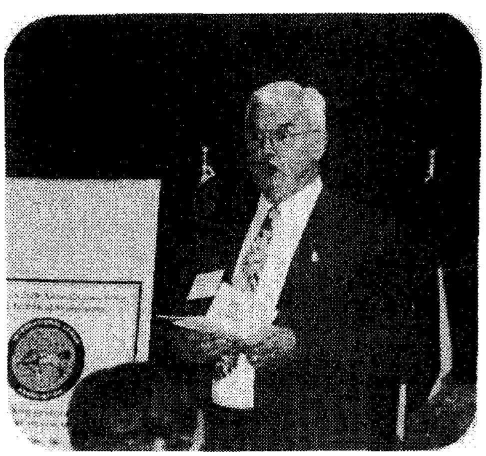
Session Chair: William Roland, President, Megapulse, Inc.

Editor's summaries of introductory presentations appear below:



John Butler, Convention Chairman, opens the meeting.

ILA President Bill Brogdon offers welcoming remarks



Co-Technical Chairmen Bill Roland, left, and Dirk Kügler

Mr. John J. Butler, Canadian Coast Guard, Chairman of the 26th Annual ILA Conference and Technical Symposium, opened the meeting with recognition for the eleven countries represented: Canada, England, France, Germany, Ireland, Italy, Japan, The Netherlands, Norway, the United States and Wales. It was noted that the rest of the world seems to be embracing Loran-C just at the time the U. S. (and Canada) are announcing their intention to terminate it.

We are here to share technical, economic and policy ideas; the Canadian Coast Guard sees this meeting as a "window on the world," a help to those of us so busy at home. As an added bonus, we shall hear shortly from Canadian Coast Guard Commissioner David Watters, with an outline of the Canadian perspective.

We welcome IALA Secretary General Torsten Kruuse, who also will be a session chair today.

Welcome to Ottawa, the capital of Canada; Canadian Coast Guard's David Waters arranged for excellent warm weather and set up all the facilities and events for our meeting.

John Butler then introduced **William F. Roland, Convention Technical Co-Chairman and Session 1 Chairman.** Bill Roland acknowledged the assistance he received from Technical Co-Chairman Dirk Kügler, of the Avionik Zentrum Braunschweig, Germany.

He also brought the group a report from Masahiro Katayama that Tatsujiro Shimasue, Chairman of the Sena Corporation, Chairman of the Japan Association for Aids to Navigation, and Honourable Chairman of the Japan Lifeboat Association, died October 4, 1997. ILA extends its sympathy to Mr. Shimasue's family and friends.

Chairman Roland then introduced ILA President Captain William J. Brogdon, Jr., for introductory comments:

We are delighted to be in Ottawa. We "foreigners" such as Bill Roland, Larry Barnett and the others from south of the border feel welcome here. ILA is international; welcome also to our growing number of members from overseas.

The Loran crowd is not always welcome everywhere. I made a trip this past summer to England. I sent e-mail to David Last. The response: David is out of the country. Then planning for the trip here to Canada, I wrote to a Coast Guard friend in Detroit, thinking about a short visit. My friend was moving to Atlanta the day before I was due to arrive... Should I be paranoid? Is it Loran, or just me?

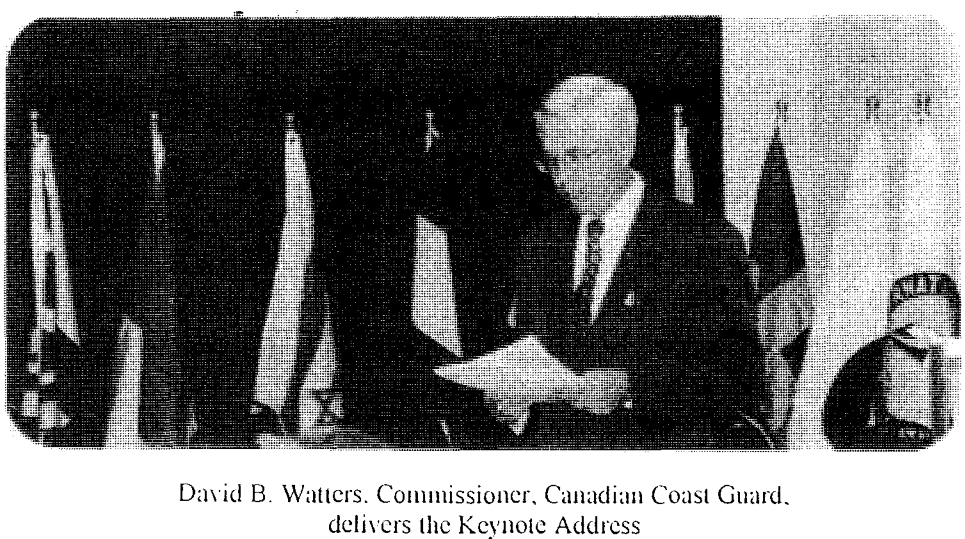
I was struggling a little with the USDOT - USCG investigative report on TV last night. There were segments on rescue swimmers, pilots, and a segment on loran – the Coast Guard people reportedly view loran as hard duty; cold islands, isolation, etc. We, on the other hand, see it as an essential signal, part of the overall navigation service.

Since our 25th annual Convention and Technical Symposium in San Diego, I have sent letters to the USCG and FAA on behalf of your Association; we received the usual replies from the bureaucracy. "Come to the 'user conferences.'" We critiqued/criticized the mini-warning users were given to get ready for the Booz-Allen and Hamilton conference supporting the USDOT Loran-C study mandated by the U. S. Congress. ILA representatives had a meeting with USCG's RAdm Hull, which we think was a very useful and open exchange, and one which was in sharp contrast to the recent difficulties we've had in communicating with the Coast Guard. RAdm Hull appreciates the new technology that has become available in the loran field -- transmitter control system changes, new receiver technology, for example. We also discussed the user requirement for two independent systems. He knew about the DOT Loran-C study, and said the USCG would help. ILA's position was that loran and GPS are synergistic, not competitive.

We were gratified to see the excellent response from the timing community at the Booz-Allen and Hamilton meeting, even with the short notice from DOT for the meeting arrangements. That session identified new user communities. ILA presented the Association's position that no one system is sufficient for safety-related positioning, navigation and timing. Changing the current mix of systems reduces safety, introduces high user re-equipage costs, changes the performance statistics which affects fishing, travel and a host of other applications.

To emphasize the timing application: backup/alternative signals are critical for basic telephone, the Internet and for cellular telephones as just a few examples. If timing fails, the whole thing fails -- emergency calls don't get out, business doesn't get done. Synergistic timing support is essential.

We appreciate the Canadian Coast Guard's strong support of the International Loran Association and of this convention. We appreciate your hosting this meeting in clean and safe Ottawa.



David B. Watters, Commissioner, Canadian Coast Guard, delivers the Keynote Address

Keynote Address

David B. Watters
Assistant Deputy Minister, Marine Services
Commissioner, Canadian Coast Guard
Fisheries and Oceans Canada

Mr. Watters was introduced by Convention Chairman John Butler:

David Watters has been Commissioner of the Canadian Coast Guard since January of 1997. He brings a varied and diverse background to government. He was assistant deputy minister for finance, overseeing crown corporations and privatization. Among his duties were to define core government services and privatize other operations.

Earlier, he was with Consumer Corporate Affairs, a national organization responsible for Canadian consumers. This group acts as a trade negotiator and is concerned with energy, mines and resources.

Mr. Watters brought to the Coast Guard his discipline and his understanding of large operations in government. Transportation keeps a large country ticking... Please welcome Commissioner David Watters.

Good morning ladies and gentlemen. Let me start by thanking you for your invitation to address this conference. Welcome to Ottawa.

The Loran system worldwide, as well as this Association, have served the transportation community extremely well for the many years of their existence. I think we can be justifiably proud of the many people who have worked to make this a tremendous success story.

In Canada we have great pride in the part the Canadian Coast Guard has played in the history of Loran, not only through our Memorandum of Understanding with the USCG which dates back to 1965, but also internationally through our involvement with IALA, the International Association of Lighthouse Authorities and IMO, the International Maritime Organization.

We appreciate our close ties and cooperation with the USCG, as well as the many firsts attained by our organization in the field. For example:

1. Canada was the first nation outside the U. S. to directly fund its own loran stations.

2. Canada was the first nation again outside the U. S. to have nationals as Coordinators of Chain Operations. These were Ed Goudie on the East Coast and Rick Hollenquist on the West Coast.

3. Canada was also the first nation outside the U. S. to operate a station in the automated-unattended mode; this of course, was in Port Hardy on Vancouver Island.

All this is to say that our history with the United States in the operation of this navigation system has been one of valued cooperation and partnership.

There are moments in history which one is able to identify as turning points many years after the fact. Not many can be seen when they occur. How many foresaw the revolutions created by the introduction of the telephone, the internal combustion engine and refrigeration? Yet each of these technologies has impacted greatly the world of marine transportation and in a way, they are so fundamental that it is impossible to think of operations without them.

The first created a communications system which enabled a company to direct its fleets from a remote point. The second abolished the ships' dependence on the vagaries of the wind, and the third allowed a quantum leap in the distance to which a greater variety of cargoes could be delivered.

We are fortunate to now be at another turning point in history, and even more fortunate, I think, to be in a position to recognize it.

The relatively recent development of the Global Positioning System has revolutionized navigation by providing continuous, all-weather positioning accuracy to a degree unmatched in history. Using its differential mode, we can now provide that continuous all-weather positioning accuracy down to a remarkable 10 meters. Who would argue that this is not progress?

The Canadian Coast Guard is, and always has been, committed to taking full advantage of new and improved technologies to deliver a safe and cost-effective marine navigation system. The introduction of GPS and DGPS is but one step along the road in systems development started after the Second World War.

Since the introduction of DECCA is the 1950s, Loran-A and subsequently Loran-C, the Canadian marine community has benefited from increasingly accurate and safer marine navigation systems. Each was an invaluable step on the road of progress, but I do not believe that anyone in this room would wish to go back to the days of DECCA or even, I might hesitate to say, CONSOL!

While safety is the number one priority of the Coast Guard, it is of no benefit to anyone if the cost of providing that safety is so onerous as to bankrupt the provider. It is axiomatic that constraints, be they size, power or financial for that matter, place limits on any product development such that efficiency is maximized and cost is minimized.

Navigation systems and services are no different.

The Coast Guard's Aids to Navigation Modernization Plan is just such a response to the changing world of marine safety. The plan is ambitious. It brings together five important aspects of the aids to navigation system, as follows:

1. Development of low-maintenance buoys

2. Automation of fixed aids such as lightstations

3. Encouragement of the use of ECDIS in Canadian waters and the development of digitized charts of Canadian waters

4. Implementation of DGPS, and finally

5. Termination of Loran-C in 2001

The last issue, I should note, is based on the assumption that the USCG will be doing the same. I would also assure you that discussions are ongoing with regard to that subject and that if the USCG decides to continue in some fashion with the operation of Loran-C that it may be necessary for the [Canadian] Coast Guard to review its own decision to close down the system.

While the type of service will change and mariners will be required to adjust, the safety of Canada's marine navigation systems will remain the same.

However, the drive for this modernization program does not originate only from the development of new technology. The government of Canada has been under increasing pressure over the past few years to reduce not only the physical size of the Public Service, but also its capital and operating budgets, as well as initiating cost-recovery initiatives, in order to reduce the deficit and "get our fiscal house in order."

The "aids modernization plan" as well as other work currently under way, will be a positive Coast Guard response to the government's program review targets. The Coast Guard is anticipating that over the period 1995-96 to 2000-01, the Marine Navigation Services program costs will be reduced from $120 million to some $60 million – a reduction of 50%.

Further, the decisions regarding the modernization program are not being taken in isolation:

1. Notices to Shipping and Notices to Mariners are, and will continue to be, issued well in advance of any changes to aids to navigation.

2. Several pilot projects have been carried out to introduce users to DGPS, and these will continue.

3. Canada was also the first nation outside the U. S. to operate a station in the automated-unattended mode; this of course, was in Port Hardy on Vancouver Island.

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Further, the decisions regarding the modernization program are not being taken in isolation:

1. Notices to Shipping and Notices to Mariners are, and will continue to be, issued well in advance of any changes to aids to navigation.

2. Several pilot projects have been carried out to introduce users to DGPS, and these will continue.

3. But most importantly, the Coast Guard will continue to consult with the full range of the user community in order to determine the level, location and degree of dependence on Loran-C as well as any anticipated future demand.

These consultations plus the continued discussions with the USCG, will be two significant factors in deciding when to close Loran-C.

In closing let me address a matter of some importance and relevance – the Canadian Marine Services Fee. The MSF was instituted in June of 1996 in response to a number of factors, namely the general government-wide movement toward a cost-recovery philosophy and the internal program review budget reductions applied to the Coast Guard. We have taken the position of, "User pay – User say" which is why we initiated the Marine Advisory Board as well as regional advisory boards.

The Coast Guard, and the marine community in Canada, is not able to continue to work in the same fashion as previously. Commercial industry must pay their fair share of the services provided. But equally important, the Coast Guard must carefully consider our client wishes while at the same time balancing the requirements of safety, economy and fair play.

In this regard, the Coast Guard "showed" its concern for the mariner when it introduced Loran-C. It is no different now that the Coast Guard is introducing DGPS.

In closing, I thank you for your invitation, for your attention, and I hope you have a productive conference.

Session 2: Radionavigation Plans and Policies (A)

Session Chair: William Roland, President
Megapulse, Inc.

Session 2: Left to right; Dirk Kügler, Vito Minaudo, Terje Jorgensen, Bill Roland

Current Status of Loran-C in Europe: A Commission View
Brian Toll, European Commission DG VII; Transport
(Mr. Toll could not attend; his paper was delivered by Dirk Kügler)

Loran-C in Europe: Status and Prospects in A NELS Perspective
Terje H. Jorgensen, NELS Coordinating Agency

The Current Status and Future Perspectives of the Loran-C SELS System
Commander Vito Minaudo, Ministero dei Transporti e della Navigazione, Italy
Italian Coast Guard Headquarters

EUROPEAN COMMISSION
DIRECTORATE-GENERAL VII TRANSPORT

DIRECTORATE A - INTERNATIONAL RELATIONS AND TRANSEUROPEAN TRANSPORT NETWORK AND INFRASTRUCTURES
Network and Infrastructures: policy

Brussels, 6 October 1997
LT/BT D(97) loran\conf3.doc

MESSAGE TO INTERNATIONAL LORAN ASSOCIATION

Subject: 'Current Status of Loran-C in Europe - a View from within the European Commission'

1. It is with regret that I am writing rather than personally presenting this short paper. Unfortunately, a number of urgent issues have arisen in Brussels.

2. The current position regarding Loran-C in the European Union is, very briefly, as follows.

3. The European Community is concerned with achieving the optimum use of all available navigation systems, achieving the best coverage and availability to support safe navigation at the minimum cost to the public purse. The Guidelines on the development of the Trans-European Transport Network[1] include as a priority issue the development of the positioning and navigation network, including both satellite systems and other systems (which are to be defined in a future European Radio-Navigation Plan).

4. In its communication on a common policy on safe seas[2], the Commission also proposed that Community action should assist in the development of radio-navigation chains. It was anticipated that this would create the economies of scale required for the application of more advanced technologies and so help national authorities achieve improvements which it would otherwise be difficult or expensive to realise. Loran-C, as the terrestrial navigation aid most widely available in Europe, was considered to be particularly

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[1] Decision N° 1692/96 of the European Parliament and of the Council of 23 July 1996 on Community Guidelines on the development of the Trans-European Transport Network

[2] COM (93) 66 final, 24 February 1993.

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Internet: brian.toll@dg7.cec.be

important[3] and the Council agreed that the system satisfied international requirements and did not prejudice the development of satellite aids to navigation[4].

5. In developing a policy, the Commission also gives considerable weight to the approach adopted by the international organisations. It is, therefore, noted that IMO recognises the present need to use at least two different and independent positioning systems and that Loran-C/Chayka[5] chains together with the US GPS and Russian Federation's GLONASS satellite systems could be component elements of the world-wide radio-navigation system. These views have largely been endorsed by other organisations considering the future systems mix, including the General Lighthouses Authority and the Internavigation Council of the CIS, and the International Association of Lighthouse Authorities (IALA) which considers that Loran-C/Chayka is an economic solution for terrestrial coverage, noting that decisions have been taken to terminate Omega and to abandon Decca in Europe. Loran-C is not generally used in aviation in the European context.

6. The Commission is now preparing three documents for presentation to the European institutions (particularly, the Council and the Parliament). These will be:

   (1) a strategy paper on the future development of wide-ranging satellite and terrestrial navigation aids (in other words, purely local systems will not be considered in any great detail);

   (2) an action plan on the development of the global navigation satellite system, in which the European Community has decided to play a role and is establishing a contribution in the form of an augmentation to the GPS and GLONASS systems. This will improve the accuracy, integrity and availability of the satellite signals over an area covering Europe, most of North and South America, Africa, much of Asia and Western Australia;

   (3) a report on Loran-C.

7. The Loran-C report will show that some European countries have in the recent past invested in improving Loran-C facilities on their territory[6]; others have simply maintained present facilities or allowed them to deteriorate[7].

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3 For technical details of the Loran-C system, *see Commission* Proposal for a Council Decision on the Loran-C radio-navigation system, COM (91) 1 final of 21 January 1991.

4 Council Decision on radio-navigation systems for Europe, (92/143/EEC); OJ L59/17 of 4 March 1992).

5 A radio-navigation system of the CIS similar to Loran-C.

6 In particular, the Northwest European Loran-C System (NELS), covering Northwest Europe and the North Atlantic, is fully operational. The parties involved are Norway, Denmark, France, Germany, Ireland and the Netherlands). The United Kingdom, which has, to date, operated a Decca chain, has now decided to join this system, provided it satisfies UK coverage and user requirements.

7 In 1993, the governments of France, Italy, Spain and Turkey, together with the Internavigation Committee on behalf of the CIS, agreed to strive jointly to maintain Loran-C coverage in the Mediterranean area for the foreseeable future. However, the antenna tower at Kargaburun, Turkey, collapsed late in 1993 and has

8. The Commission is, therefore, aware of the need to propose a clear assessment of the need for Loran-C in Europe to underpin a future strategy. It is currently actively discussing the options, especially with Member States which will have to be involved in providing the Loran-C chains if there is to be full European coverage, and has accepted the value of funding Loran-C development where the system is currently weakest - that is to say, in the Mediterranean and the Iberian peninsula, as well as the Canaries and Azores [8]. Expansion of Loran-C coverage in the Baltic area is under discussion and it is proposed that these initiatives should be encouraged.

9. Technological development is also playing a part in shaping the proposed strategy. Research has demonstrated that differential satellite corrections and integrity signals can be transmitted over the Loran-C service area (the 'Eurofix' approach is due to feature later in the conference programme). If this can gives wide area coverage, cost-effective use of existing infrastructure and back-up in case either the GNSS or the Loran-C system fails, as well as giving enhanced accuracy of 10-20 metres, it may have a good future. The European Space Agency has provisionally endorsed the value of Loran-C in improving GNSS integrity, although more detailed research is needed to finalise the position. This need for further analysis is generally true, since opinion about Loran-C is polarised between the advocates, who present apparently convincing evidence of Loran-C's value, and the detractors, who equally convincingly appear to demonstrate that Loran-C is not being used in Europe even where it is working best and that there is no need to waste time and money supporting a virtually obsolete system.

10. Furthermore, use of Loran-C for specialised applications such as tracking and tracing may present new opportunities.

11. However, the development of a suitable combined GNSS/Loran-C receiver will be necessary if full advantage is to be taken of these possibilities. Again, the Commission is looking into the possibilities of supporting development of suitable apparatus.

12. The Commission's position is not yet finalised and this note can present only a preliminary assessment of the current position. This conference may well provide further evidence to settle the position. However, the present view of the Commission is that Loran-C is potentially a useful component of the positioning and navigation network, at least in the medium term.

Brian Toll

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not yet been restored. Spain considered that the establishment of a Loran-C radio-navigation system was a political option which should be decided at European ministerial level. The Spanish station at Estartit has also not been providing signals since 1995.

8 Under the TACIS programme (technical assistance for the countries of the CIS), a plan has been developed to establish an eastern Mediterranean/Black Sea chain. Discussions are also taking place on a possible solution in the western Mediterranean area.

LORAN-C IN EUROPE - STATUS AND PROSPECTS IN A NELS PERSPECTIVE

Prepared and presented by
Chief Engineer Terje H. Jørgensen,
Head of the NELS Co-ordinating Agency
Norwegian Defence Communication and Data
Services Administration (NODECA)

for the 26th Annual Convention and Technical Symposium of the International Loran Association
«Technology Takes Loran Toward the Millennium»
Ottawa, Canada, October 5 - 9, 1997

SUMMARY

This paper reports on the current NELS status. Although the implementation started in 1992, there are still some elements remaining before the system can be regarded as completed.
I also report on significant political developments in Europe and on Loran C developments and system enhancement activities within NELS and outside. Finally, I draw a picture of how Loran C can be enhanced to play a significant role in the future European mix of system. This prospective is a personal view and does not necessarily reflect the official NELS policy.

INTRODUCTION

Work on GPS started in the 70ies. The system was implemented in the 80ies and declared operational in the 90ies. GPS has in a remarkably short time been widely adopted as the primary aid for positioning and other purposes. For some people, it has for some time been seen as the *only* aid required for safe navigation.
Amongst radionavigation experts, the need for a proper mix of systems providing sufficient integrity, availability, redundancy and continuity of services is evident. The good news is that, as the use of GPS is maturing, the need for more than one system is being more widely recognised, at least in Europe. In the NELS Co-ordinating Agency, we see this through an increased interest in Loran-C used in combination with satellite systems.
Similarly, politicians and officials in Europe have adopted a requirement for a sound mix of systems offering an answer to the growing variety of needs for accurate and reliable frequency and positioning aids for the future. A European Radionavigation Plan (ERNP) has been drafted and is expected to be approved shortly. Loran-C is in this document foreseen to play a significant role in Europe in the future offering not only excellent services complementary to those provided by satellite systems, but also doing this at a very competitive cost, both regarding implementation and operation.

NELS STATUS

Getting back to the most important challenge at hand; the completion of NELS in its initial configuration. The system is still under interim control from a control centre co-located with the Bø Loran station (CCBø). The control system used is based on the System Area Monitoring (SAM) concept used by the United States Coast Guard (USCG) in the same area until 1995.
Control from the NELS TOE (Time of Emission) Control Centre located in Brest (CCBrest) has started, and the Lessay chain has been introduced in NELS as the first of four chains under this control regime. CCBrest will take control of the remaining three chains in a transition program that is scheduled to be completed in April 1998. After some period of stand-by with complete capacity at CCBø, this control centre will be terminated. Although Norway has an option in the NELS International Agreement to establish a second NELS Control Centre in Norway, it does not seem very likely that control capacity at Bø will be maintained.
As for the establishment of a station at Loophead in Ireland, our Irish colleagues report that a Supreme Court hearing on the issue of planning permission is being prepared, and that a new legislation allowing the Commissioners of Irish Lights to operate electronic aids has been drafted. Transmissions from Loophead will be possible approximately 12 months after the Parliament approval of the draft and the final Supreme Court ruling.
In co-operation with the University of Bangor in Wales and the Norwegian company Geometrix, NELS has started a four stage programme for mapping and calculation of ASF correction data for the NELS coverage area. We are currently analysing the result from the second stage, termed Demonstration Phase, out of which will come recommendations for the 3rd phase which is the Production Phase. If the Demonstration Phase is successfully completed and the NELS Steering Committee authorises the continuation of the programme, production of the ASF Measurement System and the computer model for combing computed and measured

ASF data will start. This method will allow us to make measurements in limited areas only (near-shore), based on which correction data for the entire NELS area can be calculated. Another 2-3 years work will be required before data can be made available to receiver manufacturers.

TIMING CONTROL IN NELS

Timing control in NELS, above referred to as TOE control, is based on measurements of arrival time of signals from adjacent transmitters relative to the local clock. By combining such measurements from all stations in the system it is possible to precisely calculate the time deviation of each transmitters clock. This is done at the Control Centre which uses this information to synchronise the transmitter clocks to each other. The result is that the time of emission of signals from all transmitters of the system are synchronised. System time is also synchronised to the international time scale UTC through the time standard UTC Brest with an accuracy better than 100 ns. Under TOE control the Tds will vary all over the coverage area due to temporal changes in signal propagation speed and no attempt is made to control these variations. However, the overall TD variations are smaller with TOE control than under the traditional SAM concept. One major advantage of this system over the SAM concept is that LORAN-C and GNSS will be using the same time reference making the way for integrated GNSS/LORAN-C user equipment. Such user equipment will be able to take full advantage of the qualities of both systems resulting in improved accuracy, availability, integrity and redundancy to meet requirements which can not be met by the two systems individually.

NELS TECHNICAL SYMPOSIUM

Significant technical and political developments have been noted since the NELS International Agreement was signed in 1992. A need to address such development and arrange for a co-ordinated update of involved individuals and organisations has been recognised in NELS. A technical symposium addressing such development was therefore arranged in The Netherlands in April 1997. Some copies of the proceedings from this arrangement are available here today.

Based on highly appreciated support from key technical and political experts, the symposium was a success. It paved the way for the approval of a NELS Strategy Document containing very significant decisions for the future development of the system. The more important of these are:

Receiver Development Programme

The lack of suitable receivers available in the market and the absence of necessary marketing activities has led to a situation where a very limited number of users are actually using services provided by NELS today. Due to what is assumed to be a major political risk, mainly caused by the US indication of terminating the LORAN-C in the US in the year 2000 and the fact that few European nations are currently directly involved in Loran-C operation in Europe, the receiver industry seem to be reluctant to exploit what we see as a substantial market - competitive, fully integrated GNSS/Loran-C/Eurofix user equipment.

On this background, the NELS Steering Committee appointed a working group to address the development of low cost receivers making use of terrestrial as well as satellite based systems. The working group is supported by representatives from the University of Bangor in the UK, the Delft University of Technology in the Netherlands and Avionik Zentrum in Braunschweig, Germany. The European Commission has been approached for support in funding the development, and a solution seem to have been found. The actual development is expected to start in the next few weeks.

Eurofix Implementation In NELS

Another important initiative was the decision, in principle, to implement Eurofix in NELS. Eurofix is a new system making use of the data communications capability of Loran-C, combining differential GNSS and Loran-C so that the number of observables is increased. The implication of this is that if, for instance, only three satellites and two Loran-C pseudo ranges are available, the user is still able to calculate his three-dimensional position, whereas the two systems separately would fail to do so. Eurofix can also be used for distribution of differential GNSS corrections only and will in this mode be able to offer such corrections in the whole area of NELS coverage. Moderate modifications of Loran-C transmitters and receiver design are required to get the full effect of Eurofix. Eurofix is developed by European universities and a NELS working group is investigating the economical and technical consequences of introducing this system in NELS. As directed by the NELS Steering Committee, a specific proposal for implementation of Eurofix in NELS has been developed, and the issue is on the agenda for the 12th meeting of the Committee in Oslo later this month. A three step approach will be proposed, the first comprising stations Lessay, Sylt, Værlandet and Bø providing Eurofix coverage in all NELS nations and surrounding waters. This step will be completed and transmissions can start approximately 12 months after the decision has been made.

The second step comprise Eurofix on all NELS transmitters and a Eurofix Central Control station. This step will hopefully be addressed in the 13th meeting of the Steering Committee to be arranged in the spring of 1998. This step can be completed in 15 months. The third step is Eurofix coverage throughout the continent and surrounding areas through the use of Mediterranean Area stations and Chayka stations. Implementation of this step will have to be addressed at a later stage.

NELS Information System

The requirement for a professional information service to make NELS and Loran-C known to potential users has been on the agenda in NELS for some time. This aspect of NELS operation was again discussed at the 11th meeting of the Steering Committee and included in the strategy document as an action item for immediate attention. This action is directed towards a marketing plan including preparation of a booklet giving factual data on Loran-C and NELS, updating of a pamphlet distributed through IALA channels some time ago, standard exhibit material for use at exhibitions, professional shows etc., and the reintroduction of a NELS newsletter giving information on NELS related subjects and activities. We are presently in the process of producing the booklet and the pamphlet. Work with the marketing plan to co-ordinate all information, promotion and marketing activities will start shortly.

ENHANCEMENT OF LORAN-C COVERAGE IN EUROPE

European radionavigation policy as it is expected to be expressed in the European Radionavigation plan I have already mentioned, is directed towards achieving full Loran-C coverage of the European continent and adjacent areas. NELS represents the first step in that direction but, to reach full Loran-C coverage, additional avenues are being pursued. One is close co-operation with the Commonwealth of Independent States (CIS) in the use of their Loran-C equivalent system, Chayka. Another is continued operation and enhancement of the Loran-C transmitters covering the Mediterranean sea and adjacent land masses.

CO-OPERATION WITH CIS

Loran-C and Chayka operate on the same frequency and transmit similar navigation signals using the same time reference. In this respect the systems are interchangeable and their use, either alone or in combination, is transparent to receiving equipment. The area covered by the combined systems is significantly extended over what each system alone can provide. The system compatibility and extended coverage of the combined systems is the basis for close co-operation with the CIS.

Currently, fourteen Chayka stations are in operation in the CIS area forming the following four chains:

1. The European chain, comprising five stations located near the towns of Bryansk (Master), Pertozavodsk, Slonim, Simferopol and Syzran (secondaries);
2. The Easter chain, having four stations located near Aleksandrovsk-Sakhalinsky (Master), Ussuriysk and Okhotsk (secondaries);
3. The Northern chain, comprising four stations located in the vicinity of the town of Dudinka (Master), Taimalyr, Inta and the isle of Pankratiev (secondaries);
4. The Northwest chain, which comprises three stations located near the town of Inta (Master), on the isle of Pankratiev and in Tumanny (secondaries).

Agreement has been reached between the Russian Government, on behalf of the CIS and the Norwegian Government, to integrate the Tumanny station in the Russian Northwest chain as a third secondary in the NELS Bø chain, giving enhanced coverage north and east of the present NELS coverage in the Barents sea area. Agreement has also been reached between Russia and Germany to integrate the Slonim Chayka station in the European chain as a third secondary to the NELS Sylt chain. This enhancement will improve coverage in the Baltic.

Parties to these agreements recognise that there are many details to be addressed in the implementation of these plans but are determined to achieve the end goal of extended Loran-C/Chayka coverage.

THE MEDITERRANEAN Loran-C CHAIN

At present (1997) the operation of the Mediterranean Loran-C chain has not been resumed following the close down of the USCG Loran-C activity in the area. However, all stations are intact and some are occasionally operated for limited periods to meet special requirements. Work towards reopening of the Mediterranean chain is being pursued at inter-governmental level with the active support of the European Union and the International Association of Lighthouse Authorities. It is anticipated that operation will resume coincident with the publication of the European Radionavigation Plan presently under preparation.

THE EUROPEAN COMMISSION

The draft European Radionavigation Plan has been available for some time. I trust that the Conference attendees are familiar with the basic principles proposed in the plan and that LORAN-C is intended to play a role for different applications in the future mix of systems in Europe.

NELS is a system where 6 independent European nations co-operate They have joined NELS for different reasons. The common goal is to have NELS established in the configuration laid down in the International Agreement, that is a 9-station TOE controlled basic Loran C system. As the political and technical development introduces new aspects and new opportunities to Loran C service providers, decision-makers are faced with important decisions to be made in order to bring the system into the future, avoiding status quo which may put the future of Loran-C in Europe in jeopardy. As the ERNP is still only a draft, it should be kept in mind that the official national radionavigation policies within the 6 nations are not coherent. Still, the Steering Committee has in a very short time responded to important challenges as indicated above. But, in my opinion, this basis for the continued necessary development of Loran-C in Europe is fragile. The relatively short NELS history has provided evidence that it is not always possible to obtain the basis on which important decisions can be made within the desired time-frame. It is in this area the European Commission would play it's most important role. As the supernational element; to carry the continued development of NELS into the future co-ordinated as one element of the mix of systems in Europe. It is my hope that decisions at hand at European level can be made in the near future such that the Commission can get more directly involved in the process of development of the terrestrial European component.

THE FUTURE

The recent technological development has shown a great potential for Loran-C as the ground element of the future mix of systems in Europe providing sufficient integrity, availability, redundancy and continuity of services in a way impossible without Loran-C. My vision of the future is a Loran-C (Chayka) system covering the entire European continent, transmitting basic Loran-C services and Eurofix data (integrity messages and satellite corrections), operated co-ordinated with basic satellite services (GNSS) and satellite augmentation systems (EGNOS). Eurofix experiments made within NELS indicate excellent operational and financial suitability for the Loran-C/Eurofix to serve as the ground infrastructure for EGNOS.
Further, I can see the IALA radiobeacon dGPS services continue to provide semi-redundant system augmentation in restricted waters and harbour approaches.

How can we get there? Some of you will recall that draft conclusions of the Second International Radio Conference in Moscow in June this year embodied a paragraph defining the need for a multi-modal global basis for radionavigation planning covering the requirement for co-ordination of all present and potential aeronautical, marine, land and other use of radiopositioning services. In line with this conclusion the European Union has agreed to host a conference in support of active efforts to co-ordinate the various activities being undertaken all over the world on radionavigation systems and services. This is very much in line with NELS thinking, and I would like to use this opportunity to promote active American participation in such arrangement - addresses this side of the ocean will most surely be on the distribution list.

Supporting the global co-ordination of systems, which I think the Europeans should do, we must, in my opinion, co-ordinate our own regional activities much better than we do today. There are many players here today. The US operating GPS and Russia operating GLONASS. ESA engaged in development and later implementation of EGNOS. National authorities operating IALA radiobeacon dGPS systems. FERNS operating the Far East Loran-C system, NELS operating the Northwest European Loran-C system, and the CIS operating the European Chayka system. Potentially a SELS (South European Loran-C System) and EU in a growing key role, regionally embracing all systems and the total infrastructure, but also in local development activities. Resources are today being used to promote one solution and fighting other. The irony is that in all camps, there are representatives from the same nations fighting each other. In the end, all activities are funded by the same nations. Here is were I see the key role of the European Commission. We need the Commission to take the lead and join the forces.

Q: How were your Eurofix and Loran-C coverage diagrams developed?

Comments from various attendees: Eurofix coverage prediction may have been pretty informal. The range is at least 1000 km, except in the mountains. There is, of course, no network yet, and the coverage is just a forecast. The Loran-C coverage was done by Prof. David Last's group and NELS; see past ILA proceedings for the papers.

Q: You mentioned EGNOS. What is EGNOS really?

A: Think of the U. S. Wide-Area Augmentation System for GPS (WAAS); EGNOS is the European equivalent. The two are converging technically; their purpose is the same.

Q: When is the EU (Eurpoean Union) conference which you mentioned planned?

A: EU will hold the meeting. Invitations should be out soon, but there is no solid information now.

The Current Status and Future Perspectives of the Loran-C SELS

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BIOGRAPHY

Commander Minaudo graduated from the Italian State Institute of Navigation in 1971, he then attended the Navy Academy and as an Ensign he conducted Mine sweeping Operations.

In 1974 he left the Navy and moved to the Merchant Marine where as duly licensed Master - Ocean Going Captain, dealt with Bulk Carriers, Oil Tankers and LPG Tankers.

From 1978 through 1981, he was Professor of Navigation, Astronomy, Naval Construction and Naval Arts, he then went back to the Navy Academy and became a Harbour Master Officer.

In many Districts he dealt with Ship's Safety Inspections, Maritime Law Enforcement, Search and Rescue, Investigations, he was also on Command of Patrol C. G. Ships, Chief of Coastal State Properties Administration Office and Captain of the Port.

He created some Office Automation Systems, held courses about Computer Sciences and, as a Member of the World Association of Scientists, participated in Meteorological Forecast, Nuclear Physics and Radio Wave Earthquake Modification researches as well.

Lately he became a Loran-C Operators' Instructor, a Loran-C Chain Manager, a U. S. Navy Instructor and a U. S. C. G. Inspector for the Safety of Ships.

Early in 1997 he got the University Doctorhood H. C. in Electronic Engineering in New York.

ABSTRACT

The author discusses the Loran-C system in Mediterranean Sea after the stations of Turkey, Spain and Italy were released to host Countries by USCG and how they contributed to resume operations.

Furthermore the set up of a new office to manage the situation and to restore the signal in the whole Mediterranean Sea is shown, with appropriate management and maintenance of each station, including missing parts replacement, repairs, upgrading them.

The proposed statement of the involved countries to maintain the system up to the 2010 year, prompted the idea of finding alternative solutions to apparently missing stations.

The obvious threat of station's closure and consequent death of SELS pushed on meetings among Countries; new working groups were set up. They are considering old ideas for the improvement of the safety of life at sea, while connection of Loran-C and Chaika is being studied.

The creation of a SELS stems from the '92/143/EEC Decision and upgrading the old fashioned transmitters into solid state transmitters and new chain configurations are investigated and the North African Countries could significantly contribute to inland navigation.

INTRODUCTION

In 1988, June 16-17, the Italian Ministry of Merchant Marine Mr. Gianni Prandini met with the American Vice Transportation Department Secretary, Mrs. Mimi Weyforth Dawson, and with the State Assistant Secretary Mr. Frederick Bernthal for Ocean and Environment and Scientific Questions.

The main subject was about Loran-C and continuity of operations and cooperation between the U. S and the Italian Coast Guard, in order to improve the safety of life at sea and the continuity of the service after the stations had been released to the host countries.

In 1993 a few Italian Officers were trained at Petaluma USCG Training Center and in turn they trained all the operators that would later man the Italian stations.

A long on-the-job training was started at Sellia Marina and Lampedusa site and very soon we had operators ready to man all situations related with loran.

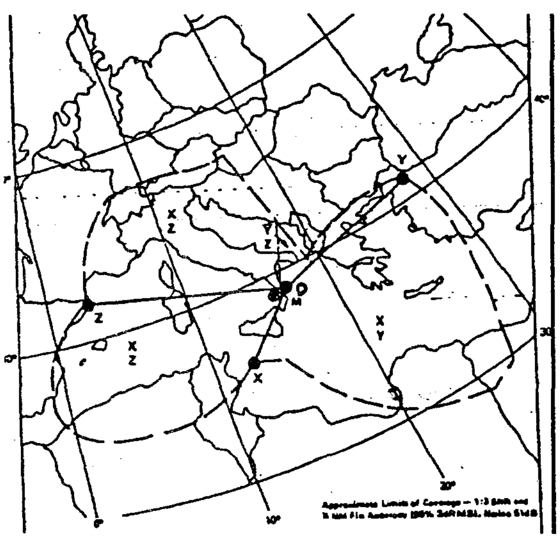
It was only on Nov. 17, 1994 that the Agreement for the transfer of the property from American to Italian Government was signed by Mr. Roberto Nigido for the Government of the Italian Republic and Mr. Janes F. Creagan for the Government of the United States of America.

About a month later, a disestablishment ceremony in both Italian stations took place and the USCG departed.

SITUATION ON THE TURN OVER

Enforced by the '92/143/EEC Decision, works were done to ensure continuity of the operations in the Mediterranean area, while the Mediterranean triad of stations was still composed of four well known stations: Sellia Marina, Italy (M), Lampedusa, Italy (X), Estartit, Spain (Z), Kargaburun, Turkey (Y);

Fig. no. 1: LORAN-C, GRI 7990, MEDITERRANEAN CHAIN



Estimated Groundwave coverage. SNR 1:3; Fix Accuracy 1/4 NM (95% 2dRMS); Atmospheric Noise 51. 2 dB above uV/m.

A new office organization was set forth in a very short time, acknowledging that agreements should have been signed among Italy, Spain and Turkey, replacing as much as possible the closed U.S.C.G. Acteur (Activities Europe) Office in London.

As soon as the U. S. Coast Guard left the stations, the excitement of broadcasting the signal ourselves was suddenly shut down, as no signal was broadcast at Estartit and Kargaburun and users expectations deluded.

Regarding Spain the proposal to manage Estartit with an Italian crew or to train a Spanish team of operators, although funded by the European Union has not yet got an answer. Regarding Turkey, the 625 ft antenna tower Italy supplied to replace the collapsed one, was never reerected.

While waiting for the European Radionavigation Plan to be issued we continued dealing with vacuum tube transmitters, and hard to find obsolete spare parts; but after great repairs were done we have brand new old fashioned equipments and towers.

Representatives met in Brussels in 1995 and 1996; more recently, Italy, France, Turkey, Russia and Ukrain, stated that they would maintain the system up to 2010.

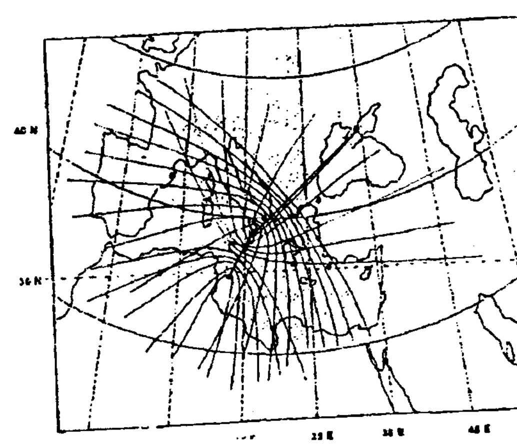
I think that the NELS (North West European Loran System) success is due to agreements between the involved countries, while upgrading the stations brought the first modern Loran-C system in Europe.

Ten years studies led us to consider implementation of the coverage as well as alternative solutions to the broken Medchain GRI 7990.

After the failure of the proposed Mediterranean-Black Sea Chain with Kargaburun on air again, an agreement between C. I. S. and Italy will connect Simferopol and Sellia Marina in spite of the great distance among them - more than 1500 km, partially on lands.

The calculations show that the signal - Sellia Marina/Simferopol - is strong enough to give a good position if intersected with the existing master/secondary pair - Sellia Marina/Lampedusa - stations.

Fig. no. 2: Sellia Marina, Lampedusa and Simferopol



Calculations show that a good coverage could apply to Adriatic Sea and Ionian Sea as well.

The first connection Simferopol - Sellia Marina is planned by the end of this year while additional investigations on the field will be made at Sellia Marina and Simferopol, using standardized equipments in static and dynamic positioning.

Furthermore, a mobile station available in Russia could be installed - istallation, tests and equipments - in a few months in Bulgaria if that country is chosen to be the best place to replace Kargaburun; political and legal considerations has to be taken into account.

The western side of the Mediterranean, where Spanish cooperation is lacking, brought the threat of a possible closure of both Italian stations; but France, the European Union Commission and Italy started a working group which found that a new station near Perpignan, France, would be suitable and would supply loran users with new hopes.

Should a three months on-the-field measurement campaign start and the resulting project approved, six months are needed for the building and facilities when a place is found, and two months are needed to erect the antenna and to install the transmitter. In one year span we could have a 250 KW brand new station.

Resuming the Medchain 7990 would remind the Mediterranean Sea mariners the great value of a radionavigation aid which provides assistance for the safe completion of voyages and reduces the probability of collisions, grounding and other accidents with threaten loss of life, property, pollution of the marine environment [1]. By improvement of safety in aviation and land transport the most direct and economical route to the destination, is ensured.

HYPERBOLIC SYSTEMS

The development of Loran-C/Chaika chains in Northwest Europe, India and Far East have made the system the most likely to be used as a terrestrial back-up or complementary system to Global Navigation Satellite Systems. Although the United States decided to discontinue the loran after 2000 further expansion of coverage may come in Europe and Asia, in Mediterranean, Black Sea.

To provide the continuity of the system low cost modular receivers should be available with ASF corrections for the effect of landpath incorporated and integrated with GNSS by manufacturers.

Satellite systems are too vulnerable to use; a terrestrial system could depend on what it can add to the overall mix of systems. Some times low frequency signals are more robust and the effects of the next solar maximum approaching around 2000, on the different systems could be a determining factor. The effect of predicted increasing levels of the next solar maximum activity could result in damage to satellites and in the immediate future temporary disabling effects of geo-magnetic storms [2].

The Selective Availability in the GPS has been announced to be released within the next ten years, but it will be replaced by "measures" to prevent hostile use. What an effect will those "measures" have?

Hybrid receivers providing combined fixes from both the present systems should be available at low cost, to enhance integrity and availability.

LORAN-C/CHAIKA AS A CARRIER FOR DGNSS

The existing Loran-C infrastructure may with some minor changes become a very powerful augmentation system for GPS, GNSS and GLONASS.

The renewed interest in the broadcasting differential corrections using loran-C signals originated in the US Coast Guard and took place in the Netherlands at the University of Delft [3]. Demonstrations of Eurofix have shown potential accuracy better than 10 metres over ranges of up to 1000 km.

Altering the position of some of the pulses with a computerized modulation technique, we can transmit differential corrections for satellite navigation systems. This concept was developed at Delft University of Technology - in The Netherlands - as part of the Eurofix project.

As the first two pulses of each Loran-C group of Eurofix modulation are meant for the blinking service only, the theoretical data transmission, with six available pulses and the low frequency of the system ranges from 175 to 70 bps suitable to carry GNSS integrity correction data. As the Loran-C band is subject to high atmospheric noise and

Fig. no. 3: A chart of Sicily, 1608

interference, the reliability of the data transmissions is improved by forward error correction, without affecting the Loran-C performance significantly.

Several alternatives and commercial services provided spot-beams from geo-stationary satellites (Racal Marine Star, Fugro Starfix) while the wide area augmentation systems (WAAS, EGNOS, MSAS) will provide integrity warnings and DGNSS by about 2000. There are other commercial DGNSS services using FM broadcast transmitters, cellular radio, as well as LF and HF transmitters.

Users can expect DGNSS accuracy better than 5 meters (95%) as the Additional Secondary Factor values of the Loran-C propagation can continuously and accurately be updated.

Transmission of DGNSS data is technically feasible with fewer loran stations and therefore less equipment than with radiobeacons, but radiobeacons are already internationally accepted, for maritime navigation as a means of transmitting DGNSS, while at present Eurofix and loran/chaika cannot be expected to become a world wide accepted standard: Eurofix can only be a European system.

Potential accuracy of the two systems seems very similar but availability of Eurofix is not yet known and a back-up system is needed.

FUTURE PERSPECTIVES

As we failed to resume operations in the Mediterranean Sea after the USCG dismissed the stations, it is very hard to make predictions about the future.

A temporary configuration, setting Simferopol on the same Mediterranean GRI - as an alternative to Kargaburun - may bring new hopes, but the coverage will be limited to the Adriatic and Ionian Seas, while the Western Mediterranean Sea still suffers from the loss of Estartit station; the cooperation with France, to establish a new station near Perpignan may contribute to maintain the system up to 2010 stemming from the '92/143/EEC Decision of February 25, 1992.

We have seen technological progress of radio broadcasting system and receivers during the years.

The Mediterranean is still dealing with old fashioned transmitters: AN/FPN-39 at Sellia Marina, Estartit and Kargaburun, and AN/FPN-44A at Lampedusa - a technology that assembled in the '60s is the effort of the early '50s.

Planning for a future loran, what a kind of future European plan can exist if the perspective is a solid state transmitters of the early '70s?

The United States of America announced to dismiss Loran by 2000; although they may change opinion, the impact on the media led shutting down studies for receivers and researches for a better technology in the broadcast system in America and in Europe.

Power generators for vacuum tube transmitter are five times more expensive than for solid state transmitters. The problems with very low frequency (VLF) broadcasting are well known together with big antenna towers, and very high power is necessary due to fading effect and combination of land and sky waves reflected at the ionosphere "D" strata[4].

Are the different advanced technologies from geostationary orbits in the Clark band and their signals, fully available?

Loran simple technology still exist and a sequence of signal from different station may be received by a relatively simple receiver. Different systems in the same receiver could of course positively affect the makes. The impact on the environmental protection and redundant and complementary system could help to improve the safety of life at sea.

Approaching the 2000 are we to install solid state transmitters (70's technology) or should we ask for new equipments which could better fit into our age?

High integrated electronic systems' construction technologies are so innovative to permit the production of CMOS semiconductors with less than 0.35 microns channels and different levels of metallization that allow 200 picoseconds propagation delay and incredibly low energy consumption.

Such technologies may allow the production of microcontrollers which may incorporate one or more DSP (Digital Signal Processing) whose hard task is to clear up the received signal with special algorithms.

Microcontrollers will then deal with the opportunity to choose land or sky signals in order to display correct calculated position coordinate. This type of integration will always make radionavigation easy and safe.

The easier for users, the harder for VLF providers who are obliged to make choices that do not correspond to the actual "low power/full integration" technological tendencies.

Recently, field effect power semiconductors have been experienced to guarantee low channel resistance within the conductive status that make them a valid alternative to controlled diode devices now employed in the most modern power RF Loran-C transmitters.

An analogous power handling problem exists in the professional broadcasting of terrestrial radiophonic and radiotelevision systems where thermoionic tubes result practically irreplaceable in handling high levels of RF energy with great reliability and low costs.

The problem of energy loss related to signal broadcast with short antenna systems where the radiating monopole is less than one fourth of wave length [5] will be overcome in the next future.

Once this result has been achieved we could replace the old vacuum tube transmitters with new technology that would also bring new providers to the systems. As Lampedusa station was installed to replace the Libyan dismissed station a new constellation of low cost automatized stations could be installed along the North African Coasts for sea and inland navigation. Ten years studies demonstrated that the Mediterranean Sea could very easily become the safest area, provided an organization like the above mentioned SELS is born and all Countries facing it are equally invited to become active members.

Coordination among countries could be fostered through the European Union or the IALA Organization as a follow up of the '92 Decision and the issue of the European Radionavigation Plan.

ACKNOWLEDGEMENTS

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Q: Is it true that if nothing happens, Italy will shut down its stations?

A: We need to modernize. There are no spare parts. We're replacing the Lampedusa tower; it's a lot of money but will do it, because we promised to do it. Other countries should also follow up on their promises. We need a connection with Chayka stations to get coverage, or closure will result. The EC is confusing; many documents are produces, but each has a different architecture.

We want to continue to 2010. We need to go to solid state systems, to reduce cost.

Q: Is there any interest in North Africa?

A: In early 60's the Libyan station was moved to Lampedusa. I have asked the EC to talk with North African countries; Tunisia and Egypt may be positive. However, three years have passed, and nothing is solid.

Mr. Kruuse, IALA: IALA would be able to hold a meeting to determine the requirement. IALA is also waiting for EC to act on their providers' meeting. Maybe IALA should host the meeting.

Mr. Minaudo: Everyone is looking at satellites now, but with concerns about solar effects, interference. We need agreements among countries.

Comment from the floor: It is sad that EC is not represented here. They need to take the lead. NELS experiences difficulties all along; we need to finalize giving loran a place in the EU structure. EGNOS is developing. There is not much time to incude loran in the system. EC commissioners need to hear now.

Session 3: Radionavigation Plans and Policies (B)

Session Chair: Torsten Kruuse
Secretary-General, IALA

Session 3: From left: Fred Forbes, David Gray, Torsten Kruuse, Christian Forst, Larry Barnett

Loran-C in The Baltic Sea: A Joint German-Russian Cooperation
Dipl. Ing. Christian Forst, Wasser-und Schiffahrts Direktion Nord

Update -- U.S. Congressional Action on Radionavigation
Larry Barnett, AB Management Associates, Inc.

Defending Loran-C in Court
David H. Gray, Canadian Hydrographic Service

Avoiding the Rocks: The Canadian Coast Guard DGPS Project
Fred Forbes, Chief, Navigation Systems, Canadian Coast Guard

LORAN-C in the Baltic Sea
A Joint German – Russian Cooperation

Christian Forst

BIOGRAPHY

Mr. Christian Forst graduated from the Technical University Aachen, Germany, with a diploma in electrical engineering in 1989. After his studies he worked as a research fellow on an industrial research program for high-power laser and microwave technology. In 1993, Mr. Forst joint the Federal German Waterways and Shipping Administration. He is the Deputy Head of the maritime Aids-to-Navigation Department within the Directorate North, Kiel. As a program manager for Loran-C in Germany he is Head of the German National Operating Agency for NELS and in general responsible for radionavigation systems implemented and operated at the German coastline.

ABSTRACT

The German Radionavigation Concept for Maritime Safety requires the provision of two complementary radionavigation systems - a GNSS Augmentation System and a terrestrial-based system.

With the introduction of the Northwest-European Loran-C System NELS most parts of the German waters are covered by LORAN-C. In order to provide a LORAN-C coverage in the western and southern Baltic Sea and to improve the performance of NELS in certain areas a co-operation with Russia is intended to add the most western Chayka Station Slonim as an additional Secondary to the NELS Sylt Chain.

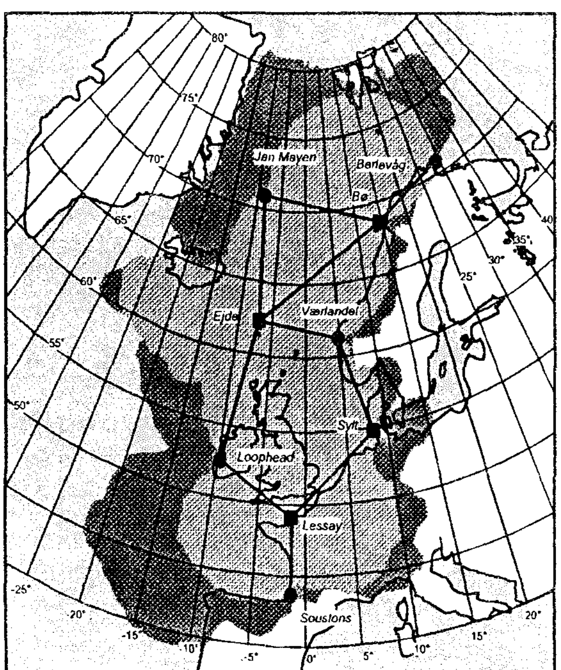

Fig. 1: Predicted coverage of the NELS Loran-C System

INTRODUCTION

In 1992 six European Nations agreed two establish the Northwest-European LORAN-C system NELS. US Coast Guard Loran-C Stations were taken over, and new stations were built. As a result, a highly reliable Loran-C system is available in Northwest Europe. The German North-Sea coastline and parts of the Baltic Sea are covered by the NELS Loran-C system (fig. 1).

Germany operates the LORAN-C Station at Sylt, which was built by the US Coast Guard in 1961 and taken over by the Federal Waterways and Shipping Administration as of January 1, 1995. The station was completely modernised. A new Megapulse solid-state transmitter was installed, the antenna was replaced and the infrastructure was updated.

In addition to Loran-C a second terrestrial radionavigation system is available in some parts of Europe - the Russian Chayka system, in particular the European Chayka Chain, GRI 8000 (fig. 2).

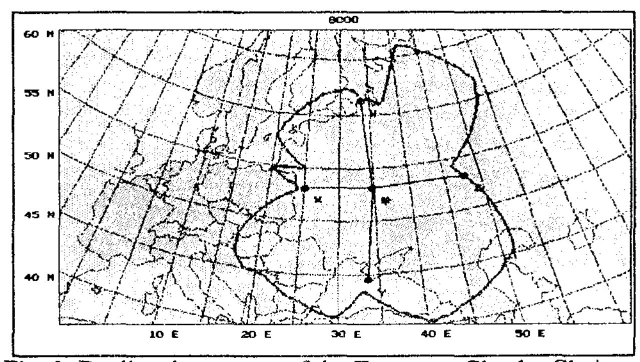

Fig. 2: Predicted coverage of the European Chayka Chain

The most western station of this chain is located close to the city of Slonim, Republic of Belarus.

The main idea which led to a German–Russian Co-operation is to link the NELS system and the European Chayka Chain by adding Slonim as an additional Secondary to the NELS Sylt Chain.

NEED FOR LORAN-C / CHAYKA IN THE BALTIC SEA AREA

The German Radionavigation Concept for Maritime Safety [1,5], which was introduced by the Federal Ministry of Transport, stated that maritime safety requires the provision of two independent, complementary radionavigation systems. The most appropriate ones are a GNSS Augmentation System – DGPS and/or DGLONASS - and a terrestrial-based system - LORAN-C and/or Chayka. This is in accordance with the relevant decisions of the European Union (EU) [2], the

International Association of Lighthouse Authorities (IALA) [3] and the German Radionavigation Plan [4].
The expansion of the NELS Sylt Chain by adding the Slonim Chayka Station as an additional Secondary will result in an:

- Expansion of the LORAN-C coverage in the western and southern Baltic Sea Area
- Increase of achievable accuracy in certain areas
- Increase of availability

Almost the entire Baltic Sea should be covered by LORAN-C or Chayka (fig. 3).

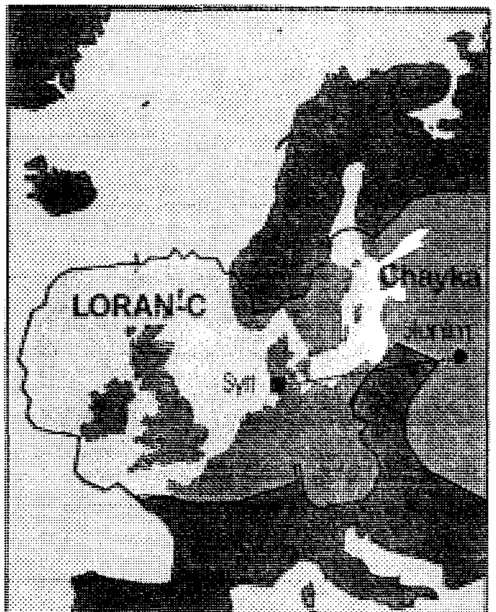

Fig. 3: Predicted LORAN-C / Chayka coverage in the Baltic, Joint Sylt Chain, European Chayka Chain

Having the shutdown of the DECCA System end of 1999 in mind, the expansion of the LORAN-C coverage in the Baltic Sea is strongly required.

PREPARATORY MEASUREMENTS IN 1996

In preparation of the expansion of the NELS Sylt Chain preparatory measurements in the Baltic Sea Area were carried out in 1996.

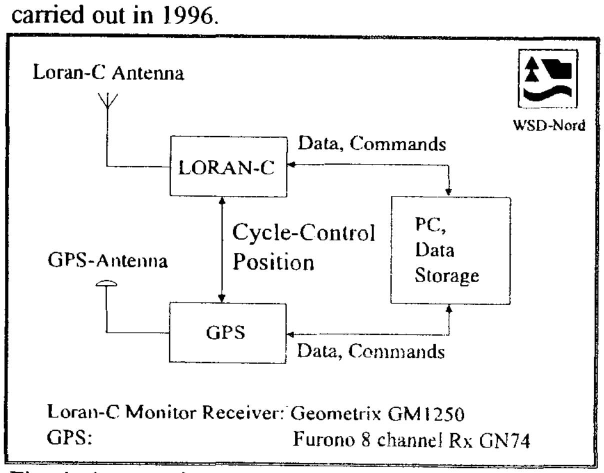

Fig. 4: Automatic measurement system

Focus was laid on the evaluation of the signal quality to be expected. The parameters of main interest were the signal strength and the Signal-to-Noise ratio.

An automatic measurement system, based on a Geometrix GM 1250 Monitor Receiver, was installed on commercial vessels on regular schedule in the Baltic Sea (fig. 4).

Although the performance of the measurement system was not as good as expected some important statements can be made:

- The signal of the NELS Vaerlandet Station in the western and southern Baltic Sea area is weaker than predicted. This is first of all due to the poor conductivity of the mountains in south Norway.
- The signal strength of Slonim as of today is sufficient in the western and southern Baltic Sea. The power level of the upgraded Slonim Station will not be less than today.

To assure a high level of service, the expansion of the NELS Sylt Chain by Slonim is required.

The Joint Sylt Chain

The Joint Sylt Chain will consist of: Sylt (Master), Lessay (Secondary), Vaerlandet (Secondary), Slonim (Secondary), GRI 7499.

The new baseline will in the beginning be operated on the basis of a bilateral German-Russian agreement. It is however intended to integrate the Slonim station into NELS as soon as possible.

In December 1996, a bilateral German-Russian Declaration of Intent concerning the establishment and operation of the Joint Sylt Chain was signed in Kiel, Germany.

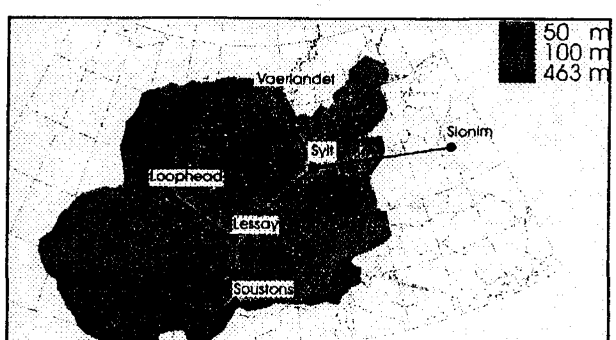

Fig. 4: Predicted coverage of the Joint Sylt Chain and the Lessay Chain

REALISATION OF THE JOINT SYLT CHAIN

The Chayka Station Slonim will be operated as a:

- Secondary in the NELS Sylt Chain, transmitting a LORAN-C signal according to the NELS signal specification [7], controled and synchronised by the NELS Control Centre Brest

- Secondary in the European Chayka Chain, transmitting a Chayka signal, synchronised according to the procedures established for this chain.

The main technical characteristics for the modernised Slonim Station are:

- One transmitter, capable to transmit LORAN-C and Chayka signals
- TOE-Control as applied throughout NELS for the LORAN-C rate
- A 32 HCG transmitter designed in accordance with the Megapulse SSX 6500 Tx, meeting the NELS standards and manufactured/assembled by A/O Gradient, St. Petersburg, Russia
- The on-site monitoring and control equipment will be in accordance with the NELS standard
- Communication will be realised via the VSAT system

THE WAY AHEAD

For the preparation of the required technical specifications an international Technical Working Group with representatives from Germany, Russia, France and Norway was established. It is expected, that the main specifications will be available end of 1997.

Megapulse Inc. Bedford, USA, and A/O Gradient St. Petersburg, Russia, will demonstrate the possibility to generate and control a LORAN-C as well as a Chayka signal with one transmitter.

In order to verify, that the TOE-Control can be applied for the new baseline, measurements are on the way at Sylt and Slonim, to evaluate the signal quality of the Slonim signal and vice versa.

International contractual negotiations have started and are likely to be finalised in 1998. It is the common intention of Germany and Russia, to bring the new baseline into operation until end of 1999.

CONCLUSIONS

By adding the Slonim Chayka Station to the NELS Sylt LORAN-C Chain as an additional Secondary, the availability and achievable accuracy of LORAN-C in the Baltic Sea will be considerably increased.

The land coverage over western Europe is significantly enhanced.

The application of NELS standards will guarantee a high quality of service.

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[4] Deutscher Funknavigationsplan 1996, Avionik Zentrum Braunschweig im Auftrage des Bundesministeriums für Verkehr

[5] C. Forst, The German Radionavigation Concept for Maritime Safety, Planning for Global Radionavigation, Moscow, June 1997

[6] Y. Nikulin, C. Forst, LORAN-C/Chayka – The Russia/German co-operation in the Baltic Sea, Planning for Global Radionavigation, Moscow, June 1997

[7] NELS Specification of the Transmitted LORAN-C Signal, NELS CA, S-006-2, 20 October 1995

Update - U.S. Congressional Action On Radionavigation

Larry P. Barnett
President
AB Management Associates

BIOGRAPHY

Larry P, Barnett, President, AB Management Associates in Washington, D.C., has 30 years of airline, trade association and aviation experience. Prior to starting his own business, Mr. Barnett spent 15 years at the Air Transport Association (ATA), the trade association of the scheduled airlines of the United States and, as Vice President of Government Affairs, had responsibility for both federal and state legislative activities on behalf of the airline industry. Since leaving the ATA, Mr. Barnett has continued to do aviation public affairs, marketing and lobbying work in Washington and, at present, he heads his own aviation government affairs and marketing company, AB Management Associates, Inc.

Mr. Barnett is a Trustee and member of the Board of Directors for the Aero Club of Washington D.C.; a member of the Board of Directors for the Aero Club Foundation; a member of the National Aeronautics Association and the Air Traffic Control Association. He holds a Bachelor of Science Degree from the University of Florida and serves on the University's Government Affairs Advisory Board in Washington.

I. INTRODUCTION

Nearly 50 years ago, Harry Truman said: "If you want a friend in Washington, get a dog". Jane Garvey, the new Administrator of the Federal Aviation Administration (FAA) has put a little different spin on Washington friendships. One of her favorite lines: "In Washington, a friend is someone who stabs you in the chest."

Just as was the case a year ago when we met it remains clear there's a wide difference of perspective among the U.S. Congress and users, on the one hand, versus key officials in the Administration and at the FAA and Coast Guard about the future of the Loran-C system.

II. POLICYMAKERS AND POLICY

The bad news is that much has happened but little has changed with respect to Administration policy related to Loran. The encouraging news is that some of the key policymakers have changed.

First, Frank Kruesi, Assistant Secretary for Transportation Policy -- and a major opponent of Loran -- has left his post at the U.S. Department of Transportation (DOT), and returned to Illinois to take on new responsibilities. It is much too early to even speculate about a successor to fill his slot at DOT.

We also have a new Secretary of Transportation, Rodney Slater. Mr. Slater served as Federal Highway Administrator just prior to being named as DOT Secretary. He is well-respected by the Clinton Administration and seems to have his the ground running in his new job. As I mentioned earlier, there is also a new FAA Administrator, Jane Garvey. She has only been in the job a few months and although she has relatively limited aviation experience, seems determined to get her arms around this very complex and difficult job. She has spent her early days in office reaching out to the broad range of aviation interests and organizations and soliciting their input and ideas.

The other key post at the FAA -- the Deputy Administrator -- has been vacant since the end of January when Linda Hall Daschle left the Agency. The nominee for that job, Dr. George Donohue, has been the subject of some controversy and criticism resulting from cost and schedule problems that have arisen in conjunction with the Wide Area Augmentation System (WAAS) program., as well as some personnel related problems that he is embroiled in at the FAA. As a result, his nomination has been twisting in the wind for months. The U.S. Senate must give its advice and consent to this nomination. the first step in that process is a confirmation hearing by the Senate Commerce Committee. No hearing date has yet been scheduled and future action on this nomination is uncertain.

In any case, there is little likelihood that Administration policy will shift much with respect to Loran with these changes in key policymakers. Nonetheless, we may, at the very least be provided a new opportunity to outline the merits of our case and get a fair audience.

III. POSITIVE POLITICAL PROGRESS

I am pleased to report to you that we are starting to see positive results with respect to some of the Loran-related legislation that enacted during 1996 and that we spent a considerable time reporting on at the International Loran Association Conference in San Diego last year.

You will recall that $4.65 million in added resources -- new money -- was provided to the FAA for Loran in the FY 1997 DOT Appropriations Bill. Those resources were ultimately transferred to the U.S. Coast Guard and are being put to good use in initiating some necessary Loran upgrades and revitalization work.

Work is finally underway in conjunction with statutory provisions included in last year's Coast Guard Authorization legislation that was fashioned to assure a continuing role for Loran and revitalization of the infrastructure. Since we will be hearing from a Booz-Allen and Hamilton representative who is involved in some work that they have been tasked with in helping to develop the Loran Plan mandated by statutory provisions included in last year's Coast Guard bill, S. 1004.

Importantly, the U.S. Congress remains supportive of our Loran objectives. In fact, we are seeing an increasing willingness by more members of Congress to be vocal in support of Loran. I would be remiss if I did not note that it has been a bonus for our efforts to have ILA members being very aggressive and helpful in stimulating Congressional support and advocacy for our perspective on the continuing role envisioned for Loran.

A word about one of most our most active champions. Senator John Kerry, a Democrat from Massachusetts, perhaps more than any other member of Congress has continued to work on our behalf. He remains interested in supporting steps to advance our efforts and he has continued to have key staff working closely with us day in and day out on the issue.

It is also noteworthy to acknowledge the increasingly solid support we're seeing for continuation of Loran from a long list of organizations and user groups. That support is being well-demonstrated in comments being submitted to Booz-Allen and Hamilton (BAH) in conjunction with work that, as mentioned before, is now underway as a result of provisions in last year's Coast Guard authorization bill.

At the September 8-9, pitifully publicized, two-day Loran meeting hosted by BAH, aviation groups including the Aircraft Owners and Pilots Association (AOPA) -- which represents about 340,000 general aviation pilots -- the Helicopter Association International (HAI) and the National Business Aviation Association (NBAA), emphasized that Loran remains a necessary and logical choice to be part of the navigation mix well into the next century. A broad cross-section of the marine community including BOAT/US, speaking on behalf of 12 million recreational boaters, said they need Loran. National Weather Service (NWS) and military representatives said they are using and need the technology. Very compelling testimony from other witnesses representing telecommunications and utility interests demonstrated that virtually the entire economy is touched by Loran because showed most of the telephone and power companies rely on Loran.

IV. 1997 - ACTION IN U.S. CONGRESS

Working with interested members of Congress remains our best alternative for success in maintaining visibility on the issue and getting positive support for our objectives.

With guidance from the ILA, we have set and are pursuing realistic goals for the 105th Congress. Before getting into a review of congressional action this year, a couple of reminders about the process in the U.S. Congress.

Congress meets in two-year sessions.
This year, 1997 is the First Session of the 105th Congress. As is often the case in the first session, there is a lot of activity, many hearings, considerable oversight and much legislation is introduced. In fact, thousands of bills are introduced but most issues are not brought to closure. All legislation, anything not acted on or finalized in 1997, will simply carry over to 1998. The only legislation that is so-called "must pass" is FY 1998 appropriations legislation on the 13 funding bills for the various Federal Government's departments, agencies and programs, along with some authorization legislation.

One substantive reminder, again this year, about the difference between authorizing and appropriations legislation. *Authorizing* legislation establishes or continues a federal program and sets maximum spending limits annually or for the life of the program.

The purse strings are held by the Appropriations Committee. *Appropriations* legislation actually provides money for a program. Appropriations acts provide for agencies to incur obligations and to make payments out of the U.S. Treasury for specific purposes.

Remember, the bottom line is there is underlying law providing basic authority for most of the FAA and Coast Guard programs to carry out their missions and programs even in the unusual circumstances when the authorizing committees in Congress run into an impasse while trying to pass authorizing legislation. That's why the Appropriations Committee can do its work.

As to Congressional action this year, we continue to focus our energy on primarily two legislative vehicles. The FY 1998 DOT appropriations bill and the Coast Guard authorization bill. Peripherally, we are also interested in any hearings by the House and Senate Aviation Subcommittees. Because there was considerable attention focused on an October 1, 1997 Hearing on the cost and schedule problems of the WAAS program, I will provide a brief report on that recent hearing held by the House Aviation Subcommittee because it is pertinent to the Loran situation.

Beginning with H.R. 2169, the FY 1998 DOT Appropriations Bill. The U.S. House of Representatives included $5 million to continue Loran revitalization. The House Report that accompanied that measure noted that $4.65 million was provided for Loran upgrades and it says it is meritorious to continue the effort. Because Congress was fully focused on major budget and tax legislation most of the early part of the year, the traditional appropriations process got bogged down and way behind schedule.

Normally, the U.S. Senate waits for the House to complete action on the DOT bill and then that body uses the House bill as a basis for its version of the DOT appropriations bill. Because of the schedule delays, the Senate approved a separate bill this year. It was silent on Loran funding.

The differing versions of the legislation have to be reconciled by House/Senate Conferees. Our goal has been to work to have the Conferees adopt the House position, providing $5.0 million for Loran. Final Conference action on H.R. 2169 should have been completed by October 1, the beginning of FY 1998. Because several controversial provisions remain unresolved, final Conference action is pending. Until there is agreement on everything there is no agreement on anything.

We have been hearing encouraging reports indicating that funding will be provided to continue Loran upgrade work. Normally, on issues like this, the conferees will split the difference between the House and Senate funding parameters. As a result, it is possible that $5 million will be provided but it is more likely that about $3 million will be agreed to in the final Conference Report.

Because only four of 13 appropriations bills were enacted by the beginning of the new fiscal year on October 1, a stopgap funding bill had to be approved to permit funding to continue and to prevent a government wide shutdown.

A 23-day Continuing Resolution was approved in order to provide additional time for work to be completed on the remaining bills, including the DOT measure. That bill permits current levels of spending to continue.

Technically speaking, under the terms of the Continuing Resolution, Loran would be provided funding of as much as $4.65 million this year if final action on the FY 1998 DOT bill was derailed. The truth is, that is highly improbable.

It is expected that final action on H.R. 2169 will be completed, perhaps as early as this week. The measure will be sent to the President and he is expected to sign it.

Turning now to the Coast Guard Authorization legislation. I would note at the outset that last year the Coast Guard bill was omnibus legislation that included many provisions objectionable to the Administration and to the Coast Guard. The Loran provisions, undoubtedly, were among those not supported by the Coast Guard.

This year, the Coast Guard bill is expected to be less ambitious and less controversial. A relatively "clean bill", H.R. 2204, has been approved by the House Transportation and Infrastructure Committee and is now pending floor action by the U.S House of Representatives. It is anticipated that the U.S. Senate Commerce Committee will also seek to act on a "clean bill although no action has been taken as yet. We have had reports that Committee action could be scheduled this week. Congress has set November 7, 1997 as its tentative adjournment date for the year. As a result, final action on the Coast Guard bill is uncertain. If, as is the target, a non controversial measure is approved by both the House and the Senate, final action is possible. In any case, we will be alert for any chance to advance our Loran objectives and will be working hand-in-hand with Senator Kerry's office if such an opportunity arises.

The last matter on which I wish to report is the WAAS Hearing held October 1 by the House Aviation Subcommittee. the Following witnesses participated: The FAA, its contractor Hughes, U.S. DOT Inspector General's Office, General Accounting Office (GAO), Department of Defense, Professor Brad Parkinson, Air Transport Association (ATA) and the Aircraft Owners and Pilots Association (AOPA).

Generally, the government witnesses testified as to a recognition and concern about significant cost growth and schedule problems with the WAAS program. Nonetheless, at this juncture, the government witnesses advocated continuation of the effort, indicating that the cost/benefits of the program outweighed its liabilities.

ATA expressed the strongest opposition to the WAAS program, restating its position that work should stop and a "time-out" be held at the end of Phase 1 in order to assess the viability of the remainder of the effort.

AOPA, indicating its support for WAAS, also made a strong case for the need to assure a continuing role for Loran as a safety enhancement and as cost-effective, proven complement to satellite technology.

In a summary of subject matter prepared as background in advance of the hearing for members of the House Aviation Subcommittee many of the problems with this program that have been aired publicly in recent months were validated.

Significantly, the following table included in the Committee material indicated that the WAAS contract cost has increased 94% (from $250 million to $484 million, about $234 million) from 1994. The total program cost has increased 59% (or $354 million) during the same period. The life-cycle cost of WAAS has increased by 72% (or $1.011 billion).

(Table 1)
WAAS Cost Estimates
(dollars in millions)

	1994 prior to contract award	1995 Wilcox Contract	1997 Hughes Contract
Contract Cost	$250	$475	$484
Program Cost with F&E money	$556	$596	$892
Program Costs with F&E and O&M money	$604	$782	$958
Life-Cycle Cost	$1,400 (through 2014)	Not available	$2,411 (through 2016)

The Committee material also points to risk areas for future cost growth and delays, indicating that many experts, including GAO, believe there is high risk for future cost growth and delays. One cited is the need for four additional GEO satellites. No contract has been signed for these satellites. Software development is also cited as another risk area.

Important concerns and questions also remain about the DOD position on a second frequency, the impact of solar activity and jamming. In fact, the Subcommittee has expressed the need to hold a closed hearing on matters related to jamming and security.

The staff background material also outlined specific examples about how the FAA has misled Congress concerning cost growth, program delays, milestones, precision landing capability requirements, budget gimmicks and the costs and timetable for decommissioning ground-based navigation systems.

V. ACTION/GOALS

- Push for positive user input to BAH.
- Attempt to build a constructive dialogue with the new DOT Secretary, FAA Administrator and other policymakers.
- Heighten visibility about communications and timing related Loran applications.
- Work hand-in-hand with ILA members, other advocates to broaden and win additional bipartisan Congressional support.

VI. CONCLUSION

At the end of the day, as much -- perhaps more -- will turn on politics as substance on the Loran issue. Congress has demonstrated a good track record on our behalf. It can shape and alter policy. Importantly Congress holds the purse strings. I urge you to stay in close communicate with your members of Congress as often as you can and at every opportunity.

I will leave you with this thought. General Charles de Gaulle, French President and statesman said: "I have come to the conclusion that Politics is too serious a matter to leave to the politicians"

Q: You mentioned Booz-Allen and Hamilton (BAH) needing hard data. There is hard data in the recent Powerboat magazine survey.

A: We provided that data to BAH.

Q: Has the policy (U.S. intent to shut down loran) been put on us at the top?

A: The new leaders at DOT and FAA are a plus; we can educate them. Congress holds the cards (the money). They are helping, whether the policy changes or not.

Q: What else should we do?

A: We have lots of evidence for the claim of good cost benefit, and we want to supplement GPS. Legislative language says to take full benefit of the common elements. Eurofix can help, also. Write your congresspeople.

Q: What about Critical Infrastructure Program.

A: Yes, it helps to have the CIP saying that we need a backup, but Congress still has the $. We can augment the discussion with CIP.

Committee on Transportation and Infrastructure

Congress of the United States

House of Representatives

Room 2165, Rayburn House Office Building
Washington, DC 20515

MAJORITY (202) 225–9446
MINORITY (202) 225–4472
http://www.house.gov/transportation/

September 26, 1997

MEMORANDUM

TO: Members, Aviation Subcommittee

FROM: John J. Duncan

SUBJECT: Hearing on Allegations of Cost Overruns and Delays in the FAA's Wide Area Augmentation System (WAAS). Hearing scheduled for Wednesday, October 1, 1997, 9:30 a.m., 2167 Rayburn House Office Building.

PURPOSE

Potentially, one of the most beneficial modernization programs the Federal Aviation Administration (FAA) is currently undertaking is the Wide Area Augmentation System (WAAS). The WAAS program will replace the current ground-based aviation navigation equipment and allow aircraft to navigate with the use of satellite technology. This program promises to provide more fuel-efficient routing of flights while increasing airport and airspace capacity. The hearing will provide a forum to discuss the program's cost increases, schedule delays, and benefits.

BACKGROUND

The Aviation Subcommittee held a hearing on the WAAS program two years ago. At that hearing, the FAA witness stated, "We expect work on the first phase of the WAAS contract to be completed by early 1998." FAA's current estimate is that Phase I will now be completed by March 1999 – one year later. In 1995, the WAAS program was estimated to cost $604 million. The current estimate is that the WAAS program will cost $958 million – a 59% increase.

Several of the FAA's equipment replacement programs have experienced cost increases and delays in the past. The most dramatic was the program to replace the air traffic control computers and displays. This program was originally called the Advanced Automation System (AAS) and was to be operational in 1993 and cost $2.5 billion. The program has been restructured so that many of the original functions have been dropped and it may cost over $7 billion and not be completed until after the year 2000.

The Committee has followed the WAAS program with the hope that it would not fall prey to the problems of AAS. However, the cost of the WAAS program is increasing, it is one year behind its original schedule, and there are significant concerns that it will experience additional delays.

WAAS

WAAS will allow aircraft to navigate using satellites. WAAS is a system that builds on, or augments, the Department of Defense's (DoD) Global Position System (GPS) satellites. The GPS is a group of 24 satellites in six orbits at approximately 11,000 miles above the earth. A GPS receiver takes in the radio signals transmitted by the satellites to determine the receiver's location anywhere on or above the earth's surface and in any weather condition.[1]

[1] Each satellite is equipped with information on where it should be located and an extremely accurate clock. When the GPS receiver gets the GPS signal, it knows the time it took to be transmitted. This information from more than one satellite allows the receiver to know its location through a process of triangulation.

GPS receivers can be installed on aircraft.

Currently, however, GPS does not meet all of the requirements for civil aviation use, and therefore can only be used as a supplemental means of civil navigation. That means pilots must continue to rely on the old ground-based radars and navigation systems.

GPS's main shortfalls are its **availability**, **integrity**, and **accuracy**.

Regarding **availability**, there are not enough satellites in the system to guarantee that the necessary 4 to 6 satellites are in range to transmit the necessary radio signals to the aircraft navigation equipment.

The GPS **integrity** is lacking because it can not adequately provide timely warnings to users about the system's malfunctions. For instance, if an aircraft is receiving navigation information to perform a landing, the notification of any inaccurate information must be provided in seconds. It could take GPS up to 15 minutes to warn the user of a problem.

The **accuracy** of GPS is not adequate enough for an aircraft to land. Therefore, additional equipment is needed to successfully land an aircraft with satellite technology.

The WAAS program attempts to compensate for GPS's shortcomings with a network of ground stations and geostationary (GEO) communication satellites. The ground stations receive and monitor the GPS signals. The accuracy of the signal will be assessed by the ground stations, and if corrections are needed, they will be sent to the aircraft via communications satellites. The GEO satellites will also function as additional GPS satellites so that the necessary 4 to 6 satellites are always available.

WAAS will augment the GPS signals so that aircraft can use satellite technology to navigate some, but not all, flight operations. Pilots will be able to use WAAS to navigate aircraft once they are in high altitude flight, or en route. En route refers to the period after the aircraft's take-off, and before the aircraft lands. WAAS can also be used for category one (CAT I) landings. CAT I landings are where the aircraft is guided with navigation technology until 200 feet above the runway. After 200 feet, the pilot guides the aircraft visually to a landing.

WAAS will not provide enough precision for Category II and III landings. CAT II and III landings are where the aircraft is guided with navigation equipment to a height of 100 feet and touch down respectively prior to landing. The FAA is planning on another system, the Local Area Augmentation System (LAAS) to provide CAT II and III landings. LAAS is now in a prototype development phase, and therefore there is no set date for delivery.

WAAS CONTRACT HISTORY

The WAAS contract was originally awarded to a team led by Wilcox Electric, Incorporated in August, 1995. The Committee held a hearing on WAAS three months after FAA awarded the contract. The FAA witness, Mr. George Donohue stated, "We believe we have one of the best teams in the country doing this." Five months later, FAA canceled the contract. FAA terminated the contract because Wilcox did not provide effective project management.

The General Accounting Office (GAO) summarized the factors FAA identified as indicators that the contract was being poorly managed:

1) inadequate staffing of the contract,
2) failure to award key subcontracts as scheduled,
3) probable cost overruns of at least $100 million and schedule delays,
4) failure to meet contract milestones for system design review and delivery of cost and schedule baselines, and
5) inadequate cost and schedule reporting.

Due to the FAA's flexible procurement rules (changed by Congress in 1995 in an attempt to help FAA better manage contracts and save money), FAA quickly identified Hughes Aircraft as the preferred replacement contractor. Hughes was a subcontractor on the Wilcox contract. An interim contract was signed with Hughes in May of 1996, and the final contract awarded on October 1996.

The contract with Hughes will produce fundamentally the same WAAS equipment as the original Wilcox contract. Hughes has the same amount of time to develop WAAS, but it is a year behind the original schedule date due to the contract termination with Wilcox.

The FAA portrays the termination of the Wilcox contract and the award to Hughes as an example of how FAA's project management has changed. In this case, the FAA identified the problem, quickly terminated the contract, and quickly re-awarded it to minimize program delays. The other companies who bid on the original WAAS contract felt the speed FAA handled the contract cancellation and award was not based on merit, but convenience, since Hughes was a subcontractor of the original Wilcox contract.

COST GROWTH AND DELAYS

Cost Growth: The cost of WAAS has increased. But before discussing the cost increases, a clarification must be made on the different ways FAA can refer to the cost of WAAS.

The WAAS project cost can be referred to in three ways: the contract cost; the program cost; and the life-cycle cost. The **contract cost** only includes the amount FAA expects to pay Hughes to develop and deliver the WAAS equipment. The **program cost** is the entire cost to implement WAAS. This includes the contract cost as well as the FAA staff to manage the contract, and any additional equipment needed including the additional GEO satellites. The **life-cycle cost** is really the total cost of WAAS. The life-cycle cost includes the program cost (which includes the contract cost), and the cost of operating and maintaining the system until 2016.

The WAAS funding is even more complicated because it has two types of program funding – that which includes funds from the Facilities and Equipment (F&E) budget account and that which includes money from both F&E and the Operations and Maintenance (O&M) budget accounts. Typically, a developmental program like WAAS is funded exclusively with F&E funds when it is being developed and funded exclusively with O&M money once it is operating. WAAS includes funds for GEO communication satellites. That cost has been included in the O&M budget because FAA's other communication costs are in the O&M budget. This can be extremely confusing and misleading since there are essentially two WAAS program cost numbers. The fair number to look at as the program cost of WAAS is that figure with both the F&E and O&M funds (this is highlighted in the table below).

As shown in the table below, the WAAS contract cost has increased 94% (or $234 million) from 1994. The total program cost (in bold) has increased 59% (or $354 million) during that same period. The life-cycle cost of WAAS has increased by 72% (or $1.011 billion).

Table 1.
WAAS Cost Estimates
(dollars in millions)

	1994 prior to contract award	1995 Wilcox Contract*	1997 Hughes Contract
Contract Cost	$250	$475	$484
Program Cost with F&E money	$556	$596	$892
Program Cost with F&E and O&M money	**$604**	**$782**	**$958**
Life-Cycle Cost	$1,400 (through 2014)	not available	$2,411 (through 2016)

*These cost estimates are at the time of signing the Wilcox contract. At the time of termination in 1996, the estimates for the contract and program costs were higher.

There are four major reasons for the cost growth from 1994 to 1997:
1) over $200 million for a FAA-imposed requirement that the WAAS software meet higher specifications including greater reliability;
2) $77 million for additional program support for FAA's oversight of the program and WAAS contractor;
3) $75 million for work performed by Wilcox and the estimated settlement costs of terminating the contract; and

4) $65 million for satellite upgrades and improvements recommended by the White House Commission on Aviation Safety and Security (the Gore Commission).

Delays: Before discussing WAAS delays, the 3 phase structure of the contract must be explained. Under the Wilcox contract, WAAS was to be completed in two phases -- Phase I and Phase II. Under the Hughes contract, there are Phases I, II, and III. Phase I is the same under both contracts. Phase II under the Wilcox contract, was broken into two parts – Phase II and III under the Hughes contract.

As shown in the table below, Phase I is now 15 months behind the 1995 schedule. At the end of Phase I, WAAS will be able to support the navigation of aircraft through out the continental US for en route and Category I landings. However, it will not have the redundancy to continue operations in the event of equipment failures and will have to be backed up by FAA's current ground-based system.

TABLE 2.
DELIVERY DATE FOR EACH PHASE OF WAAS
(note that the commission date when the system can actually be used will be a few months later)

	Wilcox Contract 1995	Hughes Contract 1997
Phase I	**Late 1997**	**March 1999**
Phase II	N/A	**April 30, 2000**
Phase III	**June 2001**	**October 31, 2001**

Most of the delays in Phase I are attributed to canceling the Wilcox contract. However, additional delays will probably occur and are discussed below. The FAA believes it can make-up for the delay in Phase II and III and the final delivery of WAAS will only be 4 months behind the original Wilcox schedule .

Risk Areas for Future Cost Growth and Delays: Many experts, including GAO, believe there is a high risk for future WAAS cost growth and delays. One of the high risk areas for cost growth is the 4 additional GEO satellites. The WAAS program needs either leased space on 4 satellites or 4 dedicated satellites. Additional satellites are needed, in part, to transmit corrective navigation signals to aircraft equipment. No contract has been signed for this.

Another risk area for WAAS is the software development. Hughes is responsible for the software development and, at this time, is meeting all of its milestones. However, most of the work that has been completed is paper work requirements. Only a small amount of the software program has been written. Hughes believes that software should first be worked out on paper which then makes writing software code easier.

DOD AND WAAS

FAA has requested that the Department of Defense (DoD) allow two frequencies for civil aviation use. Currently, GPS satellites transmit information on two frequencies: L1 and L2. The L1 frequency is used by both the military and the public (including civil aviation). The L2 frequency is used exclusively by the military.

FAA believes it needs the L2 or some other frequency because of ionosphere storms which distort the GPS signals. If there were two frequencies available, corrections could be made by knowing the typical behavior of the two frequencies and correcting the signal through triangulation

The GPS satellites orbit around 11,000 miles above earth. The GPS signals must travel through the various layers of atmosphere to reach aircraft. One of the atmosphere layers is the ionosphere, which is around 30 to 250 miles above the earth. When the GPS signals travel through the ionosphere, the signals are distorted. If the distortion was constant and/or predictable, then corrections could be made to the GPS signals. However, the distortion is not constant or predictable.

The ionosphere is effected by numerous phenomena, including solar storms and sun spots. Solar storms are the result of large, or irregular bursts of energy from the sun. Solar storms send energy into the ionosphere resulting in significant distortions of the GPS signals. Sun spots are magnetic storms which are not as well understood as solar storms, however they also unpredictably distort the GPS signals. Sun spots occur in 11 year cycles. The next peak of sun spots will be around the turn of the century and it is unclear how seriously they will effect the GPS signal.

To properly correct for the GPS signal distortions that occur in the ionosphere, FAA wants a second frequency. DoD will testify at the hearing, however, DoD is still considering whether or not to provide a second frequency. Even if a second frequency was provided, it may take as long as ten years to implement, since it would have to be on new GPS satellites.

SECURITY OF GPS AND WAAS

The GPS and WAAS signal can be jammed, which would result in partial or total malfunctioning of the WAAS system. According to the September 17, 1997 issue of the *Aviation Daily*, a Russian company, Aviaconversia, has developed a portable GPS jammer. It reportedly interferes with GPS signals up to a range of 200 kilometers.

Responding to this report, the FAA dismissed the importance of such news. An FAA spokesman remarked that the device was "nothing new" and there are "hundreds of these devices" on the market. In addition, the FAA stressed that jamming a GPS or WAAS signal can lead to serious fines and imprisonment of up to 20 years. The FAA also stresses that the current navigation systems can be jammed, however, that rarely happens.

Currently, there is no technical solution that protects the GPS and WAAS signals from being jammed. FAA is now conducting a vulnerability assessment and expects the results of this study to be completed in October 1997. Additional details cannot be given due to the sensitivity of this issue.

HAS FAA MISLED THE CONGRESS?

More so than other programs, the information on the WAAS program has been complicated at best, and misleading at worst. Below are several examples of where FAA did not publicly provide all of the information or the information that was provided was incomplete.

Cost Growth: The original cost estimate for WAAS in 1991 was $507.9 million. The mission needs statement included a cost range for WAAS –

the minimum cost estimate of $156.5 million, the most likely cost estimate of $580 million, and the maximum cost estimate of $1.224 billion. FAA did not provide the potential WAAS cost range when originally presenting the WAAS program to the Congress. The 59% increase in WAAS could have been less dramatic had FAA been more forthright about the potential cost.

Delays: FAA continues to report that Phase I of WAAS is about 15 months behind schedule. In fact, the Wilcox contract was signed 5 months behind FAA's original WAAS schedule. Therefore, Phase I of the WAAS program is 20 months behind FAA's initial WAAS estimate.

Category I Capability: There is some concern that WAAS will not meet the requirements for Category I landings – providing navigation guidance down to 200 feet. GAO is concerned that WAAS may only provide navigation guidance down to 300 or 350 feet. There are rumors that FAA is considering relaxing the requirements for Category I landings to match the capabilities of WAAS. This appears misleading and could have negative safety implications.

Milestones in the Hughes Contract: FAA and Hughes report that the WAAS contract is meeting all of its milestones. GAO agrees with this statement, but points out that the milestones have slightly changed. The milestone changes are not dramatic, however, they are favorable to the contractor. When FAA chooses to change its baseline which in turn improves the appearance of the contract, it seems misleading.

Budget Gimmicks: The FAA recently proposed "reducing" the cost of the WAAS program by transferring the cost of the GEO satellites to another portion of the FAA's budget. This budget gimmick would make the WAAS program current costs decline and remove a potential future cost growth area. This is misleading, unless the total program cost is clearly identified in all documents.

Decommissioning Current Ground Based Systems: To fully realize the benefits of WAAS, FAA must decommission its ground-based navigation aids. It costs FAA about $165 million annually to maintain the current navigation aids. FAA plans to decommission the current system by 2010, assuming WAAS is fully operational by 2001. There are some rumors that due to strong user opposition (primarily from general aviation users) FAA will not fully decommission the current system. Others argue that part or all of the current system must be in place as a back-up system. In either case, FAA arguably should include the cost to maintain part or all of the current navigational aids in the total cost of WAAS.

USERS' OPINIONS ABOUT WAAS

The Air Transport Association (ATA), which represents primarily large air carriers, will testify at the hearing. ATA is concerned that the WAAS program will cost more than the benefits it will provide. ATA believes that FAA should stop the WAAS program at the end of Phase I and re-evaluate whether or not the program should continue. ATA believes the majority of the benefits of WAAS are achieved in Phase I. FAA argues that Phase I will not achieve the redundancy necessary to provide the benefits as suggested by ATA.

The Aircraft Owners and Pilots Association (AOPA) will also testify. AOPA fully supports the WAAS system, however, they believe FAA needs to address several program issues. One issue that concerns AOPA is the GEO communication satellites that are needed to implement WAAS. In addition, AOPA believes other WAAS users should financially support WAAS since aviation will ultimately be a minority user of WAAS (other groups such as truck operators, farmers, surveyors, and individual car owners will also benefit from WAAS).

Organizations that will testify include:

The General Accounting Office
The Department of Transportation Inspector General
The Federal Aviation Administration
The Department of Defense
Hughes Aircraft
Air Transport Association
Aircraft Owners and Pilots Association
Professor Bradford W. Parkinson, who is sometimes referred to
as the Father of GPS.

Defending Loran-C in Court

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BIOGRAPHY

David H. Gray, M.A.Sc. in geodesy, joined the Canadian Hydrographic Service in 1971 where he holds the title of 'Geodesy & Radio Positioning Specialist'. His duties include radio propagation studies and ship-board calibration surveys and the preparation of the parameters for the hyperbolic lattices on CHS charts. He provides technical advice on maritime boundaries and limits to Canadian Dept. of Foreign Affairs and is responsible for the geodetic aspects of the conversion of CHS charts to be compatible with GPS.

ABSTRACT

During the past 15 years, the Department Fisheries and Oceans, Canada has used Loran-C as one of the means of locating illegal fishing activities. The author has provided expert testimony in about a dozen court cases to translate the Loran-C data into a geographic position, compute the distance to a fisheries limit, define the position's accuracy and explain why possible system errors have not compromised the data.

The author relates his experiences from these court cases and situations that did not get to trial.

INTRODUCTION

Some are born great, some achieve greatness, and some have greatness thrust upon them.
[Shakespeare, Twelfth Night]

In the latter vein, I acquired certain tasks with the Canadian Hydrographic Survey more by default than by design and I leave it to you as to their merits towards greatness. In the 1970s, the Canadian Hydrographic Service started drawing Loran-C lattices for its charts and I was given the task of incorporating the overland propagation corrections, known as Additional Secondary Factor or ASF, into them. In the 1980s, as Canada's maritime boundary expert was spending 100% of his time on the Canada/United States court case before the International Court of Justice on the Gulf of Maine international maritime boundary, I acquired the responsibility to look after the maritime boundary needs for the rest of Canada. In 1985, I was asked to appear as an expert witness in three fisheries violation trials in St. John's Nfld. to present an overlay for a chart of the Grand Banks showing the 200 mile Exclusive Fishing Zone limit. That was the start.

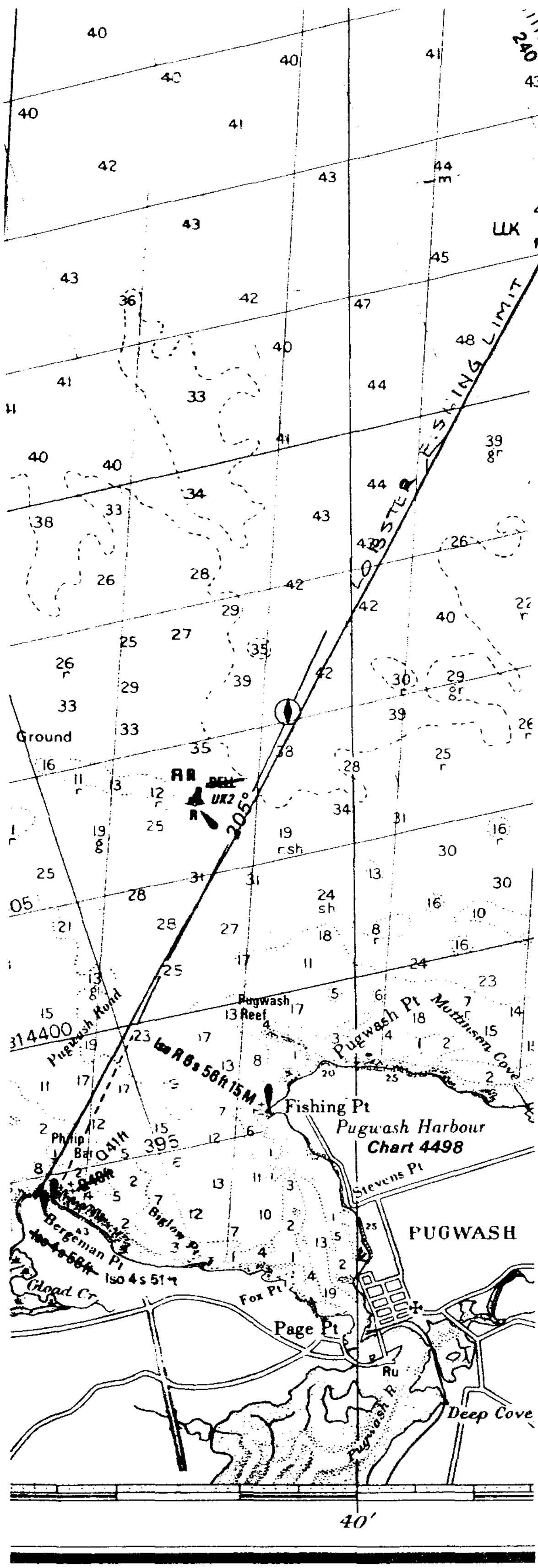
WHAT IS AN EXPERT WITNESS?

Ordinarily, a witness presents the facts to a court of law, but occasionally the court needs to know information of a specialized nature, the results of analyses, or opinions based on the facts or hypothetical situations. Expert witnesses, or "hired mouths" as I have heard them called because they can be paid, do just that. The supposed expert is called to the stand and the lawyer that called him will ask the Court that he be qualified as an expert in -- whatever. His Curriculum Vitae is presented, questions asked by both the lawyers and the judge and finally the judge will rule as to his expertise. Normally the judge does not disqualify a person as an expert, but might down weight a poorly qualified expert.

The expert evidence usually comes after the facts of the case are presented, similar to the clean-up hitter with the bases loaded. This is so that he can express opinions about the facts already presented. The lawyer presenting any witness will have gone through the line of questioning before hand sometimes just generally or sometimes a word by word dress rehearsal.

Generally, long before the court date, I have been given certain facts such as the Loran positioning information and the coordinates for the end points of the pertinent fishing limit and asked to analyze the data. At the pre-trial meeting, I like to learn *all* the facts that will be presented. Sometimes there are things that I can clear up, become aware of evidence that should be presented and, coach witnesses to be sure those facts *are* presented, and most importantly try to anticipate what the defense will attack.

During the giving of his evidence, the expert should know what points have to be made, and to use the questions posed as the spring board to get those points across. Sometimes the lawyer gives a simple open-ended question as "Mr. Gray, will you please explain to the court how the Loran-C system works?"



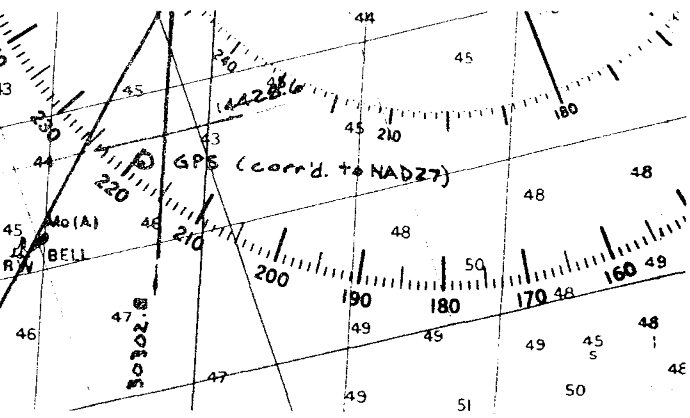


Figure 1. A fisheries violation in Northumberland Strait in 1995 using 2 Time Differences and GPS. Cases in the same area in the 1980s involved only Loran-C

LORAN-C EXPLAINED

How often have you tried to explain Loran: the master/secondary/secondary chain configuration, its pulse transmissions, time differences (TDs), hyperbolae, propagation characteristics, ASF, TD versus precise geographic calibration surveys, lattice drafting, and absolute and repeatable accuracies? Then explain away the error sources: blink, cycle jumps, skywave, radio interference, precipitation static, aurora borealis, sun-spots, and the like. Most of us do this regularly at cocktail parties and fishing lodges but how about to a sober judge and an eagle eyed defense lawyer?

CHS AND LORAN-C

CHS from 1975 to 1995 collected 122,000 data points of TDs at locations at sea surveyed by hydrographic procedures or occasionally on headlands and islands surveyed by terrestrial methods. From that data, we have built up data bases of observed ASFs. We have married that data with predictions by the Modified Millington's Method (i.e., ASF not signal strength) to get a grid of corrected predictions. For our lattices on our charts, we have either interpolated within the grid of ASF data or used a least squares polynomial fit to the observed data.

THE SIMPLE CASE

Some cases have involved the simple situation of a two Time Difference position fix. [See Figure 1] The graphical solution can be used or the mathematical TD to geographic conversion can be used if the same ASFs are incorporated in the calculations as were used in the chart lattices. The big questions to address, usually in cross examination, are the system errors since there is no redundant information.

THE NOT SO SIMPLE CASE

The Department of Fisheries & Oceans, Canada has contracted the services of Provincial Airlines to provide aircraft suitably fitted out for patrol purposes with GPS, Loran-C, radar and integrated computer graphics. The information from these sources usually comprises GPS plus Time Differences from as many as 7 master-secondary pairs from usually two Loran chains. On board the airplane, the real-time position is a Kalman filtered answer, but in post-processing, it is sometimes necessary to weed out the skywave TD and the TD based on low signal strength and those with no ASF values. A least squares solution of the remaining redundant, ASF corrected, information gives the best position determination. At that point, one can provide a rationalization of the ASF or skywave errors of the unused TDs. It is also necessary to calculate the 2-TD fix that the fisherman would have used. More time is spent explaining the complexities of the computation and less on the possible undetected system errors, although the Court needs to know that the fisherman's equipment should have been working correctly. [See Figure 2]

CROSS-CHAIN REQUIREMENTS

In the Gulf of Maine, American fishermen use 9960W and Y, whereas the Canadian fisheries patrol boats use 5930X and Y. In those situations, not only has it been necessary to deal with system errors, chain geometry, but also the consistency between chains. The Canadian fisheries officer says the American is over the line, but the American claims that he is still on the US side of the line according to the New England chain as shown on the US chart. CHS has a specific data set of coincidental TDs from both the 5930 and 9960 chains up and down the Hague Line [See Figure 3] In another case, I remember spending most of the day explaining how the International Boundary (or The Hague Line as it is locally called) was plotted on both the US and Canadian charts, the Loran chains, and the two charting agencies' versions of the lattices. My conclusion was that the American fisherman was 1 mile inside Canadian waters. I thought that I had done a good job. The next day, I overheard a US magazine reporter telling someone that the fisheries officer's action of hand-cuffing the US skipper was

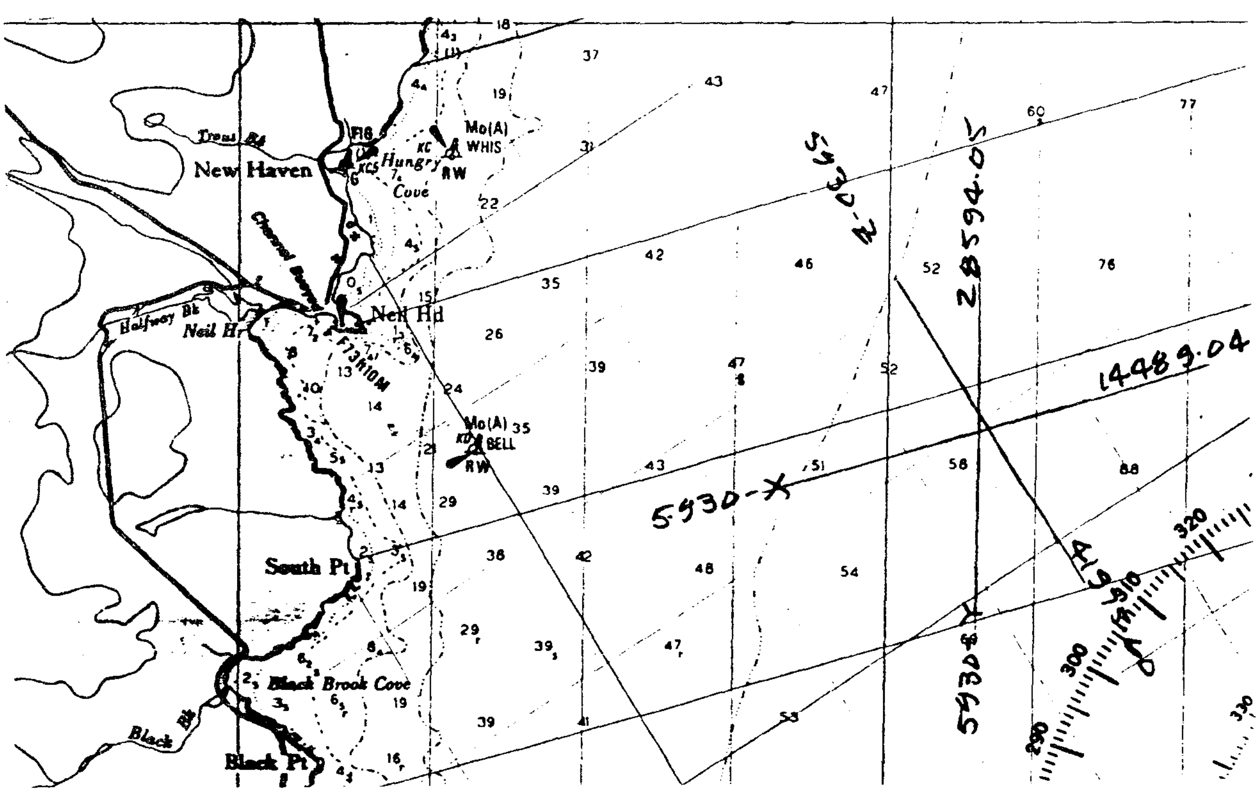


Figure 2. A fisheries violation off the coast of Cape Breton Island using 3 Time Differences.

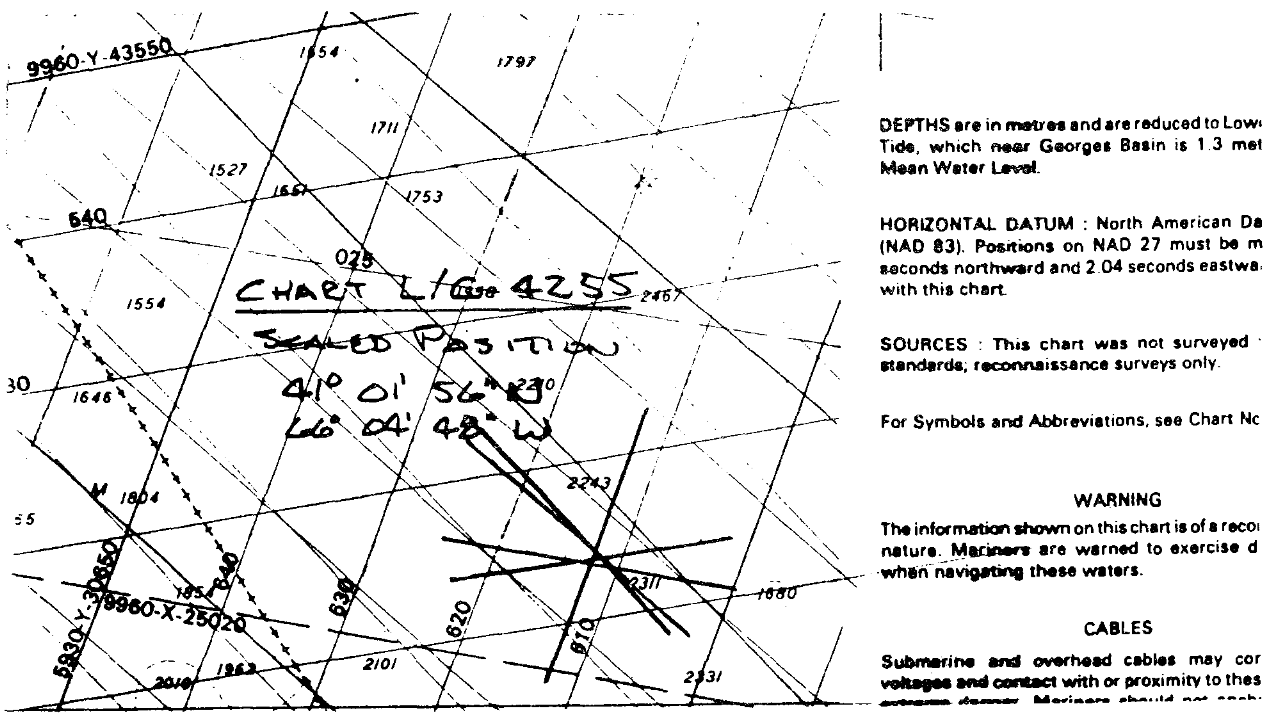


Figure 3. A fisheries violation in the Georges Bank area with 5 Time Differences from the 5930 and 9960 Loran-C Chains.

much more exciting than the harangue the previous day over the positioning. Was the reporter aware that the case would turn on the positioning not on the restraining of the skipper?

MULTIPLE SYSTEM VERIFICATION

Some of the earliest cases (mid 1980s) involved Loran TDs and Doppler satellite navigation. Both systems had to be explained and the discrepancies rationalized. The 1990s have brought GPS to the fore -- sometimes stand alone and sometimes as an integrated system. Integrated systems supposedly get the best out of all the inputs but more reliance is made on the diagnostic outputs which can be as simple as "idiot lights".

One intriguing case, which ended up with the parties involved pleading guilty, was the use of shore-based surveillance radar to detect suspected illegal lobster trap placements, retrievals and the correlation with Loran-C during the clean-up after "the sting".

LORAN-C COORDINATE CONVERTERS

In several of the cases that I have been involved with, the prosecution has presented output from a Loran-C coordinate converter and in all cases in the past ten years I have addressed the hypothetical question: "What if the defendant had been using a Loran-C coordinate converter?"

For the expert witness, coordinate converters cause considerable speculations. If one were to set up different receiver models side by side feeding off the same antenna, or closely spaced antennas, they will all give the same TDs within a very tight limit, but the computed geographic positions will be more scattered. In areas such as the Gulf of St. Lawrence where the positioning quality of the 3 TDs of 5930 taken in pairs (XY, XZ and YZ) is roughly equivalent, one cannot be sure which pair would be used by a coordinate converter, and because of overland propagation, the geographic positions are different. Unless I definitely know which pair was used in the computation, I go with the one most advantageous to the defense. Given a coordinate converter position, I presume that it was computed without ASF on the WGS-84 datum; therefore, it is necessary to compute all the TDs based on the WGS-

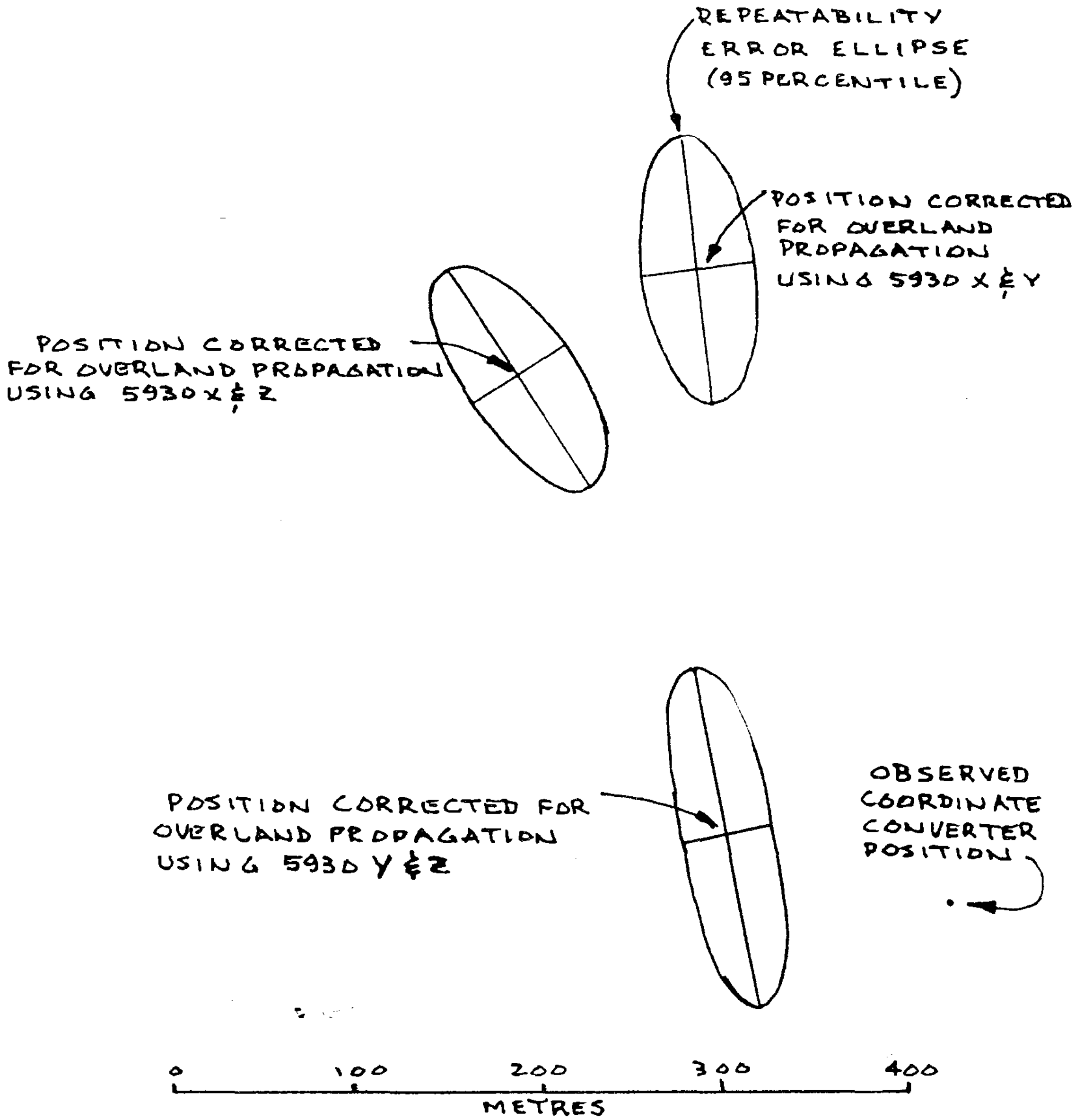


Figure 4. The necessary conversion from raw coordinate converter position to the 3 possible corrected positions based on which Time Difference pairs and applying the corrections for overland propagation.

84 positions of the transmitters and using an all-seawater velocity, then compute the actual position and error ellipse with those computed TDs taken in pairs, their ASFs and the coordinates of the transmitters on the horizontal datum of the chart (either NAD-27 or NAD-83). [See Figure 4]

CROSS EXAMINATION

Once the lawyer that presented you has gone through all your evidence, the other side has every right to cross examine you. I have yet to meet a lawyer who prepares his witness adequately for cross examination. Perhaps, because he does not know himself what will be the other side's thrust. Cross-examination is where you really show your mettle as an expert. You have to have done your homework, think fast and carefully, and hope that you have not made exaggerated claims.

Generally, opposing lawyers will try to destroy your evidence which is hard to do with something highly technical, weaken your evidence, e.g., playing on the possible system errors of Loran-C, or destroy your credibility as a witness, possibly in fields only marginally related to the case, such as typing errors in your report, or just simply a lot of "smoke and mirrors" ramblings at your expense.

After my first case, I told people that the cross examination was worse than any job interview. You have to console yourself that the other lawyer is doing his job and not to take the attack personally. Now, I find job interviews less frightening and I almost look forward to a good battle of wits with the opposing lawyer. Some lawyers have specialized in marine or admiralty cases, some hire expert advisors, and occasionally call their own expert to the stand.

SOME GENERAL GUIDELINES FOR AN EXPERT WITNESS

After having about a dozen court appearances as an expert, and having prepared for several other cases that never did get to court, may I be so bold as to suggest the following points as things that I have learned about being an expert witness?

1) Learn all the facts of the case.

2) Analyze every possible thing that you can get your hands on.

3) Take copious notes during the trial.

4) Feed questions to your lawyer to remind him of factual evidence that needs to be presented by the witness, or during the cross examination of any of the opponent's witnesses.

5) Know what facts you need to present; express them clearly and precisely and do not ramble.

CONCLUSION

The Canadian Hydrographic Service has supported another part of the same government department; namely, Fisheries and Oceans in the prosecution of illegal fishing activities through the provision of an expert witness to address specialized topics such as maritime boundaries and limits, and radio navigation systems. Loran-C has been one of those systems used for the past 15 years. To date, the Department has not lost a prosecution because of the Loran-C data. Judges have decided in favor of the Department when distances to the fishing limit have been as little as 0.1 nautical miles. Several lobster fishermen have pleaded guilty when charged with fishing over the line by a little as 100 metres as based on positions derived Loran-C Time Differences.

AVOIDING THE ROCKS
THE CANADIAN COAST GUARD DGPS PROJECT

Fred Forbes
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Marine Technical and Support Services
Canadian Coast Guard

BIBLIOGRAPHY

Fred Forbes is a graduate (1964) of the University of Alberta, Edmonton with a Bachelor of Science in Electrical Engineering. He spent 27 years in the Canadian Air Force as a maritime air navigator, holding a number of operational, staff, engineering and command positions. In 1987, he switched environments, taking up a position as a Navigation Systems Engineer with the Canadian Coast Guard. He has responsibility for engineering and life cycle management of radionavigation systems. Fred is presently Chief, Navigation Systems Electronics Engineering in the Marine Technical and Support Services Branch and is the Project Manager of the Canadian Marine DGPS Project. Fred is a member of the Civil GPS Service Interface Committee and the International Association of Lighthouse Authorities' Radionavigation Systems Committee.

ABSTRACT

The Canadian Coast Guard is implementing a marine DGPS service in Canadian waters. This service will be based on MF radiobeacon transmitters. It is expected to serve the needs of commercial navigation, Coast Guard Fleet operations and other Government operations. Its availability is expected to promote the widespread use of electronic chart navigation and thereby enhance the safety and efficiency of marine commerce. As a lead-up, the Coast Guard established a number of DGPS test bed transmissions in most maritime regions starting in 1992. Between October 1995 and the present, the CCG has purchased and installed 17 DGPS broadcast sites and five control monitors. An initial operational service is being provided in most marine areas with plans to upgrade to full operational service in 1998. The system is designed to be highly reliable and fault tolerant. This paper focuses on the DGPS service requirements, system implementation and project status.

INTRODUCTION

In 1995, the US Department of Defence Global Positioning System (GPS) became operational. A Standard Positioning Service (SPS) with an accuracy of 100 metres (95 %)is provided to the international civilian community anywhere in the world. However, differential GPS (DGPS) users have the prospect of achieving at least an order of magnitude improvement to the SPS positioning accuracy. In addition, coupling DGPS with electronic charts provides a revolution in marine navigation capability that rivals the introduction of radar. After extensive testing, the Canadian Coast Guard (CCG) has proceeded to implement a public DGPS service. At present, an initial operational service (IOS) is being provided from 17 broadcast sites covering most trafficked marine areas of Canadian waters. The Great Lakes is being covered by the USCG system which is identical to the Canadian service from the users' viewpoint. This paper describes the DGPS service requirements, system implementation and the current status and plans for the project.

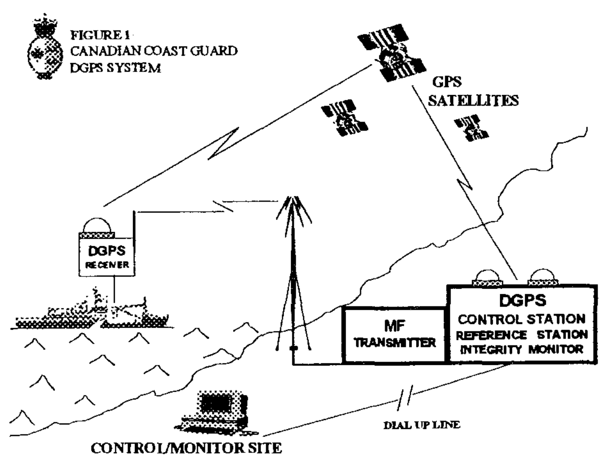
BACKGROUND

The CCG was a pioneer fleet user of electronic charts with precise positioning. In the mid-1980s, CCG icebreakers operating on the St. Lawrence River were fitted with electronic charts and microwave positioning equipment. The operational value of this combination was readily apparent during numerous winter operations. In the early 1990s, other precise positioning methods were evaluated but it soon became evident that the cost-effective solution was DGPS which would meet our needs and had the added benefit of being a common use system.

The CCG has the mandate to provide public marine radionavigation services, with Loran-C being the current example. In addition, demand for a electronic precise positioning service has been building for several years, especially as potential users become aware of the capabilities of electronic charts coupled with DGPS/GPS. The United States Coast Guard-led development in the 1980s of marine DGPS using radiobeacon transmission had been watched with interest. CCG began formulating plans for a Canadian service about the same time as the USCG initiated their project to implement DGPS in coastal and harbour areas and the Great Lakes[1]. In 1994, the CCG announced in a policy and information statement its intention to implement a DGPS service in all Canadian marine areas where traffic warranted. Since it makes sense that DGPS be provided on a uniform basis throughout North America and desirably everywhere, the methods and levels of Canadian DGPS service will be virtually identical to the USCG service.[2] The Canadian service will also adhere to international standards for transmitting DGPS corrections via marine radiobeacons. A seamless North American marine DGPS service will be provided to the public as a result of this standardisation.

In October 1995, funding was authorized for an 18 station marine DGPS system covering the east and west coasts and the St. Lawrence River. This system was justified on the basis that it would contribute to the economic development of the country, would improve marine safety and efficiency and reduce the risk of environmental accident.

Figure 1. is a pictorial representation of the CCG DGPS system. The position of the reference station receiver antenna situated at a DGPS station, is accurately surveyed. By comparing the known location with that computed with GPS, position differences (i.e. differential corrections) are derived and broadcast via MF to suitably equipped users who apply these corrections to improve their position solutions. A combined GPS receiver and MF demodulator is required for DGPS user operations.



DGPS OPERATIONAL REQUIREMENTS/LEVELS OF SERVICE

The primary operational requirements for the Canadian marine DGPS service are to provide:

- precise navigation service in Canadian waters where traffic and waterways conditions warrant;
- precise positioning in support of Coast Guard operations where cost-beneficial; and,
- precise positioning services to other Government marine agencies where fixed site broadcasts installed for the above purposes will meet their needs.

The DGPS service is designed to provide an accuracy of 10 metres or better 95% of the time. There is also a goal to provide five metre positioning in some areas for CCG operational purposes.

Broadcast Coverage defines the general area where the mariner can expect DGPS service; this is the advertised coverage area served by a DGPS station.

Until the operational system is validated, coverage from each DGPS transmitter will be defined as the area where the DGPS signal strength is at least 75 uv/metre level or has a broadcast availability (see below) of 99%, whichever is more stringent. The 75 uv/metre signal is a conservative measure and in most conditions and areas, users will have DGPS reception at signal levels much less than this.

Broadcast Availability is defined as the percentage of time over a sufficiently large measurement period that a suitably equipped user, can receive and demodulate a proper DGPS signal (one which is healthy and at specified power) at the edge of the coverage area. Broadcast availability will be at least 99% at the edge of the broadcast coverage area, taking into account the level of atmospheric and other noise.

Broadcast Reliability which depends on DGPS station equipment design and prompt maintenance response, will be at least 99.7%. In multiple coverage areas, this figure will be at least 99.9%. Reliability is engineered into the DGPS system through selection of quality equipment and components, continuous signal monitoring, reference station, integrity monitor, control station and transmitter redundancy and soft failure design. In some areas, DGPS coverage from multiple stations will overlap and if the signal is lost from a particular station it will be possible to select an alternate broadcast. This reliability means that a broadcast service failure will only occur on average once in 2 1/4 years. It also means that there will be only a 0.06% chance of failure over a 12 hour usage period. Of course these figures assume the GPS system is available.

User Availability is a function of broadcast reliability, broadcast availability and the number of stations providing coverage. The goal is to provide at least 99% user availability in single station broadcast coverage areas.

The CCG is not defining a user availability until more experience has been gained and the operational broadcasts are validated.

The quality of the DGPS receiver and its installation will also affect the reception of the DGPS signal. It is intended to eventually publish standards for DGPS receivers that will function properly with the Canadian DGPS service.

Integrity relates to the correctness and quality of the DGPS transmission. The DGPS integrity monitor (IM) will continuously monitor various performance parameters of the DGPS station, such as GPS geometry, correctness of the DGPS data and position accuracy, and transmitter performance. When the corrections data is out of tolerance, the user will be advised through the broadcast within 10 seconds. It should be noted that this integrity monitoring also improves the integrity of the GPS

SYSTEM COMPONENTS AND CONFIGURATION

The DGPS station (Figure 2) is an unmanned broadcast site-located reference station/integrity monitor (RSIM) and control

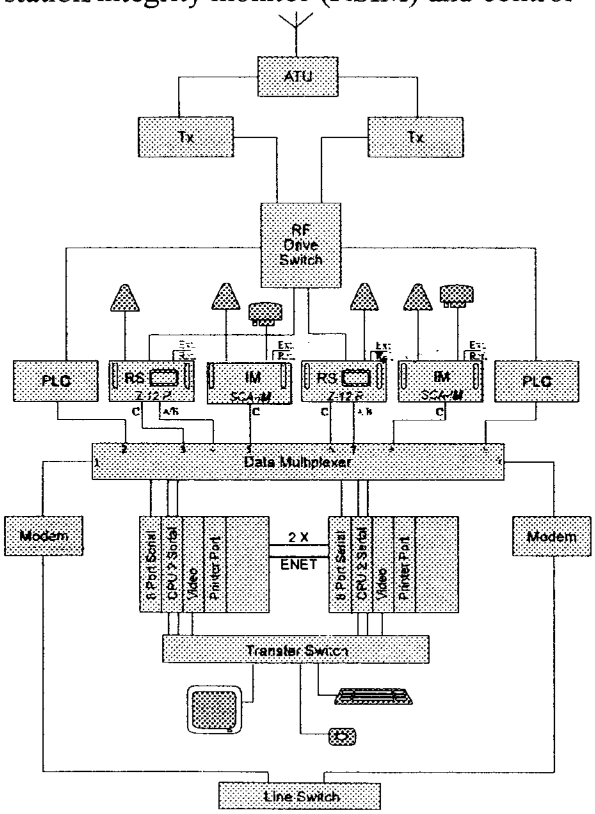


Figure 2- DGPS Station

station (CS) combination. Two independent RSIM and CS subsystems perform the core DGPS functions. One subsystem is active while the other is in hot standby mode. Each subsystem is connected to a separate transmitter exciter. The IM-RS and IM-CS communications uses the RTCM RSIM standard format and messages[3]. The active CS manages the operation of the DGPS station which operates fully automatically. The site is connected via a dial-up communications link to a DGPS control monitor (CM), located in a continuously manned regional marine communications and traffic centre.

The DGPS station is fault tolerant and with a couple of exceptions has no single point of failure. The system is self-monitoring and will automatically recover to full operational status from all but the most unlikely equipment failure. In the event of a multiple failure where the user service is affected, the user is informed through the integrity and reporting functions. In addition the CM will be immediately notified so that a maintenance response can be initiated and other CMs and broadcast stations informed of the problem. During normal operations, the CM will periodically poll each of its regional broadcast sites to check their status and download station performance data.

CURRENT CCG DGPS STATUS AND PLANS

Initial operational service (IOS) for the first 11 DGPS broadcasts were declared at the end of August, 1996. Since that time 6 additional sites have become operational. The last planned site, Rigolet on the Labrador coast has experienced some implementation difficulties and will be delayed until 1998. All five regional CMs are in operation. IOS means that

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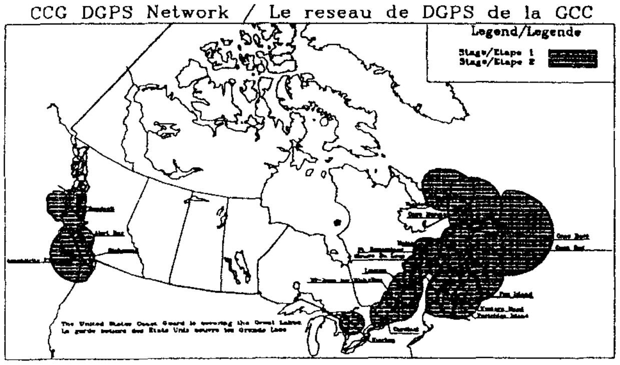


Figure 3-DGPS Coverage

broadcasts are on air and available to users. Because the service has not been validated, the accuracy, availability, reliability and integrity are not guaranteed and users are advised not to depend on the system in situations where such dependence could cause an accident. Basically it is "use at your own risk. An improved CS and CM software application program is under development and will be tested by the CCG shortly. After the new version system is thoroughly tested and de-bugged, full operational service (FOS) will be declared. At present, it appears this will take place in Fall 1998, about the same time the USCG service is expected to reach FOS.

CONCLUSION

The national marine DGPS system will cost less than $8M of public money to implement and less than $500K per year to operate. All Canadian in-land and coastal traffic areas will be covered (with acknowledgement to the USCG for the Great Lakes service) with a precise navigation system of unprecedented accuracy. Enabling the effective use of electronic charts, it ushers a new age of safe and efficient marine transportation.

REFERENCES

1) D. H. Alsip, J. M. Butler, and J. T. Radice, "Implementation of the U.S. Coast Guard's Differential GPS Navigation Service," USCG Headquarters RAD2/17/4a/1, June 28, 1993.

2) "Broadcast Standard for the USCG DGPS Navigation Service," USCG COMDTINST M16577.1, April, 1993.

3) "RTCM Recommended Standards for Differential NAVSTAR/GPS Maritime Reference Stations and Integrity Monitors," Fourth Draft of version 1, RTCM Paper 120-94/SC 104-123. RTCM SC 104 RSIM Working Group Washington, D.C., November 5, 1994.

Q: Is there complete system redundancy ?

A: Yes, except for the antenna We put backup equipment everywhere it made good sense. Antennas are generally pretty reliable.

Q: We've had problems with the antennas. What is your experience with service in restricted waters?

A: We validate accuracy, availability, integrity; once we're comfortable that it meets those levels, then we'll guarantee those levels.

Q: You guarantee the transmission, but what do we receive?

A: We guarantee the signal in space. If you have a proper installation on the ship, then you'll have the service.

Q: You guarantee the propagation path?

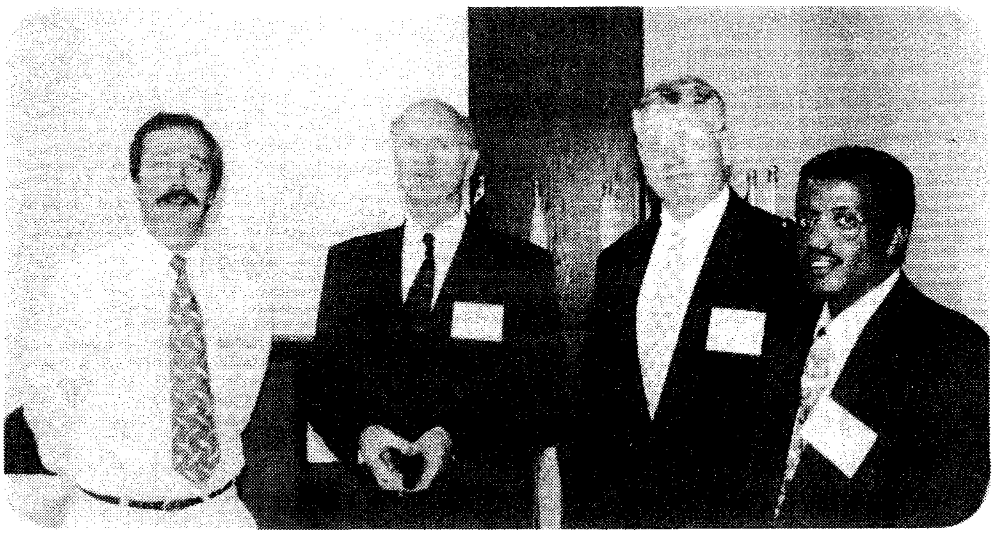
A: Yes - that's taking a bit of risk, and we're alert to that. However, we're confident, based on our studies, that our signal strength is sufficient to operate at the edge of coverage.

Q: We're getting reports of DGPS receiver problems. (Different positions shown on ships in close proximity.) This occurs when the signal is fine.

A: The system is in its infancy; everyone expected perfection, but the system is teething. You get what you pay for with receivers. We can buy DGPS receivers which cannot meet 10 meters. The bugs will be worked out eventually. A quality receiver can provide the expected service.

Session 4: Loran-C Receiver Technology

Session Chair: Prof. Durk van Willigen
TU Delft



Session 4: From left, Erik Johannessen, Durk van Willigen, Capt. Ben Peterson, Antenech Alemn Abbo

Magnetic Loop-Based Loran Receiver for Urban Canyon Applications: 1997 Update
Capt. Benjamin B. Peterson, et al, USCG Academy

Performance and Cost Trade-offs in LF H-Field Antenna Design
Erik Johannessen, Andrei Grebnev, Megapulse

Efficient FIR Filter Architecture for Loran-C Interference Rejection
Antenech Alemn Abbo, TU Delft

Magnetic Loop Based LORAN Receiver for Urban Canyon Applications, 1997 Update[1]

Benjamin B. Peterson
U. S. Coast Guard Academy

Yukie Novick and Kenneth U. Dykstra
Integrated Systems Research Corporation

Lance C. Miller
Science Applications International Corporation

Biographies

Benjamin Peterson is the Engineering Department Head at the U. S. Coast Guard Academy and earned a Ph.D. in electrical engineering from Yale University. Yukie Novick is President of Integrated Systems Research Corporation (ISRC).and earned a BS in Electronics from Jerusalem College of Technology. Kenneth Dykstra is employed as a consultant by ISRC. He earned an MS in Electrical and Computer Engineering from Rensselaer Polytechnic Institute. Lance Miller an engineer for Science Applications International Corporation and earned a BSEE from Villanova University.

Abstract

During the summer of 1996, the Office of National Drug Control Policy, the British Home Office, and the Defense Advanced Research Projects Agency funded the development of a digital H-field LORAN receiver and joint United States / United Kingdom radionavigation experiments to determine the accuracy, repeatability, and availability of LORAN in urban locations. The data measured in this experiment were taken using an H-field LORAN receiver. This decision was made based upon the results of an experiment performed in New York City during the summer of 1994 where it was determined that H-field LORAN significantly outperforms E-field LORAN in an urban environment. Details will be presented of the USCGA developed all digital H-field LORAN receiver that accepts a precise oscillator input to produce a two station time-of-arrival (TOA) fix if three stations are not available.

The first experiments were performed in London utilizing a van supplied by the United Kingdom and outfitted by a joint U.S. / U.K. team. The London data collected over a two week period indicated the LORAN receiver could consistently provide fixes with accuracy comparable to GPS SPS. The second set of experiments were performed in the New York City area utilizing a van supplied by ISRC and outfitted by USCGA, SAIC, and ISRC personnel. The New York data collected over a two week period also indicated the receiver could consistently correctly acquire and provide fixes of accuracy comparable to GPS SPS.

Preliminary details of a proposed low power implementation of the design are also presented.

Introduction

In 1994, the Defense Advanced Research Projects Agency (DARPA) funded the USCGA to conduct a comprehensive study of radionavigation signals in the New York City area. The study was performed in cooperation with several corporations including SAIC of Arlington, VA, and ISRC of Englewood Cliffs, NJ. Reference [1] presents the results of this study. The study showed that LORAN H-field signals are highly available in all areas tested, the E-field LORAN signal is less available than the H-field signal, and LORAN is more available than GPS in all areas tested. Considering these findings, the USCGA is building an H-field LORAN receiver that can be used to track vehicles or personnel in an urban environment.

In 1996, the Office of National Drug Control Policy (ONDCP), the British Home Office, and DARPA funded the USCGA development of a digital H-field LORAN receiver and coordinated a joint United States / United Kingdom radionavigation experiment to determine the accuracy, repeatability, and availability of that H-field LORAN receiver in urban locations and to compare its performance against GPS and integrated GPS/GLONASS. Two sets of experiments were conducted--one in London,

[1]Previously presented at U. S. Office of National Drug Control Policy Technology Symposium, Chicago, August 1997. Earlier version presented at the ION National Technical Meeting, Santa Monica, January 1997.

England in August 1996 and one in New York City in November 1996.

This paper describes the equipment suites used in each experiment, the LORAN receiver hardware, the LORAN receiver software, the various scenarios in the experiments, the methodology in analyzing the data and presents examples of plots, preliminary details of a proposed low power implementation of the design, and conclusions.

Hardware Description

This section contains a brief synopsis of the two equipment suites and provides a detailed discussion of the H-field LORAN receiver hardware. In both London and New York, equipment was installed in an experiment van which was driven over each scenario route. Each data collection device, e.g. laptop computers, GPS receivers, LORAN receivers, was synchronized to UTC time to within a few seconds. This allowed a comparison of the different data collected based on time. The equipment used to collect data in London differed slightly from the equipment suite used in the New York City scenarios. The main differences were the ground truth collection system and the GPS receivers. Figure 1 is a block diagram of the key data collecting hardware systems in London and New York City.

Equipment Suite

The Marconi Inertial Navigation System (INS) was used for ground truth in the London scenarios. It was reinitialized every 10 minutes which produced about 1 meter circular error probability (CEP) accuracy. The ground truth data was time tagged with UTC time so that it could be used to determine fix accuracy for the GPS, GPS/GLONASS, and LORAN receivers. The Ashtech Z-12 was the 12 channel GPS receiver used in the experiment. It functioned as a stand-alone receiver--no DGPS corrections were used. The Ashtech GG24 (GPS/GLONASS), an integrated 24 channel receiver (12 GPS and 12 GLONASS), was used to determined the benefit of a combined GPS/GLONASS receiver over a GPS only receiver in urban environments. The data collection van contained two USCGA Digital H-field LORAN receivers. They could calculate a fix in either the traditional three station time-difference (TD) mode or in a two station time-of-arrival (TOA) mode when using the cesium frequency reference. The receivers were connected to H-field antennas mounted on the van. A cesium standard or rubidium standard was used as the clock reference for the USCGA LORAN receiver. The ISRC UniTrack Map Display / Data Collection System was used to record the DGPS, GG24, and LORAN data for playback on map overlays.

In the New York experiments an ISRC UniTrack Map Display / Data Collection System with Ground Truth was used to record the DGPS, GG24, and ground truth data. A RAC-2000 device was utilized to supply the ISR UniTrack with distance information from the experiment van's electronic transmission. Based on the RAC-2000 input, the ISR system calculated the ground truth position. In the New York experiment, a Magnavox MX9212 DGPS provided real-time DGPS position .

LORAN Receiver Discussion

The H-field LORAN receiver consists of an H-field LORAN loop antenna, a pre-amplifier/band pass filter module, a Spectrum ISA board in a Pentium portable computer, and a stable clock. Figure 2 shows a block diagram of the receiver.

A stable frequency standard was required, especially for the LORAN receiver to operate in a two TOA mode. The rubidium or cesium frequency reference was used to produce this stable clock signal. The signal was used to trigger a synthesizer which produced a 150 kHz signal of appropriate magnitude and duration to trigger the convert on the analog to digital converters.

The computer used to process the LORAN signals was a Pentium portable computer with a minimum of 32 megabytes of RAM. A TMS320C30 system board (ISA format) by Spectrum Signal Processing, Inc. was used to perform digital signal processing. Two models of computers were used during the tests. In London, both computers were BSI portable computers, using a 90 MHz Pentium processor and 32 Mbytes of RAM. In New York, one BSI computer was replaced with a DFI notebook, using a 120 MHz Pentium processor and 32 Mbytes of RAM, with a docking station. The computer retrieved and analyzed LORAN data from the TMS320 board. It calculates a heading, TOA's, TD's, and position information. The computer records the LORAN data and sends NMEA-0183 position information out the serial port to the NavTrack computer.

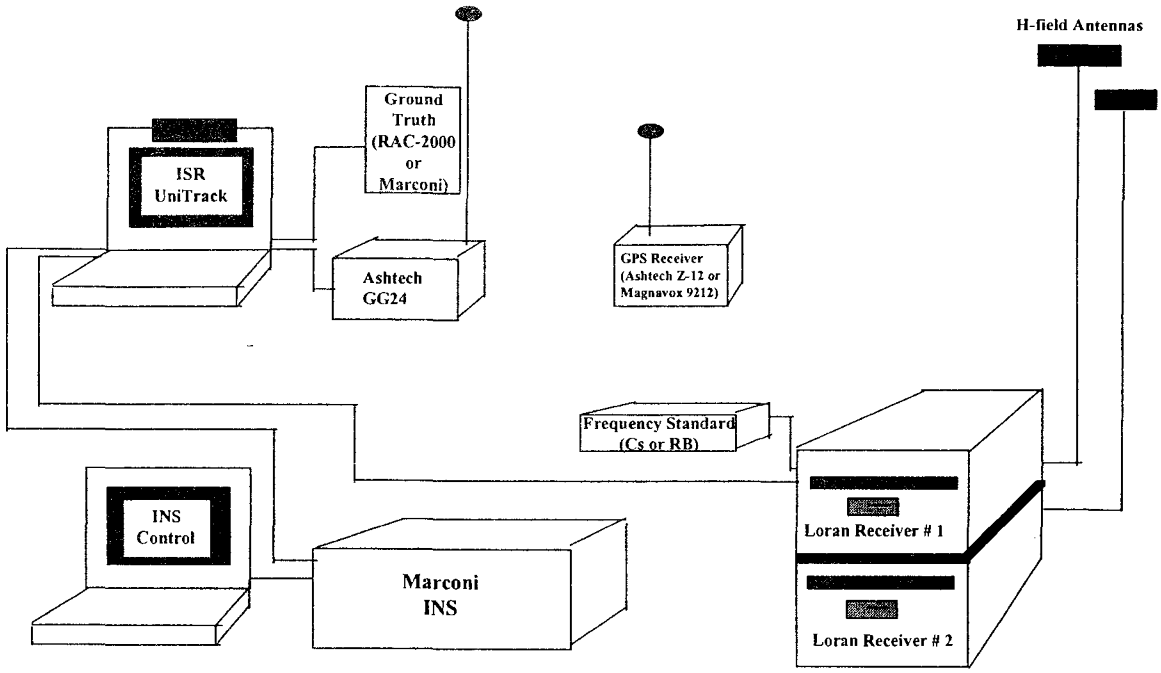


Figure 1 Block Diagram of Key Data Collecting Hardware Systems

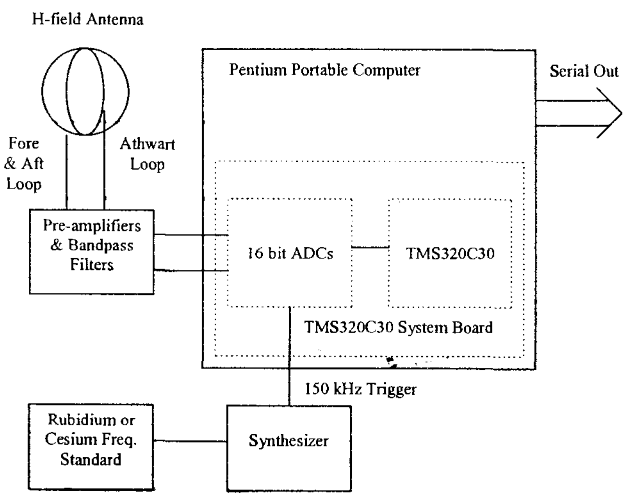


Figure 2. Block Diagram of H-field LORAN Receiver

The TMS320C30 system board is made by Spectrum Signal Processing, Inc. The TMS320C30 Digital Signal Processor contains an integer and floating point arithmetic units. It operates from a 33.3 MHz clock, performing 16.7 million instructions per second. When parallel instructions are used, 33.3 million instructions per second may be achieved. The board contains 64K words of dual port memory which can be accessed by the computer or TMS320C30. It also contains 128K of additional memory for general storage. Dual channel 16 bit A/D and D/A systems are included on the board. Sampling rates of up to 200 kHz are supported.

Antenna Issues

Several models of H-field LORAN antennas were tested and used. Manufacturers of the LORAN antennas included Megapulse, Starlink, and Cambridge Engineering Inc.. The antennas contained two magnetic loops oriented 90 degrees apart. The loops are referred to as the fore and aft loop and the athwart loop. Each antenna included its own pre-amplifier. These preamplifiers have second order responses with a -3 dB bandwidth of approximately 30 kHz.

During the tests, it became obvious that there were cross coupling problems between the two loops of the antennas. Figure 3 illustrates these problems. To collect this data, a local magnetic field was created using a one meter diameter loop antenna driven with a 100 kHz sinusoid. Figure 3 shows plots of magnitude and phase of the two crossed loops as the receiving antenna is rotated through 360 degrees. The nulls in amplitude are not very deep and when at the amplitude minima, the phase is 90 degrees from its value at the maxima due to a voltage induced by the current flowing in the crossed loop. This cross coupling causes problems in that the received phase or TOA becomes a function of the orientation of the loop resulting in position errors. Figure 4 illustrates a preliminary attempt to model and eliminate these errors in software. In Figure 4 for the Starlink antenna, the solid lines were calculated using Loop1 -0.09j * Loop2 and the dashed lines using Loop2 + 0.13j * Loop1, where j = (-1)^0.5 .

The RF signals from the fore and aft loop and the athwart loop of the magnetic loop antenna are amplified and filtered. Several types of pre-amplifiers and filters were tested during the experiments. Manufacturers of these pre-amplifiers/filters included Frequency Electronics and Stanford Research Systems, Inc. A Frequency Electronics D68H8E high pass module followed by a D68L8E low pass module were cascaded to perform the required filtering. Each module is an 8 pole, 6 zero elliptic filter. The filters are well enough matched so that they are almost identical. The overall magnitude response has a -3 dB bandwidth of approximately 24 kHz and is 30 dB down at 60 and 160 kHz. At 100 kHz, the phases of the two channels agree to within 0.25 degrees or to about 7 nsec.

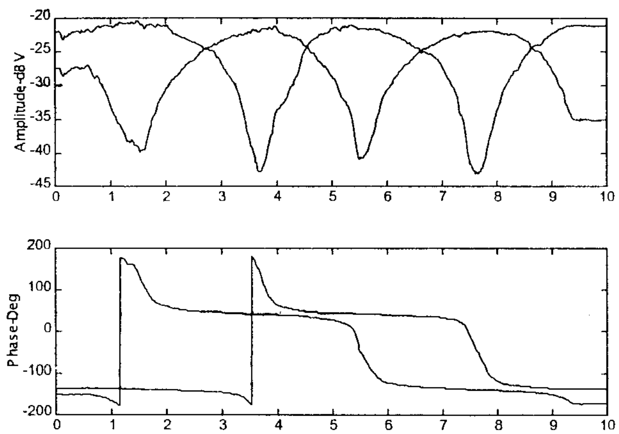


Figure 3. Response at 100 kHz as Starlink loop is rotated through 360 degrees in a local magnetic field. (Horizontal axis is time in arbitrary units.)

Software Description

The software to implement the magnetic loop LORAN Receiver was written in three different languages. The code for the TMS320C30 board was written in the TMS320C30 assembly language. The assembly language code collected, filtered, and stored the sampled signals from the magnetic loop antenna. The code that allowed the host computer to communicate with the TMS320C30 board was written in C. The C code included routines to load the TMS320C30 board, change parameters on the board, and read data from the board. The host computer code that processed the data retrieved from the TMS320C30 board was written in MATLAB. The

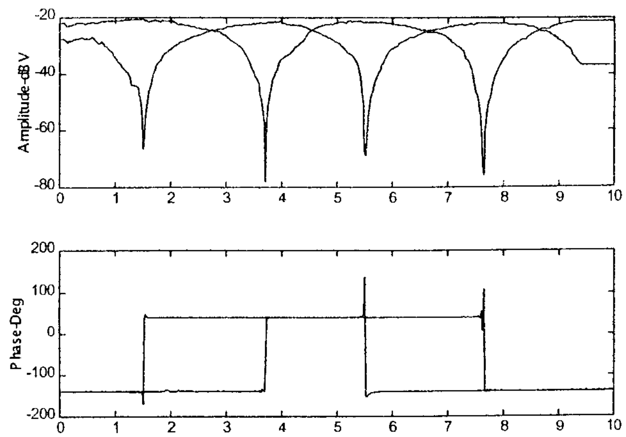


Figure 4. Elimination of cross coupling in software for Starlink antenna

MATLAB processing included filtering the data, finding the start of the LORAN pulses of the appropriate stations, calculating the heading of the antenna and beamforming the signals, calculating the zero crossings, time of arrival (TOA), and time differences (TD's), and calculating position.

Figure 5 is a block diagram of the digital signal processing algorithm that the TMS320C30 board is running. The RF signals from the fore and aft loop and the athwart loop of the magnetic loop antenna are amplified and filtered by an analog, sixth order bandpass filter with a center frequency of 100 kHz and a bandwidth of 24 kHz. The two signals are connected to channel 1 and 2 of the Spectrum TMS320C30 board where the signals are sampled at 150 kHz and 16 bits.

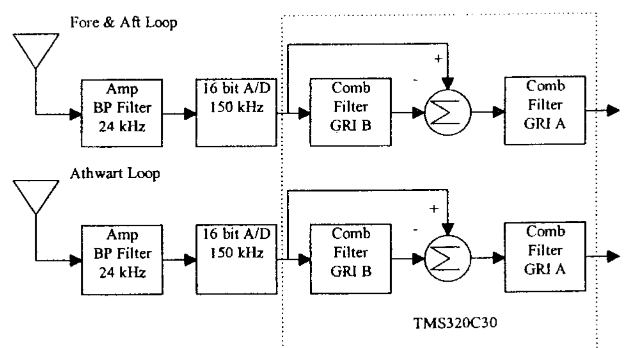


Figure 5. Block Diagram of TMS320C30 Processing.

Reference [2] presented a digital signal processing algorithm for the TMS320C30 that used a series of comb filters to notch out two LORAN GRI's and track one GRI. The TMS320C30 code uses the same algorithm, except only one GRI is notched and two channels are processed by one board. Each of the comb filters is an exponentially weighted average of the last number of phase code intervals.The transfer functions of the comb filters are of the form:

$$H_c(z) = \frac{1-a}{1-az^{-N}}$$

where $\frac{1}{1-a}$ is the time constant of the comb filter in Phase Code Intervals (PCI) and N is the length of a PCI in samples. The TMS320C30 code uses (1-a) as the multiplier of the input and (a) as the multiplier of the output which is delayed N samples. These variables are calculated and passed from the host. The output of the first comb filter (GRI B) is subtracted from it's input to form a notch filter at the GRI's harmonics. The notch filter transfer function is:

$$H_n(z) = \frac{a(1-z^{-N})}{1-az^{-N}}$$

Reference [2] illustrates the theoretical and actual responses of this type of system.

In London, GRI 7499 was tracked and GRI 8940 was notched. The time constants and lengths of the comb filters can be easily changed by the host computer to change GRI's or adjust time constants. At a sampling frequency of 150 kHz, the maximum length N of any GRI would be 30,000. The Spectrum DSP board is limited to 64 k 32 bit words of dual port memory which is easily accessible by both the TMS320C30 and the host computer. The data from GRI A, including both antenna loops (channel 1 and 2), is stored in the dual port memory (60,000 words) along with variables to control the algorithm such as N and the time constants related variables (1-a) and (a)

The host computer routines to process the LORAN signals are written in MATLAB. The program has two parts - (1) the signal acquisition, and (2) the signal tracking. During the signal acquisition, the program initializes the TMS320 board and retrieves data from the board. The program also allows the user to do additional notch filtering on the LORAN signals. The user can either manually set the filters or have the program calculate the best filter. Figure 6 shows the typical 7499 LORAN signals from the TMS320C30 board. Both loops are shown. Only one half of the PCI is shown in the figure. Figure 7 illustrates the actual spectrum, the ideal spectrum, and the filtered spectrum.

The start of the master LORAN signal is found by match filtering the two LORAN signals added in quadrature with an ideal master LORAN signal. This is done in the frequency domain using a 65,536 point FFT. Likewise, after the start of the master LORAN signal is found, the secondary signals are found using a match filter of the two LORAN signals added in quadrature with an ideal secondary LORAN signal.

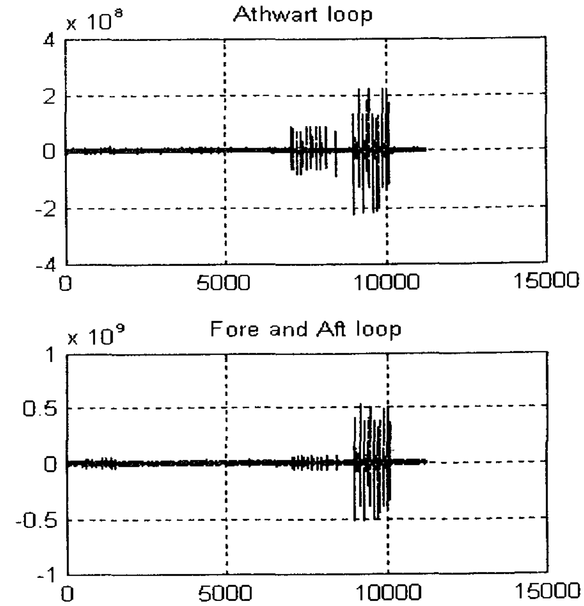


Figure 6. Typical 7499 LORAN Signal

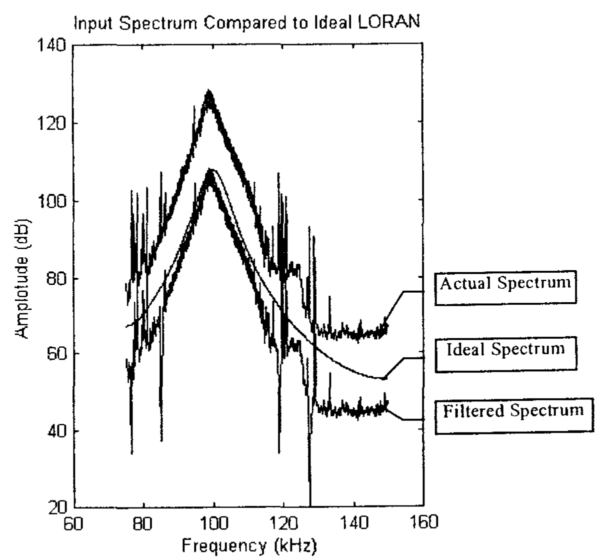


Figure 7. Actual, Ideal, and Filtered LORAN Spectrum

Figure 8 shows a typical matched filter for 9960. Once the start of the pulses is identified, one composite master and several composite secondary pulses are formed by adding the individual pulses of the LORAN signal multiplied by the appropriate phase shift. The vector size that stores the individual LORAN pulse is 64 points and starts 106 microseconds (or 16 points) before the actual start of the pulse. At 150 kHz sampling frequency, that corresponds to 426 microseconds or 42 LORAN cycles.

The measurements of the start of the pulses are later used to calculate the TOA's of the pulses.

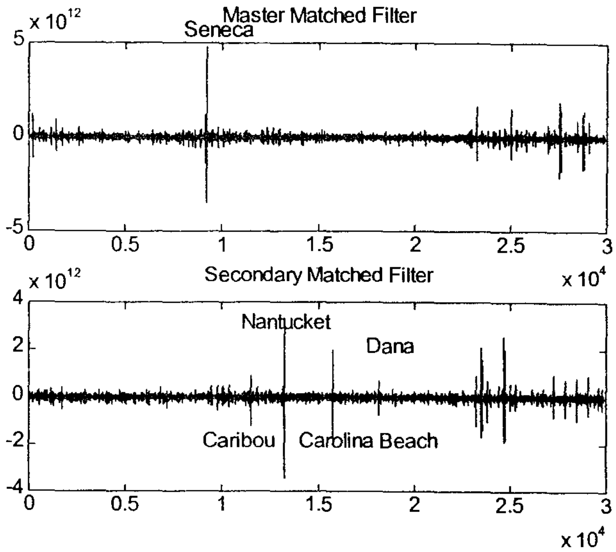


Figure 8. Matched Filters for 9960.

The program uses two methods to find the correct cycle zero crossing of the LORAN pulses. The first method involves calculating the envelope of the pulse and then the envelope ratio. When the envelope ratio equals a predetermined threshold, and the Envelope to Cycle Difference (ECD) is taken into account, the cycle zero crossing should be the nearest zero crossing. In a receiver using an E field antenna, this works well because the LORAN signal always has a positive phase. It requires that you must be able to calculate the correct cycle zero crossing within a half a LORAN cycle or 5 microseconds.

In the H field magnetic loop antenna, the signals may have either a positive or negative phase depending on the direction of the transmitting station from the antenna. This requires that, for at least one station, you must be able to calculate the correct cycle zero crossing within a quarter of a LORAN cycle or 2.5 microseconds. Once the zero crossing for one station is found, the heading can be calculated, and beamforming of the loops can be used for the remaining stations and ensuring that they all have a positive phase. During acquisition, this method is used to find zero crossing of strongest loop of the strongest station. Once the zero crossing of the strongest signal is found, a portion of its envelop is saved as a template. This template is used later to find the cycle zero crossing on the other stations by performing a least squares fit with each LORAN pulse envelope.

Since the sampling rate is 150 kHz, the LORAN signal that is centered at 100 kHz has only three samples every two LORAN cycles. The sampling rate can be expanded by performing a 64 point FFT and zero padding in frequency domain by a factor of 8 or 512 points. This produces a signal sampled at 8 times the sampling frequency or 1.2 MHz. Reference [2] discusses this algorithm in detail. Figure 9 shows the template and an "expanded" LORAN signal.

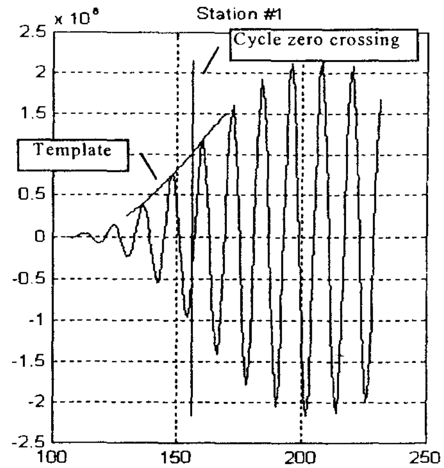


Figure 9. Expanded LORAN Pulse and Template.

After acquisition of the LORAN signal and the start of the pulses are identified, the tracking of the zero crossing and navigation phase is done. This is the main loop of the program in which the TOA's are calculated. Once the TOA's are calculated, TD's and finally latitude and longitude are calculated.

During the tracking phase, the LORAN signals are retrieved from the TMS320 board, filtered, and expanded. Next, the strongest LORAN station is identified. The envelope template formed earlier is used to find the initial guess to the cycle zero crossing. The strongest loop of this strongest LORAN station is also identified.

The first time this routine is used, the phase of the strongest signal must be determined to perform beamforming correctly. Using the strongest loop, the closest zero crossing to the initial zero crossing guess is found and used as the correct cycle zero crossing, adjusted for the ECD. This is the TOA of the strongest LORAN station. The slope of this zero crossing gives the phase of the signal. The closest positive zero crossing of the composite signal for the strongest signal is found next. The phase difference between this point and the correct cycle zero crossing is used to calculate the relative bearing of the antenna to the strongest signal. The antenna heading can easily be found from this. In subsequent loops in this routine, the fore and aft loop and athwart loop signals are correlated with the previous beamformed signal and a new beamformed signal is found. Using the beamformed signal, the closest positive zero crossing to the initial zero crossing guess is found and used as the correct cycle zero crossing (TOA of strongest LORAN station). As before, the heading can be calculated.

The remaining LORAN stations are processed by first beamforming the athwart loop and fore and aft loop signals. Once the beamformed signal is found, the envelope template is used to find an initial guess of the correct cycle zero crossing. After adjusting for ECD, the closest positive zero crossing to the initial guess is found and used as the correct cycle zero crossing (or TOA) of the LORAN station

Signal strengths are checked to see if a loss of signal has occurred. If a loss of signal has occurred for a length of time, such as would occur if the LORAN signals were blocked by interference for a time period, a flag would be set to reacquire the LORAN signal once the strengths returned. The ECD's are also checked. If the ECD of a station remains greater than 5.0 or less than -5.0 for length of time, the tracking point cycle is adjusted. Finally the position is calculated. The user can select one of three methods - calculation of latitude and longitude by (1) TD's, (2) weighted least squares of the TOA's (described in reference [3]), and (3) TOA's of the strongest two stations only.

Scenario Descriptions

London

In London we used the 7499 chain with master at Sylt, Germany and secondaries at Lessay, France and Vaerlandt Norway, Because both the Vaerlandt and Sylt stations are northeast of London, the fix geometry is rather poor. Furthermore, because Vaerlandt is more than 600 nautical miles from London, the signal strength and hence the SNR is very poor further degrading fix accuracy. Future plans call for the addition of a new station at Loop Head in southwest Ireland which should result in both excellent fix geometry and signal strength in all of England.

There were four scenarios used in London. The first scenario involve a drive from a rural area into the city of London. Moderate to high van speed is a characteristic of this scenario. The scenario was expected to last about 40 minutes. The second scenario involved a drive through London. This scenario represented a urban environment. It contained tall buildings, parks, vehicles, and a noisy frequency spectrum. Slow van speed is a characteristic of this scenario. Each scenario run was expected to take about 2 hours to complete. The third scenario involved a drive trough the urban canyons of London. The purpose of this scenario was to measure LORAN and GPS performance in a highly urban environment with many tall buildings. Slow van speed is a characteristic of this scenario. Each scenario run was expected to last about 30 minutes. The fourth scenario involved the drive from London back to a rural location This scenario followed the reverse route of the first scenario. Moderate to high van speed is a characteristic of this scenario.

New York City

There were several scenarios in the New York City experiment. However, most of the data collected was from the Urban Canyons and Suburban scenarios. Since no ground truth data was collected on the other scenarios, absolute accuracy of the radionavigation systems cannot be determined. However, fix availability was measured. The first scenario consisted of approximately a 5 city block by 5 city block rectangular grid in the Wall Street area. Slow vehicle speed, narrow streets, and tall buildings were the main characteristics of this scenario. It took about 15 minutes to complete one scenario run. The second scenario consisted of travel trough the Bronx. Power lines, two and three story buildings, and an elevated train were attributes of this scenario. A typical scenario run took about 15 minutes to complete. The third scenario was run in the vicinity of West Point in New York. It was used to determine the effect of mountainous terrain on DGPS, GPS/GLONASS, and LORAN receivers. About two hours of data were collected in this environment. The fourth scenario involved a suburban to urban run. Every morning and evening the experiment van traveled between suburban New Jersey and urban New York City. Data was collected from these runs and is typical of a person commuting to and from work each day in an urban environment.

Data Analysis

Extensive analysis was performed on the collected data to determine the availability, accuracy, and repeatability of H-field LORAN in urban locations. Envelope-to-cycle difference (ECD) plots were generated to determine LORAN signal availability. Plots of differences between LORAN and ground truth position are presented to show accuracy. Scatter plots of the position errors along with the cumulative distribution of errors are also shown. Actual and predicted TOA's are plotted (this is an indication of both availability and accuracy). Plots of TOA's from multiple scenario runs verses distance into the scenario were generated and indicate the LORAN repeatability. For the Suburban scenario in New York City, the DGPS position is plotted versus the ground truth position for comparison. The following describes the various plots. An example of each is given.

LORAN ECD verses Time

The H-field LORAN receiver calculated and stored the ECD for each LORAN signal. The ECD is the difference in microseconds between the actual tracking point zero crossing of the LORAN signal and the tracking point measured by the envelop alone. In optimum conditions, the ECD is less than 2.5 microseconds and is stable. If the signal is weak, the measurement will jump in multiples of 10 microseconds (5 microseconds for the strongest station). The receiver software continuously examines the ECD and will adjust the cycle selection. If the ECD jumps momentarily, it is an indication of interference. The ECD for each LORAN signal is an excellent indication of the LORAN signal availability. If the LORAN signal is acquired and tracked, the ECD will remain constant. Figure 10 shows a typical plot of the ECD's from the New York experiment. Note that the last two ECD's are fairly stable. The first ECD from the Seneca station shows one jump.

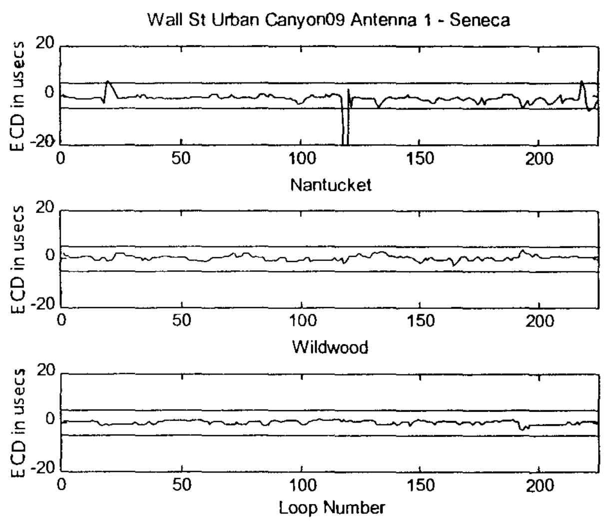


Figure 10. Example Plot of LORAN ECD verses Time. ECD's are plotted relative to nominal values.

Latitude and Longitude Verses Time

Figure 11 shows an example plot of the LORAN latitude and longitude and ground truth latitude and longitude verses time. This is an indication of the accuracy of the LORAN signals. Figure 12 shows an example plot of the LORAN position verses ground truth.

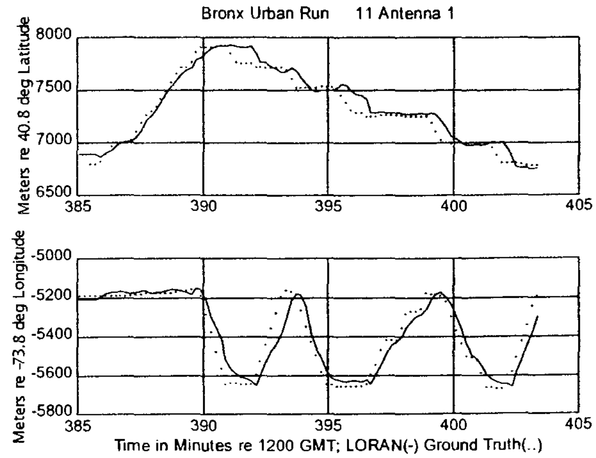


Figure 11. Example Plot of LORAN and Ground Truth Latitude and Longitude verses Time

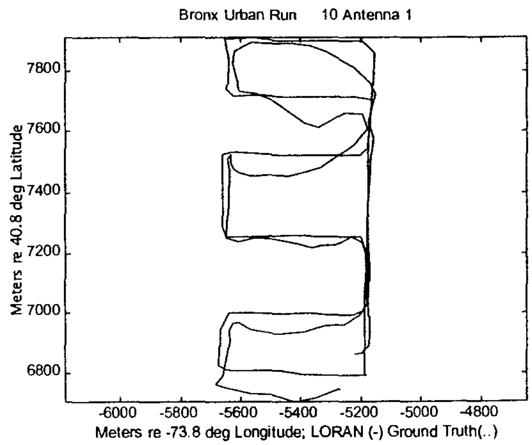


Figure 12. Example Plot of LORAN verses Ground Truth Fix Accuracy Plots.

Figure 13 shows a typical scatter plot of the error between the LORAN positions and the ground truth positions for the London urban scenario. The cumulative distribution of the error is shown in figure 14. What these plots show is that approximately 60% of the fixes were within 150 meters of ground truth in London. With the Loop Head station transmitting resulting in both better fix geometry and signal to noise ratio, fix accuracy should improve significantly. Figures 15 and 16 show comparable data for the Bronx and Wall St. scenarios in New York City.

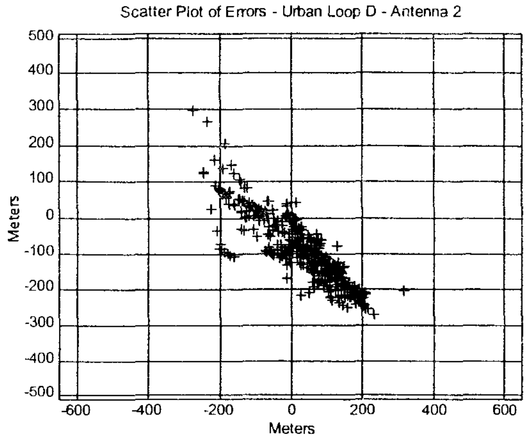


Figure 13. Example Scatter Plot of LORAN Position Error for London urban scenario.

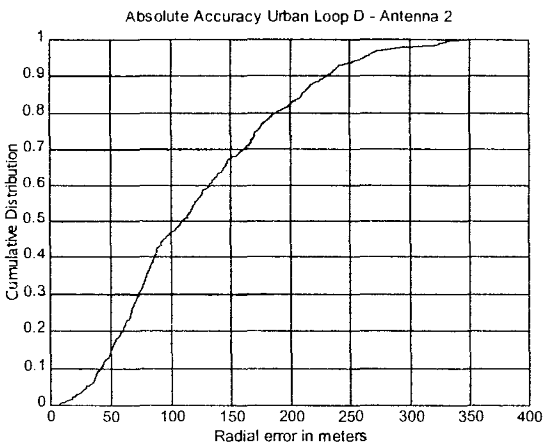


Figure 14. Example Plot of Cumulative Distribution of LORAN Position Error for London Urban Scenario.

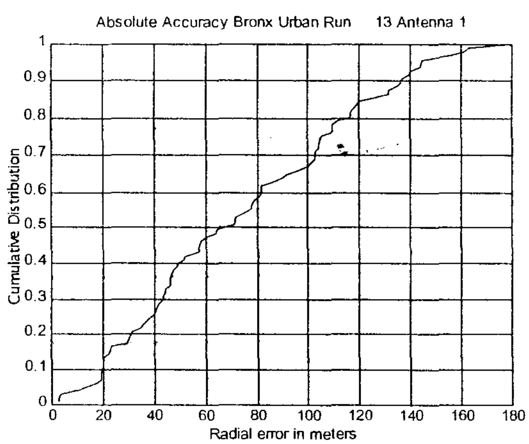


Figure 15. Example Plot of Cumulative Distribution of LORAN Position Error for Bronx Scenario.

Figure 17 shows a plot of difference between predicted and observed TOA's from multiple Bronx scenario runs verses distance into the scenario. In this example, the positive spikes occur on the left edge of figure 14 or under an elevated train. The propagation path from the Wildwood transmitter is along the train direction. For Nantucket with propagation perpendicular there was not the same phase shift. Also, the attenuation of the Wildwood signal was 10-15 dB under the train but the Nantucket signal was attenuated much less.

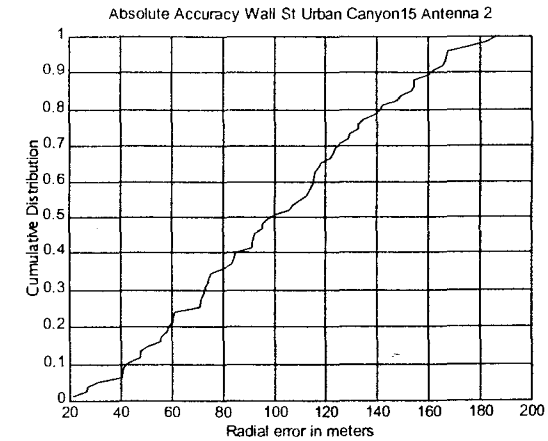


Figure 16. Example Plot of Cumulative Distribution of LORAN Position Error for Wall St. Scenario.

TOA's versus Distance into Scenario

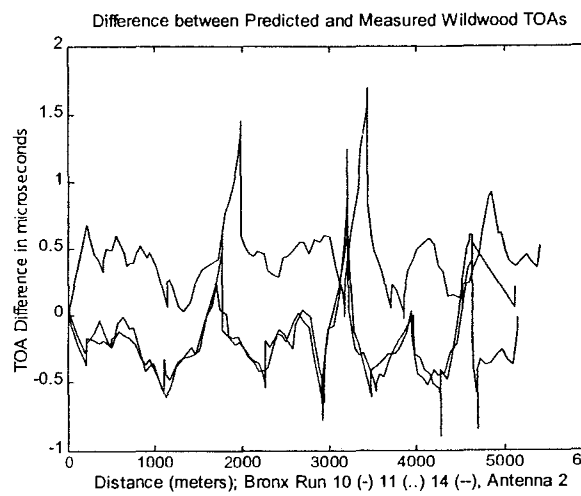


Figure 17. Example Plot of Multiple LORAN TOA's verses Distance into Scenario.

Proposed Low Power Receiver

At present ISRC and the Coast Guard Academy are cooperating in a proposal to reduce the size and power consumption of the receiver for use in urban warfare and law enforcement applications. The receiver would be packaged using the industry standard PC104 bus technology. Figure 18 shows a block diagram of the proposed H-field LORAN receiver. The three basic functions needing to be reduced in size and power and how this is to be accomplished are listed below. It is envisioned each of these functions will initially occupy one PC104 card.

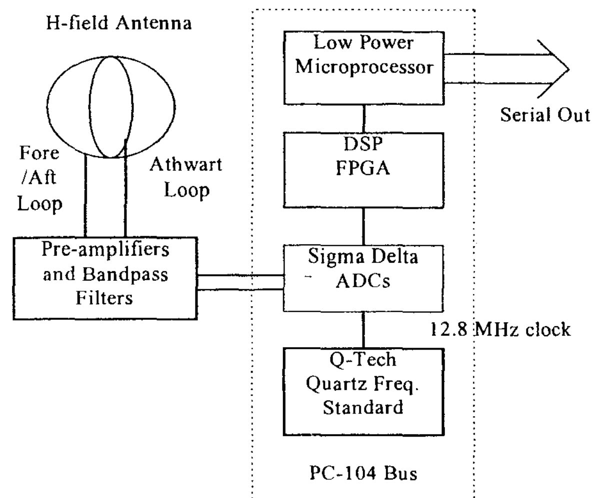


Figure 18. Proposed Low Power H-field LORAN Receiver

The Antialias Filtering and A/D Conversion

In the initial phase the combination of the high order analog antialiasing bandpass filter and the 16 bit successive approximation A/D converter will be replaced with a commercially available, low power, Sigma Delta A/D converter. The signal will now be sampled at one bit and 12.8 MHz which means the low order bandpass pre-amp need only filter out those frequencies above 6.4 MHz. This one bit data is then decimated and lowpass filtered in a series of two Finite Impulse Response (FIR) filters to produce 12 bit samples at 400 kHz and a cutoff frequency of 196 kHz.

The DSP Functions of Cross Rate Canceling/Comb Filtering

The 12 bit, 400 kHz data from the A/D conversion will then be mixed with the sine and cosine of 100 kHz. The mixer outputs will be lowpass filtered and sampled at 50 kHz. Figure 19 shows a block diagram of the antialias filter, Sigma Delta A/D Converter, and I & Q demodulator. This 50 kHz data will then be averaged with cross rate interference removed just as was done on the 150 kHz data in the 1996 version of the receiver. Present plans are that this will initially be done with a Field Programmable Gate Array (FPGA) and later phases will transition from FPGA to an Application Specific Integrated Circuit (ASIC) to further reduce size and power. In addition, the function of the commercially available lowpass A/D converter in the section above will be incorporated into this ASIC (or ASIC's) with the lowpass FIR filters replaced with logic to go directly to the 50 kHz I and Q samples.

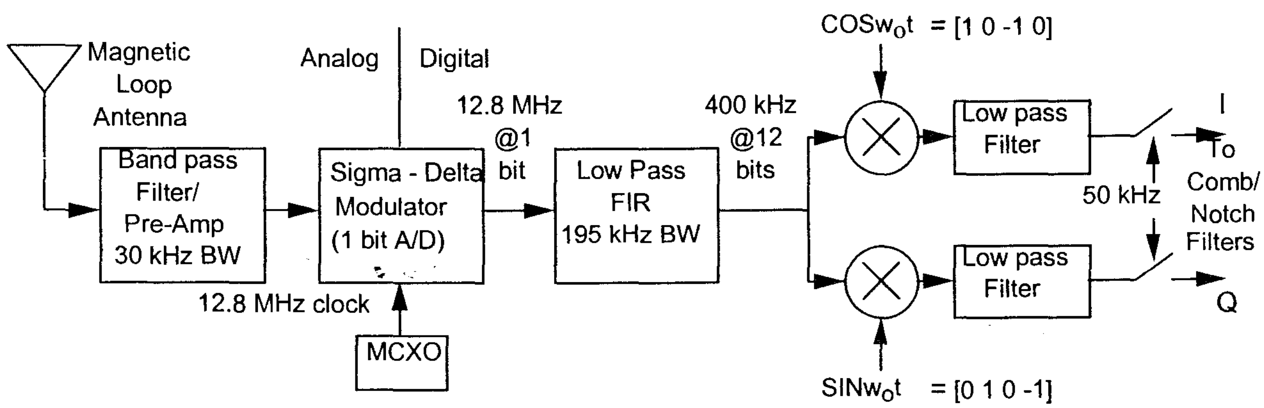


Figure 19. Block Diagram of Antialias Filter, Sigma Delta A/D Converter, and I & Q Demodulator. Repeated on each of two channels.

The Host Functions of Converting an Averaged PCI Waveform First into TOA's and then Latitude and Longitude

In the 1996 version of the receiver, these functions were performed by a program written in MATLAB and ran on a 90 Mhz Pentium computer. Initially these functions will be converted from the present MATLAB version to C++ and performed on a low power microprocessor. Whether the development of an ASIC for these functions is feasible is still being studied.

Conclusions

We have presented the design of the US Coast Guard Academy developed all digital H-field LORAN receiver which accepts a precise oscillator input to produce a two station time-of-arrival (TOA) fix if three stations are not available. In addition, the results of extensive LORAN testing in urban canyons was presented.

The first experiments were performed in London utilizing a van supplied by the United Kingdom and outfitted by a joint U.S. / U.K. team. Ground truth to an accuracy of one meter circular error probability was obtained via a combination of frequent stops at precisely surveyed locations and post processing of inertial navigator data. The London data collected over a two week period indicated the LORAN receiver could consistently provide fixes with accuracy comparable to GPS SPS.

The second set of experiments were performed in the New York City area utilizing a van supplied by ISRC and outfitted by USCGA, SAIC, and ISRC personnel. The New York data collected over a two week period also indicated the receiver could consistently correctly acquire and provide fixes of accuracy comparable to GPS SPS.

A preliminary design of a proposed low power implementation of the digital H-field LORAN receiver was also presented.

Acknowledgments

This effort was funded jointly by the Office of National Drug Control Policy, the British Home Office, and the Defense Advanced Research Projects Agency. The subroutines to allow MATLAB to communicate with the TMS320C30 were developed by LCDR Chris Kmiecik of the Coast Guard Academy. The Coast Guard Electronics Engineering Center operated the 9960T transmitter specifically to support the New York City tests and provided monitor data. Megapulse Inc. provided a loop antenna on loan and some of the ideas for modeling cross coupling in magnetic loop antennas were based on conversations with Bill Roland, the President of Megapulse.

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[1] Peterson, B. B., M. McKaughan, L. Miller, S. Bartlett, "Evaluation of Radionavigation Systems in an Urban Environment," Condensed version in Proceedings of Institute of Navigation National Technical Meeting, Anaheim, CA, January 1995. Long version available as NTIS report number PB95-190955.

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Q: Is there a dual rate capability, and what benefits do you see?

A: Minimal improvement seen; we're building the capability, but for the longer term. In London and New York City, in order to do multiple chain fixes, we had to have multiple digital signal processors. The data existed in the receiver, but we only had limited dual-port memory and could not make it available to the host computer. Trying to do it bogged down the process. In the 1997 receiver, we'll have 3 chains of data available. We'll use it if the scenario demands.

Q: Under the railways, we saw wide excursions. Did beam steering help?

A: We use the strongest signal to orient the antenna. Then the positive lobe is pointed toward the weaker stations. No null steering was used. The shifts were a shift in the signal. It was repeatable.

Q: What of null filling and steering difficulty?

A: We never tried a 3-axis loop

Q: Are you working toward production?

A: Receiver technology will be in the public domain, since it is a U. S. government development; unclassified now. It's subject to clearance (some of these factors are political and competitive rather than being based on national security) but the intent is to produce a prototype and 25 copies by October 1998.

Performance and Cost Trade-offs in LF H-Field Antenna Design

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Bedford, MA 01730

BIOGRAPHIES

Erik Johannessen received an MBA in marketing from Bentley College in 1986. He worked in a variety of capacities ending as project coordinator for new product development at International Navigation from 1974–81. Mr. Johannessen has been connected with Megapulse since 1981 where he is currently a Vice President. Mr. Johannessen is also President of A/O Gradient.

Andrei V. Grebnev received an MS degree in radioelectronics engineering in 1981 from Moscow Aviation Institute, Moscow, USSR. From 1981 until 1991 he worked at the same Institute as Senior Research engineer and later as a Chief of Receivers Laboratory. In 1991, he joined the Research Center of Russian Radionavigation Committee, where he worked as a Senior engineer and Deputy Chief of Radionavigation Systems Operation Department. Since 1993 he has been employed by Megapulse, Inc. as a Senior Hardware Engineer, where he is responsible for the design of combined loop antennas and hardware for newly designed receivers.

ABSTRACT

Future portable applications of LF or integrated LF-GPS receivers will require that the receivers be lightweight, compact and low-power. The H-field antenna advantages are low sensitivity to precipitation static and to E-field interferers, as well as simplicity of installation (low profile and no grounding) making this type of antenna attractive in many applications. Pulse phase systems such as Loran require the use of crossed loops to provide an omnidirectional antenna pattern. The ability of an H-field antenna to receive a signal of any given field strength is a function of the amount of ferrite material, geometry of the crossed loops, and permeability of the material. Increased ferrite material yields better performance at the expense of increased cost, size and weight. This paper evaluates trade-offs between cost and performance of H-field antennas as designed for the Loran system. Relationships between field strength, noise levels, and antenna design are analyzed. Experimental results indicate that in the presence of high field strengths or in applications of satellite augmentation significant reductions in size and cost are readily achieved.

INTRODUCTION

The advantages and disadvantages of loop antennas have previously been well described [1,2]. The introduction, by Megapulse, Inc., of an experimental Loran-C loop receiver [3] demonstrated the ability to solve problems such as bidirectional pattern and signal phase inversion which are caused by the lack of omnidirectivity. Design considerations that must be addressed due to the low effective heights of loops have also been discussed [4].

One of the main parameters determining the performance of any Loran receiver is the Signal-to-Noise Ratio, or SNR, at a given signal strength. It can be determined as:

$$SNR = \frac{Signal}{Atmospheric\ Noise + Interference + Receiver\ Noise} \qquad (1)$$

The effect of atmospheric noise and interference can be minimized by a proper selection of the bandpass filter and adequate number of notch filters. The effect of the receiver noise, or loop antenna preamplifier noise, is minimized by matching the output and input parameters of loop antenna and preamplifier to obtain the minimum equivalent noise level on the input of the preamp. The signal delivered by the loop antenna is primarily determined by the volume of ferrite material, length-to-diameter ratio of the ferrite, and initial permeability and obtains its maximum at *an optimum length-to-diameter ratio* (m_{opt}) [5]. Calculations show that for a ferrite material with initial permeability $\mu=1000$, $m_{opt}=108$. Thus, if the ferrite has a diameter of 1 cm, its optimum length is 108 cm! Such a geometry is unacceptable for a compact hand-held receiver.

This paper discusses the issue of trade-offs between loop antenna performance and its size, weight and cost. Three different frame configurations are discussed in the next section. A section follows which discusses the test set-up. The final two sections are a presentation of the test results and some observations and conclusions.

LOOPS TESTED

Three loop antennas were compared on the basis of performance and cost. All antennas used the same preamplifier which varied only in adjustment setting to ensure lowest equivalent noise on the input. The number of turns in the windings varied slightly from loop to loop but the variation was not more than 30% from largest frame to smallest. Therefore, the principal difference between antennas was in frame geometry and dimension. The three tested frames are depicted in Figure 1.

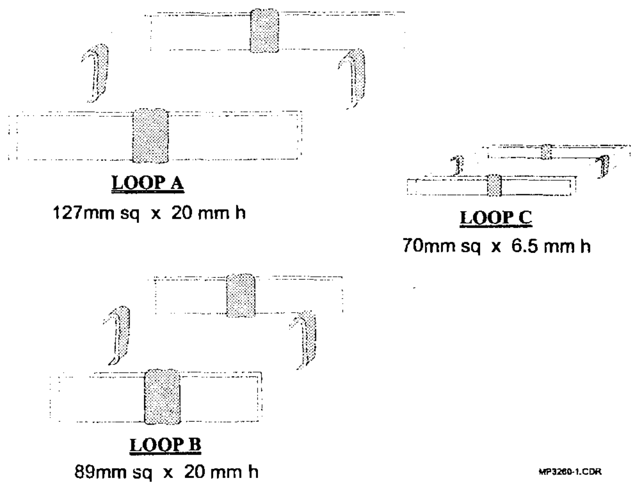


Figure 1.

All of the frames used commercially available ferrite material. Four identical bars 4 mm thick were arranged in the square as shown in the figure. Parameters for the total frame assembly are as follows:

	Vol (mm^3)	*Weight (gm)*	*Cost ($)*
A	40,640	200	16.00
B	28,480	140	11.00
C	7,280	36	4.00

DATA COLLECTION

A block diagram for the data collection is shown as Figure 2. The loop antennas were mounted on a motor-driven platform on the roof of the Megapulse, Inc. facility in Bedford, MA. Twelve notch filters were used to minimize the influence of CW interferers. The receiver used for data collection was the Accufix 520 which provides measurements of Signal-to-Noise Ratio (SNR), signal strength, and Envelope-to-Cycle Difference (ECD).

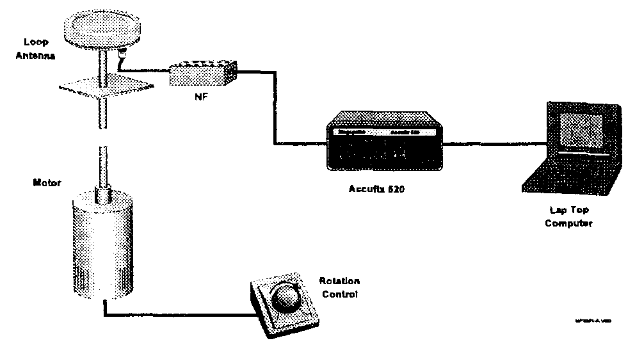


Figure 2.

Because the Accufix 520 is designed for whip antennas, only one pair of the crossed loops was used. Restrictions of equipment availability required that data sets be taken serially. Data was collected for a twenty-four hour period with the antenna oriented to the maximum of the positive lobe with respect to the remote station being measured. In the case of the Master and 4th secondary (Dana, Indiana) the relative bearing angles from the test site were small enough that the data could be collected simultaneously. The data was therefore collected over a 12 day period (four orientations for three antennas). Information on the stations is as follows:

	Power	*Dist.*	*Path*
Caribou (S1)	350 kW	549 km	land
Nantucket (S2)	400 kW	170 km	mixed
Carolina (S3)	550 kW	1100 km	mixed
Dana (S4)	400 kW	1390 km	land
Seneca (M)	800 kW	458 km	land

TEST RESULTS

The receiver was set up to output one data message every 180 seconds. The data file was imported into a spreadsheet and a series of graphs created. These graphs are presented as Figures 3-11. Field strength of the stations is shown in Figure 3. For clarity, the Caribou secondary is omitted from the Figure. Caribou data overlapped the lower range of Master and upper range of Carolina. The signal level (with a few minor unexplained deviations) is seen to be constant. The effect of decreasing antenna frame size (in other words, effective height) is well seen on each station.

Constant signal level and uniform receiver noise implies that SNR changes result from changing levels of atmospheric noise and interferers. Indeed, the day-night effect is clearly shown in Figure 5.

Figure 3. Field Strength
(Master and three Secondaries)

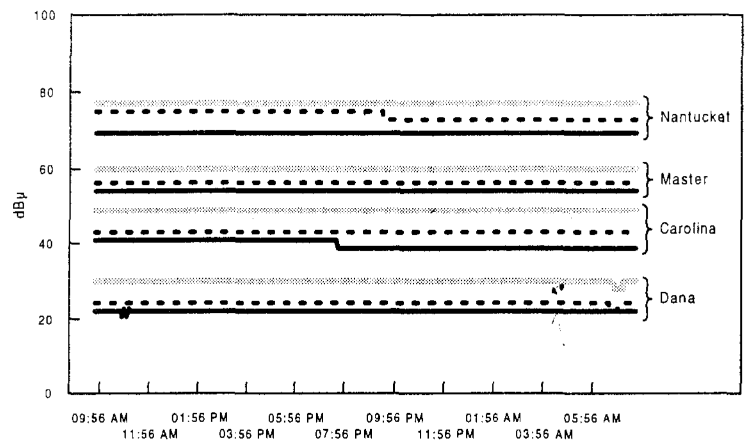


Figure 4. Master (Seneca)

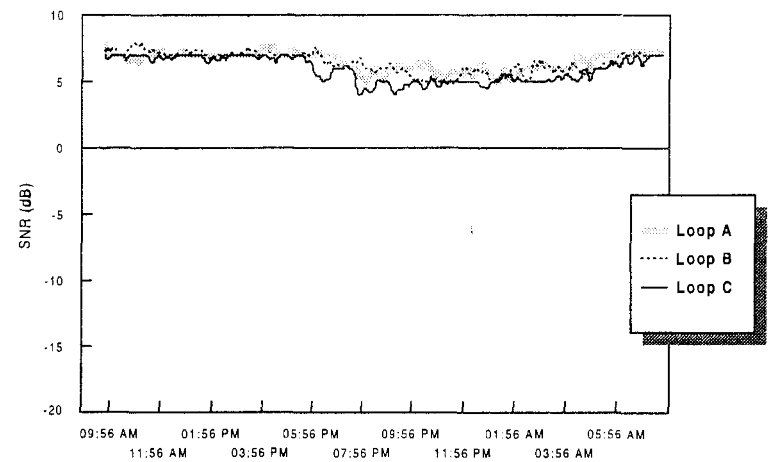


Figure 5. Secondary 1 (Caribou)

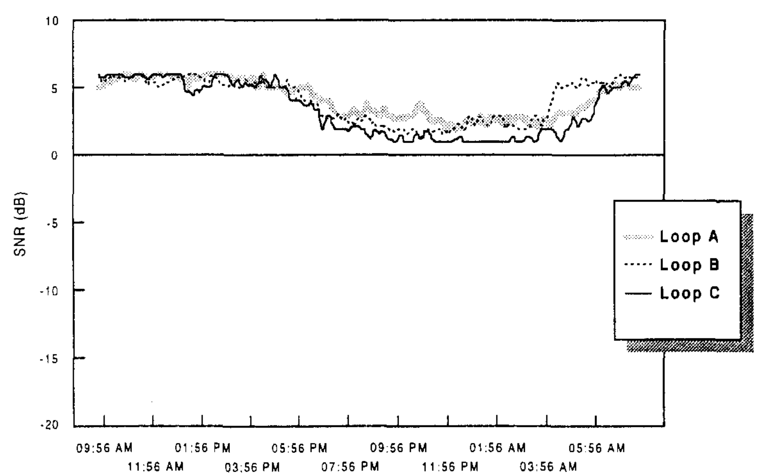


Figure 6. Secondary 2 (Nantucket)

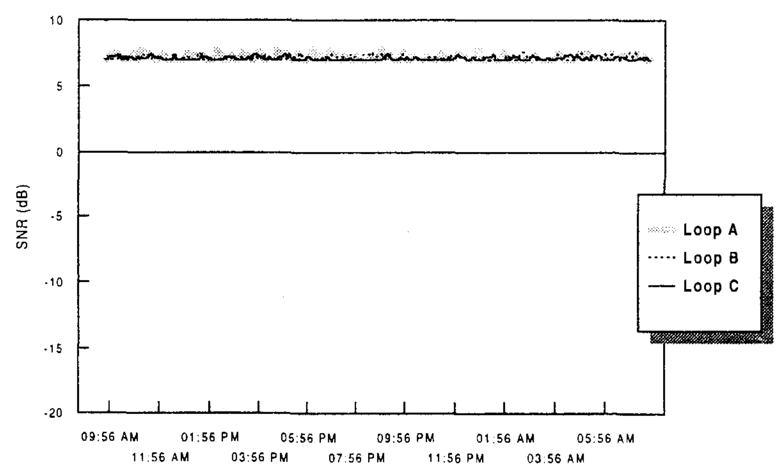


Figure 7. Secondary 3 (Carolina)

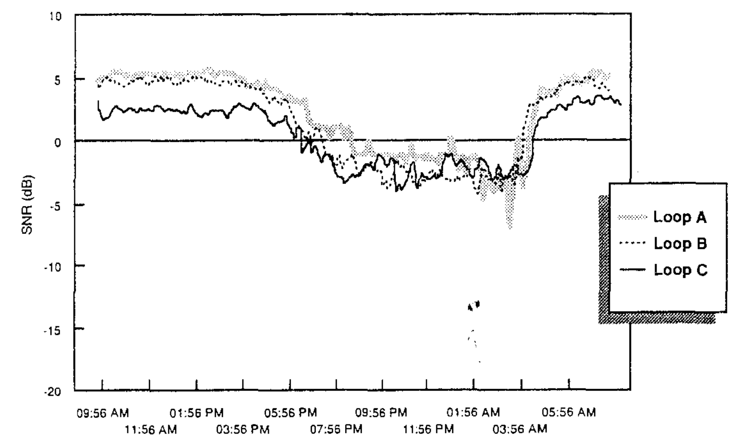


Figure 8. Secondary 4 (Dana)

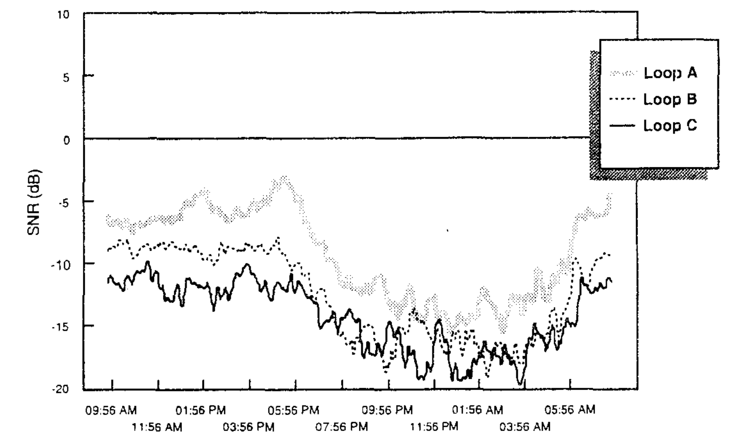


Figure 9. Loop A - 24 Hour Data Set

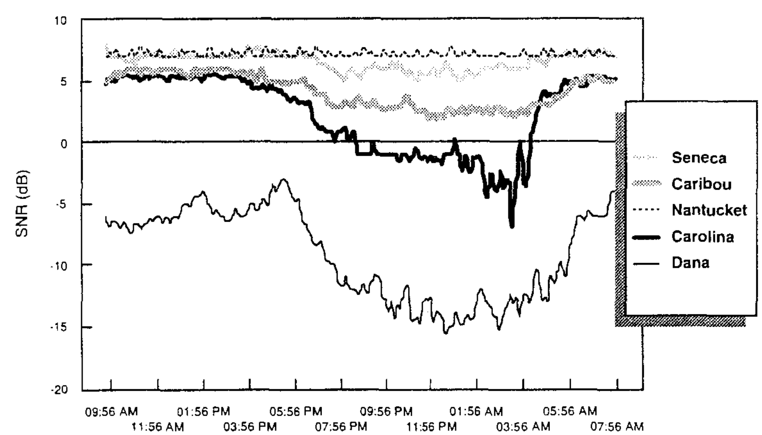


Figure 10. Loop B - 24 Hour Data Set

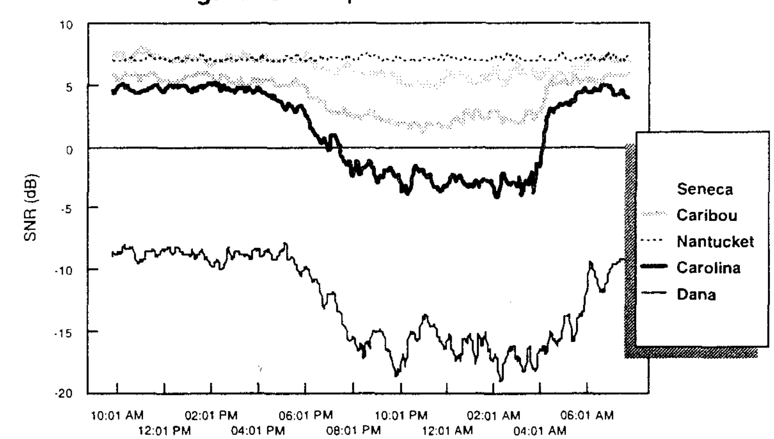
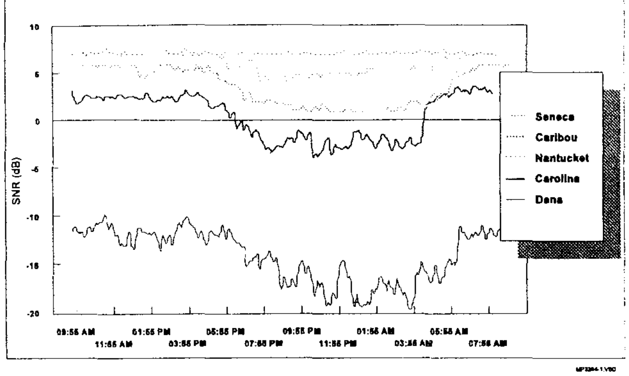


Figure 11. Loop C - 24 Hour Data Set

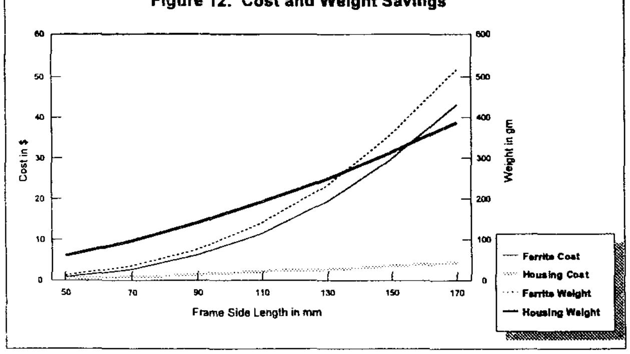


The reduction in frame size that results in lower output signal level also results in a proportionally decreased level of atmospheric noise and interferers. Receiver noise, however, is constant and will ultimately cause degradation of SNR. This effect is best seen in Figures 7 and 8. The lower signal levels of the remote stations means an approximate loss of 3 dB on Carolina and 6-7 dB on Dana between loops A and C. These losses coupled with the day-night effect suggest that frame size considerations are important in applications dependent upon reception of remote stations.

CONCLUSION

The length-diameter ratios of Loops A and C are close to equal. The Loop B ratio is somewhat less. The data presented in Figure 3 for field strength suggests that the minor performance difference between Loops B and C is more attributable to change in length than change in volume (Loop C having ¼ to ⅓ the ferrite material of Loop B). A graph based on the length-diameter ratio of Loops A and C is presented as Figure 12 to show the effective savings in cost and weight as frame size is reduced. The graph assumes an annual production volume of 10,000 units. Cost information is the direct cost to a manufacturer. Savings

Figure 12. Cost and Weight Savings



can be accrued both from reduced ferrite material and a smaller radome. It is shown that the total weight can be expected to decrease by 75% from 480 grams to 120 grams and that the direct cost is reduced 78% from $19.00 to $4.20 per unit.

The collected data indicates that savings are a function of user requirement. Generally, stations of sufficient field strength are more affected by day-night effect than frame size. Users that require a low number of stations or operate in a local area would experience greater benefits. Use of Loran in pseudo range or DGPS applications (such as Eurofix) have the greatest savings potential. Conversely, users dependent upon stations of marginal reception are greatly affected by frame size.

System owners or operators can benefit by ensuring sufficient signal strength exists in desired areas of coverage. Availability and accuracy are enhanced through reception of remote stations. Lower cost, weight and size of user equipment will increase the number of system users. High field strengths also permit use of very small loops to meet special applications.

This experiment also demonstrated that a single front-end design is capable of accommodating variation in frame size. Further research is needed on limits of miniaturization and on length-diameter ratios.

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Q: If the old system will close in a couple of years why do this - what's the agenda?

A: Ben (Peterson) hopes for use outside the US (outside US is good ... not affected by the closure of US stations). The work now is developmental only.

A: In the U. S. we hope for a change of heart on Loran turnoff. Meanwhile, DoD is welcome, but we hope to see civil uses.

Q: Which foreigners is this targeted at?

A: ...

Efficient FIR Filter Architecture for Loran-C Interference Rejection

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BIOGRAPHY

Anteneh Alemu Abbo received his B.Sc.(first class honors) from Addis Ababa University, and his M.Sc.(honors) from Eindhoven University of Technology. Currently he is a Ph.D. candidate at Delft University of Technology and participates in the GOLLUM integrated navigation receiver project. His task involves the design and implementation of signal processing units for Loran-C and MLS receivers.

ABSTRACT

Due to the large number of transmissions close to the Loran-C band, carrier wave interference (CWI) has become a serious problem in the European chains. In this paper we present a receiver architecture in which most of the interferers are suppressed by means of a high-order digital FIR filter. The remaining synchronous interferers are suppressed by notch filters, which are tuned with the help of a spectrum estimation routine.

We introduce a new FIR filter architecture based on the time-distributed *computation concept. The technique reduces silicon area and power consumption of the direct-form architecture by up to 62%. Such a performance improvement opens an opportunity for rejecting many near-band interferers by increasing the filter order. This helps to reduce the number of notch filters and the associated pulse distortion. The technique described in this paper, not only enables a cost effective digital Loran-c receiver design, but also facilitates the design of a multi-function integrated navigation receiver around a single-chip high-performance processor.*

1 INTRODUCTION

Loran-C is a terrestrial radio navigation system which provides positioning information via signals transmitted in the 90-110 kHz band. The position accuracy is degraded by interfering radio waves, also called carrier-wave interferers (CWI) [1]. The European chains are more susceptible to the CWI problem due to the numerous interferers in the vicinity of the Loran-C band.

Carrier-wave interferers are classified as: *asynchronous*, *near-synchronous* and *synchronous*, depending on the distance of the interference frequency from the nearest Loran-C spectral line [2]. The Loran-C spectral lines are given by $N/2GRI$, where $N = 1, 2, 3, \ldots$ and the GRI (group repetition interval) lies within 50 to 100 ms. A synchronous or near-synchronous interferer causes position errors which are difficult to remove by ensemble averaging in the *phase tracking* and *cycle identification* steps of the receiver. The bandwidths of the averaging filters depend on the signal and receiver dynamics, typical values are 0.1 Hz for phase-tracking and 0.05 Hz for cycle-identification. Wider filter bandwidths, which allow faster position updates, can be used when the signal-to-noise ratio is high enough.

Different strategies have been proposed to combat the CWI problem [3, 1, 4, 2]. At the system level, the interference problem is tackled by proper GRI selection. Those GRI values to which most interferers are asynchronous are chosen for implementation. On the receiver side, interference rejection is achieved by proper filtering. The filtering task is divided among an analog front-end bandpass filter, a bank of notch filters and possibly a digital bandpass filter.

In areas where there are numerous interferers, the notch filters should be selected optimally to reduce the receiver cost and minimize the Loran-C pulse distortion. To this end, FFT (Fast Fourier Transform) based spectrum analysis techniques have been proposed to identify the (near-)synchronous interferers that need to be notched out [1, 3]. The computational complexity and memory requirement of the spectrum analysis routine can be simplified by performing synchronous ensemble averaging prior to FFT [4, 5].

When there is enough processing power, a finite impulse response (FIR) filter can be used for extra interference rejection with little pulse distortion. A Loran-C receiver architecture which makes use of a FIR filter was first proposed in [1]. The filter suppresses all interferers in the stopband without any discrimination about their synchrony, which is advantageous since strong asynchronous interferers result in increase in the noise level if they are not well suppressed [2]. An increase in noise level means increase in the variance of the position error.

Even though the concept behind optimal CWI rejection has been addressed in previous works, there are still some gaps concerning a cost effective implementation of the FIR filter and spectrum estimation. In this paper, we present a new FIR filter architecture with reduced silicon area and power consumption. The architecture exploits the fact that (i) only a few filtered samples per Loran-C pulse are needed for position calculation, and (ii) the filter computations for these samples can be *distributed over time* to reduce the number of computations per sample period. The reduced computational complexity of this approach allows further increase of the filter order to reject even more near-band interferers or share arithmetic units with a digital notch filter bank.

The remaining part of the paper is organized as follows: section 2 discuses the proposed digital receiver architecture. Section 3 presents the receiver filtering requirements and the design of a bandpass FIR filter. In sections 4 and 5, we discuss filter implementation issues. A new low-cost and low-power FIR filter architecture will be introduced. A comparison of the silicon area and power consumption of the direct-form and the new FIR filter architectures is given in section 6.

2 RECEIVER ARCHITECTURE

Figure 1 shows the proposed receiver architecture. The front-end consists of a bandpass filter, an amplifier and an analog-to-digital converter. To cover an 80 dB input dynamic range, a 16-bit resolution is selected [6]. Further interference suppression is provided by the digital signal processor (DSP) via adjustable notch filters and a FIR bandpass filter. A carrier-wave interference (CWI) identification process is used to tune the notch filters to the desired location [4, 5]. Unlike the architecture in [1], the CWI identification process and the notch filter bank are placed ahead of the FIR filter to allow application of the special decimation technique described in this paper.

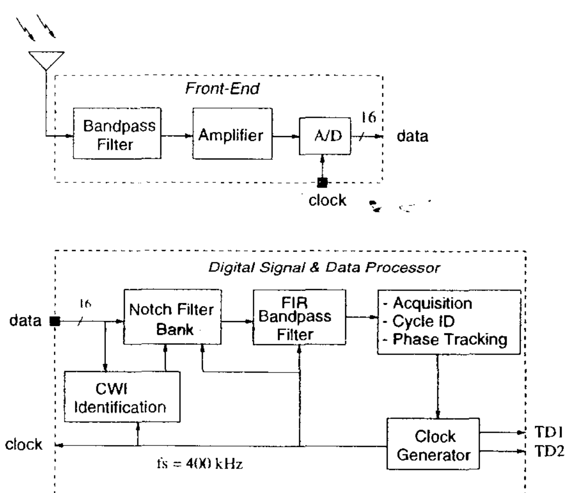

Figure 1: **A Loran-C receiver architecture**

To compute the position estimates, the receiver measures the time-differences (TD) between the arrival times of signals from a master station and at least two secondary stations. Each transmitting station sends a group of 8 pulses spaced by 1 ms and repeated at a pre-determined rate called the group repetition interval (GRI). Each Loran-C pulse has a well-defined shape that modulates a 100 kHz carrier and confines 99 % of the pulse energy to the 90-100 kHz band.

To simplify the requirements of the anti-aliasing (front-end) filter and the operations of the phase-tracking and cycle identification algorithms, a sampling rate of $f_s = 400$ kHz (4 times the carrier frequency) has been chosen. In this case, the time difference measurement needs only three consecutive samples from each Loran-C pulse. While the middle sample is used for zero-crossing tracking, the left and right samples are used to identify a specific cycle of the carrier from the pulse. As shown in figure 2, the samples are taken from the front part of the ground-wave to avoid interference from sky-wave.

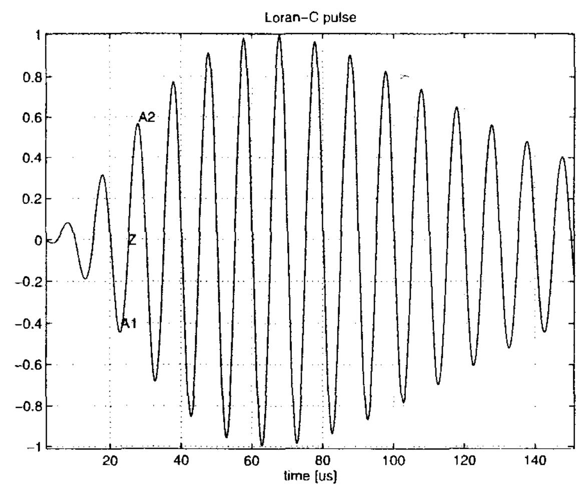

Figure 2: **Sampling the Loran-C pulse for time difference (TD) measurement**

If an improved cycle-identification technique is to be implemented, more than 3 samples have to be taken from the ground wave section [7]. Since the sky wave can arrive as early as 35 μs after the ground wave, 10 samples taken every 2.5 μs cover the ground wave section which has no or little sky wave influence. Thus, at most 10 samples per Loran-C pulse are sufficient for proper receiver operation. By performing the FIR filter operations only for these samples, it is possible to obtain large reduction in the computational complexity and, consequently, on chip area and power consumption.

3 FILTER REQUIREMENTS AND FILTERING TECHNIQUES

The desired level of interference suppression, and hence the filter order, is determined by the acceptable signal-to-interference ratio (SIR). The zero-crossing tracking error due to a synchronous interferer is given by [1]

$$T_{err} = \frac{T_p}{2\pi} \arcsin\left(1/SIR\right) \qquad (1)$$

where $T_p = 10$ μs is the period of the Loran-C carrier. To keep the tracking error within 50 ns (equivalent to a position error of 15 m) the SIR should be at least

30 dB. Assuming a worst case pre-filtering SIR of -60 dB and taking into account the 10 to 18 dB filtering by virtue of phase coding of the Loran-C pulses, the required filter suppression amounts to 80 dB [1].

Formula 1 applies to the case where there is no noise. As the SNR decreases, the dithering effect of noise tends to give a lower mean tracking error for the same input SIR value. For example, $SIR = 18$ dB after filtering can be accommodated for $SNR < 0$ dB [2].

The 80 dB stopband attenuation outside the Loran-C band implies the use of a high-order front-end analog bandpass filter, which also helps to protect the A/D converter from being overloaded by strong interferers. However, due to group delay variations, higher-order analog filters introduce large pulse distortion and increase the receiver's sensitivity to sky waves, which can arrive as early as 35 μs after the ground wave and have upto 12 dB relative strength. Thus, the analog filter order should be kept low to let the ground wave grow high enough before the sky wave becomes strong.

Figure 3 shows the frequency response of a 3rd-order Butterworth bandpass filter, which can easily be built from three resonators. It can be seen that the attenuation near the 90-110 kHz band is much less than the desired 80 dB level. The conflict in analog filter requirements, i.e., a high-order and narrow bandwidth for CWI suppression and a low-order with wide bandwidth for good sky wave tollerance, can be relaxed by using a FIR bandpass filter.

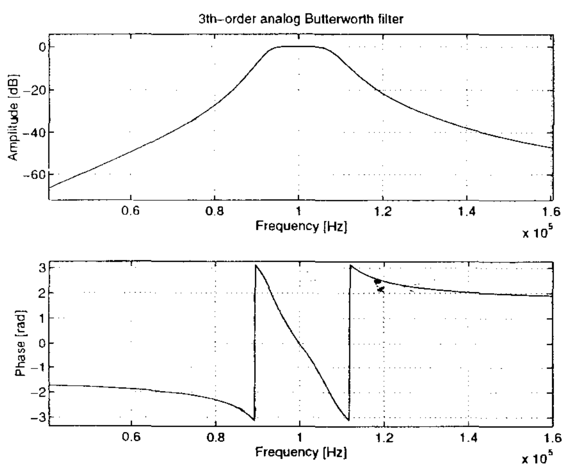

Figure 3: **Frequency response of the analog front-end filter**

Since FIR filters have a linear phase characteristics, the filter order can be increased to give a narrow transition band with little pulse distortion. However, when the filter response gets steeper, its impulse response widens and part of the sky wave energy starts to appear in the ground wave. The problem becomes serious in the case of strong sky-waves, e.g., those 26 dB stronger than the ground wave and arrive about 45 μs later [2]. Therefore, the filter order should be chosen such that the skywave influence is kept within the 50 ns error limit.

Figure 4 shows the frequency response of a 264-tap FIR filter designed using the Remez exchange algorithm [8]. The filter provides up to 62 dB interference suppression outside the 80-120 kHz band. Including the contribution of the front-end filter, a total of 80 dB or more attenuation is obtained. The remaining out-of-band (and possibly in-band) interferers are then suppressed by tuned notch filters.

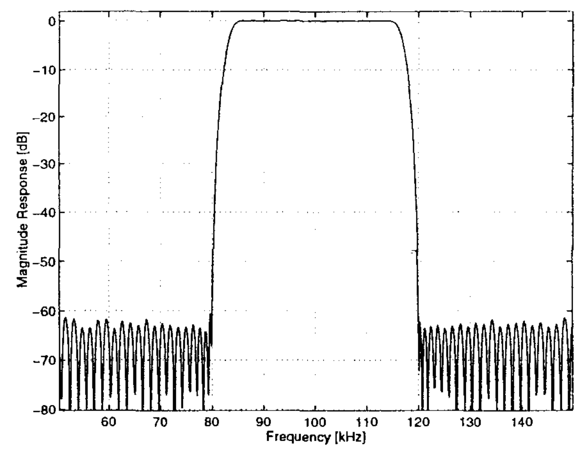

Figure 4: **Amplitude response of a 264-tap FIR filter**

The combined time-domain response of the front-end and FIR bandpass filters is shown in figure 5. The input signal, not shown in the figure, is the sum of a ground wave with unity peak amplitude and a sky-wave which is 12 dB stronger and arrives 35 μs later. In the simulation it is assumed that the sampling clock is synchronized to a zero crossing of the ground wave. It can be seen that, by tracking the cycle represented by samples 548-550, it is possible to avoid the sky-wave influence.

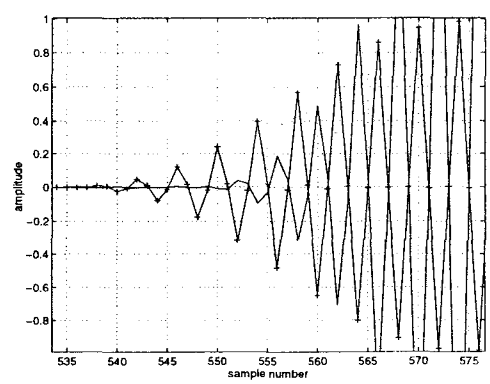

Figure 5: **Ground and sky wave responses of the combined front-end and FIR filters**

The 80-90 kHz and 110-120 kHz bands are left for protection with a bank of notch filters tuned to the most dangerous interferers. For this purpose, the spectrum analysis technique discussed in [4, 5] can be used. The method applies synchronous averaging, i.e., accumulating samples over a number of 2GRI intervals, to filter out non-synchronous interferers prior to applying FFT. The remaining (near-) synchronous interferers are determined at a resolution of about 25 Hz, which is fine enough to adjust the notch filter center frequency.

4 DIRECT-FORM FIR FILTER ARCHITECTURE

The direct-form FIR filter structure is shown in figure 6 [9]. Straight forward implementation implies 264 registers for the filter states and half as many registers for the coefficients (due to symmetry). The state registers are 16-bits wide to cover an 80 dB input dynamic range. To guarantee a 60 dB or more attenuation, the coefficient resolution is also made 16-bits.

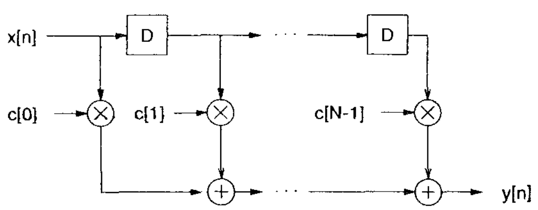

Figure 6: **The direct-form FIR filter structure**

Since the sampling rate (f_s = 400 kHz) is small relative to the clock that current VLSI (very large-scale integration) chips can handle, a single multiply-accumulate (MAC) unit can be shared among the operations. In this case the data transport rate to the MAC unit, i.e., fetching filter states and coefficients, ammounts to $2 \times 264 \times f_s = 211.2 \times 10^6$ words/sec.

A vector-register based filter architecture was proposed in [3] for a 128-tap FIR filter. Two vector-registers, each 128-registers long, were allocated for the filter states and the coefficients. A prototype of this architecture on a 1.6 μm sea-of-gates IC showed large power consumption. To reduce the power consumption and the area occupied by the registers, a RAM based approach was proposed by the same author.

5 LOW-COMPLEXITY FIR FILTER ARCHITECTURE

In this section we present a FIR filter architecture that greatly reduces the hardware complexity and power consumption of the direct-form structure. The general idea belongs to some form of decimation. We exploit the fact that a few output samples per Loran-C pulse are needed for position computation, and perform the FIR filter operation for those samples only. In simple Loran-C receivers, 3 samples including the zero-crossing being tracked suffice. When complex cycle identification methods are applied, as in [7], up to 10 samples per Loran-C pulse might be needed.

In the direct-form architecture, at each sample moment $N = 264$ multiply-accumulate(MAC) operations have to be performed, and then the delay-line be shifted to accommodate the new input data. We can reduce the number of MAC operations per sampling moment to the desired number of output samples, if we *distribute* the operations over *time*. That is, instead of computing the dot-product between the coefficient and delay-line vectors at the output moment, we weight each input sample with the appropriate coefficient just as it arrives. An accumulator is assigned for each output sample to record the weighted sample values. The accumulator is reset to zero N samples earlier, where N is the FIR filter length. Figure 7 shows the alignment of the filter impulse response for one Loran-C pulse, assuming the receiver is in the tracking mode.

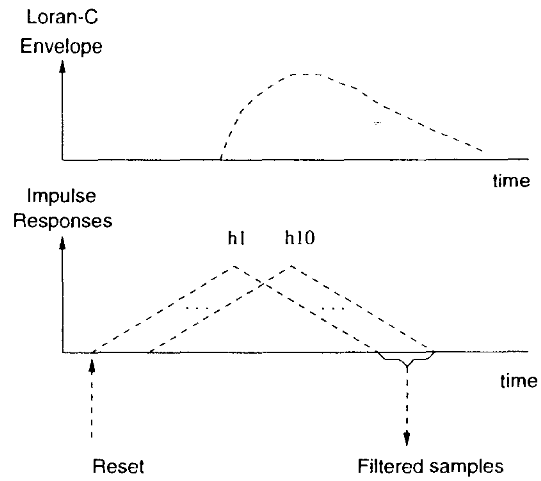

Figure 7: **Alignment of the FIR filter impulse response with a Loran-C pulse (assuming tracking-mode operation)**

During acquisition, the FIR filter delivers a group of 10 samples every milli-second. The receiver clock and its derivatives (such as the filter reset signal) are adjusted until the 8 pulses of one station are found. Similar pulse searches are conducted for the other transmitters as well. The acquisition can be split into two steps: an initial coarse acquisition, which gives the rough location of the received pulses, and fine acquisition which finds a distinct location at the front part of the pulses.

Figure 8 shows the data-flow structure of the time-distributed FIR filtering concept. Each accumulator records the weighted contribution of the input sample as it arrives. Since the filter impulse response is shifted in time for each output value, a coefficient delay-line can be used to reduce the number of coefficient memory accesses to one.

Since a computation speed much higher than the sampling rate (f_s = 400 kHz) is easily achieved, a single arithmetic unit (multiplier and adder) can be shared among all the filter operations. Figure 9 shows a pipelined architecture in which both the accumulator and coefficient pipes are shifted 10 times in each sample interval (T_s = 2.5 μs). While data in the former pipe keeps on circulating until the contents are read out by the processor, the latter one is updated with a new coefficient at the end of each rotation (10 shifts). Both pipes are reset to zero at the beginning

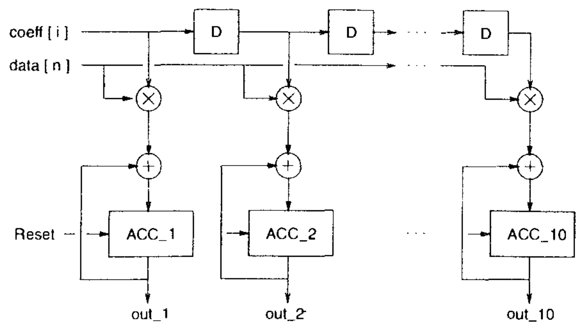

Figure 8: **Architecture for time-distributed FIR filtering**

of every filter session, i.e., at 1 kHz rate synchronous to the receiver clock.

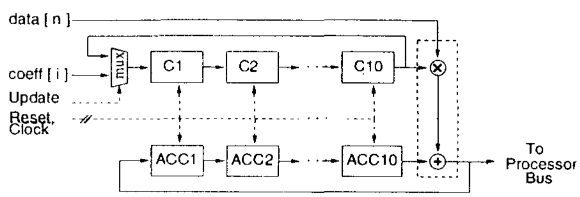

Figure 9: **Pipelined multiplexing of a single arithmetic unit among the FIR computations**

5.1 Hardware Complexity and Power Consumption Issues

Due to the absence of a full length of data delay line, the new FIR filter architecture has less hardware demand than the direct form implementation. The fact that a few computations per sample interval ($T_s = 2.5\ \mu s$) are performed implies a relatively lower clock speed, which in turn leads to lower power consumption. One can see that these advantages vanish when the number of time points at which outputs have to be computed increases.

For the same data and coefficient resolution, say 16-bits, a comparison of the silicon area consumption can be made between the direct-form and the time-distributed architectures. Since the multiplier output can be quantized into the 16 most significant output bits and the filtering process doesn't amplify the signal, a 16-bit accumulator resolution is sufficient.

The direct-form architecture requires 264 delay-line (data), 132 coefficient and 1 accumulator registers, i.e., a total of 396 registers. The time-distributed architecture, on the other hand, requires 132 coefficient, 10 delay-line (coefficient) and 10 accumulator registers, in total 152 registers. The register saving is about $1 - 152/397 \approx 62\%$. Further area saving is possible by storing the coefficients in an on-chip ROM. Even though the access speed of a ROM is slower than that of a register or a RAM, it can still be used since the distributed computation requires a few coefficients per sample interval.

To determine the saving in the power consumption of the FIR filter, we need to compare the total circuit capacitance that is charged and discharged (C_T) and the switching frequency (f_c). The average consumed power of a CMOS circuit is given by [10],

$$P = C_T \times V^2 \times f_c \tag{2}$$

In both time-distributed (TD) and direct form (DF) approaches, the multiply-accumulate (MAC) unit contributes to power dissipation through the capacitance (C_{MAC}). A 16-bit array multiplier has $16 \times 16 = 264$ multiplier cells and a final 16-bit full-adder [10]. Each multiplier cell is made up of an AND gate and a full-adder.

A worst-case estimate of the switched capacitance of a given circuit is, at least for the purpose of comparison, just the number of (n-mos,p-mos) transistor pairs in the circuit times the pair capacitance, C_{np}. The exact power consumed depends on the nature of the data that propagates through the circuit. The assumption here is rather worst case as it considers each capacitance to change state every time it is clocked.

From the OCEAN sea-of-gates library [11], the capacitance estimates are $16C_{np}$ for a full-adder, $18C_{np}$ for a multiplier cell and $16C_{np}$ for a register cell (D-type flip-flop), where a typical value for C_{np} is 0.12 pico-farad. Thus, $C_{MAC} = C_{multiplier} + C_{accumulator} = (264 \times 18C_{np} + 16 \times 16C_{np}) + (16 \times (16C_{np} + 16C_{np})) = 5520C_{np}$. The capacitance of a 16-bit register is $C_{reg} = 16 \times 16C_{np} = 264C_{np}$.

The approximate switched capacitance of the direct form architecture becomes $C_{T,DF} = C_{MAC} + 397C_{reg} = 110,328C_{np}$. The corresponding figure for the time-distributed approach is $C_{T,TD} = C_{MAC} + 152C_{reg} = 45648C_{np}$.

In general, the difference in power consumption between the two FIR filter architectures arises from two factors:

1. reduction in circuit capacitance: $C_{T,TD} = [45648C_{np}/110,328C_{np}]C_{T,DF} = 0.41C_{T,DF}$, and
2. the lower operating frequency, $f_{c,DF} = 264 \times f_s$ versus $f_{c,TD} = 10 \times f_s \approx 0.04 f_{c,DF}$.

However, since the direct-form filter can be stopped (not clocked) right after the desired 10 samples have been computed, the contribution of the second factor need not be included. Under this condition, both filters perform the same number of MAC operations. The only difference is that the direct-form completes the operations in a short time while the distributed-computation approach completes the same number of operations over a longer interval. Thus, even though $f_{c,DF} > f_{c,TD}$ and the power bursts differ, the consumed energy (= *power* × *time*) depends only on the total switched capacitance. Thus, from the above relative capacitance values, the distributed-computation approach consumes 62% less energy.

6 CONCLUSION

In this paper, a new high-performance FIR filter architecture has been presented. It applies a *time-distributed* computation technique to reduce the number of arithmetic operations per sample interval to those desired for position calculation. The architecture doesn't need a data delay-line, instead it uses an accumulator per filter output. In applications like Loran-C, where a few samples per pulse are sufficient, this approach has a silicon area and power advantage over the conventional direct-form FIR filter architecture. Preliminary estimation for a 264-tap FIR filter indicates a 62% saving in silicon area and power consumption by using the new architecture.

The savings can be used to increase the FIR order and suppress more interferers; however, there is a limit set by the sensitivity to sky wave due to the impulse response stretching. It is, though, possible to use the extra processing power to realize digital notch filters which provide better stability than their analog counterparts. Currently, we are developing a sea-of-gates prototype which contains four notch filter biquads and the FIR filter proposed in this paper.

ACKNOWLEDGEMENTS

The author would like to thank Prof.Dr.Ir. Ralph Otten and Ir. L.K. Regenbogen for their constructive suggestions and guidance during the course of this work. Thanks are also due the Smart Telecom Solutions (STS) Company for financing the project. Regular discussions with Ir. H. van Leeuwen and Ir. W. Zwart of STS have been very useful.

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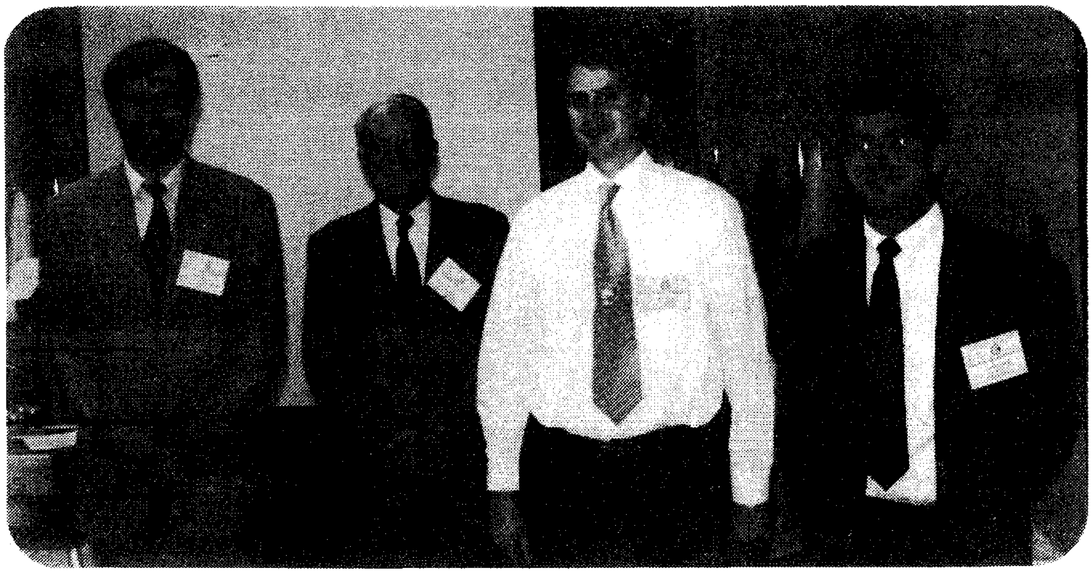
Q: This was actual loran passed through the filter?

A: Yes

Session 5: Integrated GPS & Loran-C Receivers

Session Chair: Christian Forst
Wasser-und Schiffahrts Direktion-Nord, Germany



Session 5: From left: Christian Forst, Bob Lilley, Dirk Kugler, Mike Braasch
Not shown: Raymond A. Agostini

Potential of Hybrid GPS/Loran-C Receivers
Dr. Dirk Kügler, Avionik Zentrum Braunschweig

U. S. Coast Guard Loran-C Receiver Modernization
Raymond A. Agostini, USCG Loran-C Support Unit

Performance of Loop Antennas in Aircraft; Modern Loran-C Receiver Performance
Dr. R. Lilley, Dr. M. Braasch, Ohio University Avionics Engineering Center

AVIONIK ZENTRUM BRAUNSCHWEIG

"The Potential of Hybrid GPS/LORAN-C Receivers"

Dr. Dirk Kügler, Avionik Zentrum Braunschweig

Situation of LORAN-C in Europe (1)

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- European Commission identified LORAN-C as the most suitable terrestrial component of the future European Radionavigation-System
- IALA concluded that "LORAN-C/Chayka would be the most economic solution for providing terrestrial coverage"
- A "European Baseline Radionavigation Plan" will be published through the European Commission

Situation of LORAN-C in Europe (2)

AVIONIK
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- Northern Europe is covered by a complete new and upgraded NELS System
- OMEGA and Decca will disappear before 2000
- NIS and European Commission support joint LORAN-C/Chayka chain in Mediterranean Sea

Is there a future for LORAN-C in Europe?

Where are the LORAN-C users?

- Worldwide about 1.3 million LORAN-C users
- Aviation
  Especially USA [AOPA about 130.000 users]
- Marine
  Coastal Waters [4.8% of German Marine fleet]
- Land
  Car Navigation, Fleet Management
- Time + Frequency
  Telecommunication, power-line networks

User Requirements [DRAFT ERNP]

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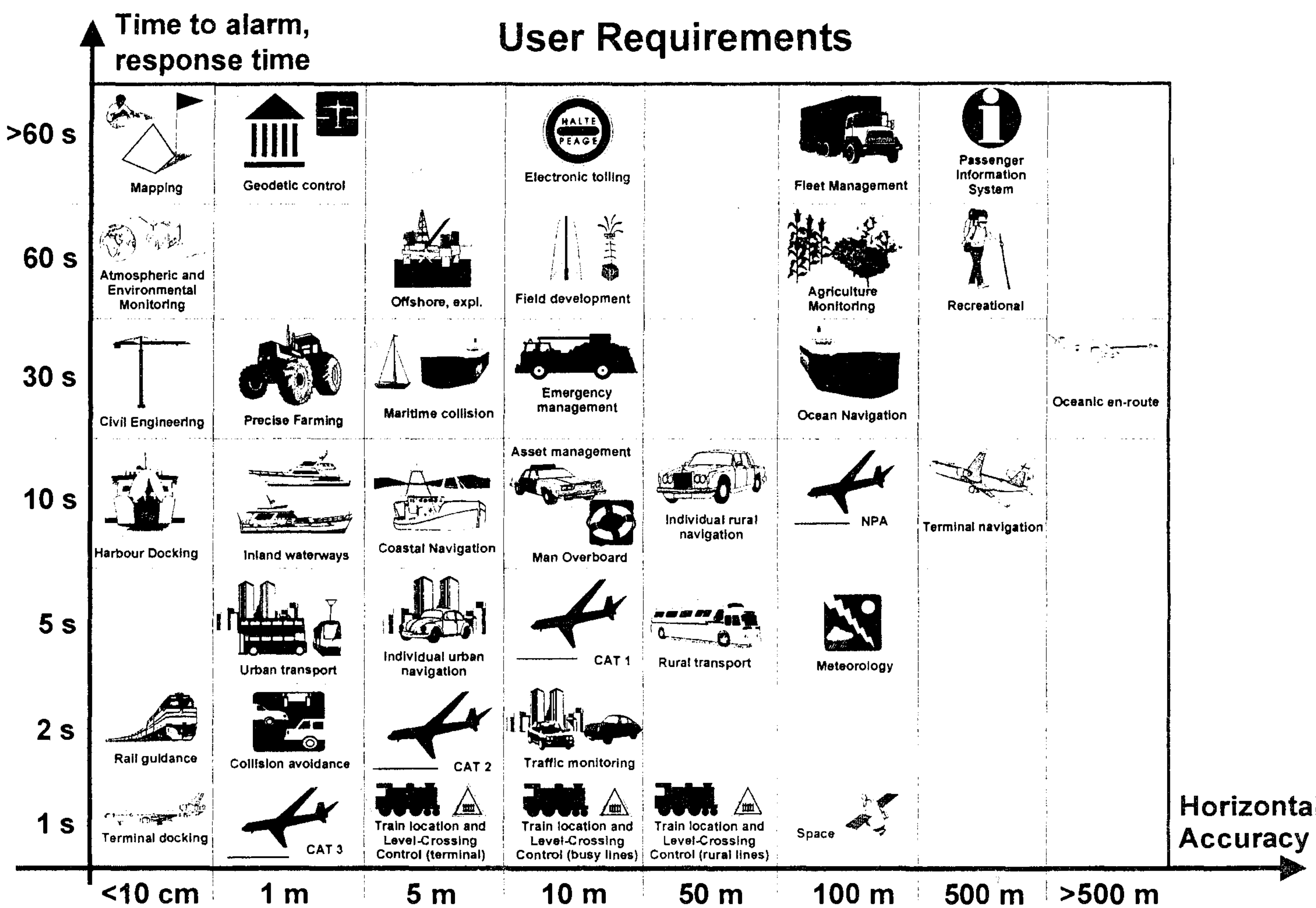

Current LORAN-C Receivers available

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- Geometrix: OEM-board, about 3.000,- USD
- MLR: Full Receiver about 3.000,- USD
- MORS: Full Receiver about 15.000,- USD
- LOCUS: Full Receiver about 10.000,- USD
- A/O-Gradient: Chayka about 800,- USD

Radio Navigation Plannings

- US Federal Radio Navigation Plan (FRP)
- European Radio Navigation Plan (Draft ERNP)
- German Radio Navigation Plan (DFNP) "Deutscher Funknavigationsplan"
- other national plans

ERNP System Mix for Aviation

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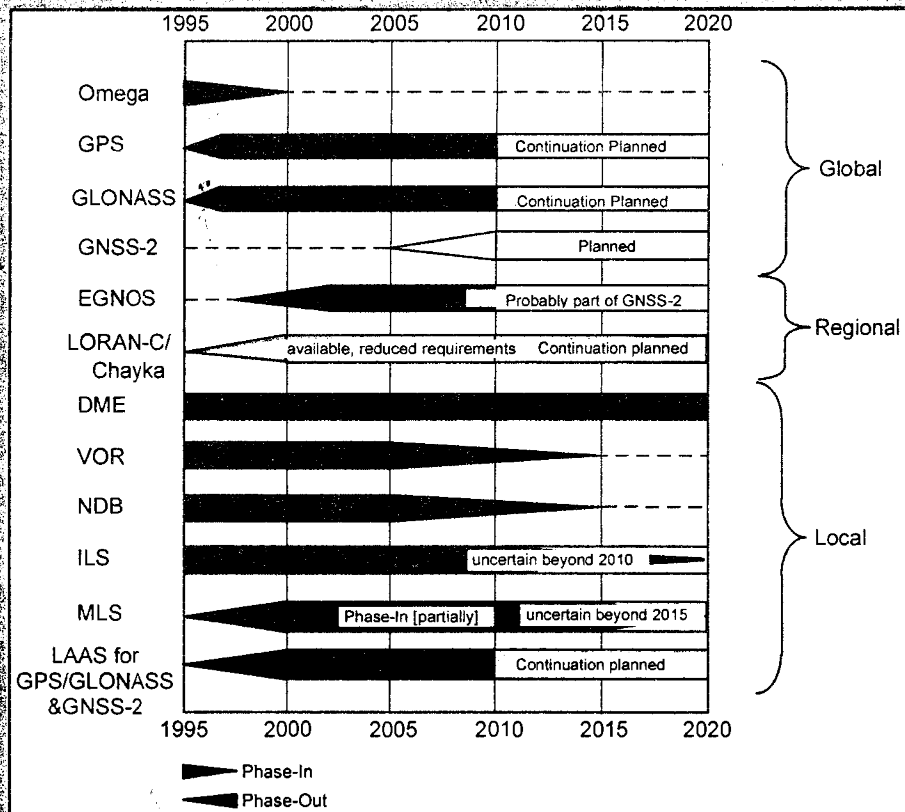

Overall System mix

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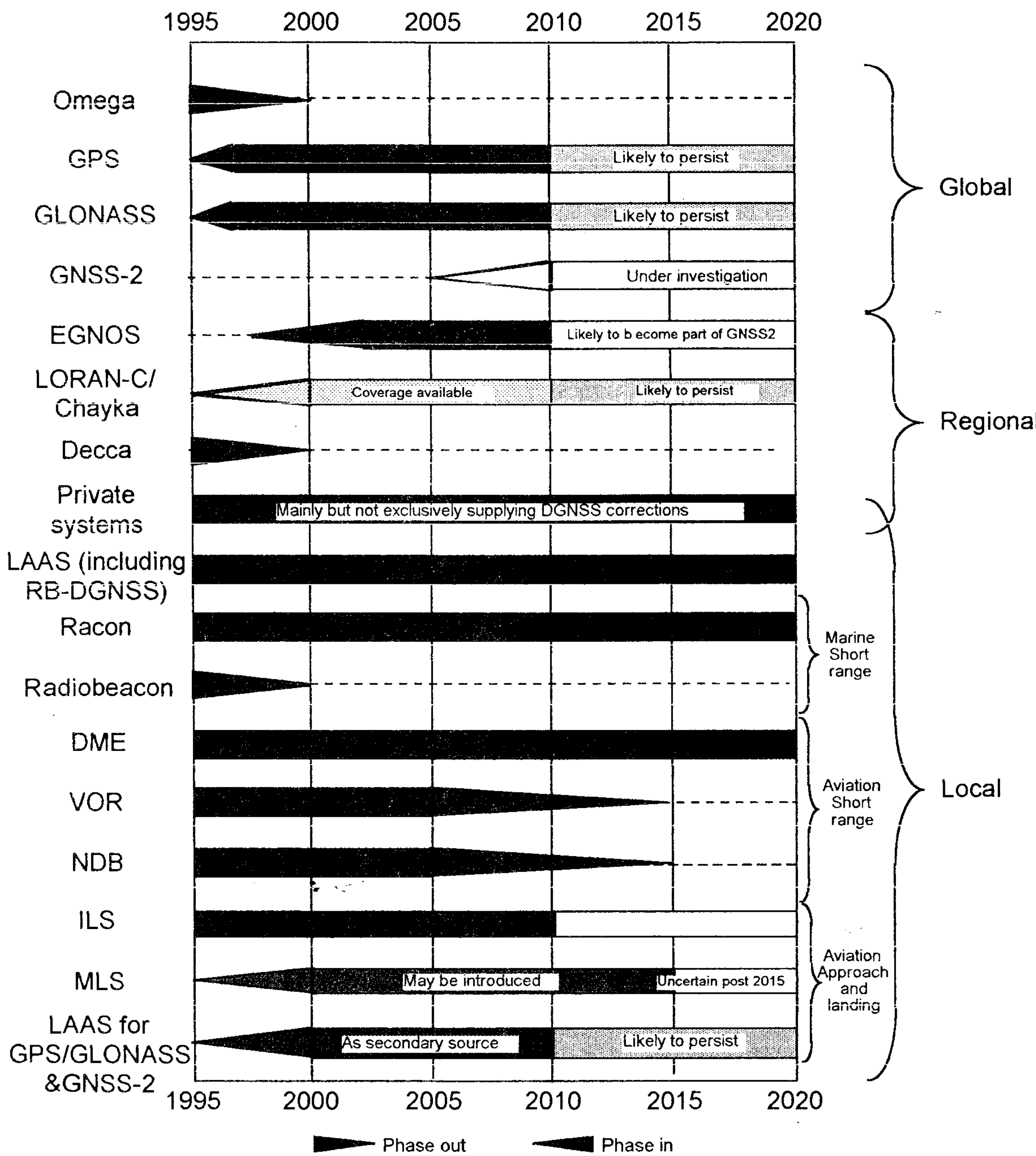
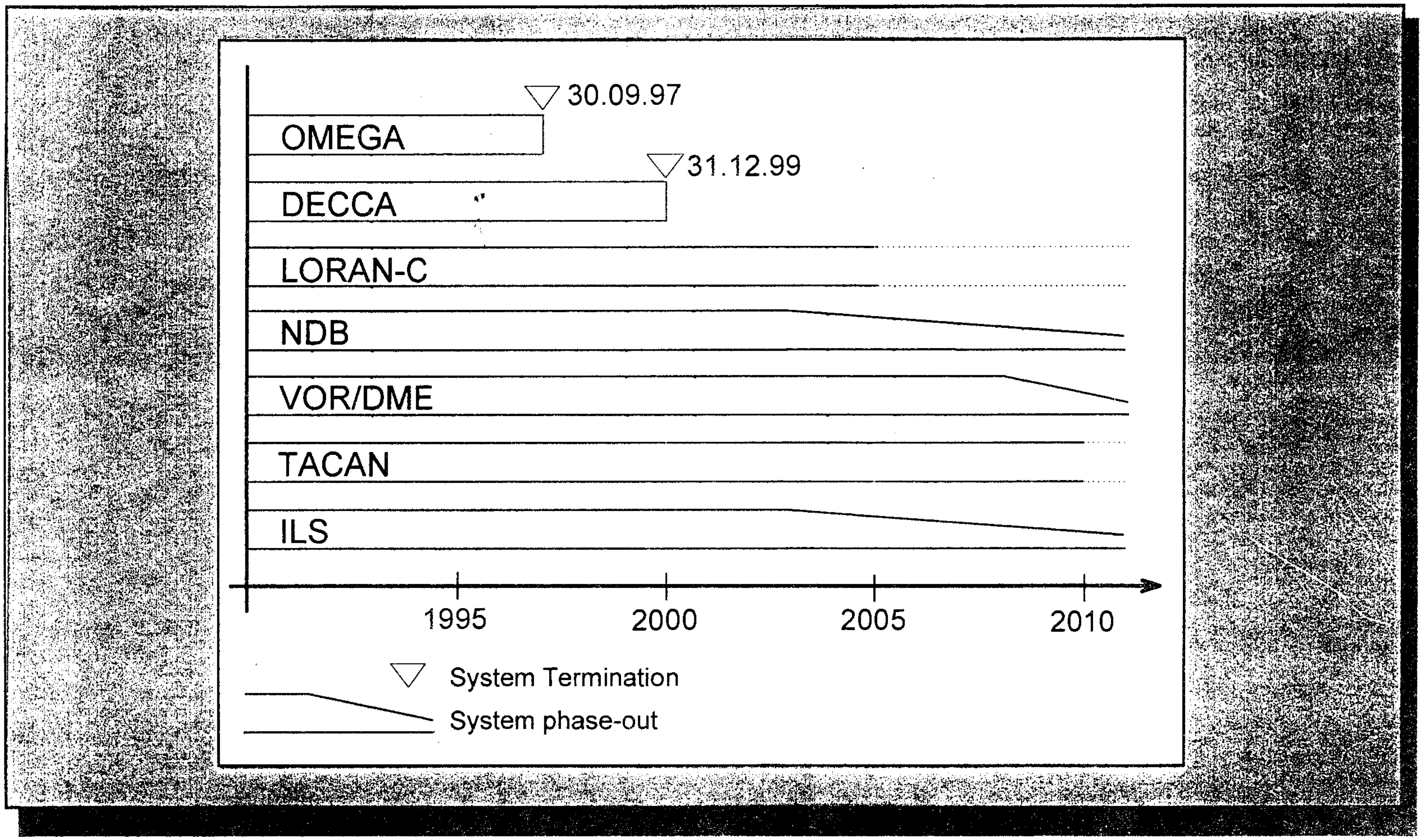


[DRAFT ERNP]

DFNP 1996 System Planning



System Planning for GNSS1/2

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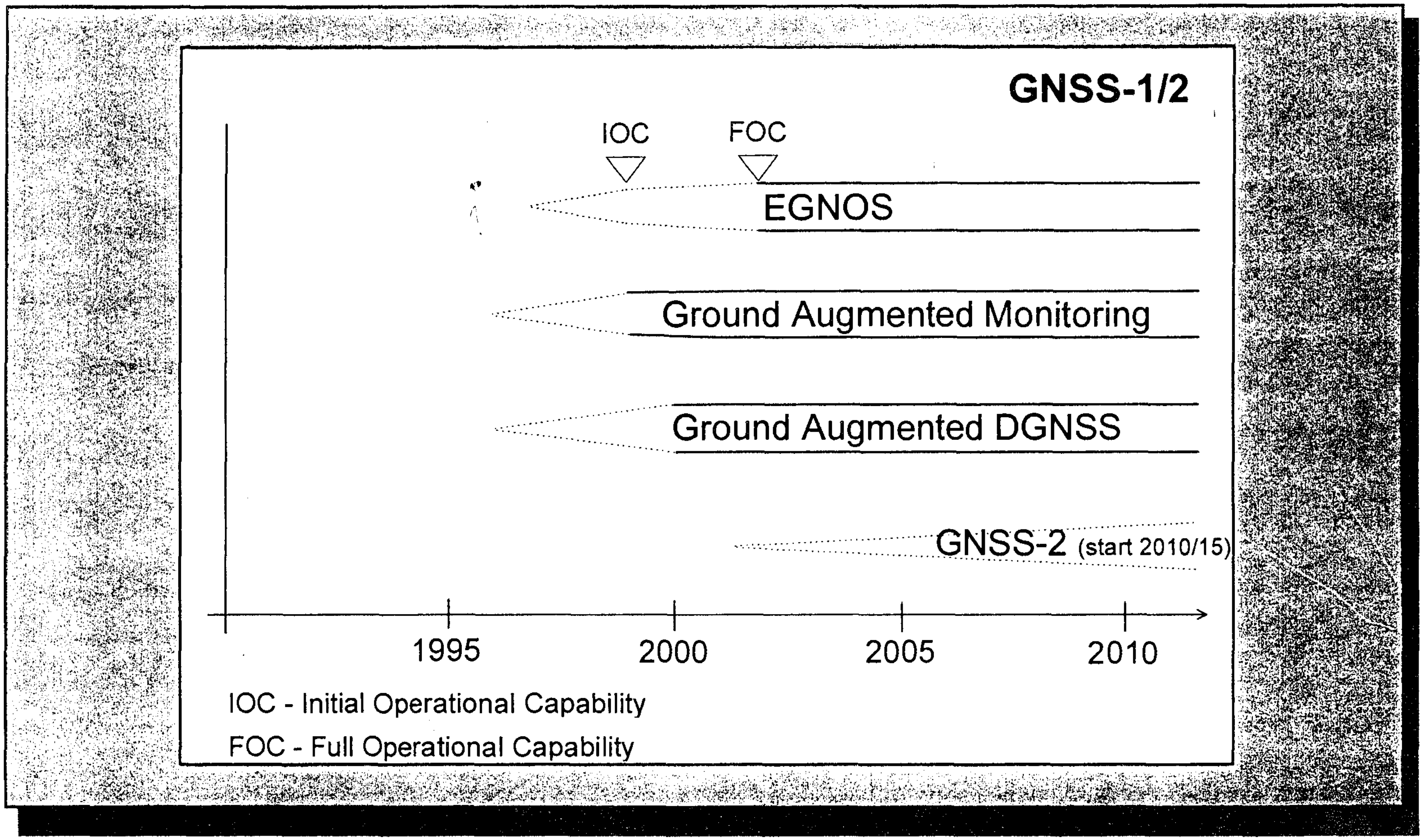

OMEGA and DECCA

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- OMEGA
  - hyperbolic navigation system
  - 8 stations provide a worldwide coverage
  - number of users slowly decreases
  - system termination planned for late 1997
- DECCA
  - maritime hyperbolic navigation system
  - strongly decreasing user demands
  - end of system operation planned for end 1999

GPS and GLONASS

- GPS
  - FOC since 1995
  - large number of users, increasing
  - augmentation systems
  - problems: institutional, availabilty, integrity
- GLONASS
  - complete constellation since 1996
  - small number of users
  - higher accuracy but similar problems as GPS
  - less developed receiver market

GLONASS Deployment - 17.04.1997

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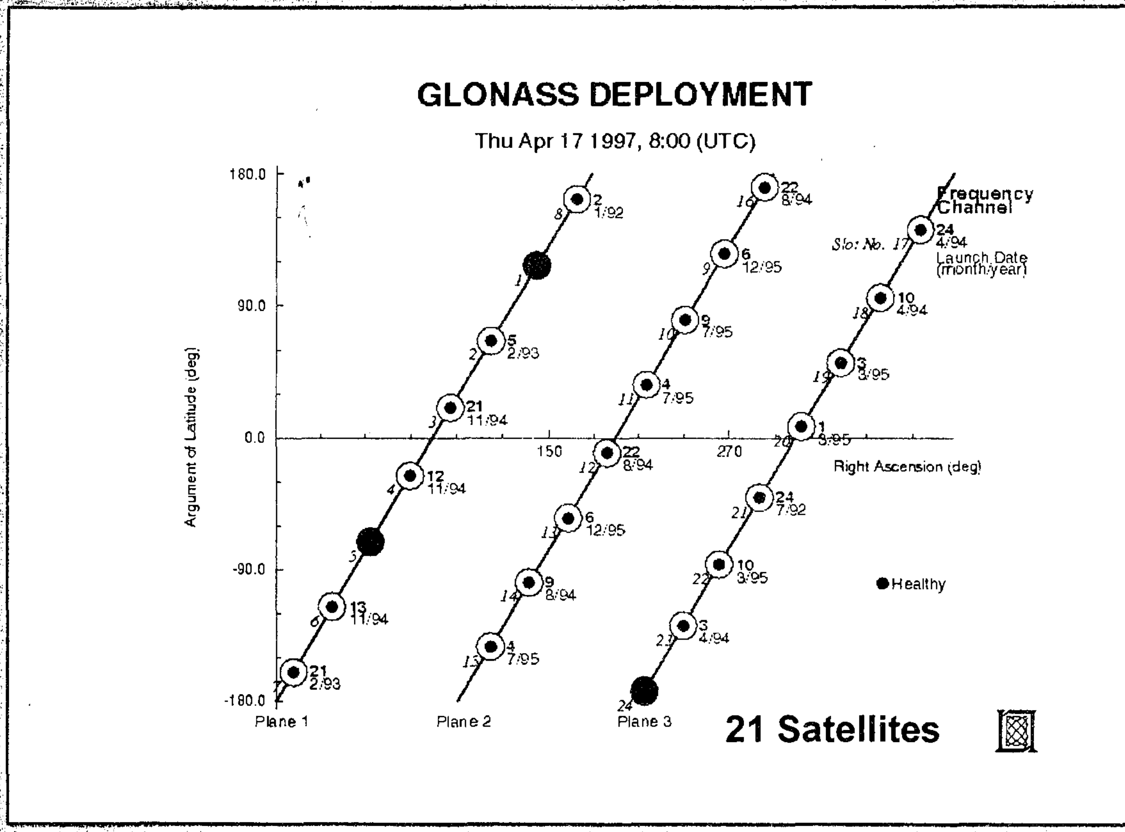
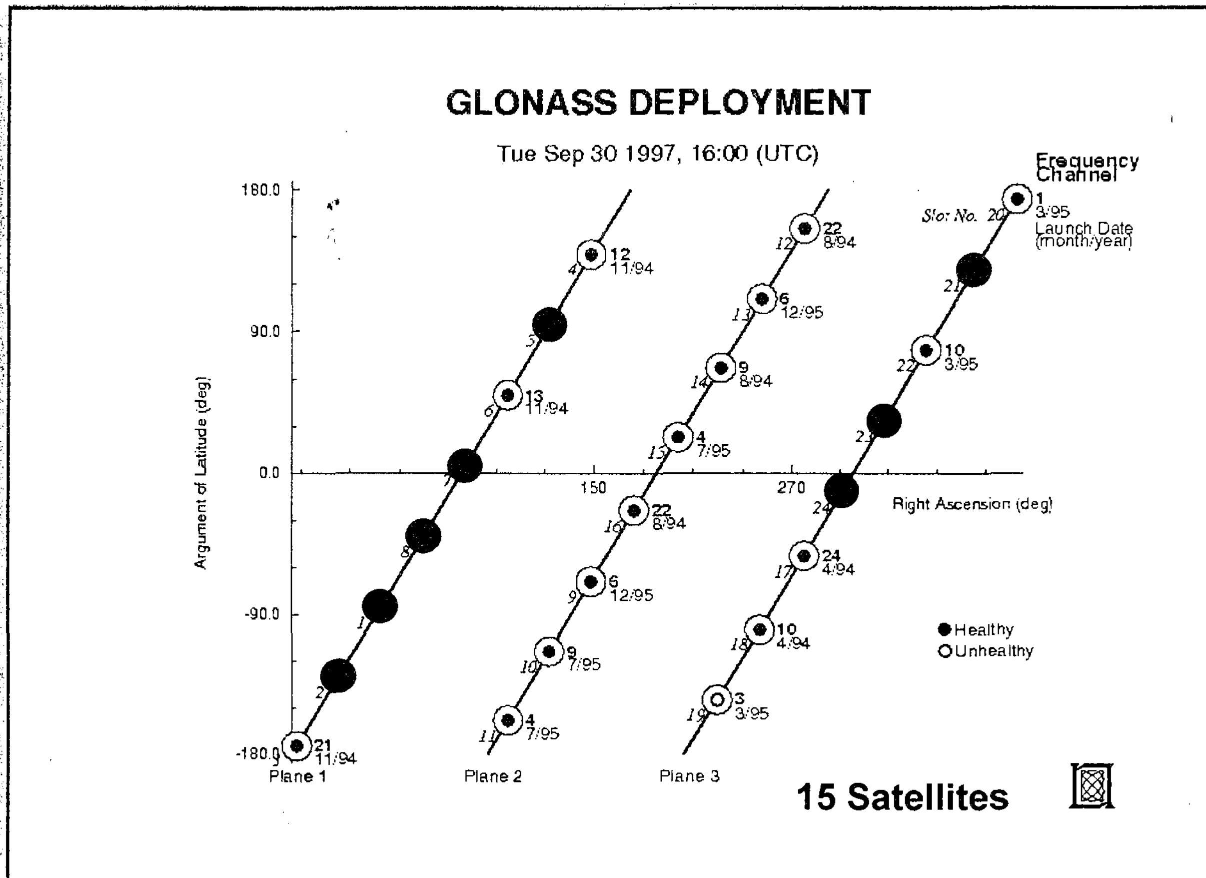


GLONASS Deployment - 30.09.1997

AVIONIK ZENTRUM BRAUNSCHWEIG



GPS Deployment - 30.09.1997

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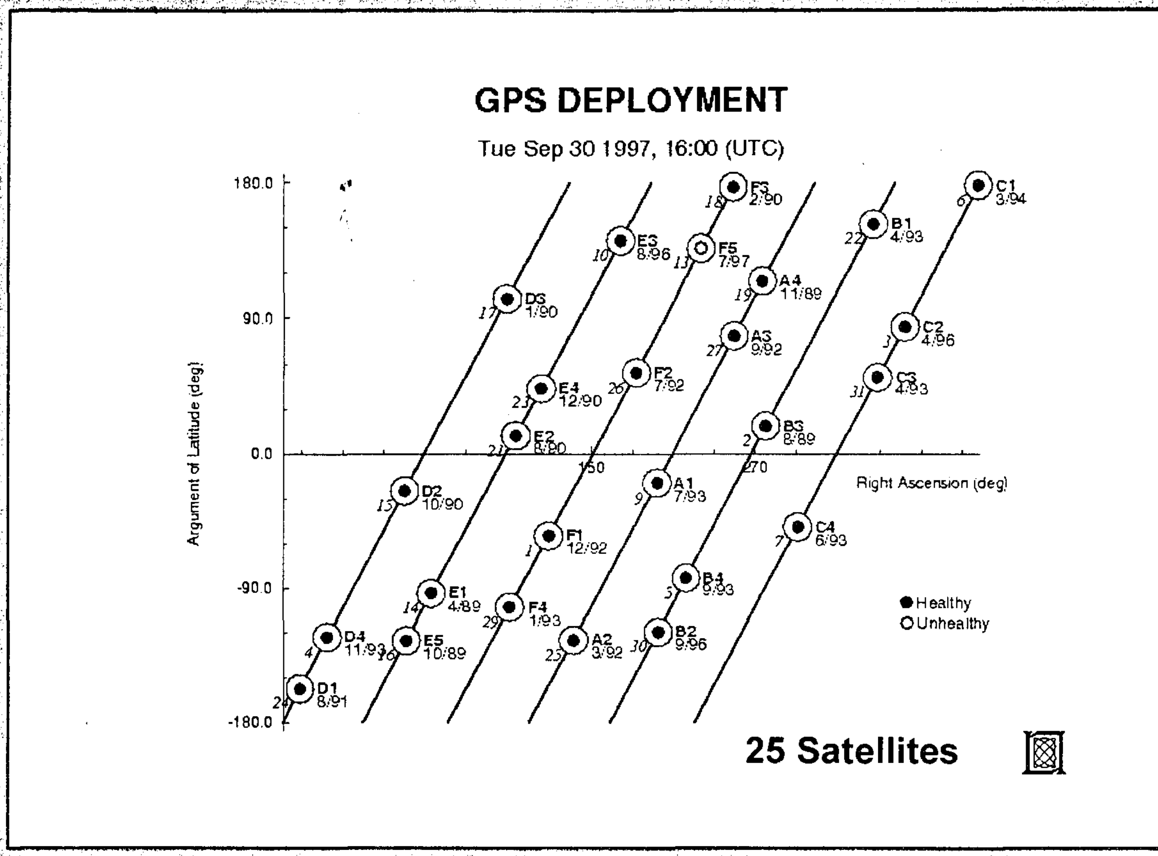
BRAUNSCHWEIG



Comparison of GPS and LORAN-C attributes

Attribute	(D)GPS	LORAN-C
Accuracy	++	o
Availability	o	+
Integrity	-*	++

++ = very good, + = good, o = sufficient, - = bad

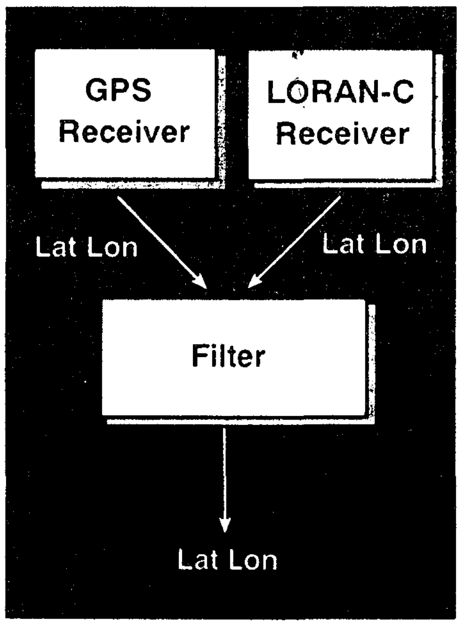
* can be enhanced through local integrity broadcast

Possibilities for Combination

Combination based on:

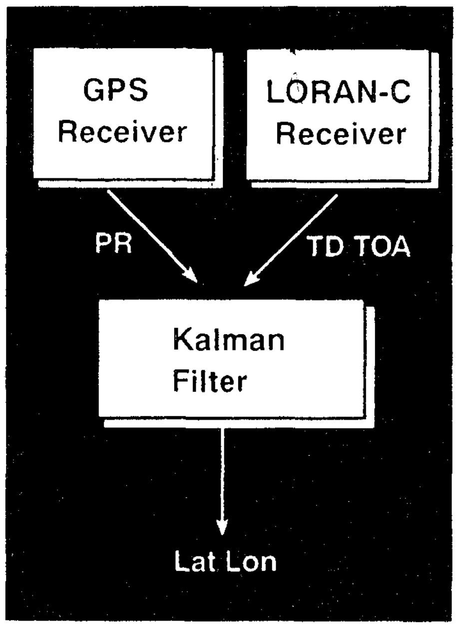
- Position Data
- Raw Data
  "time differences" (TD) for LORAN-C and
  "pseudo ranges" (PR) for GPS/LORAN-C
- Raw Data
  "time of arrival" (TOA) for LORAN-C and
  "pseudo ranges" (PR) for GPS

Combination on Position Data



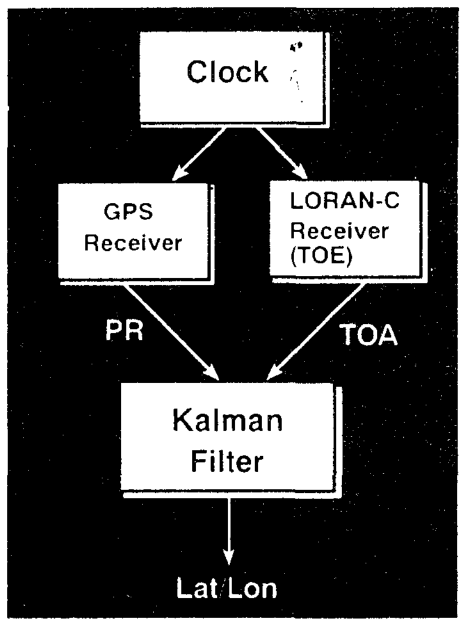
- Two independent position solutions necessary
- Integrity of single navigation system cannot be enhanced
- Combined system integrity can be enhanced:
  ↳ In case of GPS outage, LORAN-C works "*stand alone*"
- Easy system integration

Combination based on raw-data



- Combined navigation solution can be achieved in case that single solution is not available
- Enhanced integrity and availability
- Calculation of DOP values possible

Joint clock combination



- Number of unknown variables can be reduced
- Common clock for GPS and LORAN receiver necessary

Enhanced Integrity of Combined GPS / LORAN-C Systems

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Number of Satellites

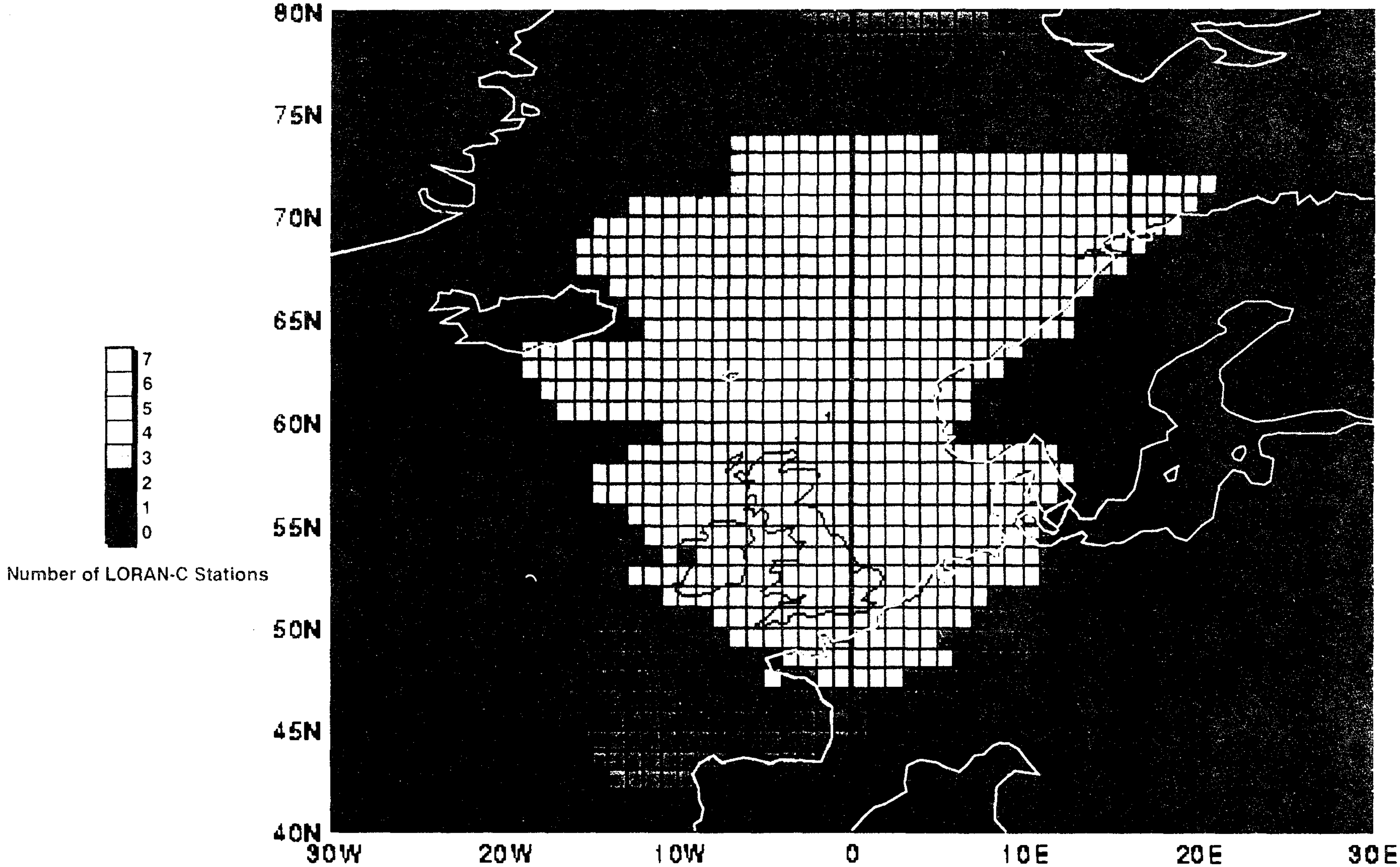
Number of avaible LORAN-C Transmitters

LORAN-C \ GPS	0	1	2	3	4	5
0	–	–	–	2D	3D [2]	3D Integrity
1	–	–	–	2D	3D [2]	3D Integrity
2			2D	3D [2]	3D Integrity	3D Integrity
3	2D	2D	3D [2]	3D Integrity	3D Integrity	3D Integrity
4	2D [1] Integrity	2D [1] Integrity	3D Integrity	3D Integrity	3D Integrity	3D Integrity

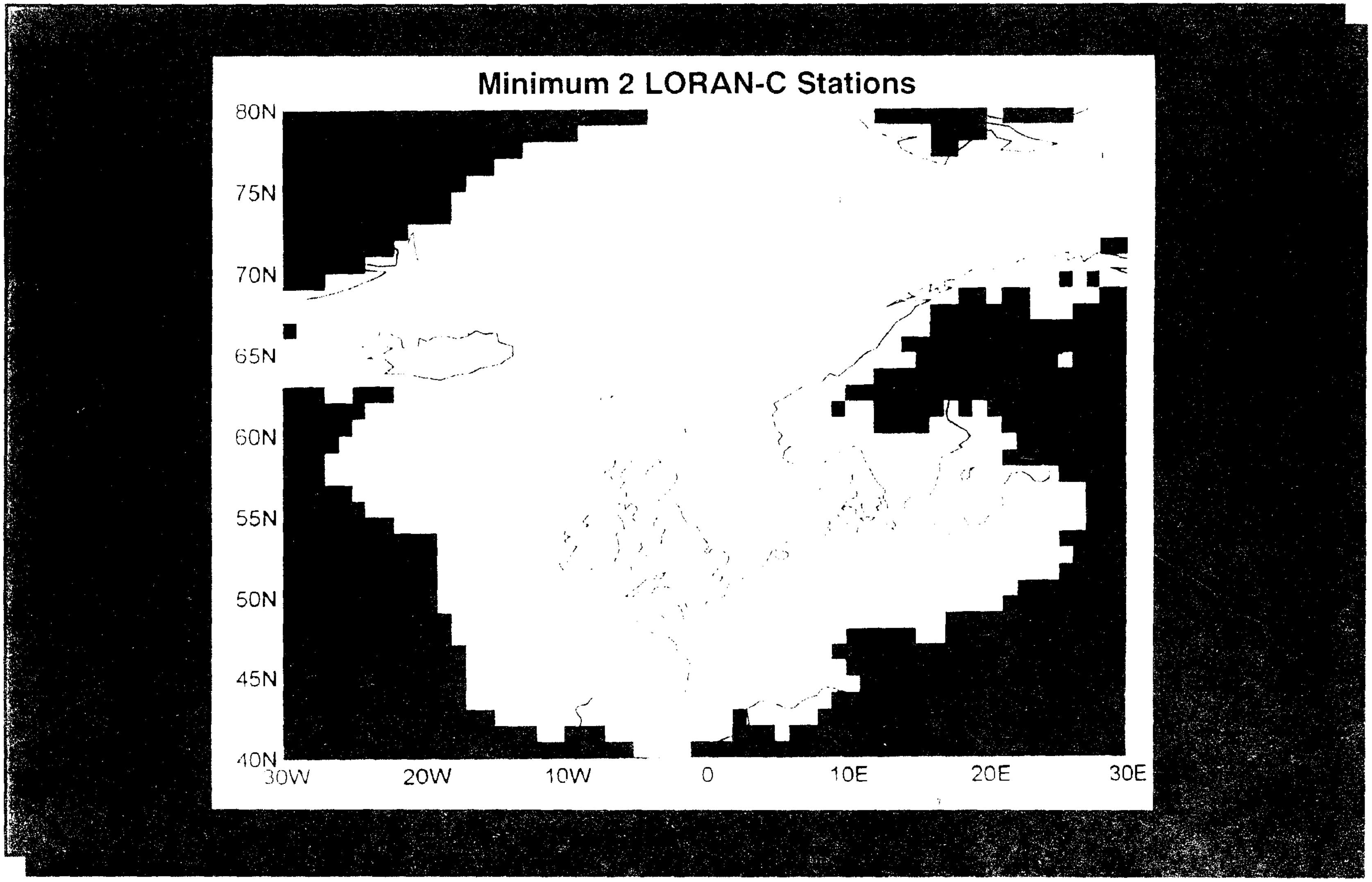
[1] For principal reasons LORAN-C is not suitable for altitude determination

[2] 3D or 2D + Integrity

LORAN-C Multiple Coverage within NELS



Multiple Coverage within NELS (incl. Chayka Station Slonim)



Estimated Costs per User for GPS, Civil GNSS and LORAN-C

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Operation & Maintenance per Year [Mio. US $]					
	GPS DoD, 1991	GPS (estimated)	civil GNSS (estimated)	LORAN-C USA (1995)	LORAN-C NELS (estimated)
	200 - 300	500 - 1.000	200 - 400	17	3
Users	**costs per user/year [US $]**				
10.000	—	—	—	1.700	300
100.000	2.000 - 3.000	5.000 - 10.000	2.000 - 4.000	**170**	**30**
1.000.000	**200 - 300**	**500 - 1.000**	**200 - 400**	**17**	**3**
10.000.000	**20 - 30**	**50 - 100**	**20 - 40**	1,7	0,3

LORAN-C Position (hyperbolic mode)

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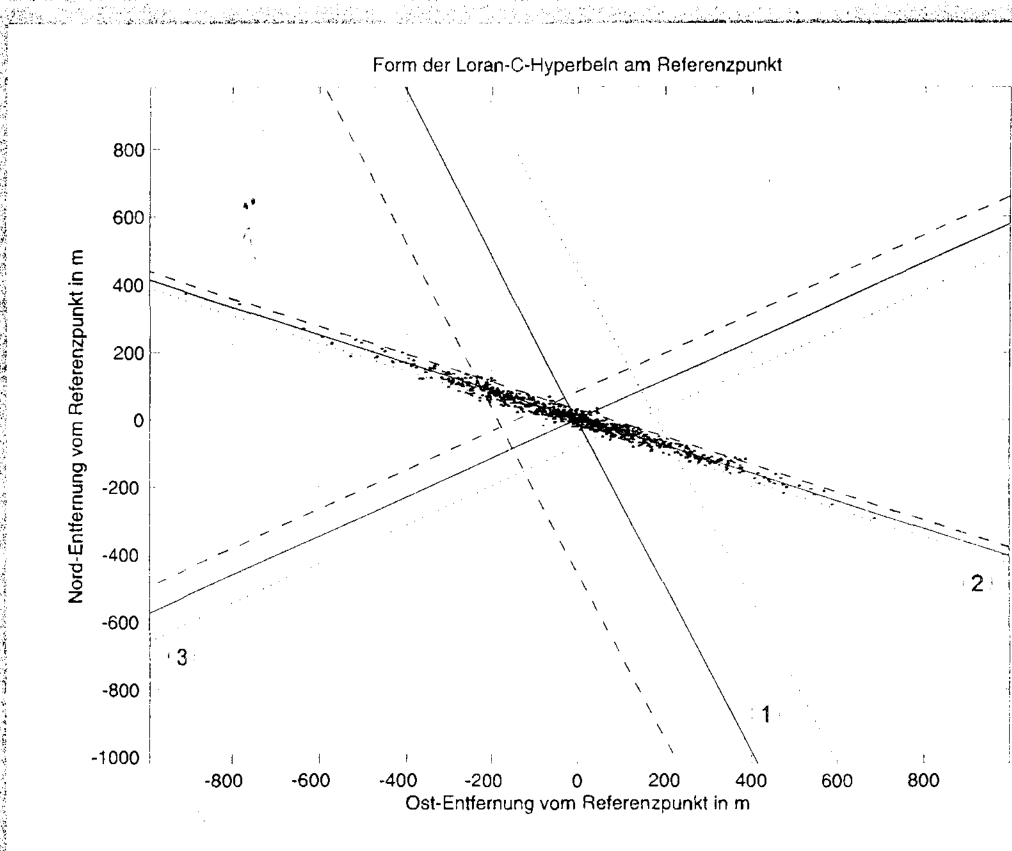
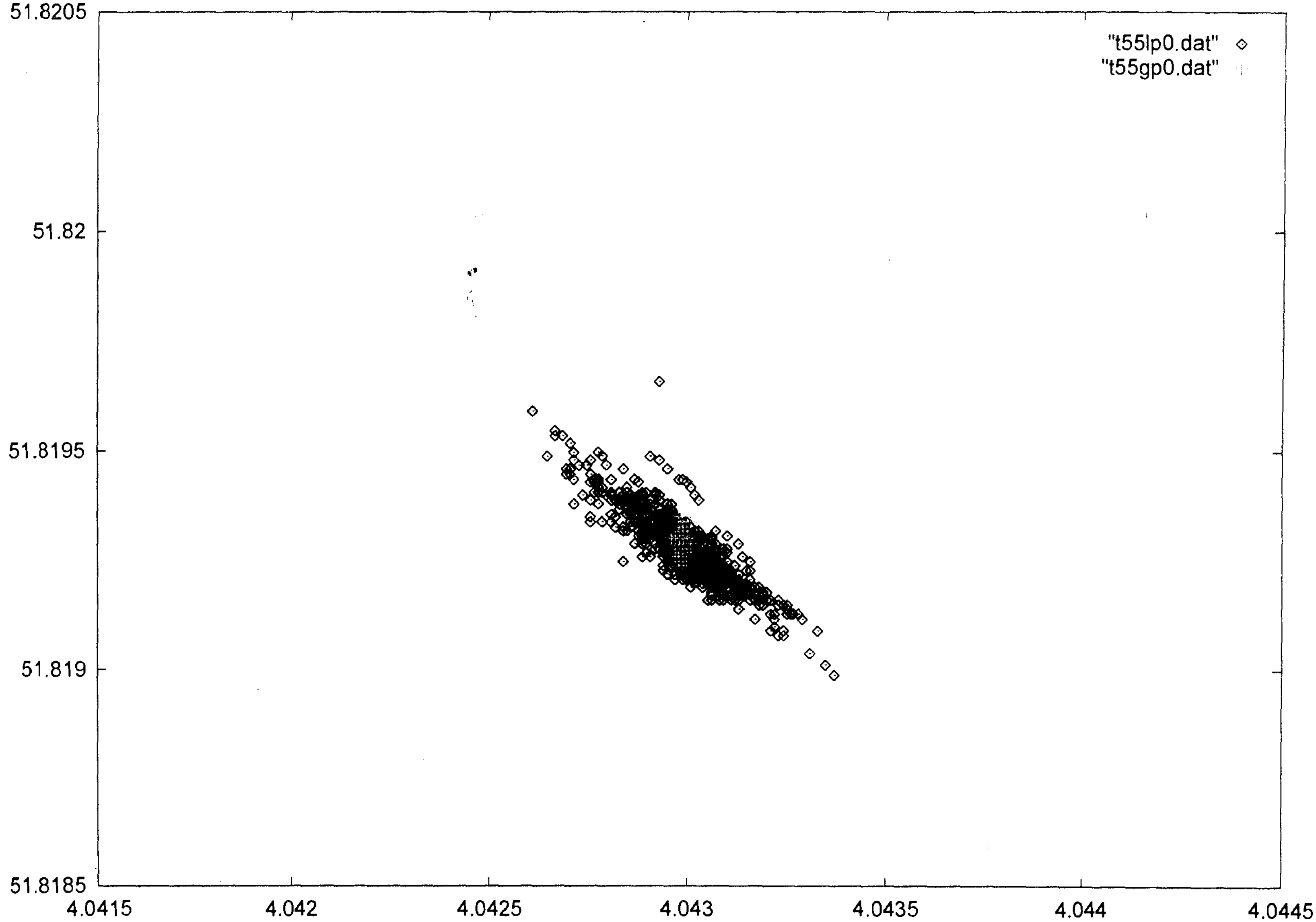
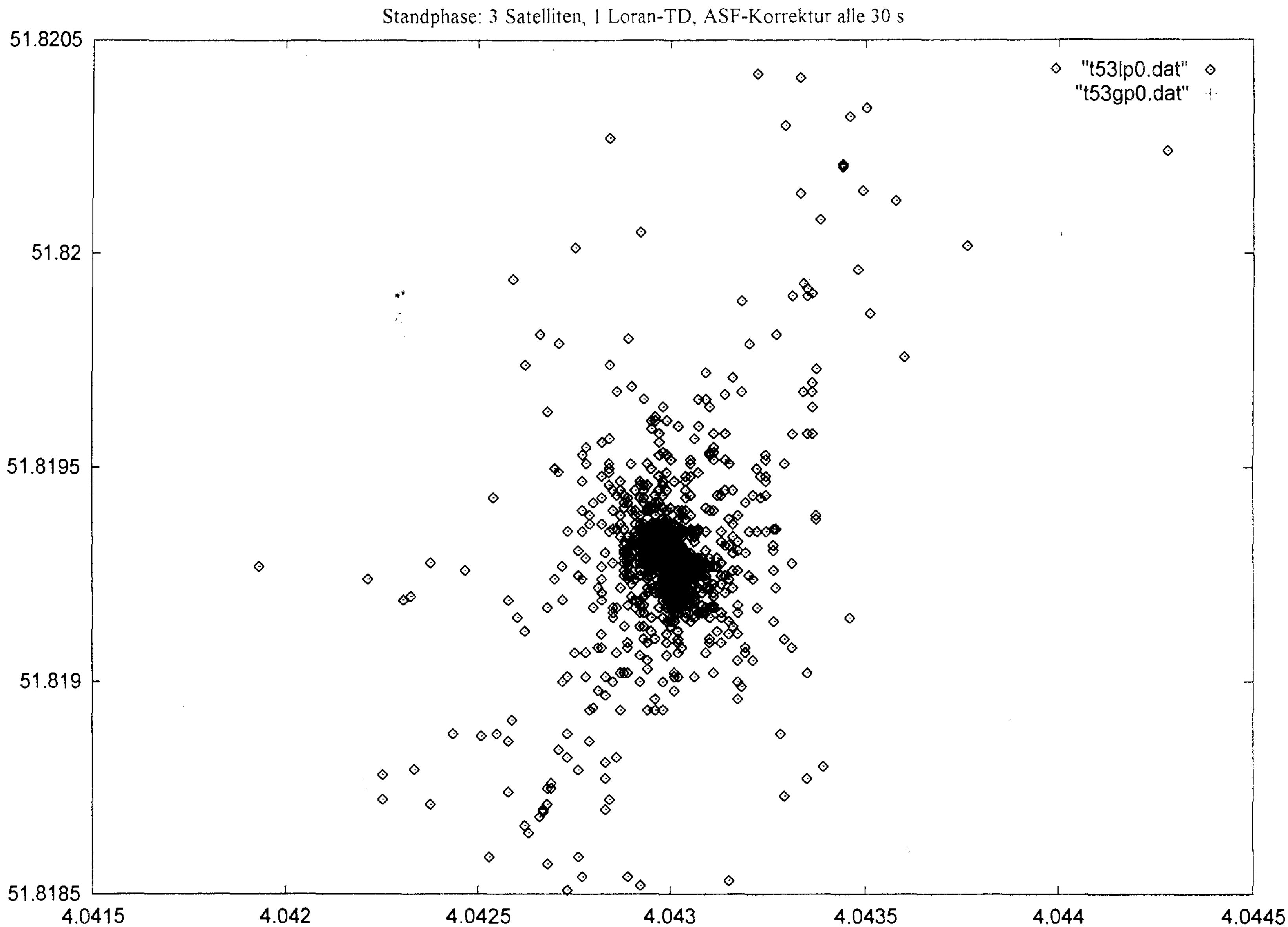
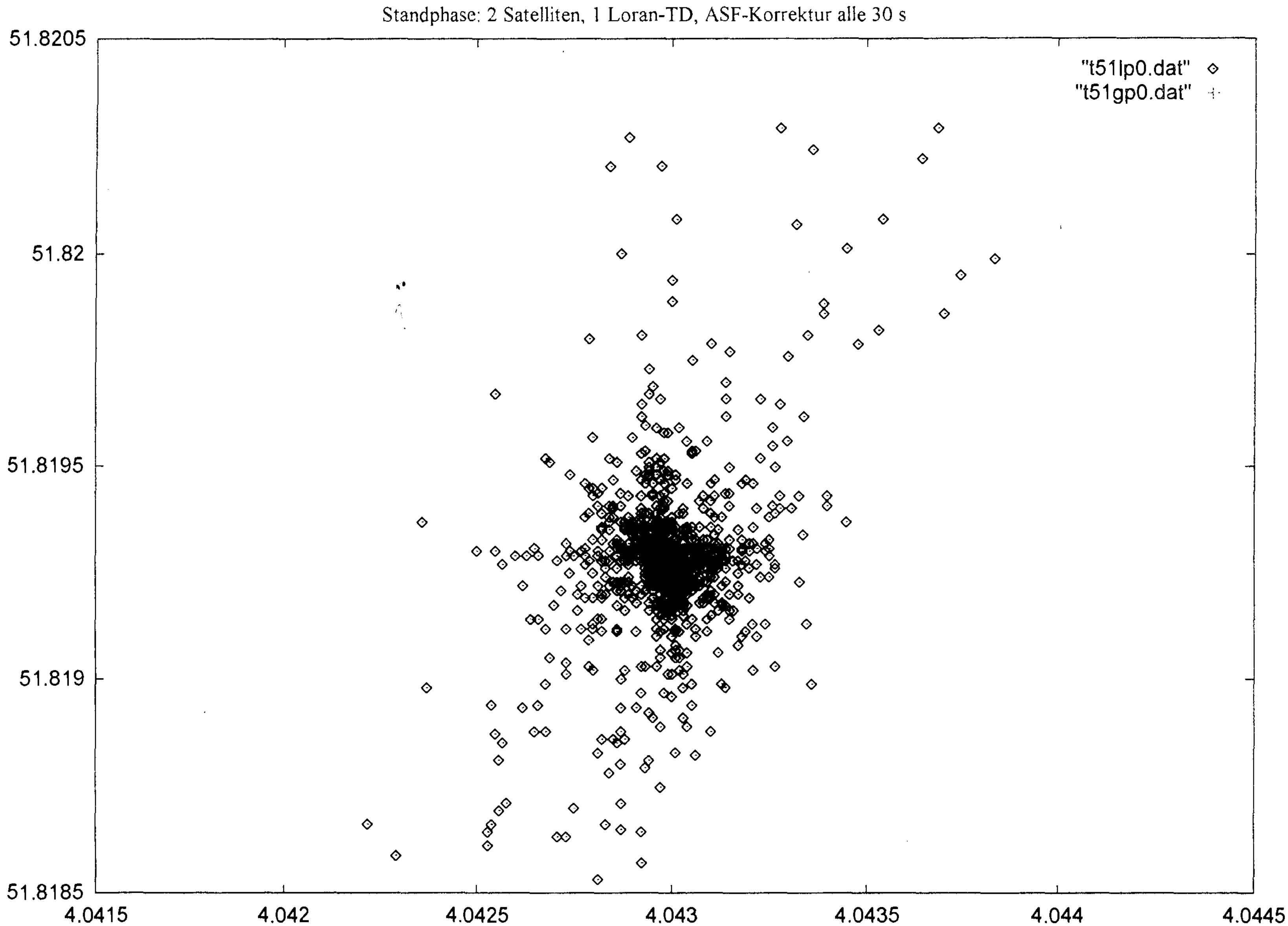


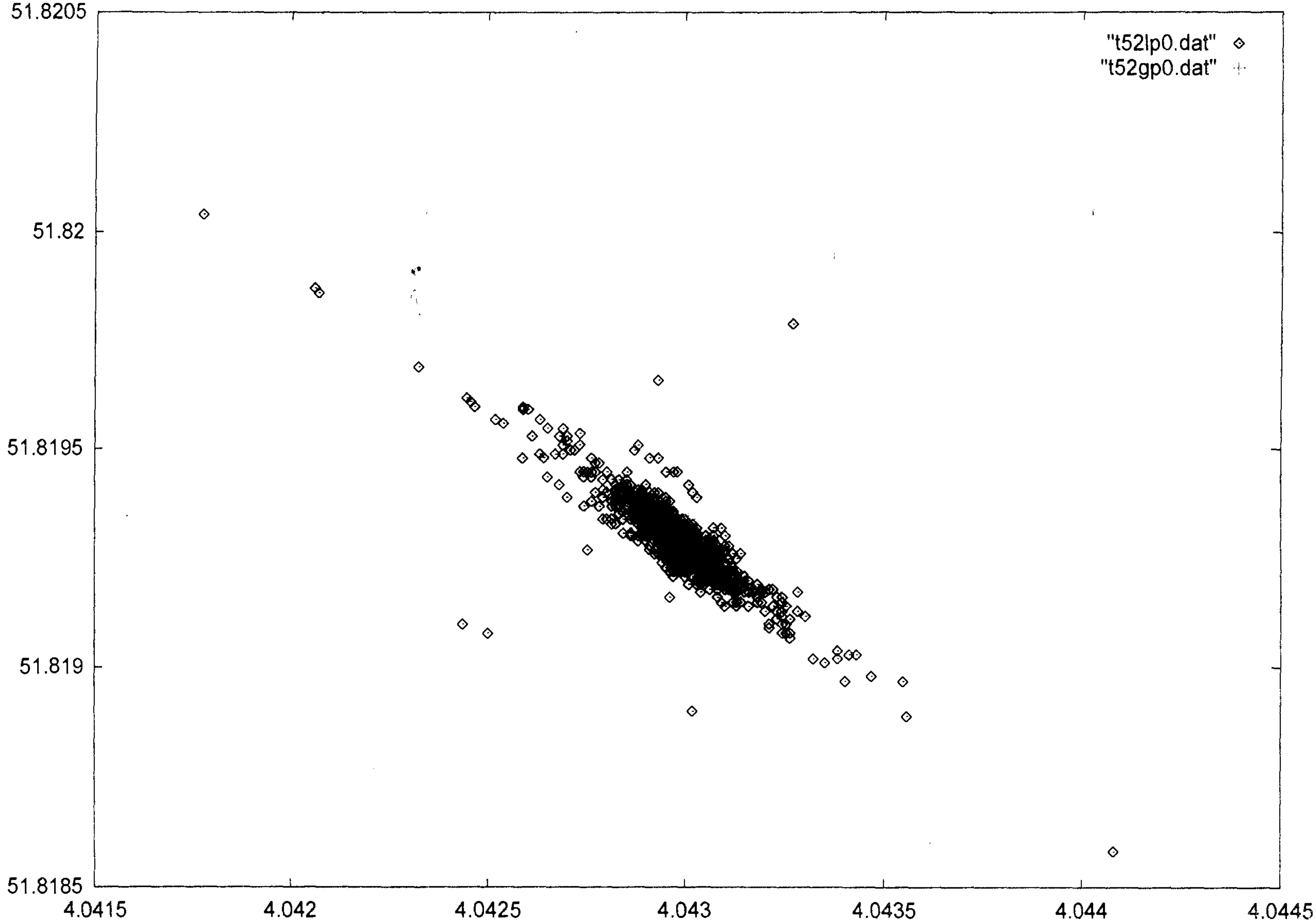
Standphase: alle Satelliten, 4 Loran-TD, ASF-Korrektur alle 30 s

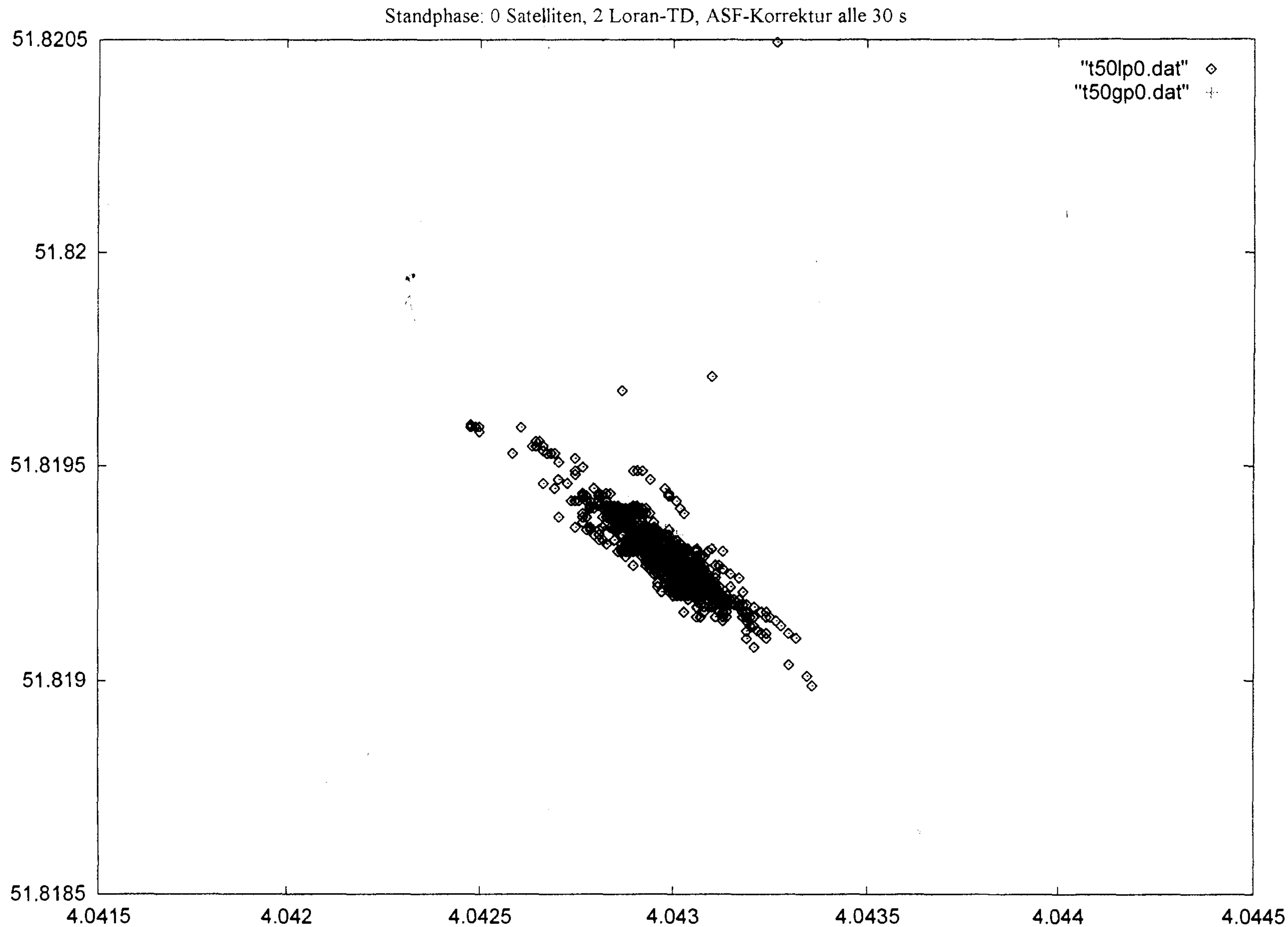


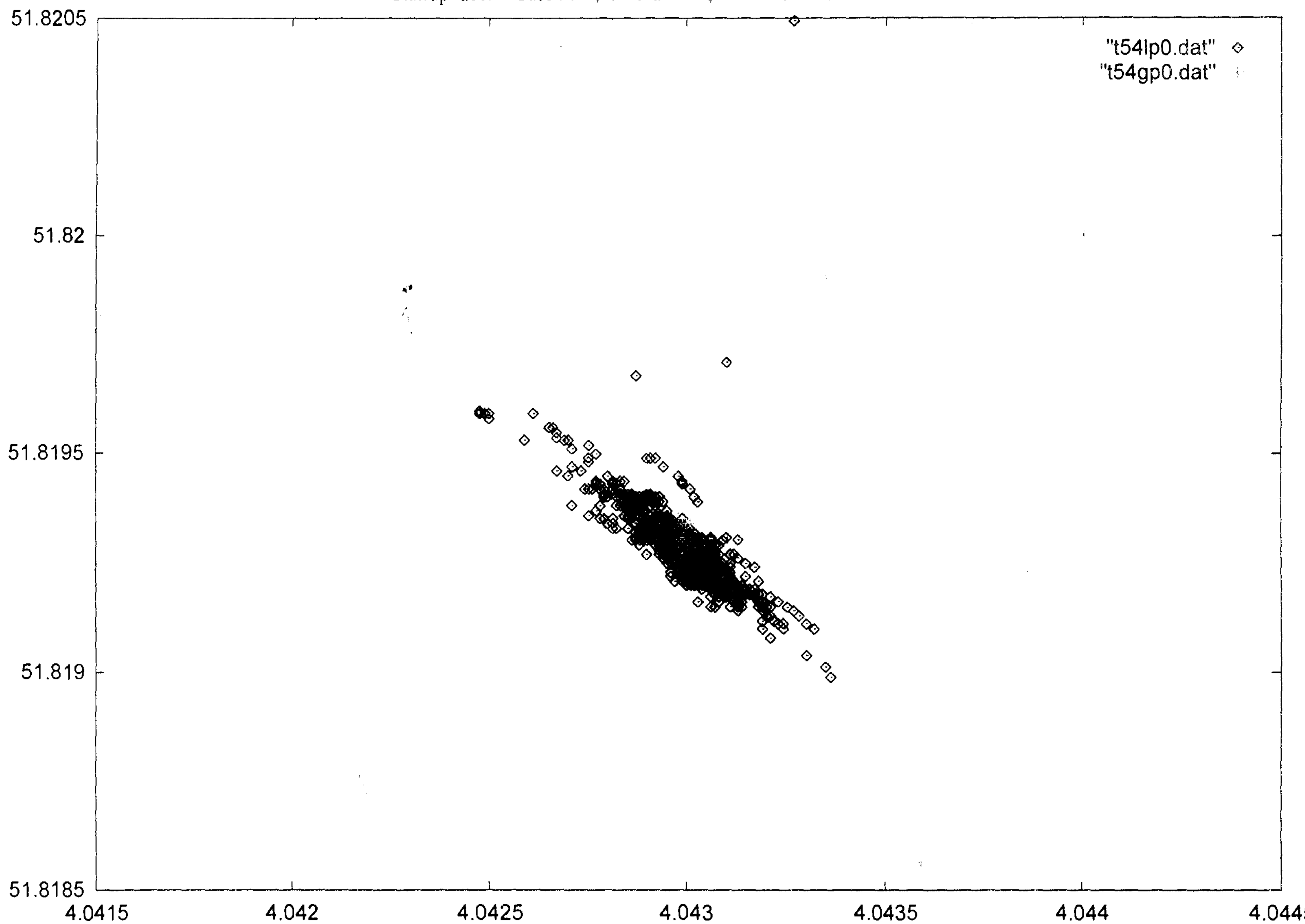

Standphase: 3 Satelliten, 1 Loran-TD, ASF-Korrektur alle 30 s
"t53lp0.dat"
"t53gp0.dat"
51.8205
51.82
51.8195
51.819
51.8185
4.0415
4.042
4.0425
4.043
4.0435
4.044
4.0445


Standphase: 2 Satelliten, 1 Loran-TD, ASF-Korrektur alle 30 s
"t51lp0.dat"
"t51gp0.dat"
51.8205
51.82
51.8195
51.819
51.8185
4.0415
4.042
4.0425
4.043
4.0435
4.044
4.0445

Standphase: 2 Satelliten, 2 Loran-TD, ASF-Korrektur alle 30 s




Standphase: 0 Satelliten, 2 Loran-TD, ASF-Korrektur alle 30 s
"t50lp0.dat"
"t50gp0.dat"
51.8205
51.82
51.8195
51.819
51.8185
4.0415
4.042
4.0425
4.043
4.0435
4.044
4.0445



Standphase: 0 Satelliten, 4 Loran-TD, ASF-Korrektur alle 30 s

Conclusions

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- GPS and GLONASS need augmentation for many areas of applications
- Terrestrial radio navigation system have complementary characteristics
- LORAN-C/Chayka are most appropriate
- Combined Receiver develoment is essential and time critical
- Eurofix combines efficiently DGNSS and LORAN-C
- Eurofix needs to be implemented within existing LORAN-C systems

Q: Aren't there inexpensive receivers available for the work?

A: We need to get the data-stream out; the lesser-expensive units don't have data ports. We need time-or-arrival receivers. No receivers are available in Germany now, since the system is brand new.

Comment from the floor: If Loran increases clock accuracy in TOA mode, then in a combined-system receiver it can improve GPS vertical accuracy as well as horizontal.

U.S. Coast Guard Loran-C Receiver Modernization

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BIOGRAPHY

Mr. Agostini has worked as an Electrical Engineer at the U.S. Coast Guard Loran Support Unit (formerly the Electronics Engineering Center) since 1991. He has previously worked for TEL Instrument (Buffalo, NY) and System Planning Corporation (Arlington, VA). Mr. Agostini received BSEE (1986) and MSEE (1990) degrees from the University of Buffalo.

ABSTRACT

All Loran-C signals broadcast in North America are presently monitored by a combination of Austron 2000 and Austron 5000 Loran-C receivers.

One Austron 5000 receiver is located at each of 29 Primary Chain Monitor Set (PCMS) sites situated throughout North America. These sites have been located in the user area to obtain the best representation of the transmitted Loran-C signal. They "see what the user sees". These PCMS sites extract information from the Loran-C signal and route it back to a Loran Control Station. The Control Station makes the corrections needed to keep the transmitted Loran-C signal in tolerance and initiates blink or takes the offending station off-air if tolerance cannot be maintained.

Austron 2000 receivers are located at Loran-C Transmitting Stations (LORSTAs). These receivers interface directly to the transmitting equipment and are used primarily to assist operators in restoring wayward Loran-C signals to tolerance.

Both the Austron 2000 and Austron 5000 receivers have been in continuous service since the 1970's. The USCG plans to replace these older receivers and their associated equipment with a single modern Loran-C receiver.

This new receiver system will be more reliable, less labor intensive to operate and will provide the system operator with more information than is presently available. This new receiver system is described and compared to the present Austron 2000 and Austron 5000 receiver systems. Information is provided on the schedule and scope of the receiver installation and testing to date and possible future improvements to the USCG monitoring system.

INTRODUCTION

All Loran-C signals broadcast in North America are monitored and controlled by the USCG and the Canadian Coast Guard (CCG). These services are required to keep all broadcast Loran-C signals within prescribed tolerances whenever possible, and to blink the Loran-C signal when tolerance cannot be maintained. This paper describes the equipment and procedures of the USCG, but in general, these descriptions apply to the CCG as well.

In order to control broadcast Loran-C signals, the USCG employs two distinct methods of Loran-C monitoring: Remote Monitoring and Local Monitoring. Each Loran-C Station in North America is simultaneously monitored by at least one Local Monitor and one Remote Monitor. Remote Monitors are used to maximize accuracy during normal operations. Local Monitors are used to get out of tolerance Loran-C stations back into tolerance. Each method of monitoring employs its own unique Loran-C receiver.

MONITORING AND CONTROL

Remote Monitoring

Remote Monitoring provides the input for the routine control of all Loran-C baselines. Remote Monitoring provides the critical information used to control the Loran-C signal more than 99% of the time. One Remote Monitoring receiver is located at each of 29 Primary Chain Monitor Set (PCMS) sites situated throughout North America. These sites have been located in the user area to obtain the most accurate representation of the transmitted Loran-C signal. Since the Remote Monitor "sees what the user sees", minimizing the error seen the Remote Monitor also minimizes the error seen by the user.

Time Difference (TD) and Envelope to Cycle Difference (ECD) information is extracted from the Loran-C signal every 10 seconds and is sent to the Loran Control Station via a packet switching network. The Control Station determines if any timing adjustments are needed to keep the transmitted Loran-C signal in tolerance (as accurate as possible) and sends commands to the LORSTA if adjustments are needed. The Control Station initiates blink or takes the offending LORSTA off-air if tolerance cannot be maintained.

Although Remote Monitoring offers the best possible accuracy, the response time of a Remote Monitor is often slowed by atmospheric and other types of noise that exist between the LORSTA and the Remote Monitor site. Consider the case of a sudden change in a baseline's TD due to a change in the time of transmission of a distant Loran-C station. If the Remote Monitor observes that distant station with a Signal to Noise Ratio (SNR) of +4dB, the average error of each sample would be about 1uS [1]. The Remote Monitor would require at least [1.00/0.010]**8 = 10,000 samples to determine the new TD to within +/- 10nS. Further, if the Loran-C signal jumps far enough, the receiver may have to start the entire acquisition process from the beginning to find the Loran-C signal at its new location. Observed SNR at USCG Remote Monitoring Sites can drop below 0dB overnight and during periods of inclement weather. During these times, Remote Monitoring is simply not responsive enough to effectively assist in the recovery of a distant Loran-C Station.

Austron 5000 Receiver

The Loran-C receiver used for Remote Monitoring is the Austron 5000 shown in Figure 1. This receiver was designed in the 1970's and unlike the Austron 2000, can be controlled from a remote location. The PCMS sites which house the Austron 5000 are completely unmanned. The Austron 5000 Loran-C Receiver is controlled by a dedicated DEC PDP-8 mini-computer shown in Figure 2.

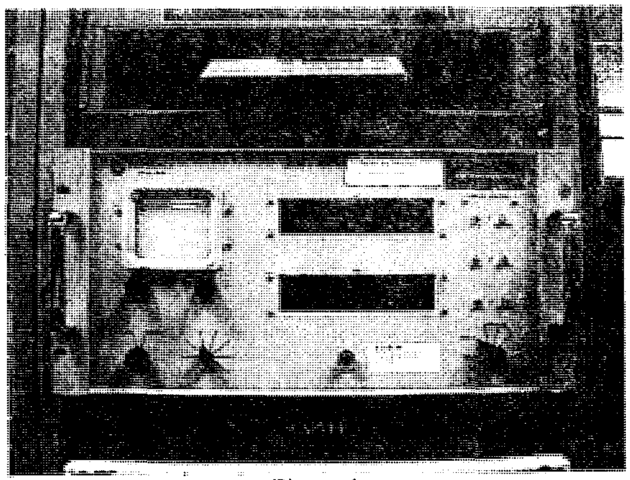


Figure 1
The Austron 5000 Loran-C Receiver

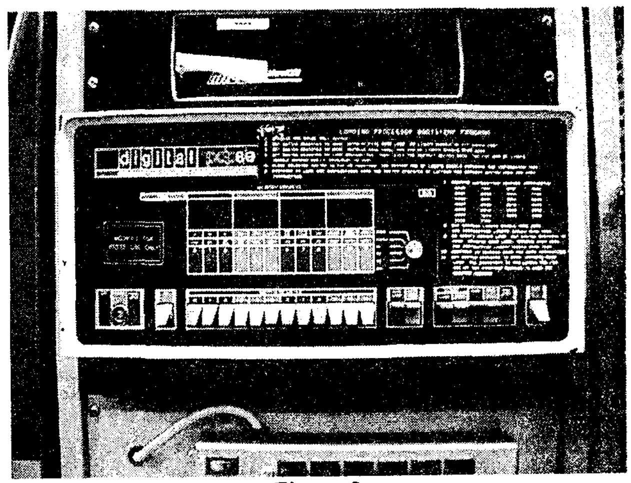


Figure 2
PDP-8 Computer

The PDP-8 computer was introduced in 1965 and was hailed as the world's first mini-computer (after the mini-skirt of the day). It was the most successful small computer of its day. The PDP-8E used by the USCG was introduced in 1971 and has 16 Kbytes of memory and a clock speed of 800 kHz.

Although the Austron 5000/PDP-8 combination can be operated from a remote site, its maintenance costs are very high. Due to its high failure rate, every PCMS site has a spare PDP-8 computer. Even with this, technicians must be dispatched to the PCMS site every time there is an equipment failure, even if the problem only takes a few minutes to repair. In Alaska, the technicians must be flown into some sites, at a cost of several thousand dollars, often just to restart or swap out the PDP-8 computer. Since the Austron 5000 and PDP-8 are both more than 20 years old, equipment failures are becoming more frequent with each passing year.

Local Monitoring

The second type of Loran Monitoring employed by the USCG is Local Monitoring. The Local Monitor is comprised of an Austron 2000 receiver, a Time Interval Counter (TIC), and a Phase Comparator (all described later). The Local Monitor provides information for control of a baseline during a casualty (a sudden change in transmitting conditions that places the Loran-C signal out of tolerance, typically due to equipment failure). The Local Monitor sacrifices accuracy for speed. They are needed because, when a casualty occurs, watchstanders are not overly concerned with optimizing the accuracy of the transmitted signal, rather they are concerned with getting the signal back into tolerance...Fast!

Local Monitoring is more responsive than Remote Monitoring because the Local Monitor is physically located at the LORSTA, not hundreds of miles away, in the user area. There is at least one Local Monitor at every LORSTA in the USCG. Because the Local Monitor is physically located at the LORSTA , there is no significant noise between the transmitted Loran-C signal and the Local Monitor. Thus, the Local Monitor can immediately reflect any change in the timing of the Local Loran-C signal. Changes in the timing of remote Loran-C signals are, of course, subject to the slowing effects of external noise.

Austron 2000 Receiver

The heart of the Local Monitor is the Austron 2000 Loran-C receiver shown in Figure 3.

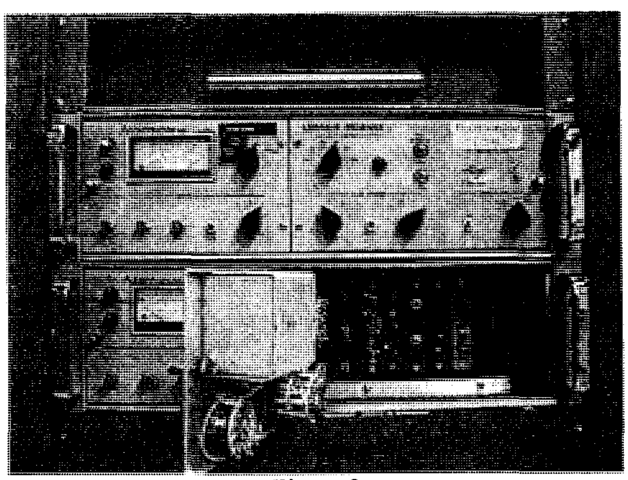


Figure 3
Two Austron 2000 Receivers

The Austron 2000 receiver was designed in the early 1970s. All receiver settings (e.g., GRI, Receiver Gain, Time Constants) are set via physical inputs (e.g., thumbwheel and toggle switches). Station personnel must physically manipulate the receiver in order to acquire and track any Loran-C signal. Thus, the receiver can never be operated from a remote location. There are from one to six Austron 2000 receivers at every LORSTA in North America.

Acquisition of a Loran-C signal with an Austron 2000 is achieved through the following process.

- Externally trigger an oscilloscope via the GRI OUT output of the Austron 2000.
- View the incoming RF on channel A of an oscilloscope.
- View receiver strobes on channel B of an oscilloscope.
- Look at the positions of all visible Loran-C stations within in the GRI. From the relative positions of the signals, determine which signal is the station you want to acquire.
- Add channel A and B together, and manually place the receiver's strobes on the 3rd positive going zero crossing of the Loran-C signal.

Station personnel are required to do this within two minutes, which is difficult enough to do when the signal looks like that shown in Figure 4.

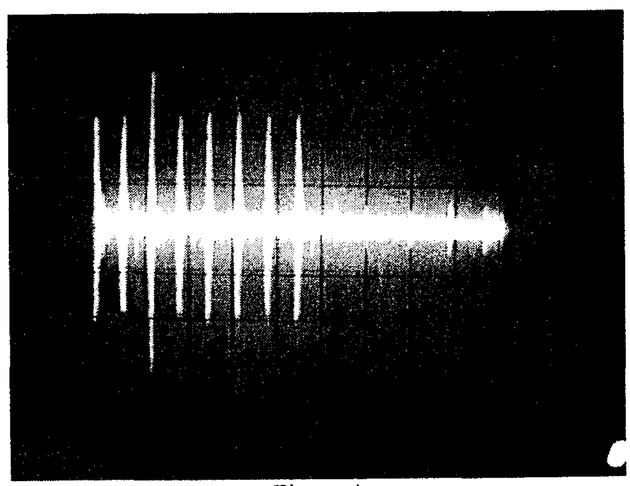


Figure 4
9960-X as seen from Wildwood, NJ

The signals often look more like that shown in Figure 5.

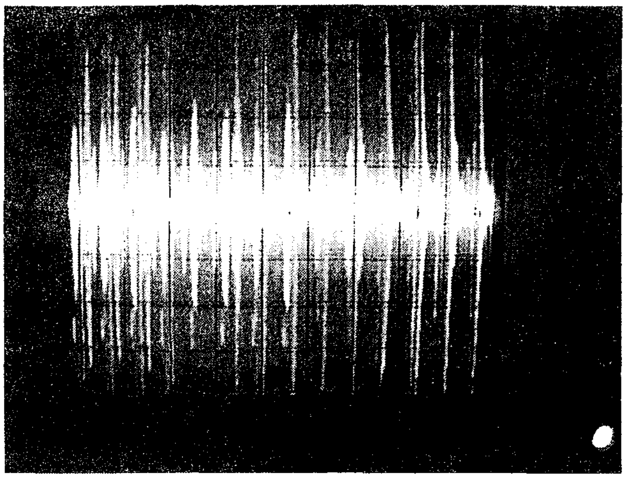


Figure 5
9960-W as seen from Wildwood, NJ.

At times, it becomes difficult to see the desired station at all, let alone determine which is the 3rd positive zero crossing.

Other Local Monitoring Equipment

The Austron 2000 receiver tracks only a single remote Loran-C station. A TIC and Phase Comparator must be used to relate the timing of this remote Loran-C station to the timing of the Local Loran-C station.

The relevant outputs of the Austron 2000 are:

1) A 1/PCI squarewave that is phase locked to the remote Loran-C station.

2) A 1MHz sinewave that is phase locked to the remote Loran-C station.

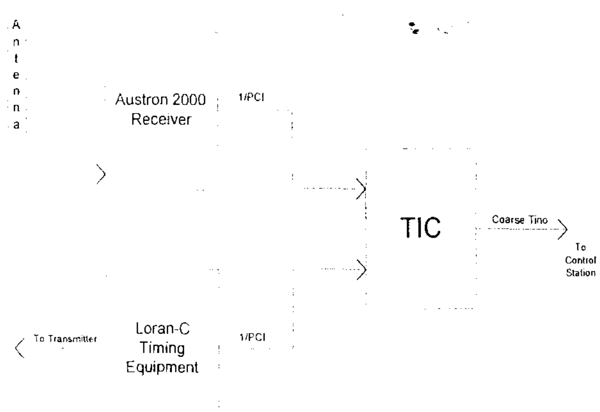


Figure 6
Generation of Coarse TINO

The 1/PCI square wave from the Austron 2000 is compared to a similar square wave from the local station's timing equipment by the TIC as seen in Figure 6. The TIC reports the time interval between the two signals, which is a quasi-TD called Coarse Time Interval Number (TINO). The resolution of Coarse TINO is 100nS.

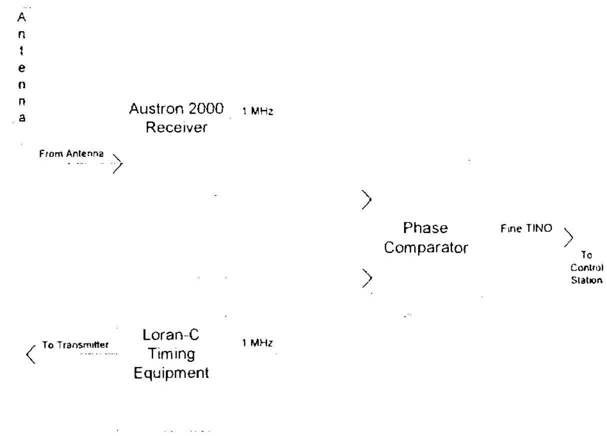


Figure 7
Generation of Fine TINO

Similarly, a 1MHz sine wave from the Austron 2000 is compared to a similar 1MHz sine wave from the Local Station's timing equipment by a phase comparator built into the back of the Austron 2000 as seen in Figure 7. The output of the phase comparator, Fine TINO, is an analog (0-5V) signal which measures the phase difference between the two 1MHz inputs with an accuracy of about 10nS.

Although the Austron 2000 cannot be controlled from a remote location, its outputs (Fine and Coarse TINO) can be seen at the Control Station through the dedicated monitoring equipment of the Local Site Operating Set (LSOS). The inability to remotely operate the Austron 2000 receiver is a major obstacle in the path of LORSTA personnel reductions.

FUTURE USCG MONITORING SYSTEM

The LRS-III

The replacement receiver for both the Austron 5000 and Austron 2000 receiver is the LocUS LRS-III shown in Figure 8. This receiver is based upon a 16MHz 68303 processor and offers several advantages over its predecessors.

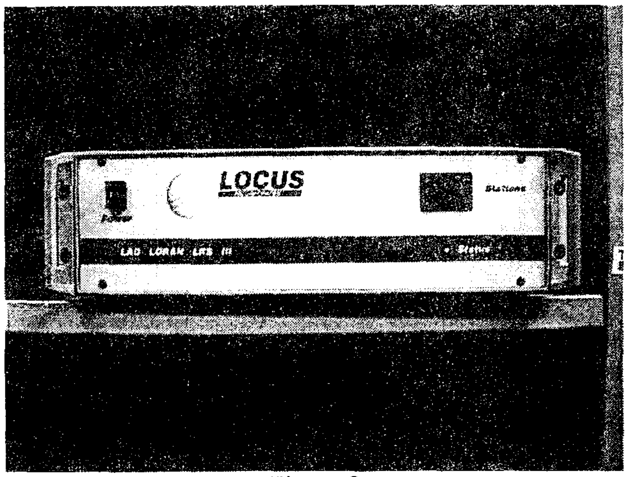


Figure 8
The LocUS LRS-III Loran-C Receiver

Maintenance: Modern single board electronics are much more reliable than older receivers and computers.

Automatic Notch Filters: Both the Austron 2000 and Austron 5000 operate with an external notch filter chassis. Technicians must periodically check the drift of these notch filters and scan for new interferers with a spectrum analyzer. The LRS-III incorporates 12 automatic notch filters, automatically scans for new interferers and corrects for filter drift, freeing technicians from this chore.

Easier Receiver Placement I: PCMS Sites are typically housed in standalone fiberglass huts, often situated at very remote locations to protect them from destructive localized Continuous Wave Interference (CWI) interference sources (e.g., switching power supplies). With the automatic notch filters of the LRS-III, PCMS sites may now be moved to more accessible locations (e.g., in occupied buildings).

Easier Receiver Placement II: The Austron 2000 and 5000 both use a 35' passive antenna; the antenna employed by the LRS-III is a 4' active antenna. The smaller antenna of the LRS-III will allow the receiver to be placed in locations with height restrictions (e.g., airports) where the 35' antenna would not be allowed.

Waveform Information: Presently, at the control site, watchstanders have no way to view the Loran-C signals they are controlling short of driving out to a LORSTA or PCMS site (hundreds of miles away) and viewing the signal on an oscilloscope. The LRS-III can send a digitized representation of any station it tracks. This will help watchstanders discriminate between changes in propagation delays (which should be corrected for by the LORSTAs) and offsets due to skywave (which should not be corrected because the effects of skywave are localized).

Casualty Control: Currently, the Austron 5000 is of limited use during a casualty because it cannot acquire Loran-C signals if they are outside of their expected timing slots. The LRS-III will automatically find all Loran-C stations within a given GRI, even if one or more stations have jumped out of their assigned timing slots.

Ease of Operation: Many of the more tedious functions (e.g., checking nominals) of the Austron 5000 have been automated in the LRS-III. Since each watchstander may be required to operate up to seven Remote receivers at a time, ease of use is very important.

Remote Operation: Unlike the Austron 2000, the LRS-III can be operated from a remote site.

Fewer Receivers: Since the LRS-III can track multiple stations while the Austron 2000 cannot, one LRS-III will be able replace up to five Austron 2000s.

Future Improvements I: Although the LRS-III will support the outputs of the Austron 2000 receiver (i.e., 1/PCI and 1MHz outputs), it will also make this information available over its primary communication's interface. This will relieve the LSOS system of the responsibility of measuring and transmitting the Coarse and Fine TINO.

Future Improvements II: The function of any Automatic Blink System (ABS) is to compare the Time of Emission (TOE) of a locally broadcast Loran-C signal to some "true time" and to quickly start blink whenever the local Loran-C signal is too far out of tolerance. The oscillator of the LRS-III is stabilized via a weighted average of all received remote Loran-C stations. This can be considered a "true time". The LRS-III is already monitoring the TOE of the locally broadcast Loran-C signal, and can easily compare it to its own internal "true time". The LocUS thus might be able to fulfill the minimum requirements of an ABS system. We will test the ability of the LRS-III to meet the minimum requirements of ABS. If it does, we will be able to implement a simple ABS system that will require almost no additional hardware, and will add almost nothing to the station's workload.

Current Status

The LRS-III receiver has already been field tested as a replacement for the Austron 5000 receiver at USCG PCMS Sites Wildwood, NJ; Sandy Hook, NJ; New Orleans, LA; Attu AK and Kodiak AK. The LRS-III replaced the Austron 5000 at Sandy Hook, NJ and was used to control the 9960 X-ray and Yankee baselines during the entire month of July 1997. We have experienced almost no problems with the LRS-III and response from the field has been very positive.

The LRS-III receiver has not yet been field tested as a replacement for the Austron 2000 receiver because several modifications have yet to be made. The final LRS-III receiver will replace one Austron 2000 receiver at each secondary station and up to five Austron 2000 receivers at each Master station.

Future Plans

The Loran Support Unit (LSU) is scheduled to replace all Austron 5000 (Remote) receivers by the end of 1998, and all Austron 2000 (Local) receivers by the end of 1999.

ACKNOWLEDGMENTS

I would like to thank the crews of LORSTAs Seneca, Malone, Kodiak and Attu for all their help in developing and testing the LRS-III receiver.

REFERENCES

[1] Peterson B. B. and Hartnett, R. J., "Measurement Techniques for Narrowband Interference to LORAN", WGA Technical Symposium, Oct. 1999, pp. 78-88.

Comment from the floor: Your presentation clearly indicates U. S. intends long loran operation – it's new stuff!!

Response: An FAA "windfall" provided the money.

Performance of Loop Antennas on Aircraft

An informal report on "work in progress"

Robert W. Lilley, Ph. D.
Avionics Engineering Center
Ohio University

Introduction

During FAA efforts in the late 1980s to implement Loran-C as a system for instrument approach guidance, criticism was leveled at the system in the name of p-static interference. P-static was said by some to deny Loran-C guidance just when the user needed it most.

This may have been at least partly true at that time, because inexpensive electric-field "whip" antennas were used, often without careful preparation of the installation site on the airframe. Also, there was evidence that aircraft owners and operators were not careful to provide and maintain airframe discharging devices. To be fair to these owners and operators, it was natural that emphasis on dischargers might decrease over time, as most aircraft radios were moved away from the low frequencies where p-static is often most energetic.

When it became obvious that Loran-C would be a popular system among aviators, offering "free" distance measurement and much new flight-management information even for low-end aircraft, FAA interest in p-static and its minimization increased. Ohio University performed studies to demonstrate the effectiveness of various types of discharge devices.

The University outfitted its Piper Saratoga aircraft with discharger wicks at locations specified by Robert Truax, an airframe charging expert and discharger manufacturer, and approved by Piper Aircraft. The dischargers could be removed easily to facilitate experiments in actual weather conditions. The airframe has proven to be very "quiet" electrically with these dischargers in place. No loran outages have been documented even in heavy precipitation or when flying near thunderstorms. With the dischargers removed, however, the loran data is lost immediately upon entering even mild precipitation or cloud.

Additionally, the Avionics Center's DC-3 aircraft was equipped with instrumented discharger wicks to permit measurement of the discharge current as a function of location on the airframe. Also, a system for artificially charging the airframe in flight was installed, so that controlled experiments could be performed without having to search for weather conditions conducive to airframe charging.

Now that Loran-C is once again being considered by some as a continuing part of the aviation navigational suite, the dreaded "p-static" demon once again appears in conversation. As a response to this continuing criticism of loran, magnetic-loop antenna developments have been initiated. Drawing from experience during the Omega era, we expect that h-field devices will be less sensitive to electrical interference caused by the high-voltage, low-current discharge mechanisms during flights in precipitation or cloud.

This year, Ohio University began a cooperative program with Megapulse, Inc. to test one example of a Loran-C h-field antenna in actual flight-weather conditions. The objective, of course, is to determine whether the h-field antenna outperforms an e-field antenna in weather conditions conducive to airframe charging.

Electrical Noise Generated in Flight

Airframe charging occurs when electrons are knocked free from particles of ice or water which impact the aircraft during flight. As might be expected, more speed means more such collisions and thus a higher rate of charging. A highly-charged airframe can give rise to visible glow ("St. Elmo's fire") during corona discharges and to noticeable discharge to fingers when placed near the windscreen. Essentially, the whole process can be compared (loosely) to the arc drawn when touching a doorknob after shuffling across a carpet.

Once the charge is transferred to the airframe Through this "triboelectric" process, there are three main mechanisms for equalization of charge between the airframe and the surrounding space. Each can be troublesome in its own way and each requires separate attention by maintenance personnel.

- **Arcs**

Arcs occur when different elements of the airframe are charged to different voltages. Such differences can occur due to corrosion or loose components, but can also occur for stranger reasons. One noise case was solved when it was discovered that a metallic emblem was glued to the aircraft's painted surface, rather than being screwed or riveted. The non-conductive paint and glue formed the dielectric for a capacitor, which then arced when the potential difference between the emblem and the airframe reached high values.

Arcs cause broadband noise, and are relatively energetic.

- **Streamers**

Streamers are arcs which form across dielectric surfaces such as windscreens and radomes. (Special coatings are required on aircraft where composite skin or structural materials are used, to avoid noise or more serious effects of high-rate charging.)

The efffects of streamers are similar to arcs, but to minimize their energy, conductive coatings are required. Much effort has been expended to develop optically clear coatings for windscreens and RF-transparent coatings or loading methods for radomes. The coasting must obviously be connected to the airframe; in the windscreen case, the glue often used to seat the plastic window can act as an insulator. A method must be found for conducting the surface charge across this barrier.

- **Corona**

Of the three discharge mechanisms, corona is perhaps lowest in instantaneous energy, but can be most troublesome due to its frequency-selective nature. When the airframe is charged, packets of charge leave the trailing edges (and antenna tips and other convenient spots), and these ions are carried away by the slipstream. The amplitude of each of these events is approximately constant, determined by the trailing-edge geometry. (Ions can escape at lower potential levels from points with very small radius of curvature.)

Discharger wicks are made up of bundles of very fine wire in an attempt to provide a low-energy discharge path for accumulated charge on the airframe. Discharger length and resistivity are design parameters which can be varied to enhance performance in selected frequency ranges.

If the charging rate (the input of charge from collisions with precipitation particles) increases, the corona mechanism must liberate ions more frequently to equalize the charge. Therefore, the corona current consists of more-or-less constant amplitude events with a varying repetition rate proportional to the airframe charging rate. This repetition rate can easily reach 100 KHz. (In fact, the rate can occur at 30, 90, 150, 9960 Hz, or other audio frequencies of great interest to navigation-aid designers. Perhaps most troublesome is that the corona pulses look just like digital pulses, and when they get into digital systems through corroded joints or poor grounds, big trouble can result intermittently and thus stealthily.

Corona currents can be in the nano-ampere range, but when originating from an airframe charged to over 100,000 volts, noticeable noise may result. It is in this environment that our navigation equipment must operate, and it is in this environment that Omega operated successfully on aircraft large and small, generally using h-field antennas.

Maintaining the Airframe

It is possible to "quiet" a particular model of aircraft, by designing the discharge wick installation appropriately given the airframe shape. However, once those aircraft are in service. The variations in maintenance frequency and technique can cause individual differences. Each owner and operator needs to be alert to methods for minimizing airframe-charging/discharging noise. The foregoing description of the noise mechanisms gives hints for successful maintenance. Eliminate corrosion, maintain and test discharger wicks, replace wicks when burnt or after a close encounter with lightning, maintain conductive coatings on radomes and windscreens.

There are test sets which can be used to detect "hot spots" on particular aircraft. Trouble with loran or other avionics may signal airframe-noise as a cause. It can be fixed; it just takes careful attention to detail.

The Megapulse Loop Antenna and Receiver

In the late 1970s, Ohio University tested Omega monitor receivers for the U. S. Coast Guard involving both whip and loop antennas. At the time, the loop required complex heading sensors to allow appropriate combination of the signals from the two loops as the user vehicle changed heading.

In the Megapulse receiver, simplified loop-switching logic is implemented, which serves the same function, without an external sensor. For these tests, Megapulse implemented in hardware an "omni-directional" output so that existing loran receivers could use the combined signal from the orthogonal crossed loops.

The Megapulse Loop receiver is a complete loran sensor, but for these tests its only function is to determine the loop switching parameters for each station and drive the omni-directional output. Absolute heading is not required by this receiver, and knowledge of initial antenna azimuth not important.

Other than that, Megapulse is relatively quiet about details of this antenna and its control logic. We know that at least one other organization is working on similar problems, so there could be competition at work!

Antenna Testing on the Aircraft

Test plans include initial ground tests with and without the aircraft engine running, to test the installation. Then, with dischargers removed and with simultaneous data recorded from receivers with e-field and h-field antennas during flight into precipitation and cloud, any significant differences between the antenna types will become evident. The data-collection installation was planned with these objectives in mind.

The Megapulse antenna and receiver were provided to Ohio University this past summer, and it has been installed on the test aircraft as seen in Figures 1. Notice that we used the under-tail position which we learned from the Omega days, tends to maximize the distance from the engine and to use an electrically quiet airframe position, from the standpoint of skin currents. The e-field whip for the operational loran receiver can be seen atop the aircraft.

Figure 2 shows a close-up. Megapulse actually had the cover off at one point to make an adjustment, but I can't show you those secrets...

Inside the aircraft (Figure 3), the Megapulse Loop receiver (right), power supply (lower center) and laptop computer for data collection are mounted to center-seat shelves which are the standard data-collection configuration for that aircraft. Note the II-Morrow Loran-C receiver mounted under the Loop receiver. There is an identical II-Morrow unit in the aircraft instrument panel. The II-Morrow 612-A was chosen due to its approval under the FAA's Early Implementation Program for Loran-C instrument approaches. These units are shown in preparation for ground testing.

The block diagram in Figure 4 shows the Megapulse Loop Receiver and its antenna, with the "omni-directional" output feeding the "experimental" II-Morrow Loran-C receiver. The "operational" loran receiver is fed by the standard II-Morrow e-field "whip" antenna on top of the aircraft. . The experimental receiver was checked against the aircraft's operational receiver of the same model, and found to provide signal-to-noise performance to within +/- 1 dB. The laptop records serial data from both II-Morrow receivers. An additional serial data port is available, for monitoring diagnostic and positioning data directly from the Megapulse receiver, when necessary.

The data recording is controlled by laptop software, which also provides output in real time for monitoring the process. Event marks can be inserted at any time, with descriptive text. Event marks serve during post-flight processing to synchronize the data streams from the two receivers. The window shown in Figure 5 allows monitoring of data reaching the operational II-Morrow receiver; a similar window allows viewing the experimental receiver.

Figure 6 shows a small example of recorded data from both receivers, with one event mark ("Take Off") at the top. Figure 7 gives a sample of Megapulse diagnostic and position data, which is useful for Loop receiver post-flight analysis by Megapulse.

The map in Figure 8 shows flight paths during early testing near the Ohio University Airport. (The airport is right under the multiple paths to the southwest of Albany.) Loran-C chain 9960 was used; this chain offers excellent geometry and signal strength in Ohio. The access road is visible, as is position data taken during taxiing operations. Repeated flights are shown, with natural differences between flight paths when not aligned with the runway as a precise visual reference. The long legs of the pattern are approximately six nautical miles in length.

These test flights uncovered the need for some adjustments in tracking software in the Megapulse receiver; one receiver unlock event can be seen about over the town of Albany. As we present this paper, those adjustments are underway at Megapulse.

Future Work

We will do flights at a constant altitude with slowly varying heading (360-degree turns) in clear air. Signal level will change only as antenna pattern changes, and noise will remain constant since position will change only slightly. SNR will thus show antenna pattern variations with heading.

We will fly straight runs through clouds conducive to charging and p-static. Signal strength should remain constant due to small position changes, but noise will vary as charging occurs. SNR data will show any variations between whip and loop antennas.

We will try flights with discharge wicks installed and with them removed, for baseline data.

The winter season is to be desired – heavy frontal snow is the best charging mechanism.

Q: Was the racetrack pattern Megapulse data or II Morrow data?

A: Megapulse

Q: What about the little "L" characters in the data plot?

A: Erik Johannessen, Megapulse – That is the Megapulse software, which is velocity based - we skip a measurement now and again because of the high speed and indicate it this way.

Author: Note during climb the data is continuous when the speed is slower.

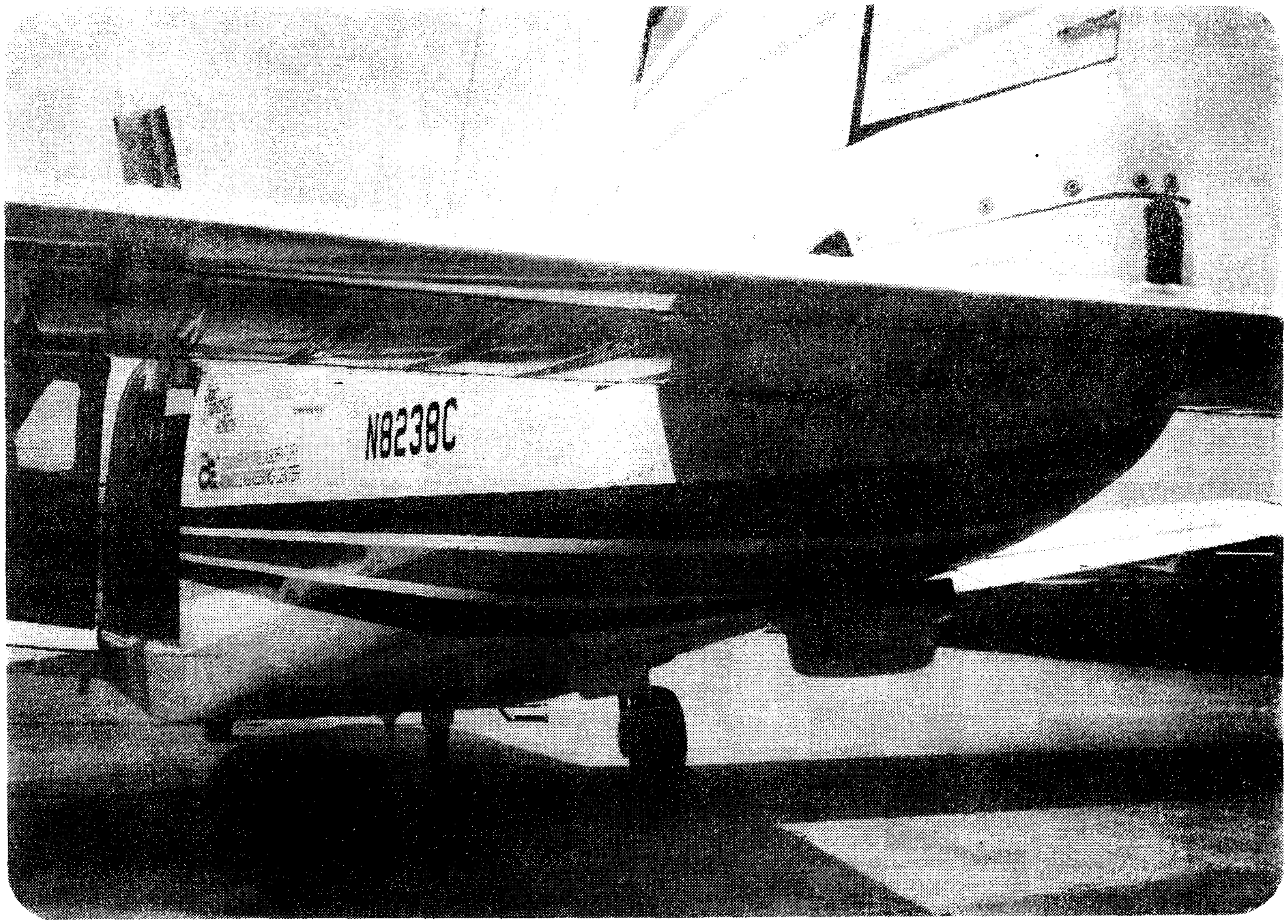


Figure 1: Megapulse Loop antenna mounted on Piper Saratoga aircraft

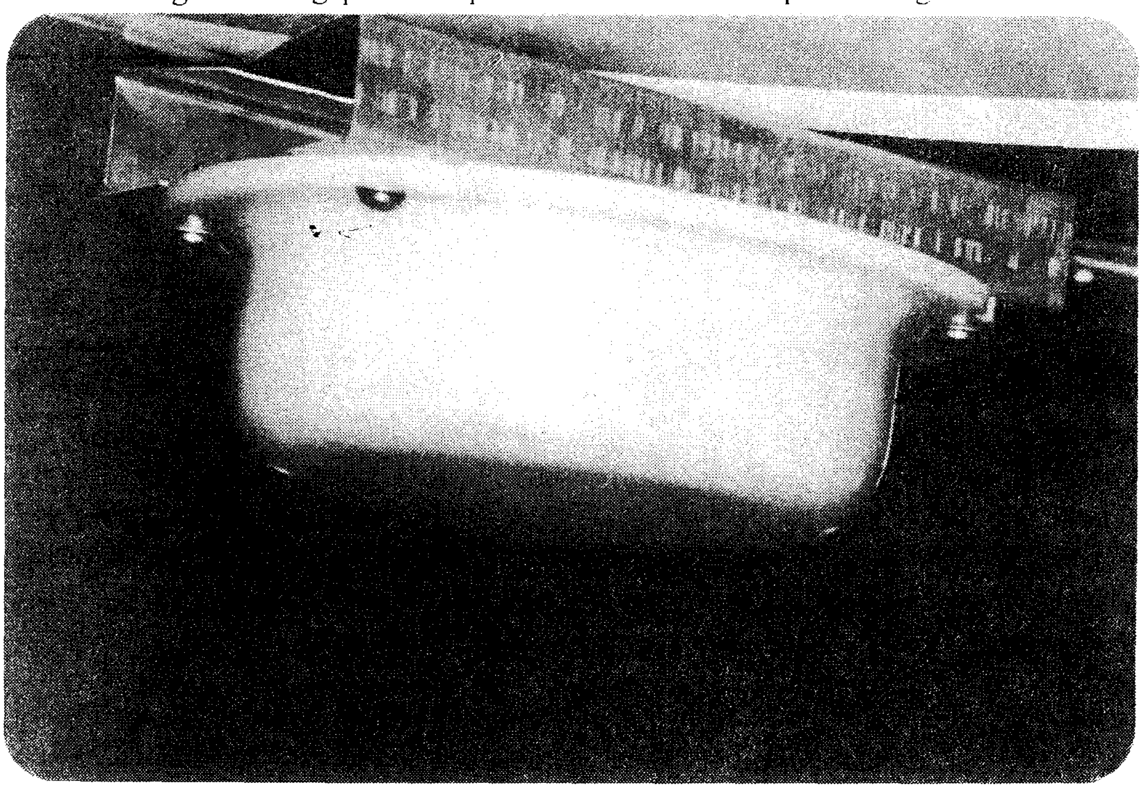


Figure 2: Close-up of Loop antenna

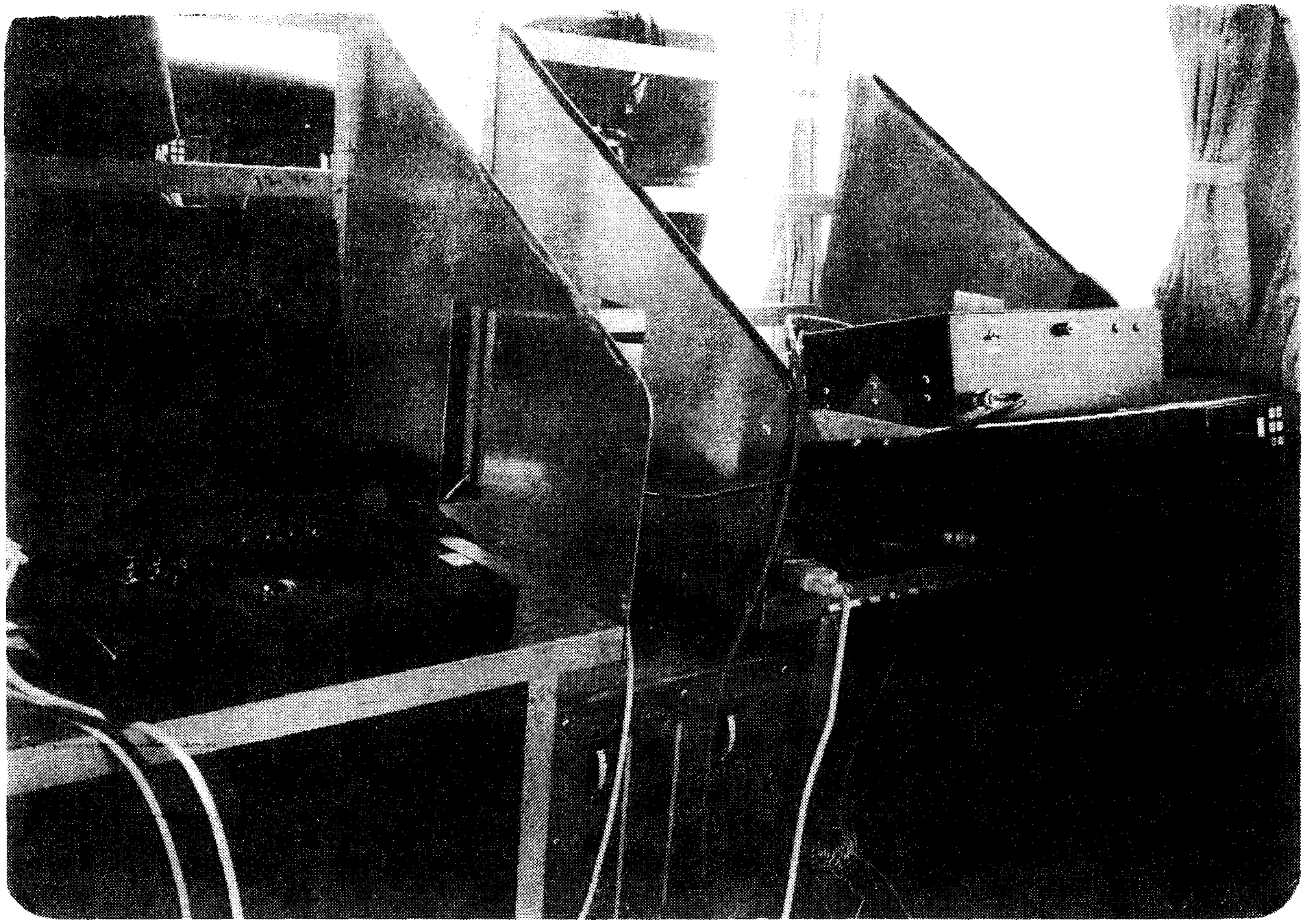


Figure 3: Loop receiver, "experimental" II-Morrow receiver and computer under ground test

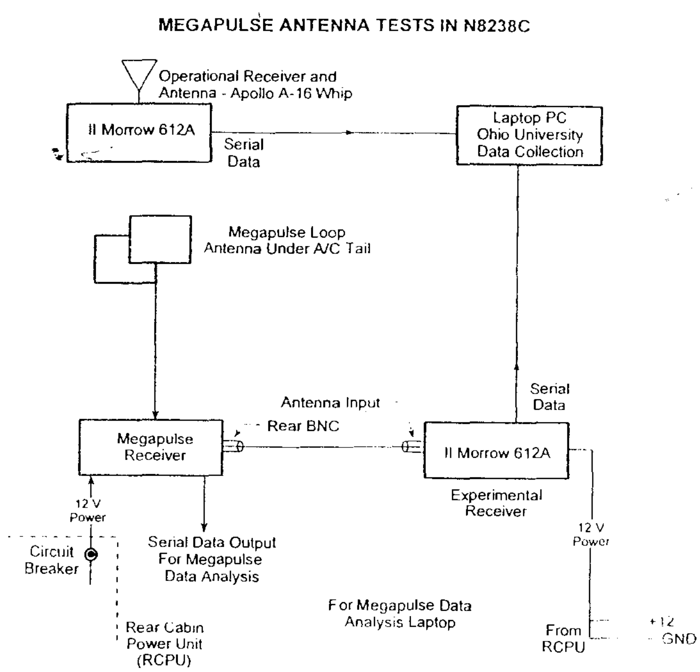


Figure 4: Block diagram of test configuration

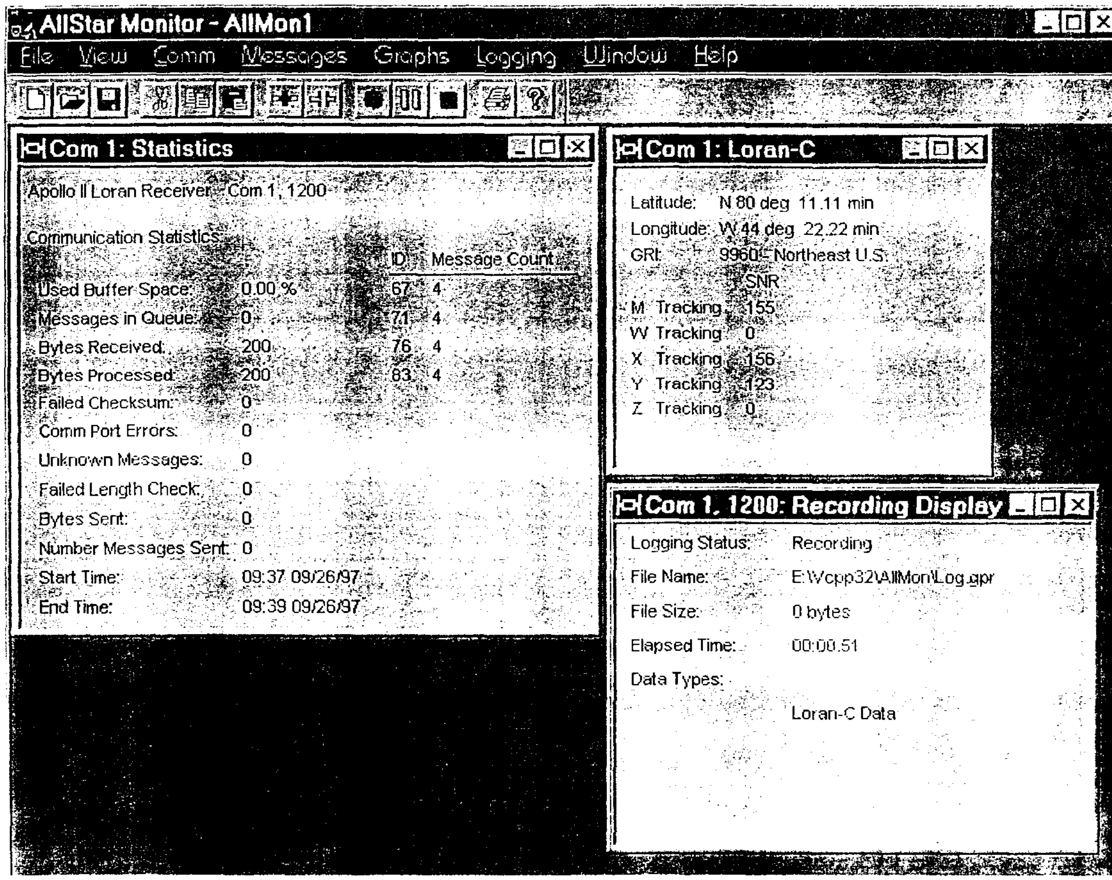


Figure 5: Receiver data window

Thursday 9-25-97 @ 2:30 pm
UNI Pattern

Front Loran Receiver					Back Loran Receiver (MegaPulse's)				
Latitude	Longitude	M	Y	Z	Latitude	Longitude	M	Y	Z
Take Off					Take Off				
N 39 12.54	W 82 14.55	245	224	237	N 39 12.55	W 82 14.53	243	227	233
N 39 12.52	W 82 14.60	246	226	238	N 39 12.53	W 82 14.57	242	227	232
N 39 12.50	W 82 14.65	245	226	238	N 39 12.51	W 82 14.62	242	229	233
N 39 12.48	W 82 14.69	245	228	239	N 39 12.49	W 82 14.66	241	229	233
N 39 12.46	W 82 14.74	246	229	239	N 39 12.47	W 82 14.71	240	231	232
N 39 12.44	W 82 14.78	245	230	239	N 39 12.46	W 82 14.76	240	232	232
N 39 12.42	W 82 14.82	245	231	238	N 39 12.43	W 82 14.80	241	233	233
N 39 12.40	W 82 14.86	245	232	239	N 39 12.40	W 82 14.85	241	232	233
N 39 12.37	W 82 14.89	244	233	239	N 39 12.37	W 82 14.87	240	234	233
N 39 12.33	W 82 14.93	244	234	240	N 39 12.34	W 82 14.90	240	234	233
N 39 12.30	W 82 14.94	243	235	240	N 39 12.31	W 82 14.92	240	234	233
N 39 12.26	W 82 14.96	243	235	240	N 39 12.27	W 82 14.94	241	235	233
N 39 12.22	W 82 14.96	244	236	240	N 39 12.23	W 82 14.95	241	235	234
N 39 12.18	W 82 14.96	243	236	239	N 39 12.20	W 82 14.95	242	236	234
N 39 12.14	W 82 14.95	243	237	240	N 39 12.16	W 82 14.94	241	236	233
N 39 12.10	W 82 14.93	244	238	239	N 39 12.13	W 82 14.93	241	236	234
N 39 12.05	W 82 14.91	243	238	239	N 39 12.08	W 82 14.91	241	236	232
N 39 12.01	W 82 14.89	244	239	238	N 39 12.03	W 82 14.89	241	236	233
N 39 11.96	W 82 14.85	244	240	237	N 39 11.99	W 82 14.86	242	236	234
N 39 11.93	W 82 14.83	244	240	237	N 39 11.96	W 82 14.83	242	236	232
N 39 11.89	W 82 14.80	244	240	238	N 39 11.92	W 82 14.80	241	236	233
N 39 11.84	W 82 14.76	244	239	237	N 39 11.88	W 82 14.77	242	235	232

Figure 6: Recorded position and SNR data sample from operational (front) and experimental (back) receiver serial channels

```
99600000    45    45     0   11      -798 250  40 1 1 0   16126914     91    41
51  -15      -306 253   1 1 0 0   28529650     32     17      15   -2      -799 250
40 1 1 1   42531544    309   307     3    2       -777 250  40 0 1 0   56717269
193   177    15     8      -757 250  40 0 0 1   39.217384    82.180016
   99600000    45    45     0   13      -798 250  40 1 1 0   16129515   302
41    98  -15      -381 254   1 0 1 0   28529616     31     17     14   -2      -
799 250  40 1 1 1   42531623    309   307     3    3      -777 250  40 0 1 0
56717643   200   177    22     9      -757 250  40 0 0 1   39.217756
82.179408
   99600000    45    45     0   14      -798 250  40 1 1 0   16212914      0
41    41  -15      -444 254   1 1 1 1   28529633     31     17     14   -1      -
799 250  40 1 1 1   42531893    308   307     1    3      -777 250  40 0 1 0
56718074   202   177    25     9      -757 250  40 0 0 1   39.217848
82.178608
   99600000    45    45     0   12      -797 250  40 1 1 0   16215764     32
41     8  -15      -406 253   1 1 1 1   28529596     32     17     15   -1      -
799 250  40 1 1 1   42532097    309   307     3    4      -778 250  40 0 1 0
56718479   204   177    27     8      -756 250  40 0 0 1   39.218192
82.177896
   99600000    48    48     0   15      -798 250  40 1 1 0   16139988     35
44     8  -15      -456 253   1 1 1 1   28529569     38     20     18   -1      -
799 250  40 1 1 1   42532271    305   309     4    4      -778 250  40 0 1 0
56718864   202   180    22     9      -757 250  40 0 0 1   39.218456
82.177208
   99600000    42    42     0   14      -798 250  40 1 1 1   16142595    115
38    77  -15      -469 254   1 1 0 0   28529593     37     14     22   -1      -
799 250  40 1 1 1   42532322    305   304     1    4      -778 250  40 0 1 0
56719266   190   174    15    10      -757 250  40 0 0 1   39.218784
82.176512
```

Figure 7: Megapulse receiver diagnostic data sample

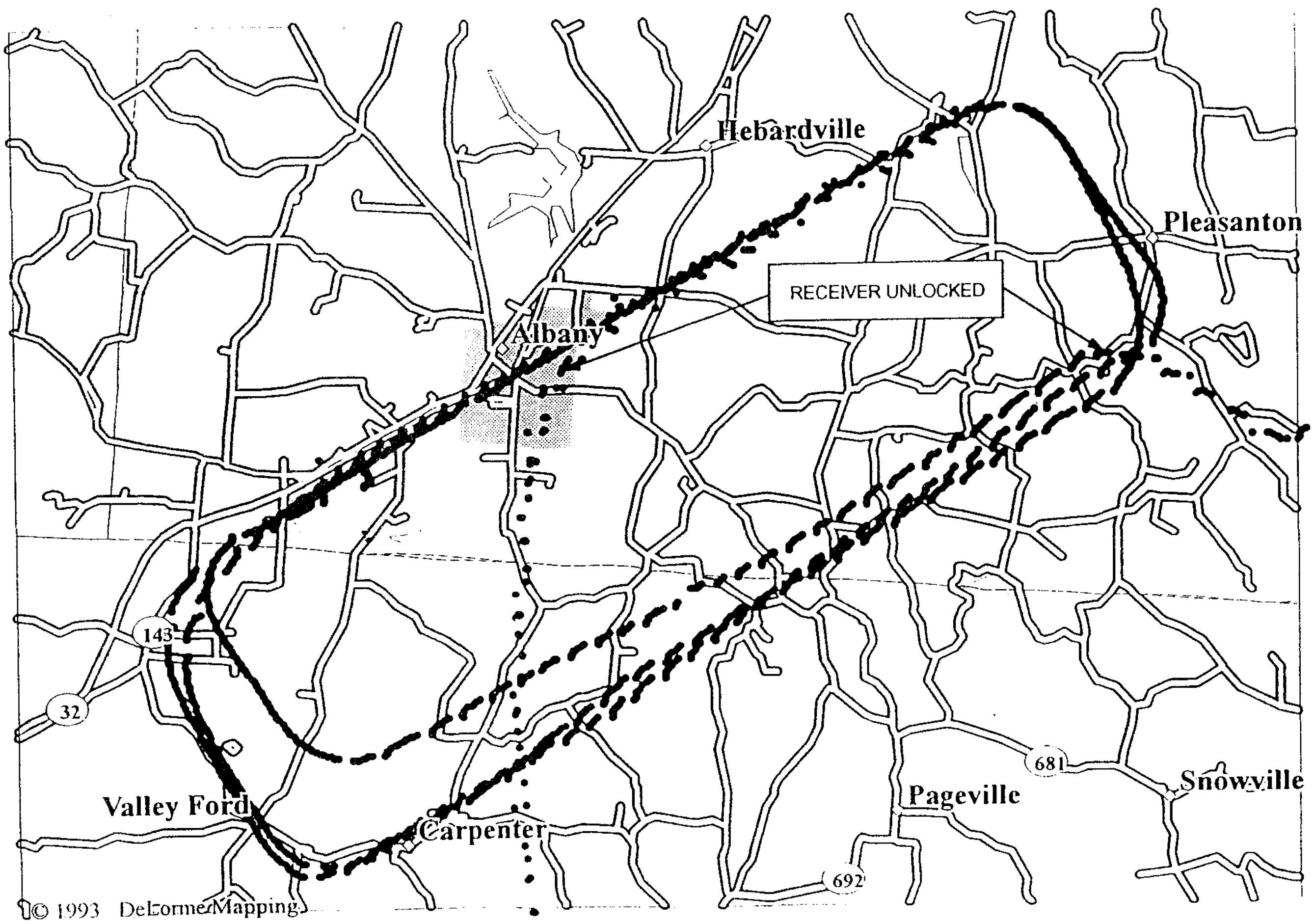


Figure 8: Preliminary tests; aircraft flight tracks from Megapulse receiver output

Modern Loran-C Receiver Performance

Dr. Michael S. Braasch
Avionics Engineering Center
Ohio University

Dr. Braasch presented a paper which was produced in cooperation with his wife, Soo Braasch. Viewgraphs are included on the following pages.

In introductory remarks, Dr. Braasch emphasized the following points:
Backup systems are needed, even for GPS. Some hand-held GPS receivers actually display a message to this effect when they are powered-up.

The results show loran biased but stable; GPS accurate longer-term but noisy short-term, due to Selective Availability. Direct comparison scatterplots are included.

Good flight-test results were obtained, even with a receiver optimized for static operation.

Modern Loran Receiver Performance: Ground and Flight Test Results

Soo Y. Braasch
Ohio University

Session 5: Integrated GPS and Loran-C Receivers
ILA - Ottawa, Canada - Oct. 5-9, 1997

OVERVIEW

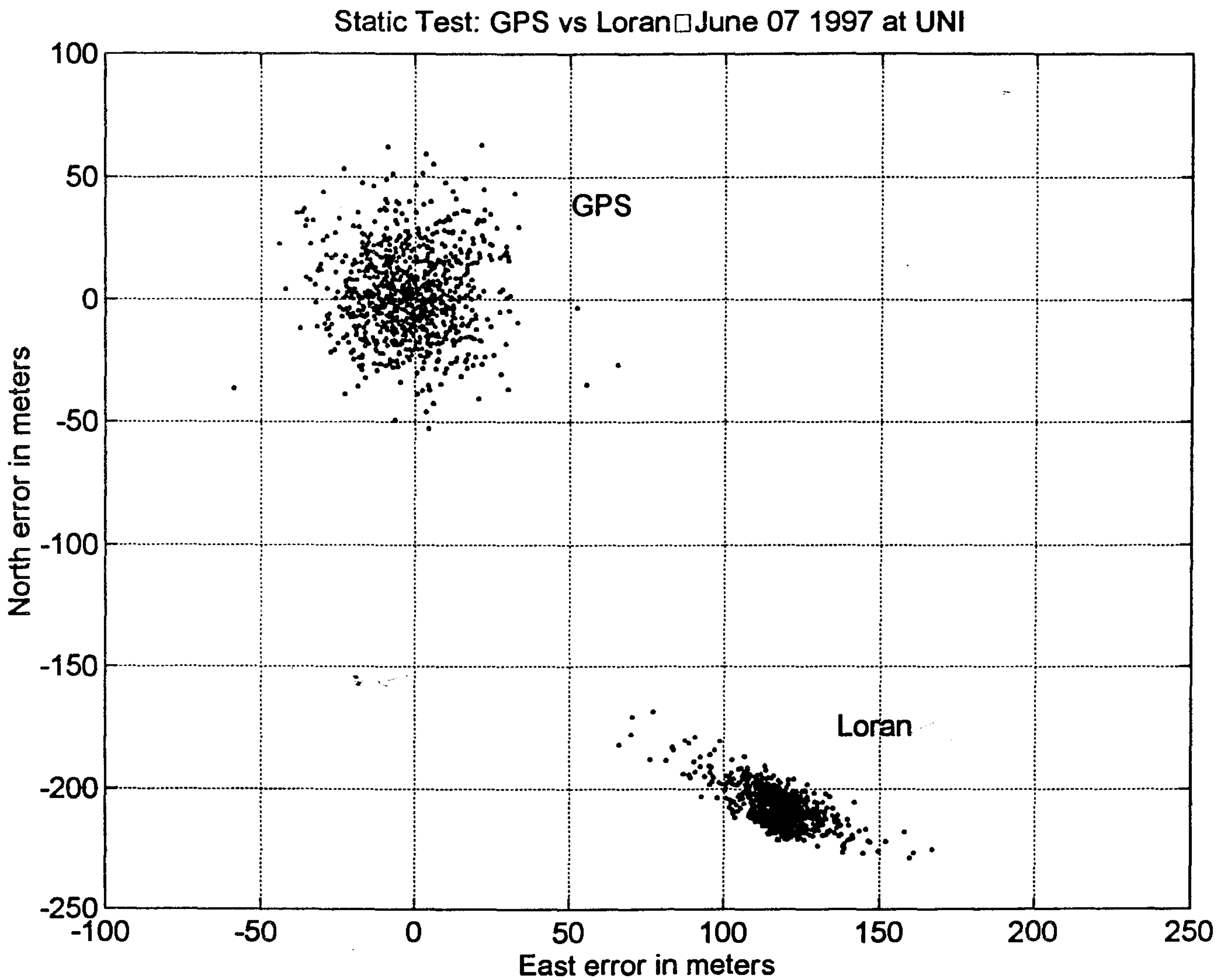
- **Motivation**
- **Test Set-Ups and Results**
  - **Static Test**
  - **Taxi Test**
  - **Flight Test**
- **Conclusions**

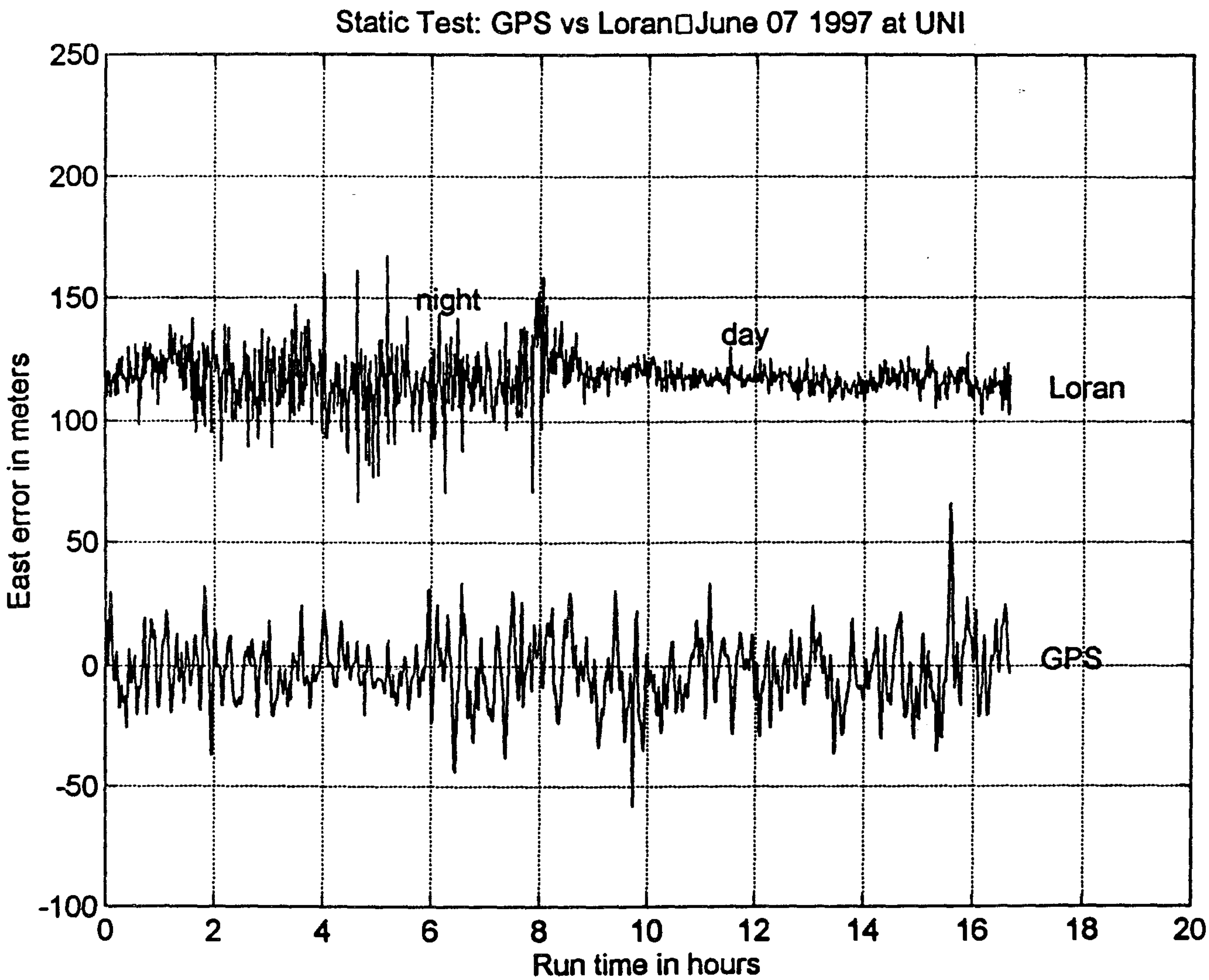
Motivation

- Virtually All TSO'd Loran Receivers Have Been Built With 10 To 15 Year Old Architectures
- Modern Digital Architectures Achieve Significant Performance Gains
  - Multi-chain tracking
  - Improved SNR
  - Effective increase in coverage region
- What Is The Actual Performance Of Modern Receivers?

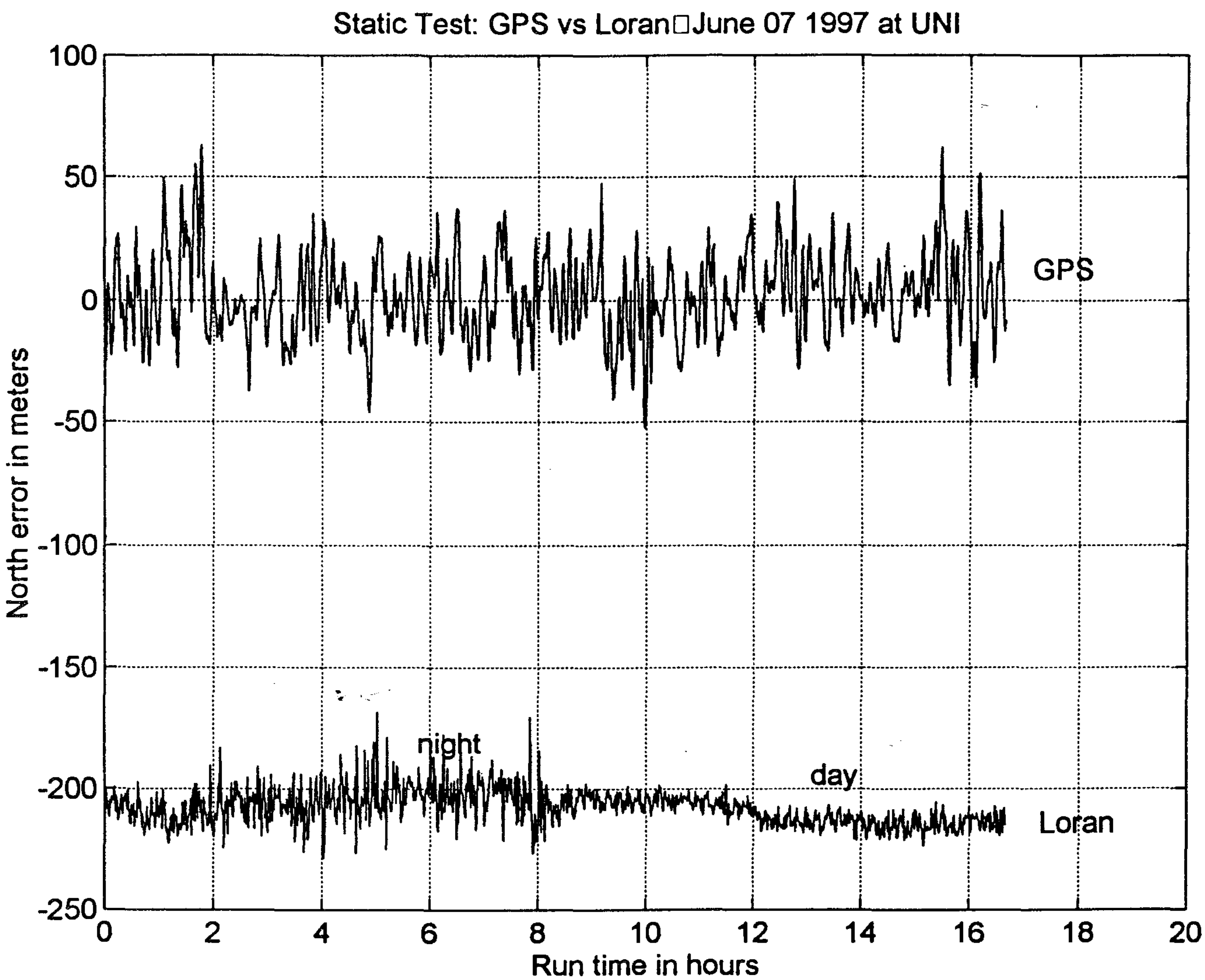
Test Scenarios

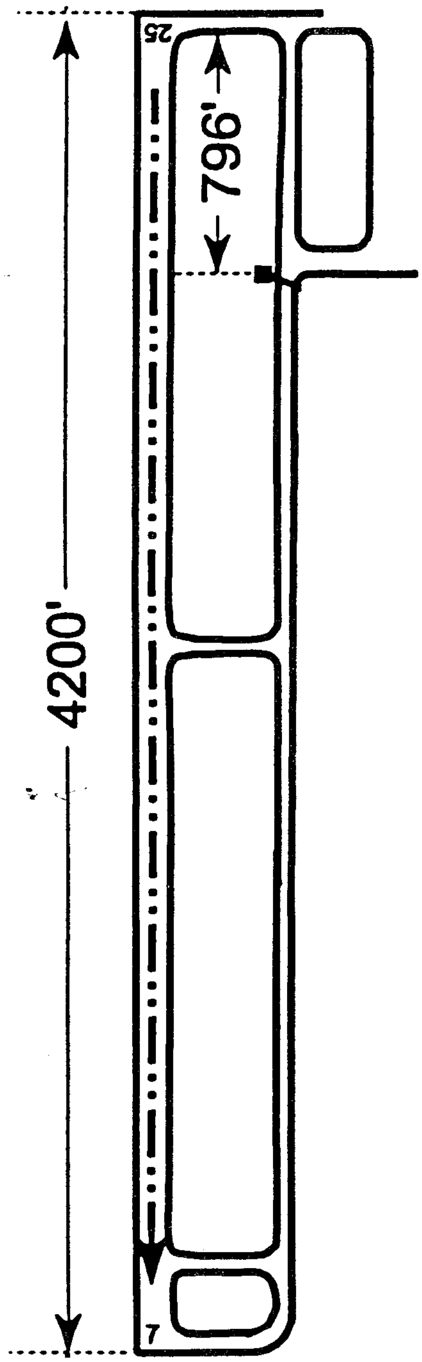
- Locus Loran Receiver And NovAtel GPS Receiver Used For All Tests
- Static Test: Antennas sited on the roof of the Avionics Engineering Center (AEC) Hangar at the Ohio University Airport (UNI)
- Taxi and Flight Tests: Receivers were installed in the AEC Piper Saratoga (PA-32)
- Taxi Test: Taxiways around UNI
- Flight Test: Between UNI and Pickaway County (CYO)

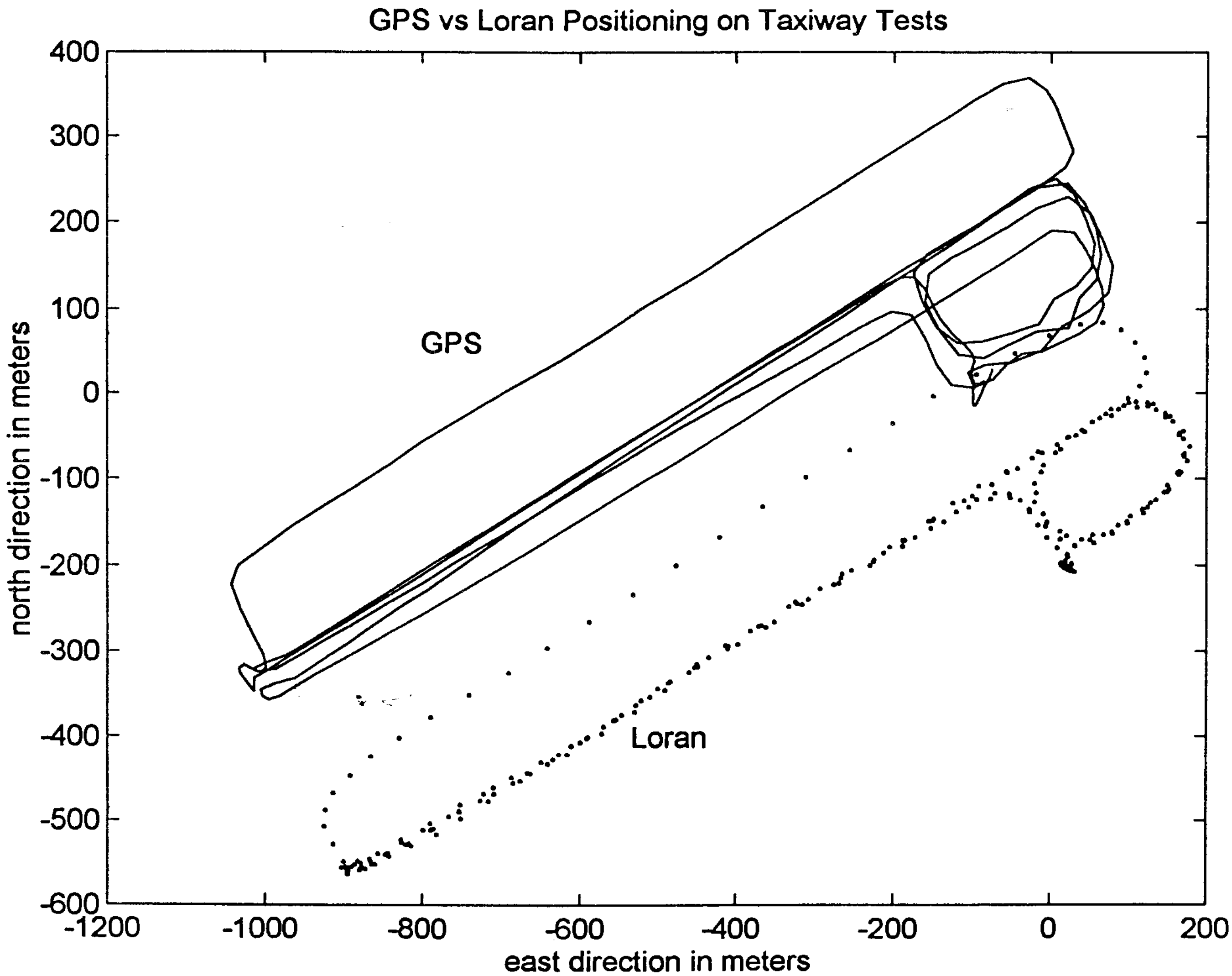

Static Test: GPS vs Loran June 07 1997 at UNI
100
50
0
-50
-100
-150
-200
-250
North error in meters
GPS
Loran
-100
-50
0
50
100
150
200
250
East error in meters

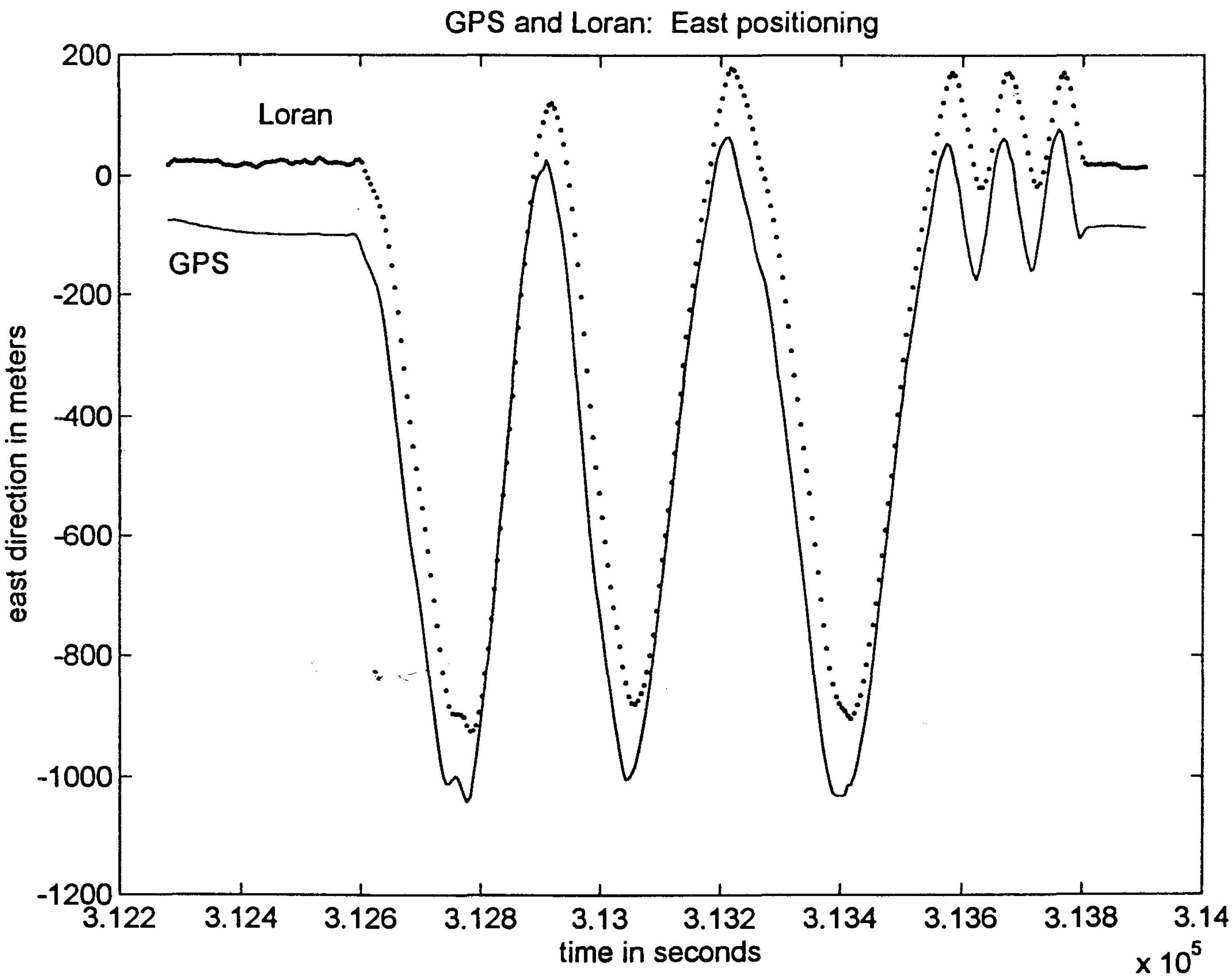


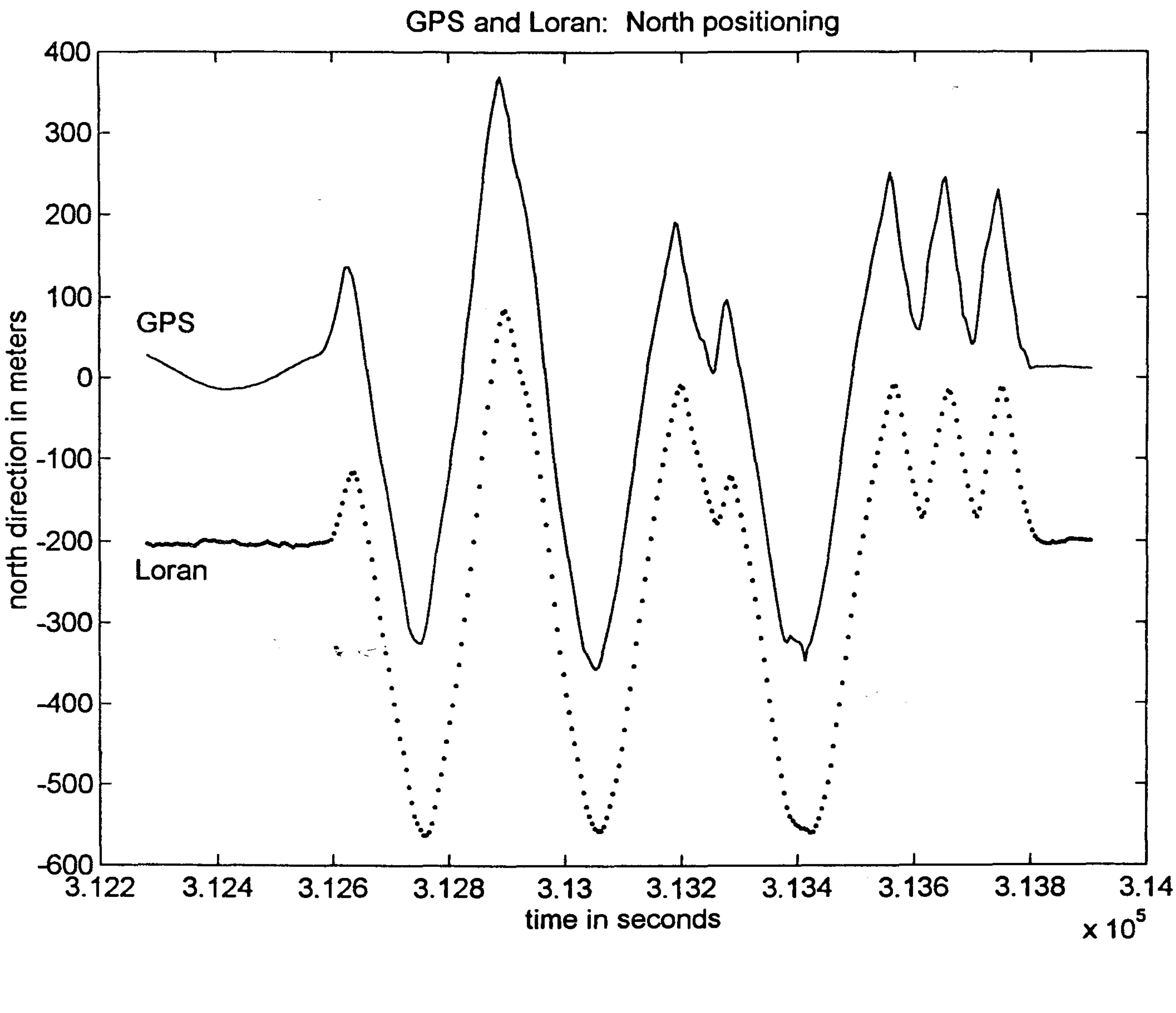
Static Test: GPS vs Loran June 07 1997 at UNI
250
200
150
100
50
0
-50
-100
East error in meters
0
2
4
6
8
10
12
14
16
18
20
Run time in hours
night
day
Loran
GPS

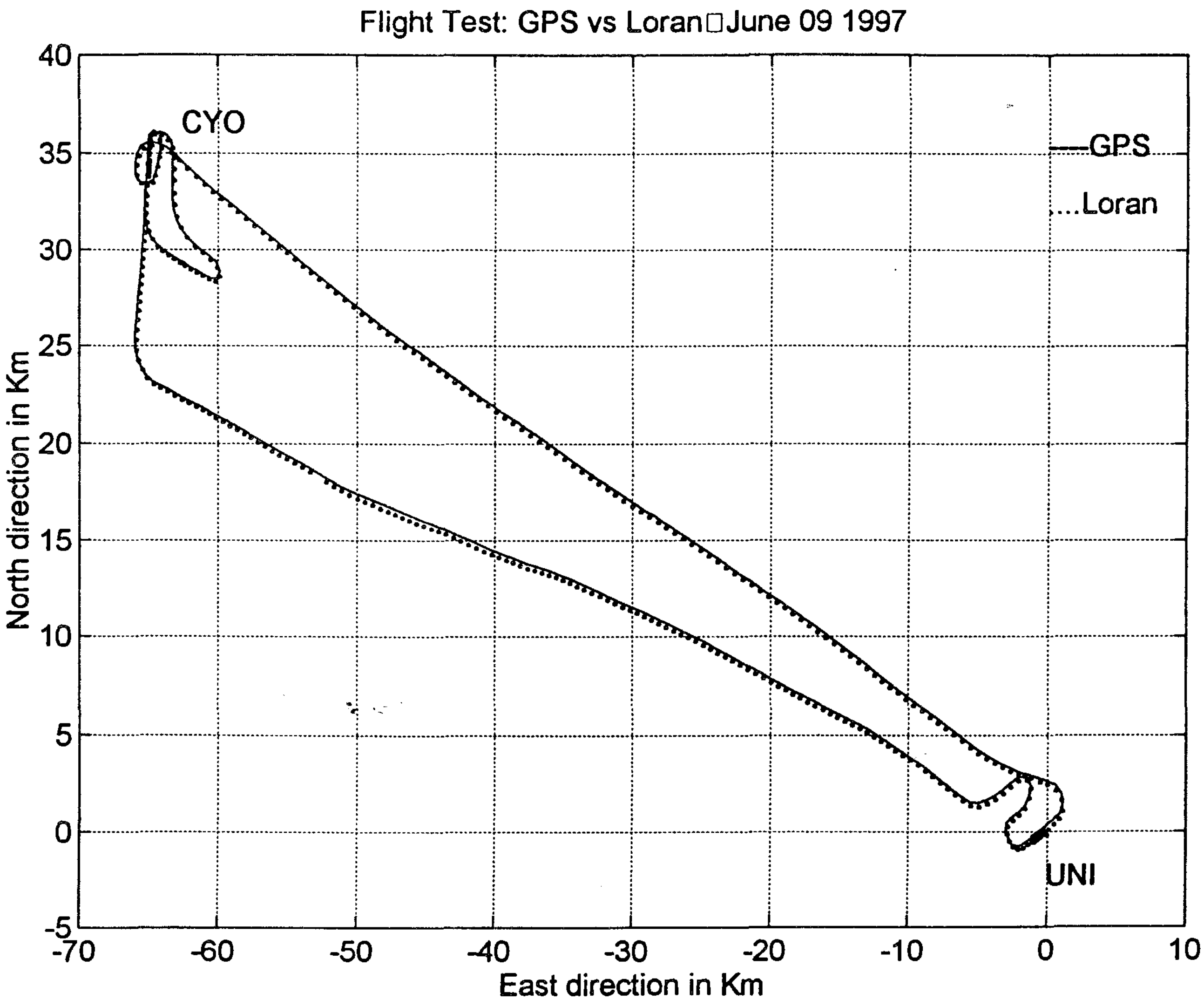

Static Test: GPS vs Loran June 07 1997 at UNI
100
50
0
-50
-100
-150
-200
-250
North error in meters
0
2
4
6
8
10
12
14
16
18
20
Run time in hours
GPS
night
day
Loran


4200'
796'
25
7

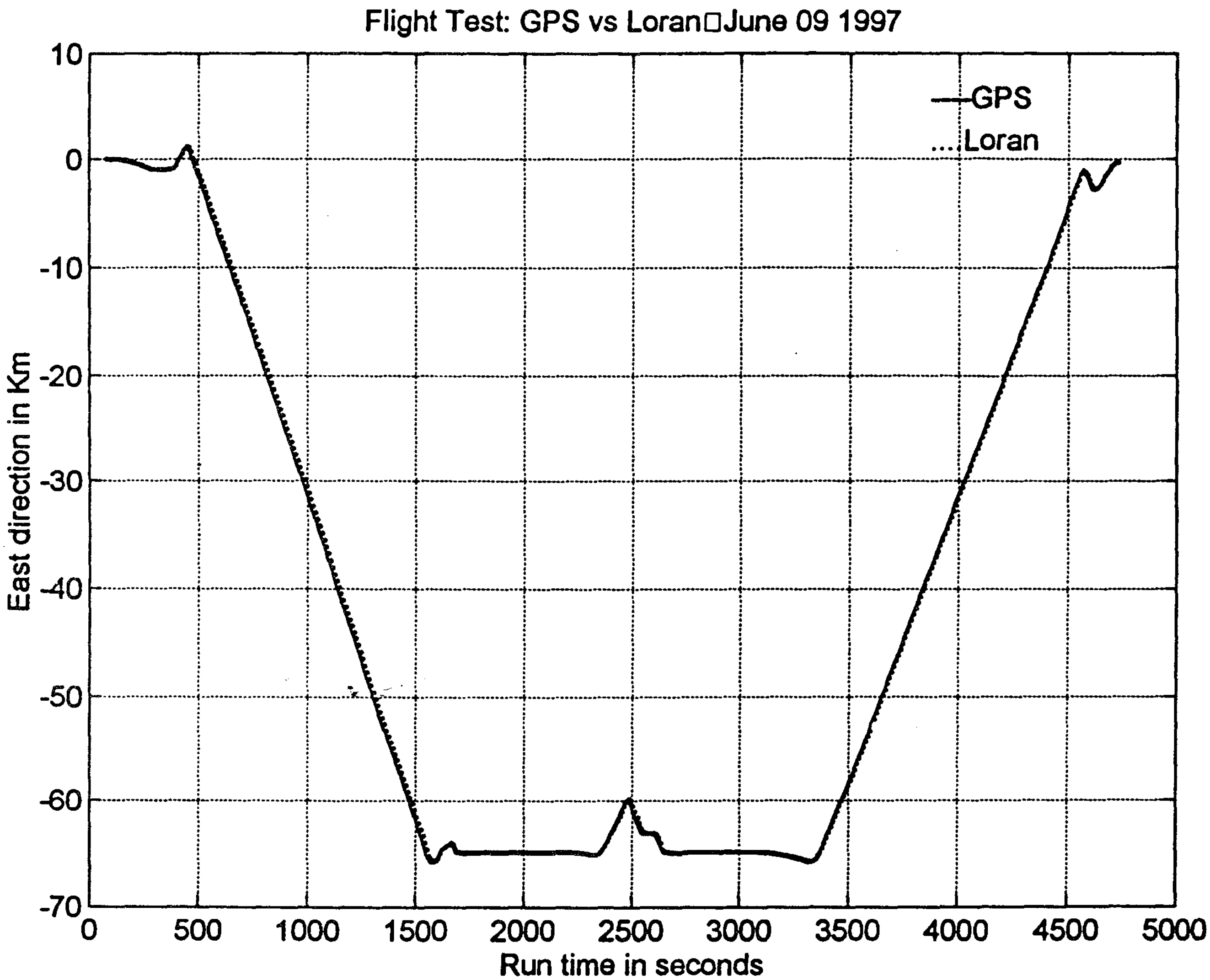

GPS vs Loran Positioning on Taxiway Tests
400
300
200
100
0
-100
-200
-300
-400
-500
-600
north direction in meters
-1200
-1000
-800
-600
-400
-200
0
200
east direction in meters
GPS
Loran


GPS and Loran: East positioning
Loran
GPS
east direction in meters
time in seconds
x 10^5
200
0
-200
-400
-600
-800
-1000
-1200
3.122
3.124
3.126
3.128
3.13
3.132
3.134
3.136
3.138
3.14

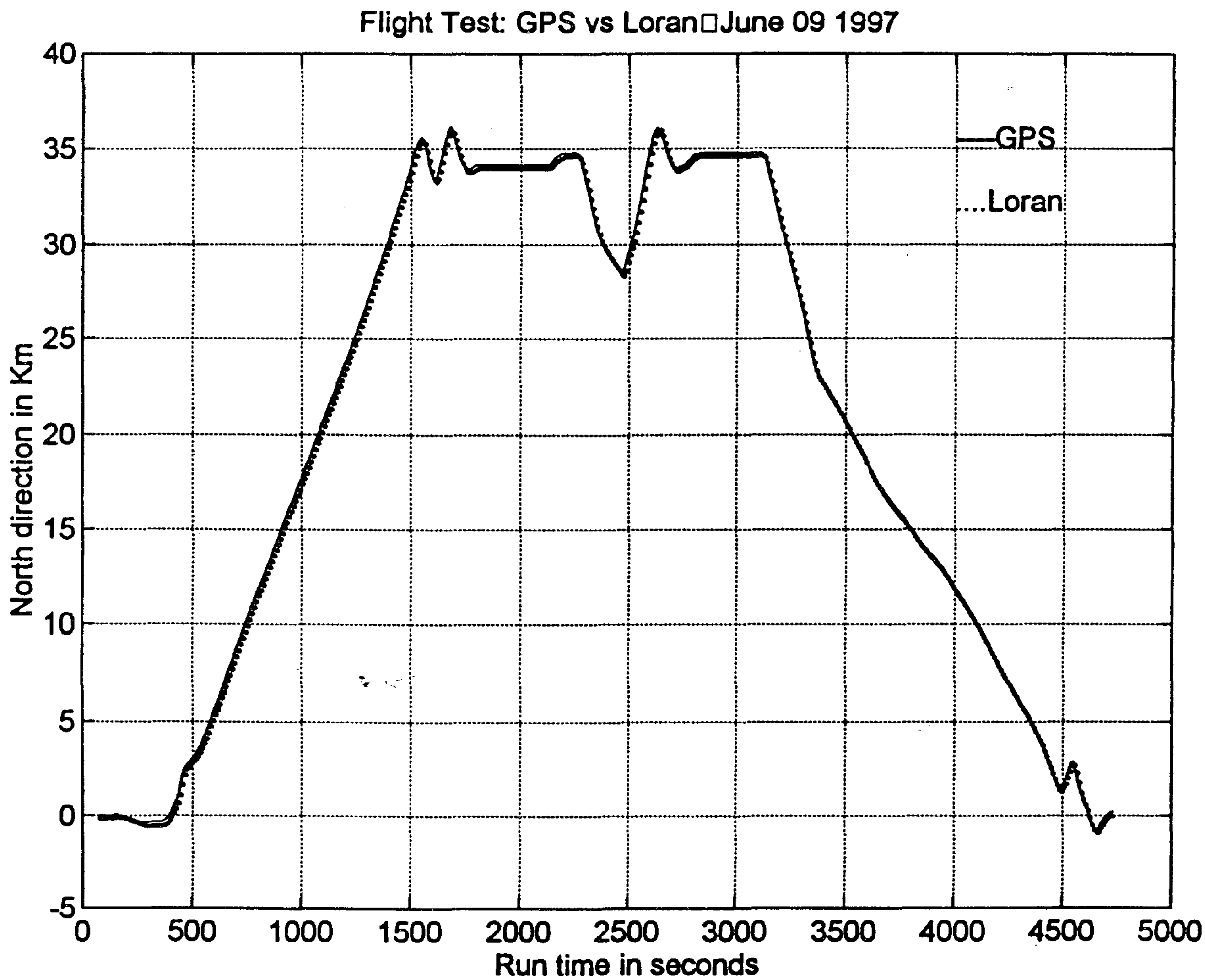

GPS and Loran: North positioning
north direction in meters
time in seconds
x 10^5
GPS
Loran
400
300
200
100
0
-100
-200
-300
-400
-500
-600
3.122
3.124
3.126
3.128
3.13
3.132
3.134
3.136
3.138
3.14



Flight Test: GPS vs Loran□June 09 1997
CYO
UNI
—GPS
....Loran
North direction in Km
East direction in Km
40
35
30
25
20
15
10
5
0
-5
-70
-60
-50
-40
-30
-20
-10
0
10



Flight Test: GPS vs Loran June 09 1997
GPS
Loran
East direction in Km
Run time in seconds
10
0
-10
-20
-30
-40
-50
-60
-70
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000


Flight Test: GPS vs Loran□June 09 1997
North direction in Km
Run time in seconds
—GPS
...Loran
40
35
30
25
20
15
10
5
0
-5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

CONCLUSIONS

- Test results confirm the fact that Loran is an excellent backup and complement to GNSS
- Stability of Loran is far better than for GPS with SA
- Loran bias may easily be calibrated when GPS is available with integrity
- A state-of-the-art GPS/Loran receiver would provide accuracy, integrity, availability and continuity for oceanic, en-route, terminal and non-precision approach phases of flight

Q: Good for you - going metric!

Loran is far better than GPS with Selective Availability at present levels. Your results are good. What were the geometries for Loran; SNR's etc.?

A: Nearly ideal geometry, with good SNRs.

Q: Wouldn't a 15-year old receiver have given these results?

A: Yes – a traditional receiver would do this in Athens. This one will do it everywhere. Also, it is robust enough to work in the aircraft.

Comment: After 2000, even if U. S. loran goes off, you can navigate in Ohio using NELS!

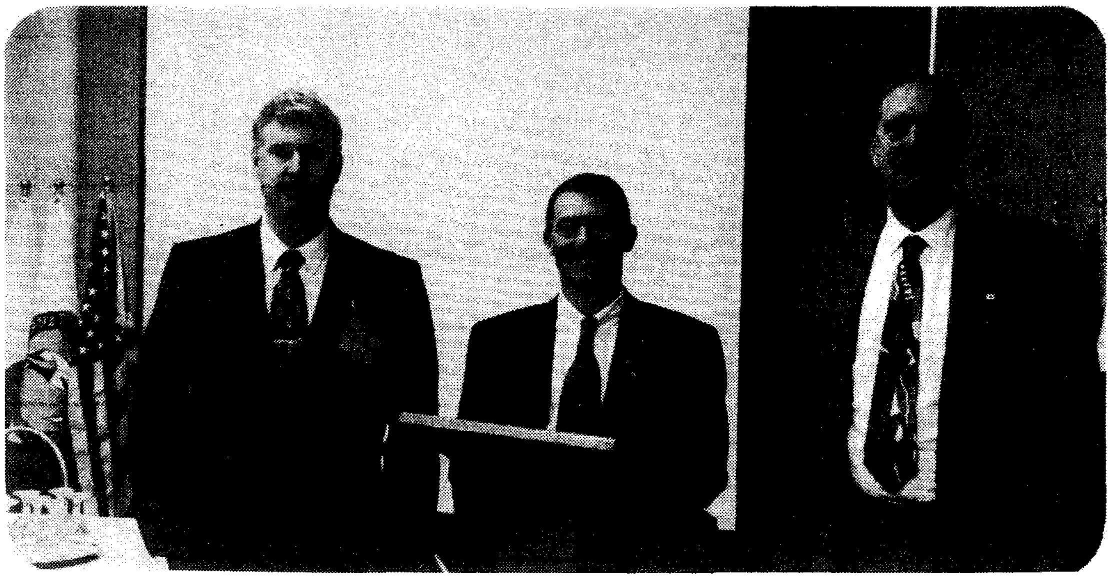
Q: Isn't large coverage a disadvantage at night when the long-range stuff is noisy?

A: Certainly, and you need to weight the components of the solution appropriately.

Comment from the receiver manuacturer: The unit was tracking 27 stations at night. The receiver can can process out much of the skywave stuff if needed. This test used the receiver in single-chain mode. Multi-chain would be even better.

Session 6: Upgrading Loran-C Transmitter Sites and Control Systems

Session Chair: Gary Running
Director-General, CCG Marine Navigation Services



Session 6: From the left, David Lynch, Alan Arsenault, Gary Running (LCdr Shue appears in the Session 8 photograph)

Canadian Coast Guard: Operating Loran-C 1965 to 1997
David J. Lynch, Canadian Coast Guard

U.S. Coast Guard Loran Consolidated Control System (LCCS)
Alan N. Arsenault, USCG Loran Support Unit

U.S. Coast Guard Prototype Time of Transmission Monitor (PTOTM)
M. J. Campbell and E. A. Paulus, USCG Loran Support Unit
(Paper presented by LCdr Charles Schue, III, USCG.)

CANADIAN COAST GUARD OPERATING LORAN C 1965 TO 1997

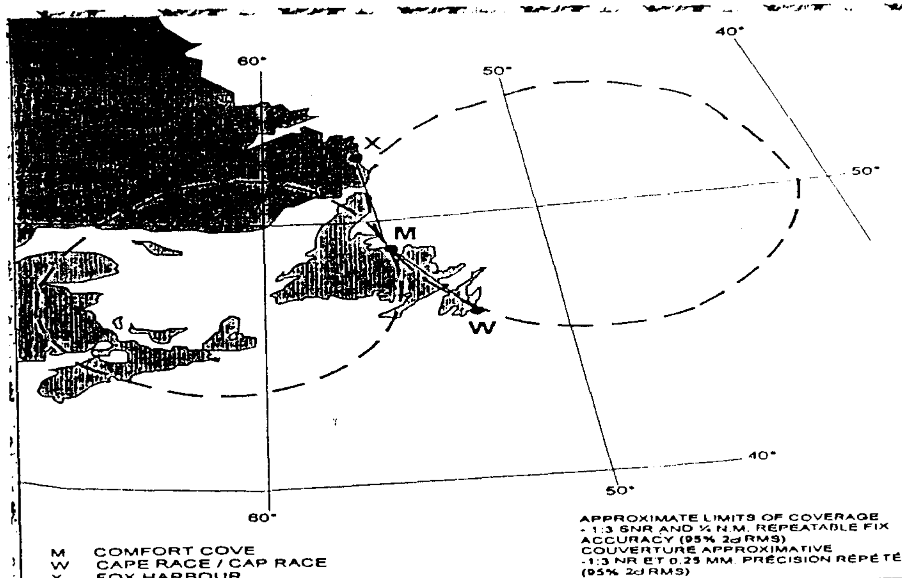
OUTLINE

- LORAN C LOCATIONS IN CANADA
- CLIENTELE AND USER SURVEY
- THE MANAGEMENT PLAN
- REDUCING OPERATING COSTS
- LORAN C OF THE FUTURE
- STRENGTHS
- CHALLENGES
- SUMMARY

LORAN C EASTERN CANADA

ST. ANTHONY
LORAN C CONTROL AND MONITOR STATION
5930 CEC
7270 NEC

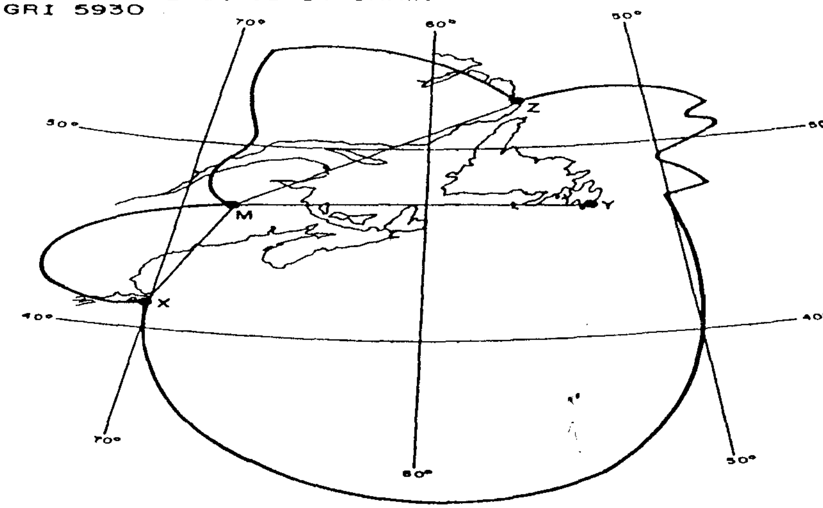
COMFORT COVE	FOX HR.	CAPE RACE	PCMS SITES	NANTUCKETT	CARIBOU
7270 MASTER	7270 X-RAY 5930-ZULU	7270-WHISKEY 5930-YANKEE	LUMSDEN MONTAGUE CAPE ELIZABETH	5930-XRAY	5930-MASTER



LORAN-C COVERAGE (PREDICTED)
NEWFOUNDLAND EAST COAST CHAIN (7270)
LORAN-C COUVERTURE (APPROXIMATIVE)
CHAÎNE DE LA CÔTE EST DE TERRE-NEUVE (7270)

LORAN – C

CANADIAN EAST COAST CHAIN
GRI 5930



M CARIBOU
X NANTUCKET
Y CAPE RACE
Z FOX HARBOUR

APPROXIMATE LIMITS OF COVERAGE - 1:3 SNR AND 1/4 N.M. REPEATABLE FIX ACCURACY (95% 2dRMS) WITH NOISE LEVEL AT 50 dB, EXCEEDED ONLY 5% OF THE TIME.

5

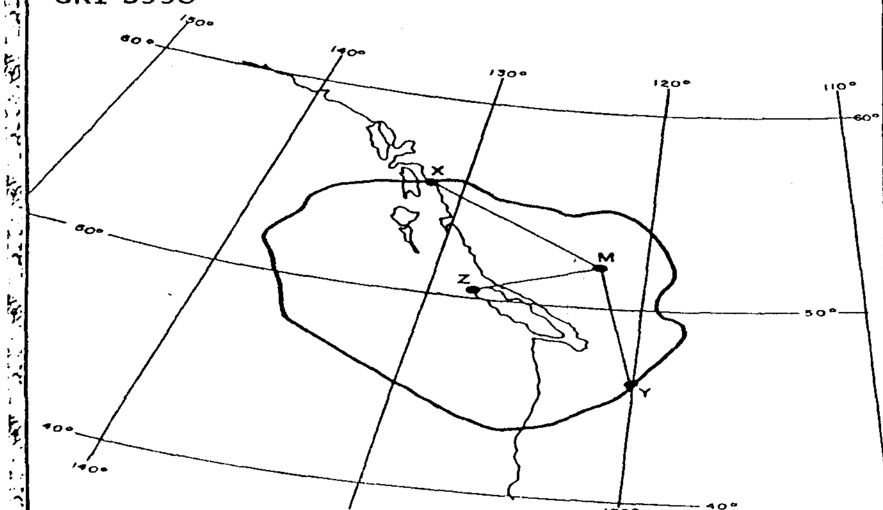
LORAN C WESTERN CANADA

WILLIAMS LAKE LORAN C CONTROL STATION 5990-MASTER			
SHOAL COVE 5990-XRAY	GEORGE 5990-YANKEE	PORT HARDY 5990-ZULU	PCMS SITES ALERT BAY WHIDBEY ISLAND SANDSPIT

6

LORAN – C

CANADIAN WEST COAST CHAIN
GRI 5990



M WILLIAMS LAKE
X SHOAL COVE
Y GEORGE
Z PORT HARDY

APPROXIMATE LIMITS OF COVERAGE - 1:3 SNR AND 1/4 N.M. REPEATABLE FIX ACCURACY (95% 2dRMS) WITH NOISE LEVEL AT 44dB, EXCEEDED ONLY 5% OF THE TIME.

7

CLIENTELE

- MARINE COMMUNITY
- AVIATION INDUSTRY
- TELEPHONE COMPANIES
- ATMOSPHERIC SERVICES

8

CLIENTELE USER SURVEY

- SURVEY INFORMATION
  - CONDUCTED DECEMBER 1996
  - TARGETED FISHING VESSEL OWNERS IN THE NEWFOUNDLAND AND LABRADOR MARINE COMMUNITY
  - CONSISTED OF 4600 QUESTIONNAIRES
  - AIMED TO DETERMINE UTILIZATION OF NAVIGATIONAL AIDS AND DEVICES

CLIENTELE SURVEY RESULTS

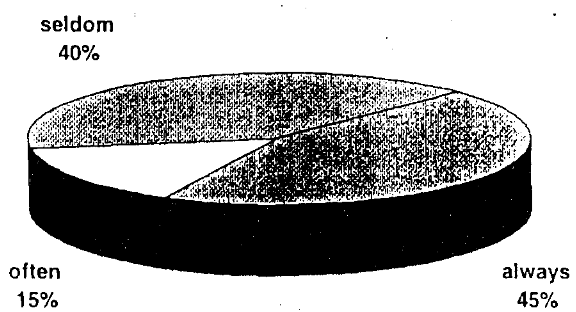
SIGNIFICANT FINDINGS

- LARGER VESSELS TRAVELLING FURTHER TO THE FISHING GROUND REPRESENT THE GREATEST PERCENTAGE OF VESSELS WITH GPS.
- MORE THAN HALF THE GPS USERS WHO RESPONDED STILL USE LORAN C

10

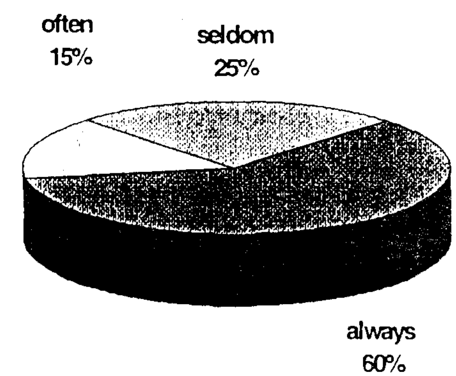
SURVEY RESULTS

Frequency of use of Loran C 7270



SURVEY RESULTS

Frequency of use of Loran C 5930



MANAGEMENT PLAN

- MAINTAIN THE LEVEL OF SERVICE
- REDUCE THE OPERATING COST
- PROVIDE AN AFFORDABLE SERVICE

METHODOLOGY

PROACTIVE MANAGEMENT

- RESEARCHING TECHNOLOGY
- IDENTIFYING EFFICIENCY'S
- JUSTIFYING RESOURCES
- EFFECTIVE IMPLEMENTATION

METHODOLOGY

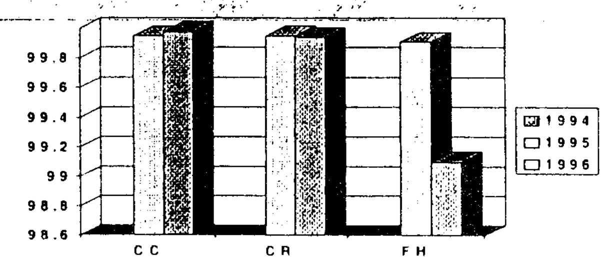
BALANCING CHANGING TECHNOLOGY WITH GOOD MANAGEMENT

- SOLID STATE TRANSMITTER
- REMOTE OPERATING SYSTEM
- MODIFICATIONS AND UPGRADES
- EDUCATED MAINTENANCE PRACTICES

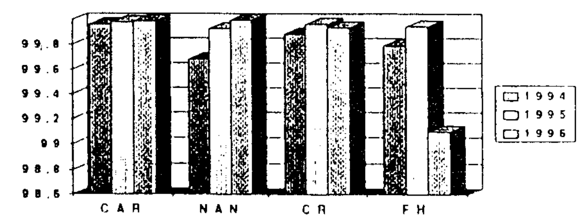
- REDUCTION IN STAFFING LEVELS
- REMOVAL OF 24 HR WATCH
- REDUCED CALLOUT RATE
- FEWER MOM OFF AIR

STATION AVAILABILITY %

7270



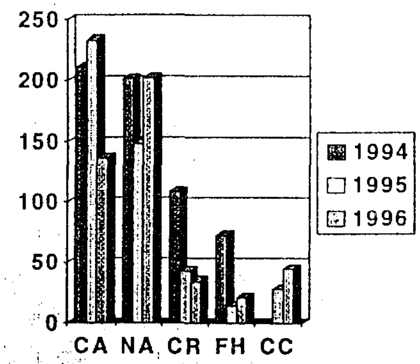
5930



MOMENTARY OFF AIR

REDUCING MOM OFF AIR

- EXPERIENCED STAFF
- RELIABLE POWER
- TIMELY MAINTENANCE SCHEDULING
- MODERATE WEATHER CONDITIONS



REDUCING COSTS THROUGH STAFF REDUCTIONS

MAJOR CHANGES

70'S

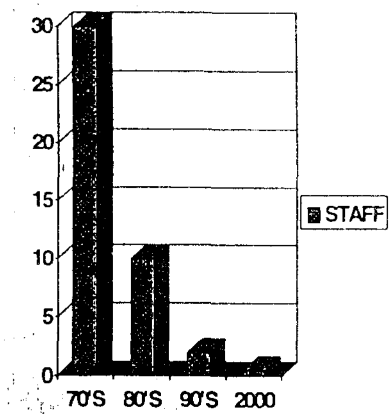
- HYDRO POWER AT CAPE RACE
- SOLID STATE TIMERS

80'S

- REMOTE OPERATING SYSTEM
- SOLID STATE TRANSMITTER

90'S

- PROVEN RELIABILITY FACTOR
- CONSOLIDATED CONTROL
- NEW TECHNOLOGY



TYPICAL TRANSMITTER SITE TODAY

- STAFF
  - ONE WORKING SUPERVISOR
  - ONE WORKING LEVEL TECHNICIAN
- AVERAGE CALLOUT'S
  - 15
- AVERAGE OVERTIME
  - $5000.00
- AVERAGE BUDGET
  - $250,000.00

NEW TECHNOLOGY

- CONSOLIDATED CONTROL
- STATE OF THE ART TIMING EQUIPMENT
- MODERN RECEIVERS
- NEW ROS

TYPICAL LORAN TRANSMITTER SITE OF THE FUTURE

- STAFF
  - UNMANNED
  - SUPPORTED BY REMOTE MAINTENANCE
- AVERAGE CALLOUT'S
  - 15
- AVERAGE OVERTIME
  - $5000.00
- AVERAGE BUDGET
  - 100,000.00

STRENGTHS

- RELIABLE SYSTEM
- COST EFFECTIVE
- PROVIDES ACCURATE TIMING
- WORKS WELL IN CONJUNCTION WITH GPS.
- HAS SIGNIFICANT CLIENTELE
- PARTNERSHIP WITH THE USCG

INTERNATIONAL AFFILIATION USCG AND CCG

- INTERNATIONAL AGREEMENT
  - OPERATIONAL PROCEDURES
  - MAINTENANCE MANAGEMENT
  - ROLES AND RESPONSIBILITIES
- ENGINEERING SUPPORT IN EQUIPMENT DESIGN AND MODIFICATIONS
- LOGISTICAL SUPPORT IN PURCHASE AND REPAIR OF SPARES
- SUPPORT IN PROVISION OF TRAINING

CHALLENGES

- RESOURCE REDUCTIONS
- SUPPORT TO EXISTING EQUIPMENT
- ALTERNATE SYSTEMS
- FEDERAL RADIO NAVIGATION PLAN

SUMMARY

- THERE IS SIGNIFICANT CLIENTELE WHO STILL RELY ON LORAN C
- REDUCTIONS IN OPERATING COSTS HAVE BEEN REALIZED THROUGH NEW TECHNOLOGY
- THE LEVEL OF SERVICE HAS NOT BEEN COMPROMISED
- OPERATING COSTS CAN BE FURTHER REDUCED
- THE CANADIAN AND USCG CAN WORK TOGETHER TO PROVIDE AN AFFORDABLE SERVICE

25

Q: With solid state transmitters already in use, I assume you weren't including reduced power consumption in going to C$100,000 per station per year?.

A: One station always uses its own power, and is more expensive (C$110,000 annually for fuel for Fox Harbor). The real reduction is in people.

Q: Do the pie charts indicate the people that do not have loran, or those that do?

A: The questionaire said "seldom, often or frequently" use Loran. Those who did not answer may be considered to be those without loran (possibly).

Q: Does it say whether the user is using a coordinate converter or TDs?

A: The questionnaire did not distinguish between these modes.

Q: Any use of back lobe in St Lawrence, or chain 5930?

A: The questionnaire broke the geography into 8 sections. One of these would have been the Gulf of St. Lawrence area.

Q: Is it centralized maintenance?

A: Remote maintenance refers to a station that is unmanned, with on-call plus preventive maintenance (say, once or twice a year).

Q: Brogdon. Impressive. Were the values to the clients assessed?

A: I know what you're asking. The most I can say is that there is a significant number of fisherman using loran. It is difficult for us to focus on other groups, based on the information on the questionnaires.

Q: When was the study done?

A: The survey was done in 1996.

Comment from floor: The St Anthony control station was reduced by 4 people, reducing costs there also. Something over C$200,000 per year

The United States Coast Guard Loran Consolidated Control System (LCCS)

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1.0 BIOGRAPHY

Alan Arsenault is a Lieutenant (recently selected for Lieutenant Commander) in the United States Coast Guard (USCG) and is presently assigned as the Executive Officer of the Coast Guard Loran Support Unit (LSU) in Wildwood, New Jersey. He has completed tours as Project Manager and Assistant Branch Chief in the Loran-C Branch at the Coast Guard Electronics Engineering Center (EECEN), as Project Officer in the Electronics Technology Division at Coast Guard Headquarters, and as Operations, Communications, and Electronics Material Officer aboard the U.S. Coast Guard Cutter BRAMBLE stationed in Port Huron, Michigan. LT Arsenault received a BSEE degree from the U.S. Coast Guard Academy in 1988 and a MSEE degree, specializing in communications and digital signal processing, from the University of New Hampshire in 1994.

2.0 ABSTRACT

The primary mission of the U.S. Coast Guard Loran Consolidated Control System (LCCS) is to monitor and control Loran Transmitting Stations (LORSTAs) and Primary Chain Monitor Sets (PCMSs) currently functioning as part of the United States Loran-C Radionavigation System. This monitoring ensures all LORSTAs are on-air and transmitting within established limits; or when not, report degraded system performance. The LCCS replaces the Remote Site Operating Set (RSOS), Calculator Assisted Loran Controller (CALOC), Chain Recorder Set (CRS), and Teletype (TTY) systems previously located at the Loran Control and Monitor Sites (CONSITEs).

The LCCS is a computer-based system consisting of a processor, several user interfaces, displays, several access/storage devices, and a communications interface with existing LORSTA and PCMS facilities. The LCCS is configured on the Hewlett-Packard (HP) HP9000/J210 series workstation purchased from the Navy Tactical Advanced Computer (TAC-4) contract. This UNIX-based computer platform is capable of controlling two Loran chains simultaneously. Data is collected from LORSTAs and PCMS sites associated with a specific chain, processed, stored, displayed, and acted upon by the LCCS. The FTS-2000 X.25 Packet Transport Network (PTN) is used for transfer of control and monitor data.

The final Continental United States (CONUS) switchover to the Loran Consolidated Control System occurred in August 1997. A description of the deployed LCCS hardware and software is presented and information is provided concerning the scope of proposed follow-on LCCS-related project work, including installations in Alaska and Canada, and code upgrades at the new CONUS Control Sites.

3.0 BENEFITS

Prior to LCCS, there were three CONUS Loran-C CONSITEs (Seneca, NY, Malone, FL, and Middletown, CA) in the Coast Guard's CONUS Loran-C program, each staffed by approximately 20 people. Each of these CONSITEs had immediate operational control over two Loran-C chains, which were individually composed of four to six transmitting stations. By centralizing the control functions of these three stations, thereby removing the Watchstander responsibilities at the CONSITEs, the number of billets was reduced to four at Solid-State stations and five at Tube stations. The LCCS project further consolidated the control functions of three of the domestic Loran-C sites into the U.S. Coast Guard Navigation Center (NAVCEN) organization. Consolidating all Loran-C control functions at NAVCEN allowed significant personnel savings for the U.S. Coast Guard. LCCS also greatly simplifies the Loran Control Watchstanding procedures by taking several inputs, processing them, and displaying all pertinent information.

4.0 SYSTEM HARDWARE

The LCCS equipment receives data from remote PCMS sites, LORSTA TTYs, and LORSTA Local Site Operating Sets (LSOS - the other half of RSOS). The system decodes, interprets, processes, displays, logs, and helps the Watchstander with the decision-making process (the USCG Loran Support Unit is currently working on automatic control features). Figure 4.1 illustrates the basic functionality of the LCCS. Figure 4.2 shows a block diagram of the LCCS.

The HP J210 is the heart of the LCCS. The J210 is comprised of dual PA7200 120 MHz processors using 48-bit virtual memory addressing. Primary cache is 256Kbytes directly mapped on a 64-bit bus. The LCCS contains two mirrored internal 4 GB fast-wide differential SCSI-II hard disk drives operating on a 20 MB/second fast-wide differential bus. Mirrored hard-drives, each containing the J210 Operating System, LCCS executable code, LCCS run-time libraries, and the LCCS database, ensure the integrity of all Loran data. A failure of one drive alerts the Watchstander without degrading system performance or data storage capabilities. A failed drive can be replaced and mirroring re-enabled at a planned time convenient for all stations monitored/controlled by the affected LCCS. An external CD-ROM drive, two 4mm DAT drives, and 3.5 inch floppy drive are accessed via a 5 MB/second single-ended SCSI-II bus. The J210 has 416 MB of main memory (4x64 MB plus 10x16 MB) and supports two RS-232 460.8 Kbps communication ports, one Centronics 300 KB/seconds parallel printer port, five 32-bit 33 MB/second Extended Industry Standard Architecture (EISA) card ports, and up to four 32-bit 142 MB/second graphics displays. The single-ended interface can accept up to seven devices and the fast-wide interface can accept up to fifteen devices. Dual 20-inch 1280x1024 monitors, external speakers, a color printer, and an Uninterruptible Power Supply (UPS) capable of running the LCCS for over 30 minutes without commercial power complete the system. The user interface is via a combination of two touchscreens, two keyboards, and two trackballs (one each per chain). Figure 4.3 shows a photo of the operate LCCS installed at the U.S. Coast Guard NAVCEN located in Petaluma, CA. This system monitors and controls the U.S. West Coast and North Central U.S. Loran chains. The console contains the entire LCCS in one roll-around unit. This enables the LCCS to be easily positioned in any office-type setting. Figure 4.4 shows a rear view of the LCCS equipment installed in the console.

The LCCS equipment currently installed at the USCG NAVCENs have a complete "cold" spare backup system available (one per NAVCEN location). The sparing level provided contains all hardware with the exception of the commercially-available external computer speakers and full compliment of installed RAM modules. All LCCS hardware with the exception of the console, external speakers, Data Service Units, trackballs, and extra internal processor are purchased from the U.S. Navy's TAC-4 contract and covered by a full HP warranty until 15 January, 2001. The TAC-4 response time for failed items is less than 24 hours.

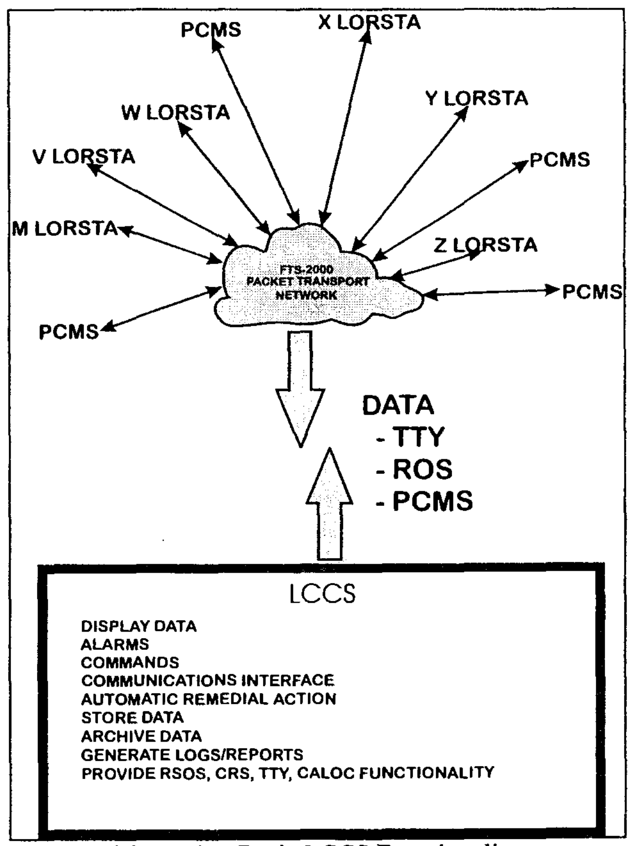


Figure 4.1 Basic LCCS Functionality

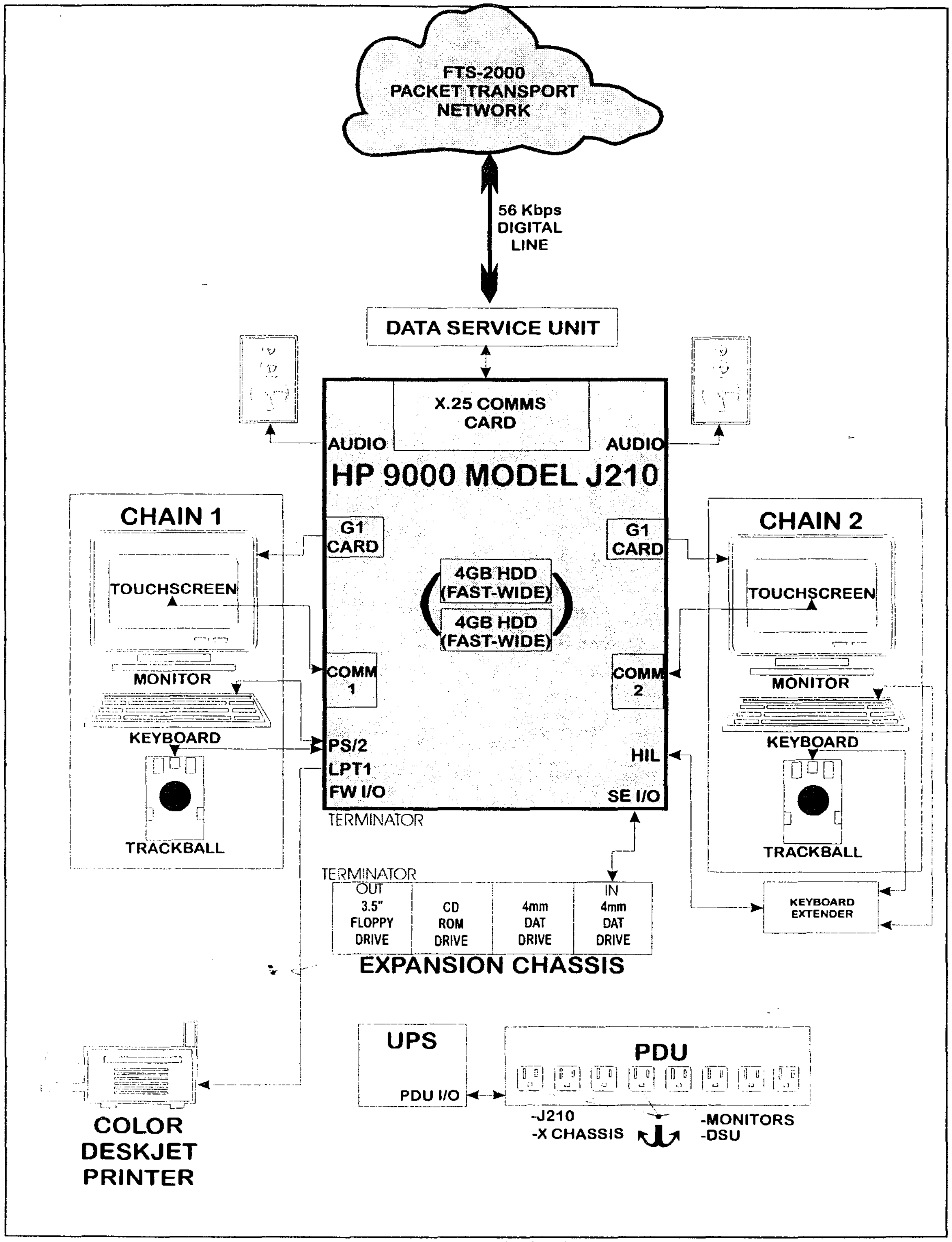


Figure 4.2 LCCS Block Diagram

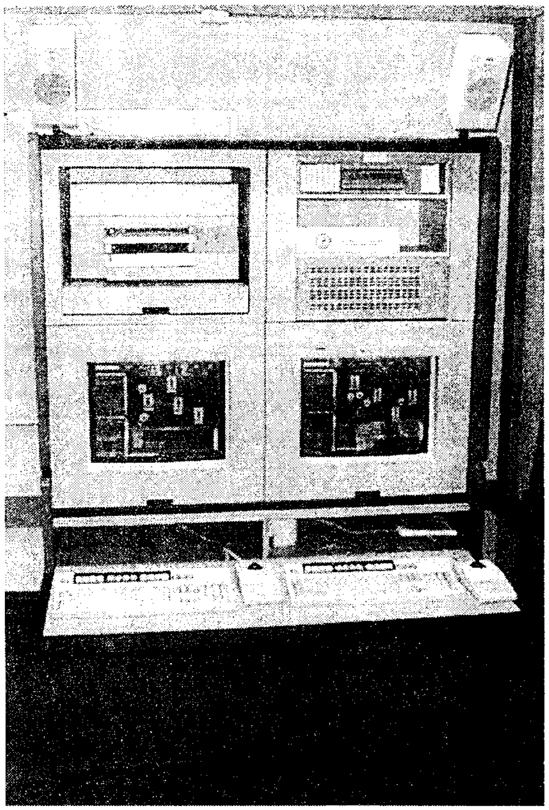


Figure 4.3 Front View of the LCCS Console

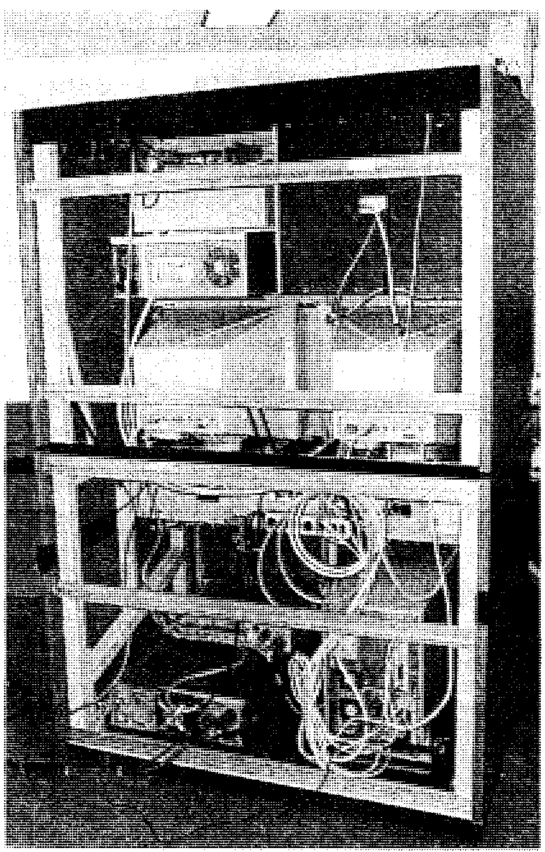


Figure 4.4 Rear view of the LCCS Console

5.0 COMMUNICATIONS

The LCCS is linked to Loran Stations and PCMS installations via a 56 Kbps digital phone line. This line ties the LCCS to LORSTA LSOS equipment, LORSTA TTY equipment, and PCMS site PDP-8 computers via switched virtual circuits. Each LCCS uses one X.25 Link EISA Programmable Serial Interface (PSI) adapter card which performs Packet Assembler & Disassembler (PAD) functions, one Data Service Unit (DSU), and one 56 Kbps 100 channel digital phone line to tie into the AT&T PTN. Berkeley Sockets, a sub-set of BSD IPC, are used to programmatically interface custom LCCS code with the communications adapter card. Figure 5.1 shows a typical Loran chain communications configuration. FTS-2000 specifies that the X.25 PTN has a 99.76% availability and data transfer delay of less than 0.15 seconds coast-to-coast. Data Service Units, serviced by AT&T, are repaired or replaced in less than 24 hours if a casualty occurs. The LCCS can operate with other "leased" or "dedicated" communications schemes by adding an additional PAD, a modem eliminator, and tying these into existing modems or multiplexers. A backup LCCS communications system prototype is being developed by the USCG Loran Support Unit in Fiscal Year 1998. This prototype system will consist of an additional X.25 phone line for each LCCS and another independent communications system, as necessary, to provide a true backup for the existing LCCS communications network.

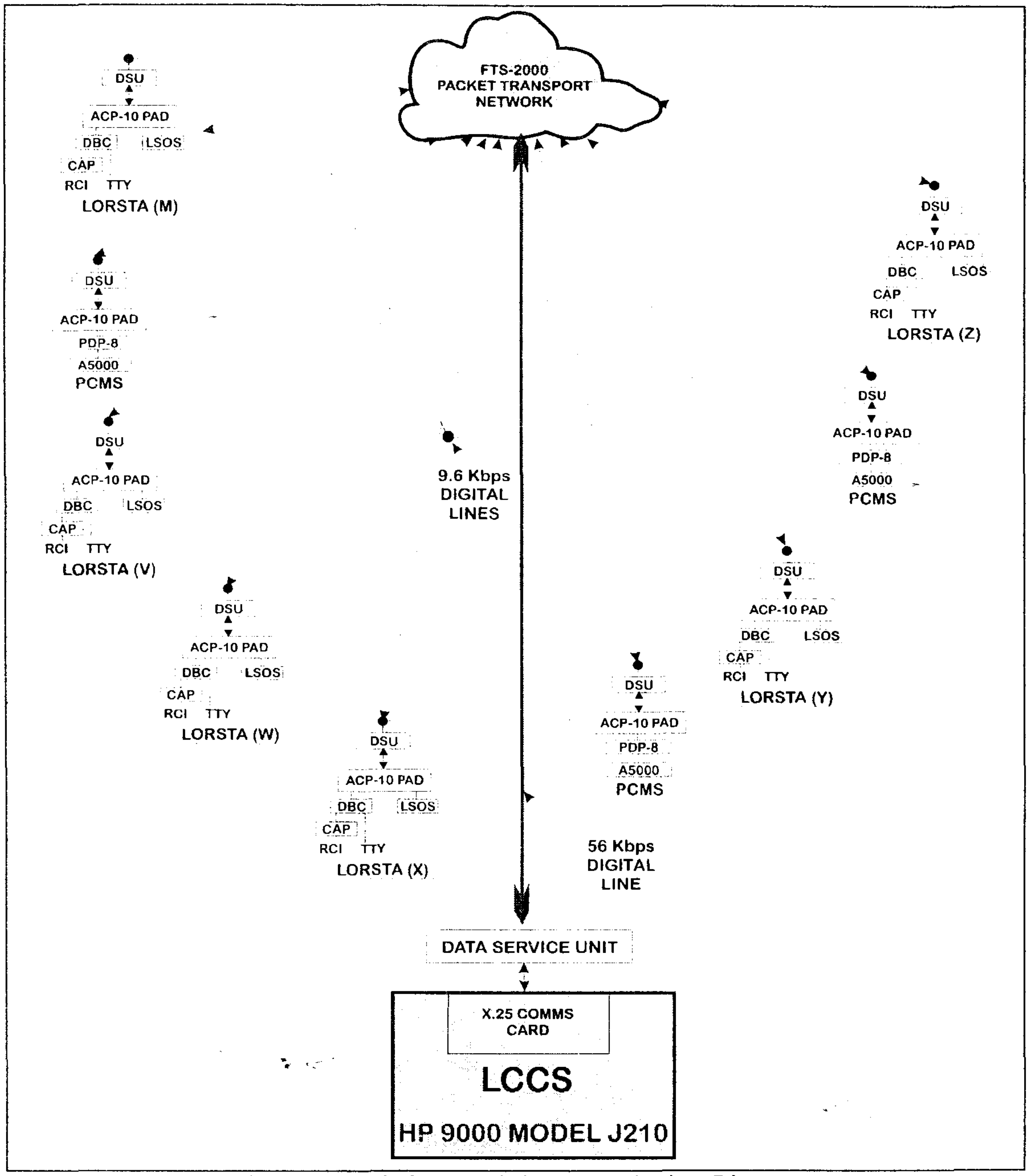


Figure 5.1 Typical Loran Chain Communications Diagram

6.0 LCCS SOFTWARE

The LCCS software is a custom Coast Guard software application written in the C++ programming language and developed by personnel at the USCG Loran Support Unit. This software "runs" on the HP-UNIX 10.10 Operating System. Much emphasis was placed on the Graphical User Interface (GUI) to ensure ease of use by taking a vast amount of information and displaying it in an organized manner. The GUI was written in a combination of X-Windows, Motif, C++, and C programming languages. The LCCS data storage and recovery subsystem is centered around an Informix database application. This database provides the required data integrity of all Loran data: keeping 90 days of data on-line at all times. Data is backed up to tape daily and monthly. This section will focus on the LCCS GUI, providing examples of some of the major system screen displays.

6.1 LORSTA Initialization Screens. A screen as shown in Figure 6.1 is available to the user for each LORSTA in the chain. This screen displays all LORSTA and PCMS controlling data values and allows the user to change certain values. Any changes made which require a transmission to a LORSTA or PCMS site occur automatically once the "START" button is selected.

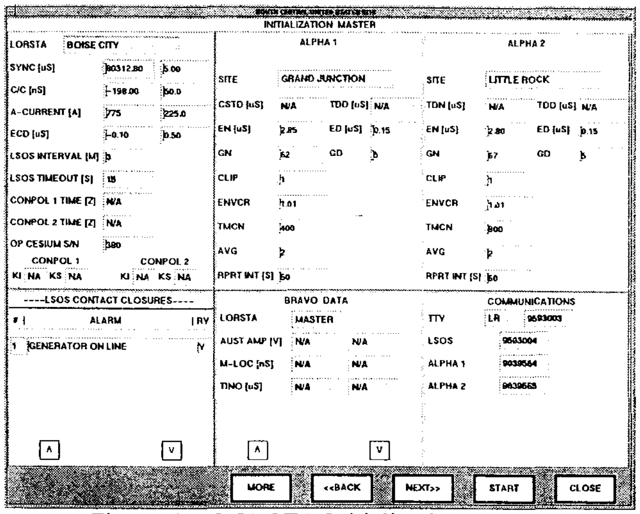


Figure 6.1 LORSTA Initialization Screen

6.2 Chain Display Screen. After the startup process, the user is presented with a screen as shown in Figure 6.2. As part of the initialization sequence, LORSTA sites turn green if all equipment at the LORSTA is fully operational and the station is transmitting in tolerance. PCMS sites turn green if communications are properly established and the site is fully operational for all baselines. This screen presents the user with the status of, and provides an interface with the entire Loran chain. This display provides the interface for the chain TTY and all administrative and system maintenance functions. This includes a running list of all LORSTA and PCMS site alarms and commands, data archive functions, communications statistics information, system time set functions, printing of reports, system sample, change of watch functions, and the LCCS on-line help package. The Chain Display Screen is intended to be the primary LCCS user interface screen.

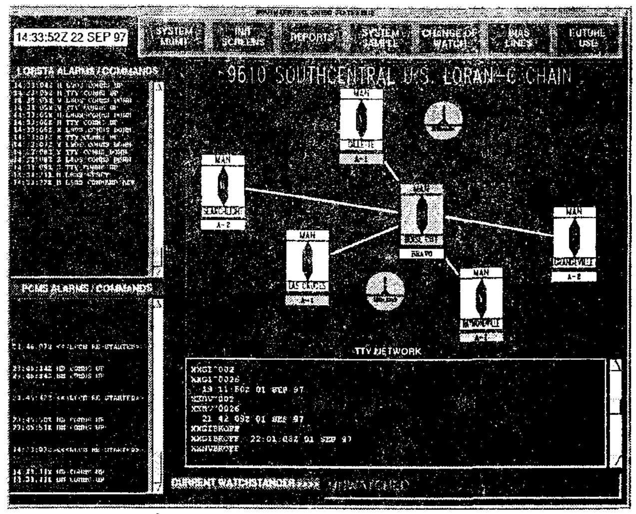


Figure 6.2 Chain Display Screen

6.3 LORSTA Display Screen. After activation of a LORSTA icon on the Chain Display Screen, a screen as shown in Figure 6.3 (Example of a Master LORSTA) is presented to the user. This screen graphically displays LORSTA TTY and LSOS information and provides a GUI for the LCCS Watchstander to interface with this equipment. This interface includes a display for all LORSTA LSOS data, a running list of all LORSTA alarms and commands, the status of the operate signal path equipment, and display counters for off-air, blink, and unusable time during the Loran day. In addition, functions are included for blink, watch call, phase adjustments, changes of control mode, changes of operational mode, oscillator commands, timer commands, and transmitter commands. LORSTA Display Screens vary slightly between Solid-State (SSX) and Tube-Type (TTX) transmitting stations. In addition, there are slight differences between Master and Secondary LORSTAs.

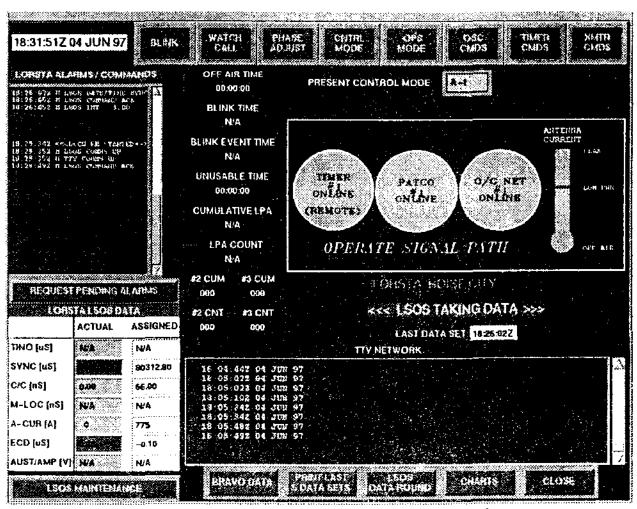


Figure 6.3 Master LORSTA Display Screen

6.4 PCMS Display Screen. After activation of a PCMS icon on the Chain Display Screen, a screen as shown in Figure 6.4, is presented to the user. This screen graphically displays PCMS stripchart information and provides a GUI for the LCCS Watchstander to interface with PCMS equipment. This includes a window (a *window* is a sub-set of a *screen*) as shown in Figure 6.5 to provide the Watchstander with a text interface to the PDP-8 computer/Austron 5000 receiver, a running list of all PCMS alarms and commands, and automatic PCMS nominal setting features.

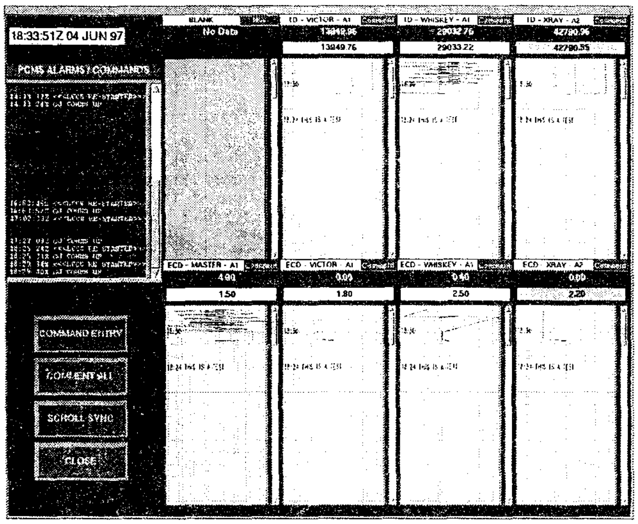


Figure 6.4 PCMS Display Screen

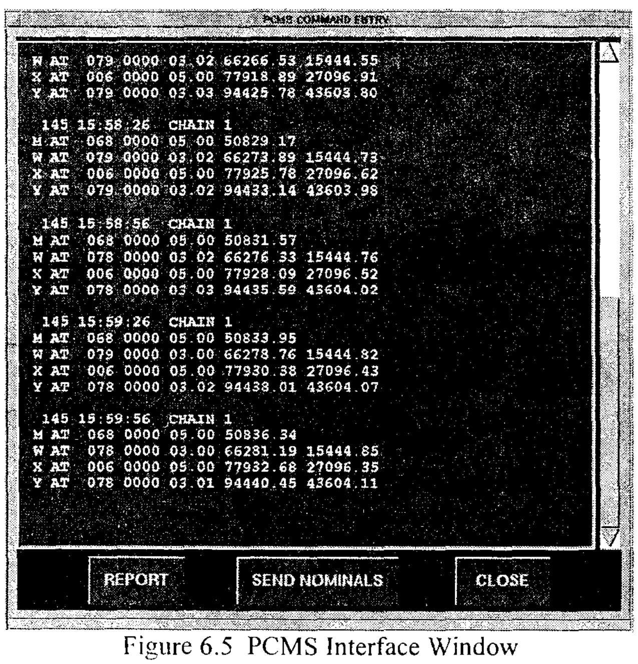


Figure 6.5 PCMS Interface Window

6.5 Bias Line Screen. After activation of the "BIAS LINE" button on the Chain Display Screen, a screen as shown in Figure 6.6, is presented to the user. The LCCS uses a Time Difference Controller (TDC) algorithm designed similarly to the CALOC control algorithm which calculates required Linear Phase Adjustments (LPAs) and updates the Bias Line screen. This screen displays cumulative Time Difference Error (TDE) and current TDE for up to five baselines. The Bias Line plot changes plotting point characteristics according to the Legend when changes in control are made.

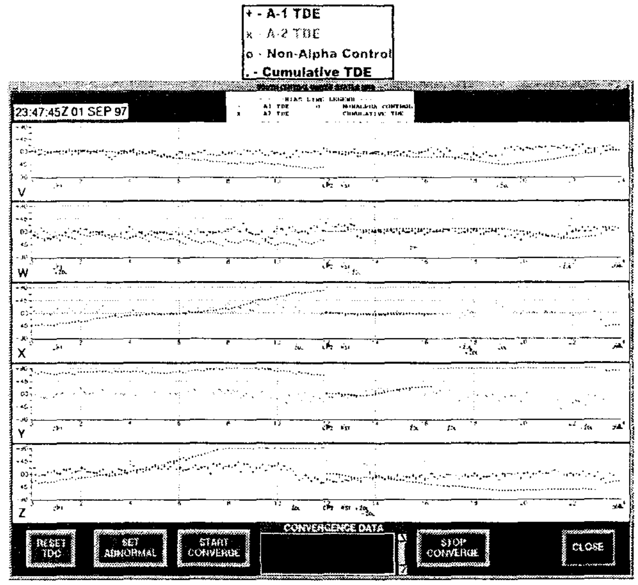


Figure 6.6 Bias Line Screen

6.6 Reports Window. After activation of the "REPORTS" button on the Chain Display Screen, a window as shown in Figure 6.7, is presented to the user. This window allows the user to select an array of reports, logs, and data to output to the color printer. These reports include printouts of PCMS charts, Bias Line charts, ROS charts, TTY data, PCMS interface data, LORSTA and PCMS alarms and commands, and the Daily Operations Report. In addition, the reports interface allows the user to restore Loran chain data from tape to the system in order to print desired information. Ninety days of LCCS data is kept online at all times. If the requested data is dated prior to the past 90 days, LCCS queries the user to insert the proper back-up tape. The user may select any number of items to print at any time.

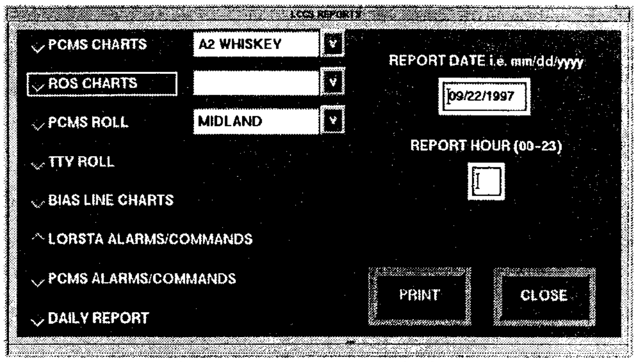


Figure 6.7 Reports Window

7.0 CURRENT STATUS

LCCS is currently installed and operating at the following locations:

USCG Navigation Center, Alexandria, VA

- Southeast U.S. (SEUS) Loran Chain
- Southcentral U.S. (SOCUS) Loran Chain
- Northeast U.S. (NEUS) Loran Chain
- Great Lakes (GLKS) Loran Chain

USCG Navigation Center, Petaluma, CA

- U.S. West Coast (USWC) Loran Chain
- Northcentral U.S. (NOCUS) Loran Chain

CONSITEs Malone, FL, Seneca, NY, and Middletown, CA have been converted to their standard LORSTA configurations. The USCG Loran Support Unit is currently completing the LCCS Operator's Guide and putting the finishing touches on the application code.

8.0 FUTURE PLANS

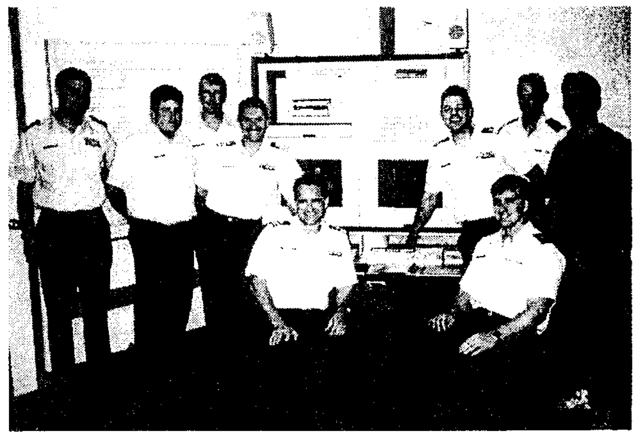
The USCG Loran Support Unit plans to continue work on the LCCS in Fiscal Year 1998 (1OCT97 – 30SEP98). This work includes the addition of some automatic control features to the software, development of a backup communications scheme, installation of LCCS in Kodiak, AK (Gulf of Alaska and North Pacific U.S. Loran Chains), LCCS procurement, staging, shipping, and installation assistance for Canadian CONSITEs at Williams Lake, British Columbia (Canadian West Coast Loran Chain) and St. Anthony, Newfoundland (Canadian East Coast and Newfoundland East Coast Loran Chains). In addition, the Loran Support Unit will work on development of a Time Difference Control System (TDCS) to replace the Russian-American Chain CALOC.

9.0 ACKNOWLEDGMENTS

I would first like to thank the LCCS Project Team, of which I was once Project Manager. Both Coast Guard and Contractor teams put in thousands of hours of overtime to get this high-risk project completed on time and within budget. The following were part of "TEAM LCCS":

Coast Guard TEAM LCCS:

- LCDR Charles Schue
- LT Steve Bartlett
- LT Chris Stout
- CWO Kirk Montgomery
- ET1 Mike Luna
- LT Al Arsenault
- LT Jim Koermer
- Mr. Dave Hartley
- ETC Brian Bensen
- ET3 Bill Sage



Coast Guard ***TEAM LCCS*** in Petaluma, CA!!

Contractor TEAM LCCS:

- Mr. Brian Addison
- Mr. Peter Braswell
- Mr. Guy Salisbury
- Mr. Rob Mueller
- Mr. Scott Reed
- Mr. Ed Campbell
- Mr. Eric Vermeulen
- Mr. Matt Young
- Dr. Przemek Nowicki

Thanks also go out to U.S. Coast Guard Headquarters and the U.S. Coast Guard Navigation Center (Alexandria, VA) and Navigation Center Detachment (Petaluma, CA).

10.0 REFERENCES

1. United States Coast Guard Loran Consolidated Control System (LCCS) Operator's Guide, Version 1.0, CG7610-01-GF5-9101 (DRAFT).

Q: Are there year 2000 problems in the system?

A: We are as confident as AT&T, MCI, Sprint and all the others are. I know that's not much of an answer, but we've been asking the companies. The loran software and hardware is Y2K prepared, but we don't have the communication companies on paper yet with a promise.

Q: What's the stereo sound system for?

A: Different beeps for different problems on different chains. We were told not to let it talk to us. (We still have the CD stereo playback, but the training is holding so far... The internal PC speaker also works, if the sound card fails.)

Q: We've been using $17 million per year as the operating cost; what's the number for 1998? 1999?

A: I don't know the correct dollar figure. I'm the technical guy. In CONUS, we'll save $1M just from these new systems, and after we bring in Canada and Alaska, it will be more.

Comment by Capt. J. Doherty, CO USCG Navigation Center: The whole logistics trail is affected. Not in place yet. On personnel, 235 people last year, reduced by 60 people at the stations, and increased NAVCEN by about 30 people. $40K per year per person. Expect to save similar numbers in Kodiak sites.

Q: What about aviation blink? Does Consolidated Control (CC) supplant the FAA system?

A: This will help, but it will not *do* ABS. That's a real-time, at-the-station thing, while this CC system is dependent on communication lines, etc.

U.S. COAST GUARD PROTOTYPE TIME OF TRANSMISSION MONITOR (PTOTM)

M.J. Campbell and E.A. Paulus
U.S. Coast Guard LORAN Support Unit
Wildwood, NJ 08260-3232

BIOGRAPHIES

Michael J. Campbell has been with the LORAN Support Unit (LSU), and its predecessor, the Electronics Engineering Center (EECEN), for 24 years. He has been directly involved with the LORAN-C radionavigation system for the last 15 years. He managed and/or participated in projects which installed and calibrated the timing and transmitting equipment at 14 U.S. and Canadian Coast Guard (CCG) LORAN-C stations, and calibrated the emission delays for the Newfoundland East Coast Chain and the Petropavlovsk/Attu Chayka/LORAN-C baseline in the Bering Sea.

Ernest A. "Bud" Paulus has been with the LSU and EECEN for 12 years. He is the chief of the solid state transmitter (SSX) laboratory and is regularly called upon to assist LORAN-C station personnel with their most difficult timing and transmitting equipment problems. He participated in projects which installed and calibrated the timing equipment at 2 U.S. and 2 Canadian Coast Guard LORAN-C stations.

ABSTRACT

The prototype time of transmission monitor (PTOTM) system was developed to provide a simple, low cost, alternative method to monitor the time of transmission of the LORAN-C signal at the transmitting station. Although the PTOTM system may have to defer, in terms of absolute accuracy, to two-way satellite time transfer techniques, and, to common view techniques, it does not require the initial and/or recurring expense of either. It has a distinct advantage over far-field time of reception techniques, in that it measures timing relationships directly to the transmitting antenna's current waveform, as prescribed by USCG COMDTINST M16562.4A, [1] thereby reducing or eliminating the possible error sources introduced by receiver system delays, propagation delays and propagation phase shifts. [2,3,4] Also, since the PTOTM system is not affected by LORAN-C propagation path variations, it promises improved stability in the TOT measurement data.

INTRODUCTION

EECEN project W1280, completed in 1995, examined the feasibility of using unkeyed GPS timing receivers to establish an on-site UTC reference. [5] The final project report, and several of the references cited in that report concluded that what has been termed the "all in view" technique for determining GPS time, based on the received signals from many satellites, can be a viable, near real time method of UTC transfer. The "all in view" technique can be enhanced by GPS timing receivers which have multiple, parallel channels, and which use processing algorithms which are designed to mitigate the effects of selective availability (SA), multipath reception, or other anomalies in the received signals. Careful calibration of all system delays, including the determination of precise coordinates for the receive antenna, will reduce fixed offsets and biases. Relatively long term averaging of the receiver's time signal can significantly reduce the effects of the white noise phase modulation introduced by peacetime SA, [6] and will also tend to further reduce the deleterious effects of propagation path variations and multipath reception.

The U.S. Naval Observatory (USNO) publishes a 2-day averaged UTC(USNO MC) - GPS time difference (TD), determined by a process which averages data from each satellite in the GPS constellation. That published TD, which, recently, has rarely exceeded 20 nanoseconds, can be applied as an additional correction factor to the averaged GPS time determined by the PTOTM system.

PTOTM SYSTEM CONFIGURATION

The basic PTOTM system consists of a GPS timing receiver, a time interval counter (TIC), a LSU developed reference timing generator (RTG), and a clamp-on current transformer. The following is a brief description of the key features of each component:

GPS Timing Receiver

The GPS timing receiver is a six channel "all in view" type with the aforementioned algorithms to mitigate the effects of SA and reception anomalies. The receiver manufacturer claims an accuracy to UTC (USNO-MC) of 40 nanoseconds RMS, and an Allan deviation frequency stability of 3x10^-12 per day, with SA enabled. The timing receiver's key outputs are a TTL level 1PPS signal and a TTL level 5 MHz clock. Once the receiver has achieved its normal operating condition, the relationship between the 1PPS and the 5 MHz clock has been shown to have phase stability on the order of 1 nanosecond. The receiver was taken to NIST, in Boulder, CO, and operated for several days, on a known antenna location, while its 1PPS output was compared to UTC(NIST). One 12 hour, and two 24 hour test periods indicated that the mean difference from UTC(NIST) was 13 nanoseconds with an averaged standard deviation of 33 nanoseconds. This delay, as well as all other known constant system delays can be offset by using the receiver's cable delay function. Another key feature of the timing receiver is its ability, by averaging 90,000 fixes over a 25 hour period, to determine its own antenna position with sufficient accuracy to preclude the necessity to have the antenna position professionally surveyed. The receiver manufacturer claims a positioning accuracy of 10 meters. Tests at the LSU, directly over an NGS surveyed marker (B-order) for several days, indicated an average spherical positioning error of less than 5 meters.

Time Interval Counter

The TIC is a relatively low cost unit, with a high stability time base (2.5x10^-9), high measurement resolution (750 picoseconds discounting trigger errors), and other key features which make it very suitable for TOT measurements at LORAN-C transmitting stations. Specifically, the TIC can perform limit testing and statistical computations on up to 1 million measurement samples, and several measurement setups can be stored in memory for easy recall.

Reference Time Generator

The RTG, developed at the LSU, is based on the W0923 Timing Generator, which is part of the "Hot Clock" emission delay measurement (EDM) equipment suite, developed under EECEN Project W0923. [7] The RTG consists of two circuit cards. One is a standard Programmable Digital Repetition Rate Generator (PDRRG), which is the heart of USCG LORAN Timers used to generate the LORAN timebase at transmitting stations. The PDRRG uses the 5 MHz from the GPS timing receiver to generate a pseudo LORAN timebase, which is phase locked to the GPS 1 PPS. The second circuit card provides a means to synchronize the pseudo LORAN timebase to the actual LORAN timebase, generates a standard zero crossing (SZC) timing strobe, and has a blanking signal input which can be used to cancel the effects of blanking the master signal at dual rated LORAN stations.

Clamp-on Current Transformer

The clamp-on current transformer and cable provides a means to sample the transmitting antenna current and provide that signal to the TIC. To calibrate the delay in this system, the PTOTM transformer and cable were directly compared to the transformer and cable used in the USCG standard "Hot Clock" EDM equipment suite.

LORAN TIME OF COINCIDENCE

A LORAN time of coincidence (TOC) occurs when the beginning of the first LORAN-C pulse of phase code interval A (PCI-A) is coincident with the UTC second. USCG COMDTINST M16562.4A defines the beginning of an ideal standard LORAN-C pulse to be 30 microseconds before the start of the fourth cycle of the 100 KHz carrier frequency, also known as the SZC. LORAN repetition rates are such that TOCs occur relatively infrequently. There are usually hundreds of seconds between TOCs. Figure 1 shows the time relationship between UTC and the signals at a properly timed LORAN-C master station at a TOC.

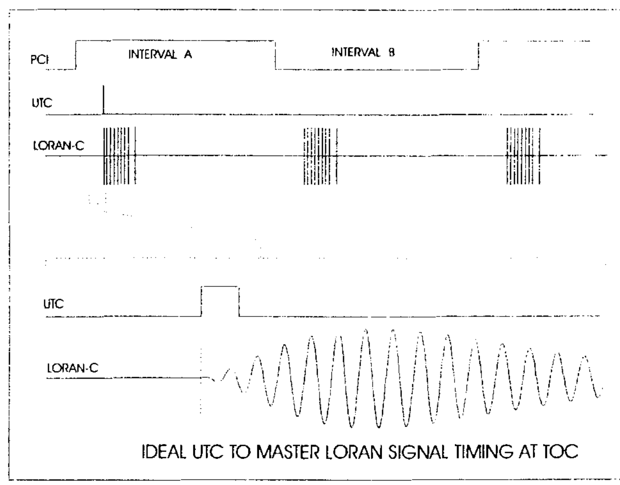


Figure 1

Although USCG COMDINST M16562.4A gives no specific guidance on how to measure the UTC - LORAN TD, it does state that all specifications for the transmitted LORAN signal are defined in terms of the current waveform at the base of the transmitting antenna. The PTOTM system adheres to that antenna current waveform definition of LORAN, and therefore LORAN TOT.

TOT MEASUREMENT BACKGROUND

Since TOCs are so infrequent, direct measurement of the UTC-LORAN TD presents some difficulties. Project W0923 overcame the difficulties by generating a pseudo-LORAN rate, clocked by the 5 MHz from a portable cesium. The pseudo-LORAN rate was selected to be evenly divisible into one second, e.g., 50,000 microseconds, thereby ensuring synchronization between that pseudo-LORAN rate and the cesium 1PPS time reference. The pseudo-LORAN timebase was allowed to be reset by that 1PPS reference, effectively producing a TOC between the start of the pseudo-LORAN timebase and the 1PPS reference each and every second. A LORAN timing strobe, generated by that pseudo-LORAN timebase, then had a constant time relationship with the 1PPS reference, at each TOC, which could be easily calibrated. Since both the timing strobe and the 1PPS reference were generated by the same cesium clock, and since the pseudo-LORAN timebase was allowed to be reset by the 1PPS reference at a TOC, the time relationship between the LORAN timing strobe and the 1PPS reference, as calibrated above, remained constant, at each subsequent TOC, no matter what the LORAN rate, nor how infrequent were the TOCs.

Essentially, the above system allows the generation of a cesium based timing strobe at a repetition rate where it can be easily calibrated against a 1PPS reference, then, allows that calibration to be transferred to another, less amenable repetition rate, e.g., 59900 microseconds at LORSTA Williams Lake. That timing strobe can then be directly compared to the SZC of the LORAN transmitting antenna current waveform.

PTOTM CALIBRATION AND OPERATION

The PTOTM uses that same concept, replacing the 1PPS and 5 MHz from the portable cesium with their counterparts from the GPS timing receiver, to monitor the TOT at a LORAN master transmitting station. The monitor process is also a two step process.

RTG Calibration Factor T1

Although the phase relationship between the timing receiver's 5 MHz and 1PPS remains constant once the receiver has achieved normal operating condition, the actual phase relationship can vary from receiver to receiver, and can vary within the same receiver if power has been lost and then restored. Since the receiver's 5 MHz provides the clock for the pseudo-LORAN timebase, and the 1PPS provides the reset pulse for the pseudo-LORAN timebase, any phase variation between the two will affect the relative TD between the 1PPS reference and the timing strobe generated in the RTG. For the purposes of this discussion, that relative TD is referred to as T1, which must be calibrated whenever the timing receiver loses power.

Figure 2 is a representation of the PTOTM system components and the interconnections required to accomplish the T1 calibration process.

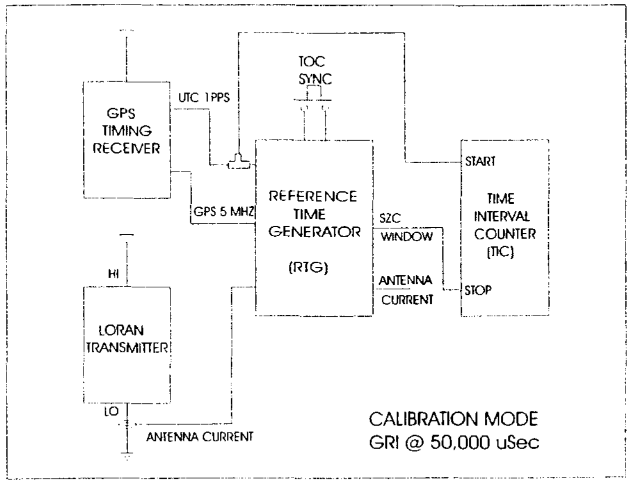


Figure 2

In the T1 calibration mode, the PDRRG in the RTG must be programmed for a pseudo-LORAN repetition rate of 50,000 microseconds. The PDRRG timebase, clocked by the timing receiver's 5 MHZ, is then allowed to be reset by the GPS 1PPS from the timing receiver at a TOC. This synchronization at a TOC is accomplished by depressing the TOC SYNC pushbutton, then, releasing the pushbutton during the second immediately prior to the TOC second (Remember, at a repetition rate of 50,000 microseconds, all seconds can be TOC seconds). The subsequent GPS 1PPS from the timing receiver will reset the PDRRG timebase, causing the start of the pseudo-LORAN Phase Code Interval A (PCI-A) to be coincident (discounting circuit delays) with the GPS 1 PPS at TOCs (each second in this case).

Once synchronization has been accomplished, any timing strobe derived from the PDRRG timebase, and therefore from the timing receiver's 5 MHz clock, will have a constant time relationship with GPS 1PPS at all subsequent TOC seconds. The SZC Window is such a timing strobe. It is generated in the RTG at a nominal 27 microseconds after the start of the pseudo-LORAN rate phase code interval (PCI), and therefore, at a nominal 27 microseconds after GPS 1PPS at every TOC second.

Figure 3 shows the nominal timing between the GPS 1PPS and the SZC window.

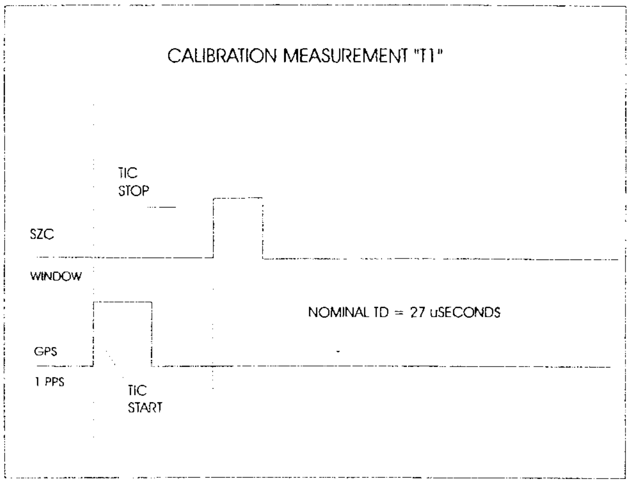


Figure 3

Precise measurement of the constant time difference (TD) between the GPS 1PPS and the SZC Window can now be accomplished and recorded as T1. Several hundred measurement samples are recommended so that the standard deviation of those samples can be used as an indication of a successful measurement process. The TIC setup to accomplish this measurement has been stored in the TIC memory, and can be recalled at the push of a button. Tests at LSU show that T1 is very constant, with standard deviations less than 2 nanoseconds. Long term tests also show that, once calibrated, T1 will remain constant, so long as the timing receiver does not lose power.

Measurement Of Mean Time Difference T2

Figure 4 is a representation of the PTOTM system components and the interconnections required to accomplish the T2 measurement process.

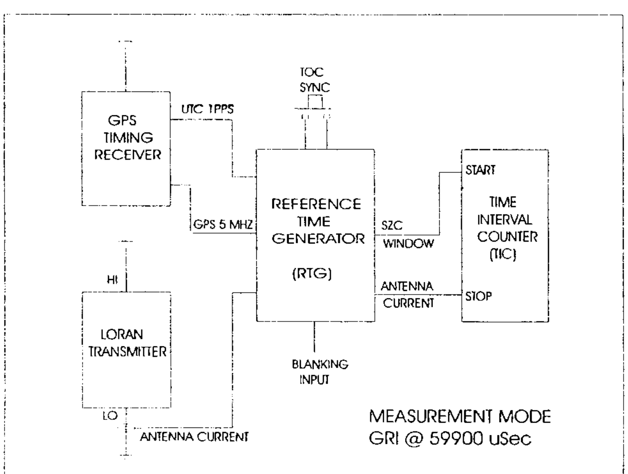


Figure 4

In the T2 measurement mode, the PDRRG in the RTG must be reprogrammed for the actual LORAN repetition rate, 59,900 microseconds in this example. The PDRRG timebase, still clocked by the timing receiver's 5 MHZ, is again allowed to be reset by the GPS 1PPS from the timing receiver at an actual TOC second for that particular LORAN rate. This synchronization at a TOC is accomplished by depressing the TOC SYNC pushbutton, then, releasing the pushbutton during the second immediately prior to the actual TOC second. The subsequent GPS 1PPS from the timing receiver will reset the PDRRG timebase, causing the start of the pseudo-LORAN PCI-A to be coincident (discounting circuit delays) with the GPS 1 PPS at all TOC seconds. Additionally, if the master station's transmitted signal is timed properly, the start of the pseudo-LORAN PCI-A will be coincident with the start of the first transmitted pulse in the actual LORAN PCI. If that is indeed the case, the RTG SZC Window will span the actual SZC of the antenna current waveform. Figure 5 shows those that ideal timing relationship.

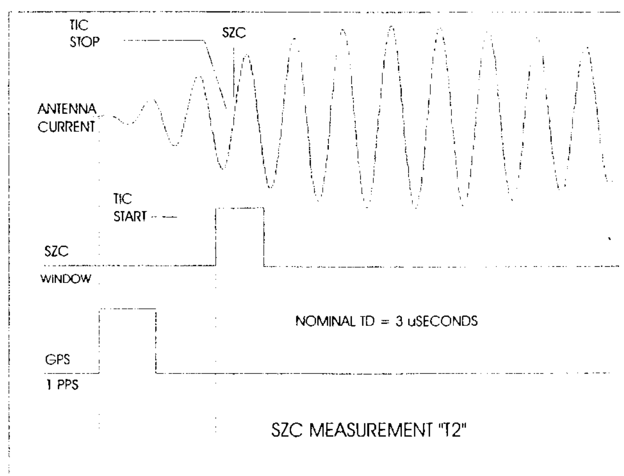


Figure 5

Since SA is at work, and since there may be some small amount of phase modulation in the transmitted signal, a large number of samples, over a relatively long period, are required to make an accurate determination of the mean T2. We elected to use the full power of the TIC and take a measurement sample every PCI. In the case of LORSTA Wiliams Lake, with a group repetition interval (GRI) of 59900 microseconds, we are taking approximately 721,000 (2 GRIs to a PCI) measurement samples per day. We are confident that, with such a large number of contributing samples, the deleterious effects of SA and other GPS propagation anomalies are all but eliminated from the resultant daily mean T2. Long term measurements at LORSTA Williams Lake, and shorter term measurements at LORSTA Seneca, indicate that the daily mean T2 can be determined by the PTOTM system with the standard deviations of the measurement samples consistently in the 35 nanosecond range. That consistency in the standard deviation of the measurement samples could be an indication that the GPS timing receiver manufacturer has delivered on his accuracy claim (40 nanoseconds RMS to UTC(USNO)).

UTC(USNO) - LORAN TIME DIFFERENCE

Under the following ideal conditions, the sum of T1 and T2 should be equal to 30 microseconds +/- 0.040 microseconds:

1. The GPS timing receiver produces a 1 PPS that is within 40 nanoseconds RMS of UTC(USNO).
2. All systematic delays in the PTOTM system have been properly accounted for.
3. The SZC of the antenna current signal is the reference point for TOT measurement.
4. The LORAN signal is properly timed and free of phase modulation.

The TD between 30 microseconds and the T1+T2 sum is the approximate UTC(USNO) -LORAN TD. This TD can be further refined by incorporating the GPS 2-Day Filtered Time Differences published by USNO.

FUTURE PLANS

Test results from demonstration installations at LORSTA Williams Lake, BC, Canada, since May 1997, and LORSTA Seneca, NY, since August 1997, have been very promising. USCG LSU now plans to proceed with a project to install a final form TOTM system at all USCG and CCG master transmitting stations before the end of 1998.

An added benefit of the PTOTM system is that it can provide very stable data, in almost real time, to the USCG and CCG LORAN Operations Centers. This can be used as a tool to control the drift rates of the cesium frequency standards at the LORAN stations. Automatic steering of the master station operate cesium frequency standard, via the operate phase microstepper, is possible.

CONCLUSIONS

The consistency in the standard deviations of the measurement samples of the 1PPS at NIST, and the T2 measurement samples at LORSTAs Williams Lake and Seneca, could be an indication that the GPS timing receiver manufacturer has delivered on his accuracy claim (40 nanoseconds RMS to UTC(USNO)). It is unlikely that we can actually realize a measurement accuracy of 40 nanoseconds, however, sufficient accuracy to help meet the 100 nanoseconds requirement of Public Law 100-223, is within the capability of the PTOTM.

ACKNOWLEDGMENTS

Very few of the concepts that have been discussed in this paper, or that contributed to the successful design of the PTOTM system are original. The excellent work by the late Martin A. Letts, which resulted in the design of the "Hot Clock" Emission Delay Measurement Equipment Suite, made this project an easy one.

We would also like to thank Victor Zhang, for allowing us to visit his NIST laboratory to calibrate the GPS timing receiver delays.

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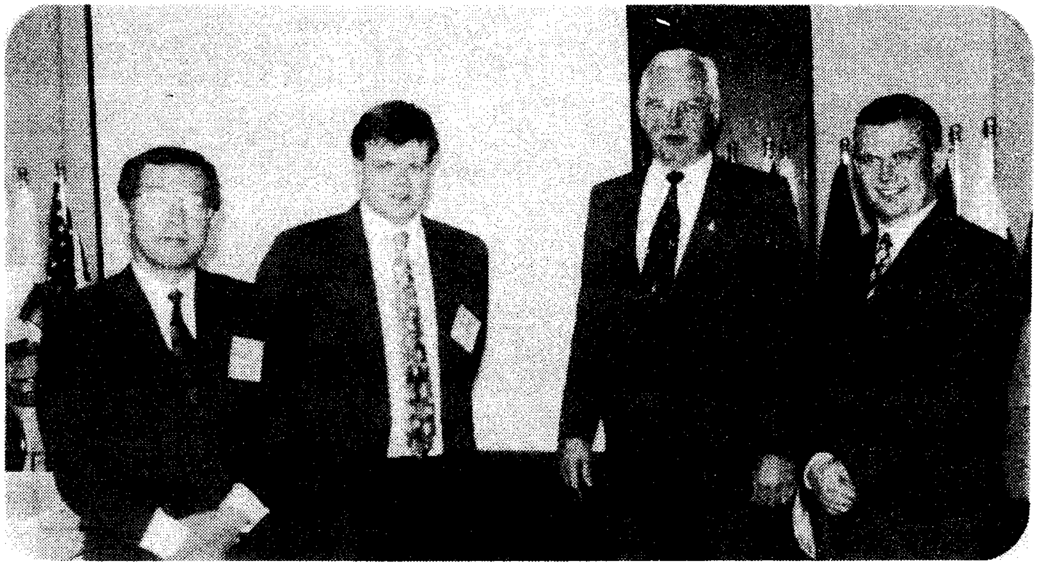
7. M.A. Letts, USCG Electronics Engineering Center Project W0923, "Emission Delay Measurements", Final Report, 1980.

-Note- The views expressed herein are those of the author and are not to be construed as official or reflecting the views of the Commandant, U.S. Coast Guard, or U.S. Department of Transportation.

Comment from the floor: The system is principally used for frequency control and synchronization; more sophistication will be added for routine UTC synchronization.

Session 7: Loran-C Propagation & Timing

Session Chair: Terje Jorgensen
Northwest European Loran-C Service



Session 7: From left, Nobuyoshi Kouguchi, Paul Williams, Bill Roland, Terje Jorgensen; below, Walt Dean

Distance Characteristics of Received Pulsewave Signal in the Northwest Pacific Chain
Nobuyoshi Kouguchi, Kobe University of Mercantile Marine

Mapping Additional Secondary Factors for the Northwest European Loran-C Chains
Prof. David Last, University of Wales

UTC Synchronization System
William F. Roland, Megapulse, Inc.

Expectations for Solar Cycle 23
Joe Kunches, NOAA Space Environment Center
(Paper presented by Walt Dean)

Distance Characteristics of Received Pulsewave Signal in Northwest Pacific Chain

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October 8,1997

Biography

Nobuyoshi Kouguchi was born in Japan, in 1955. He received the B.Sc. degree in nautical sience from Kobe University of Mercantile Marine, in 1978.

From 1979 to 1991, he joined the Marine Technical College as a Research Associate and was promoted to an Associate Professor. Science 1991, he has been an Associate Professor at Kobe University of Mercantile Marine and from 1996 to 1997 he was a Captain of Training ship of same University. His research has focused on the evaluation of radio navigation system (especially Loran and GPS), Radar signal processing and automatic control for ship.

Abstract

In July 1996, in order to evaluate the distance characteristics of the received LOran-C pulsewave, we had an experimental voyage at a distance of 500km-1100km from W station in Northwest Pacific Chain. In this experiment, we prepared for two same measurement systems. One was set up on our training ship (moving site) and the other was set up on our university (fixed site). At both sites, S.N.R., time difference and received pulsewave forms were recorded simultaneously and continuously. As a result of processing the recorded pulse wave, three pulse distortion measures (Envelope-to-cycle difference, Change of half cycle length and phase modulation term) were analyzed and the distance characteristics of these measures were obtained. Consequently it is found that the change of half cycle wavelength have a good characteristics for ASF correction.

1 Introduction

Global Positioning System had been developed by US and is completely operational now. With the advent of GPS, many navigational applications has been developed and by means of the differential and kinematics GPS more precise position had been obtained easily and briefly . As a more accurate and stable information of the vehicle position would be obtained continuously, we will be able to control the vehicle more safely.

At present a greater part of interest is direct to GPS, even the vehicle control with risk of accident will be depend on GPS. From a navigators standpoint of view, it is proper that a navigation system is prepared for some backup systems and kept a good redundancy, because a complete system dose not exist at all. Even the GPS is not satisfied with every tasks.

Now radionavigation systems is classified two basic systems. One is a land-based system (LORAN, OMEGA etc.), and the other is a satellite based one(GPS, GLONASS). When we intend to evaluate a navigation system, some performance indexes that have different weighted factor due to various state of vehicle are utilized. Ordinarily we can use four indexes as follows,

· reliability
· integrity

· accuracy
· coverage

Comparing two basic systems in terms of above indexes, the satellite based system is superior to the land bases one at two performance indexes of an accuracy and coverage, but another performances give an opposite superiority to two systems. It is considered that the satellite system has a limitation of improving a reliability and integrity. Because the satellite is always rounding the earth and can't be repaired immediately if an accident is occurred to it. Further more it does not always maintain accurate repeatability. Then in order to construct a more robust navigation system, it is considered that two basic navigation systems must be hybridize. If this hybridization realize, I think that the Loran absolute accuracy should be better than 150m (2drms) at least.

The error source of Loran is classified to the geometrical error, instrumentation error and propagation error. There are two essential problems for reducing total error less than 150m. First problem is the timing accuracy that must be kept up to 0.01 microsecond order, and second problem is a precise propagation time of pulse (ASF correction value) that should be estimated up to 0.1 microsecond. Then we proposed the ASF correction method that uses the received pulse distortions (ECD and CHACLE).

This paper presents a part of feasibility study on ASF correction by means of the received pulse distortion, and shows some results of analyzing the data of experimental voyage in 1996. In this experiment, we recorded many received pulses of the secondary station (W:Gesashi) in the Northwest Pacific Chain (8930) at two site simultaneously. One site is our training ship (moving site), and the other is our university (fixed site). After the data of two site are compared, we show the distance characteristics of the received pulse wave distortion measures.

2 Measurement system

The measurement system [2] consists of two parts; hardware and software. The hardware part is to receive and record the pulsewave, and the software is to process the pulsewave form to estimate and measure some distortion measures. Fig.1 shows a block diagram of the hardware used in this experiment, which is expected to ensure the precise pulse shape recording. In the Loran-C receiver, the pulse which is used to trigger signal for A/D conversion is generated synchronizing at SSP(standard sampling point) of the first pulse of the master station pulses. The RF signal coming in from antenna and coupler (of bandwidth wide enough for Loran-C RF signal) is converted to a digital signal with 10bits resolution and 100MHz sampling frequency at the above SSP timing. The digital signal thus converted is then accumulated up to 100 times and then taken its average. This average of 100 pulses is then recorded in the hard disk as a received Loran-C pulse shape. This system has a Lubisium oscilator to get more presice trigger signal.

Fig.2 shows the data processing flowchart for estimatating and measuring the distortion measures. Now a recorded pulse is decided the standard sampling point (SSP), and then it is separated to in phase and quadrature components. After two components are processed by L.P.F. , these are used to estimate the ECD and mesure the PMT(Phase Moduration Term). The definition of three pulse distortion measures used in this paper are described and two distance characteristics with three different conductivities are showed as follows,

1. ECD (Envelop to Cycle Difference):
   With this B.P.F., an envelope of the pulse is reproduced. Then ten sampling points, i.e. SSP, 4 points each before and 5 point after SSP with intervals of 2.5 microsecond in between, are obtained, with which ECD is estimated by least square error method.
   Fig.3 shows distance characteristics of ECD. It is clear that ECD has some different gradient for each conductivities.

2. CHACLE (Change of Half Cycle LEngth): [1]
   Half cycle length before and after SSP is measured and used to calculate CHACLE following the equation below.
   CHACLE = (half cycle length after SSP)
   - (half cycle length before SSP)
   Fig.4 shows distance characteristics of CHACLE. Same as ECD, CHACLE has some different gradient for each conductivities, but these gradients has more linear than ECD.

3. PMT(Phase Modulation Term: [2]
   Phase shift is calculated from in-phase and quadrature component of the lowpass filtered sig-

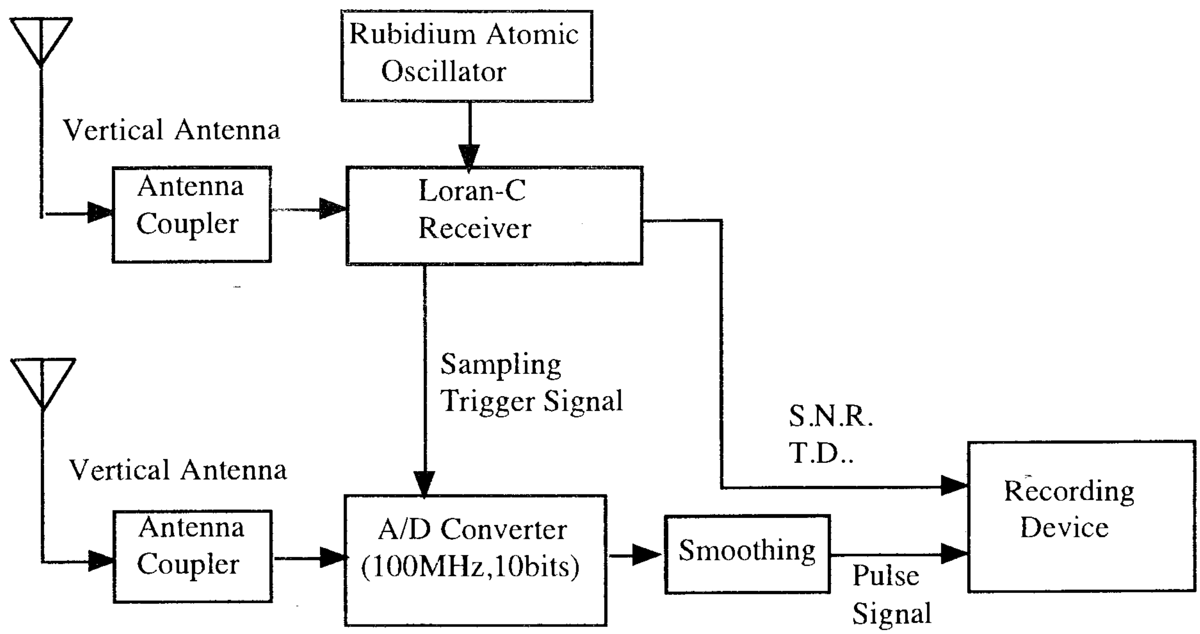

Figure 1:HardwearPart Block Diagram

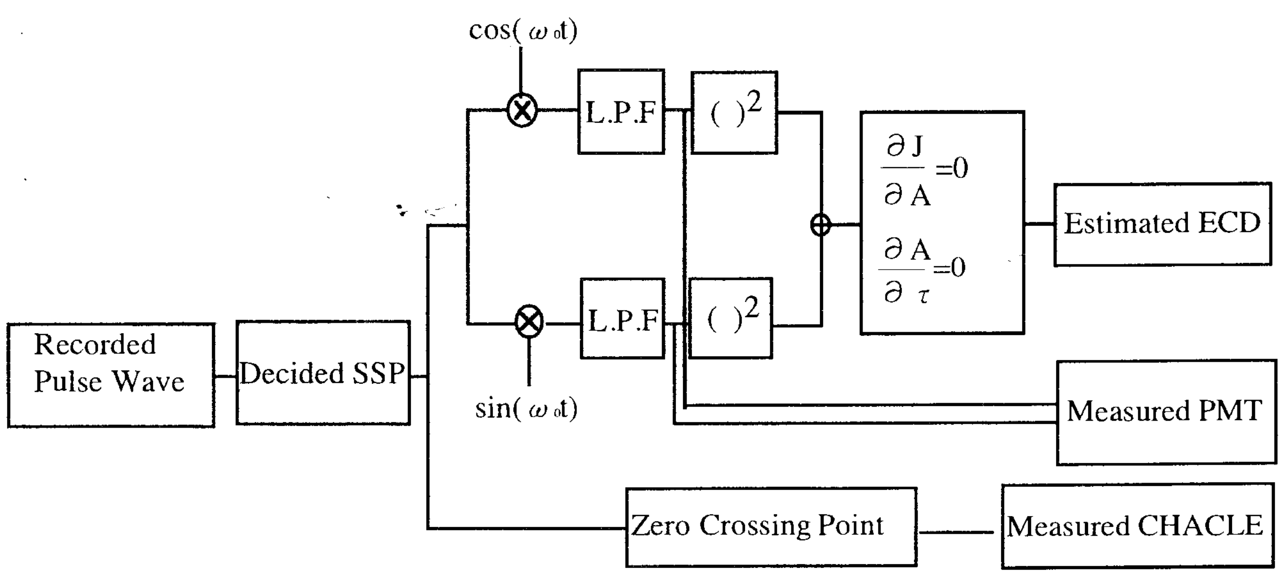

Figure 2: Softwear Part Processing Flowchart

nal. For that purpose 100 phase data are collected from this signal in the vicinity of SSP, and then estimated the phase modulation term at SSP by least square method. As being considered that the phase shift thus calculated at the SSP has a strong correlation with CHACLE, we could use one pulse distortion measure to correct the ASF.

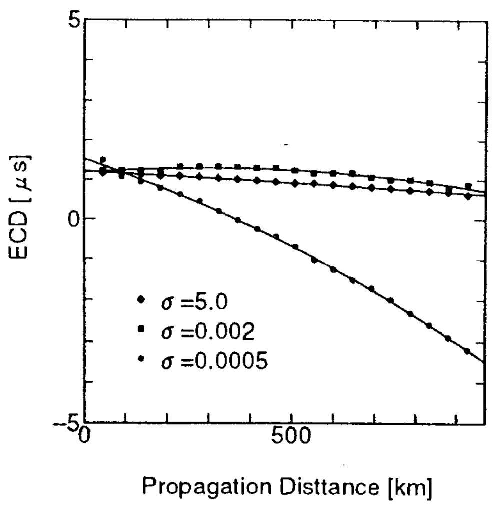

Figure 3: Distance characteristics of ECD

3 Experimental results

3.1 Outline of experiment

From July 24 to August 1 of 1996, the experiment was done to evaluate the distance characteristics of the distortions during our experimental voyage, and the experimental area is shown in Fig.5. In this figure, the position of 6 large dots are indicated the location of each port site on our voyage. The measurement system was installed and measured pulse wave shapes both at our training ship (moving site) and university (fixed site). In these measurement system, ECD, S.N.R. and other characteristics were measured of the transmitted signals from W (Gesashi) stations in Northwest Pacific Chain(8930). In this section, first we showed the results on fixed and berthed site, and next the distance characteristics of the distortion measures.

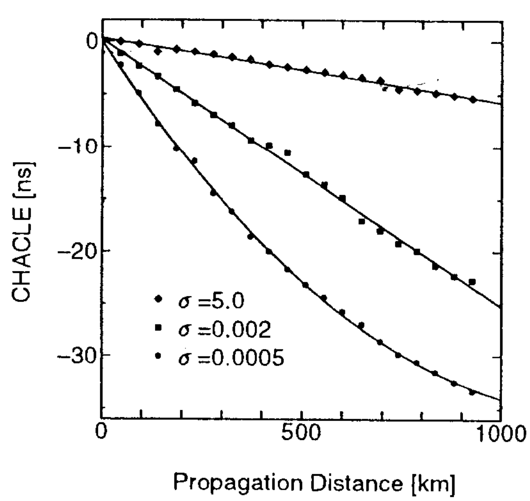

Figure 4: Distance characteristics of CHACLE

Figure 5: Measurement area

3.2 Characteristics of distortion measures

On experimental voyage, we had six ports (Nagasaki, Sasebo, Hakata, Yamaguchi, Onomichi, Takamatsu). The experimental results during each berthing are shown in Tab1 together, and the time variations of three distortion measures are shown in Fig.6~8. In these results, as the value of S.N.R. is larger, each standard deviation value becomes smaller. Then our distortion measures will be more accurate according to increasing the number of averaging pulse or using the loop antenna [4]. It is considered that these measurement results was accepted as good, because these standard deviations (S.D.) of each distortion measure indicated reasonable value and had suitable stability.

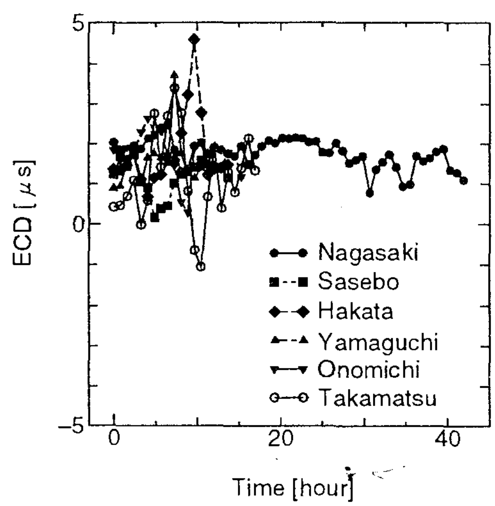

Figure 6: ECD variation at port sites

The experimental results on voyage for the W secondary station pulse received in moving site is shown in Fig.9~11, and the distance characteristics of each pulse distortion measure are indicated. In Fig.9 the estimated ECD does not have usual property that decrease with the propagation distance, rather it has an tendency to increase with the distance. It is considered that the main reason of ECD behavior is due to a saturation error on digitizing the wave. On the other side in Fig.10,11, the measured CHACLE and PMT have distance characteristics that was mentioned before section [1]. In this experiment it is mentioned that

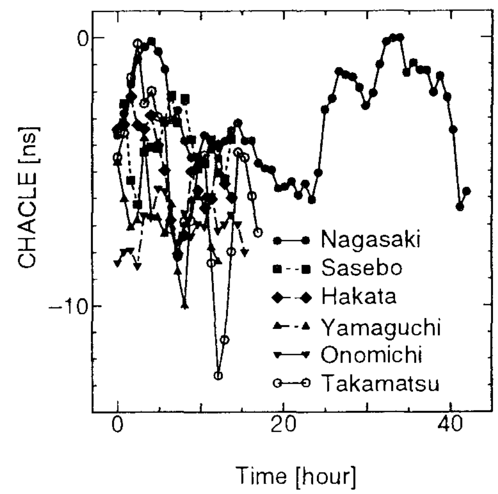

Figure 7: CHACLE variation at port sites

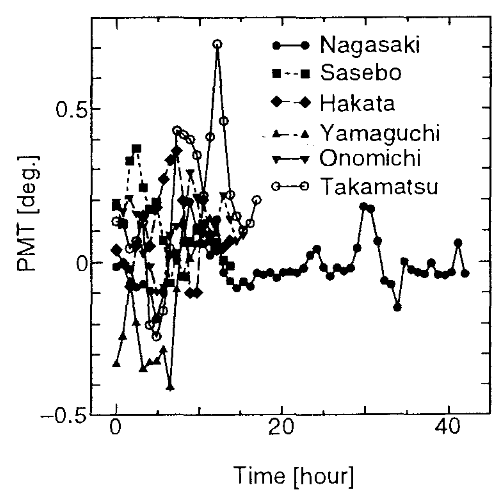

Figure 8: PMT variation at port sites

Table 1: Results at fixed and port site data

Location	No. of wave data	Dist. from W (Land Dist.) [km]	S.N.R.		ECD		CHACLE		PMT	
			M.[dB]	S.D.	M.[μs]	S.D.	M.[ns]	S.D.	M.[deg]	S.D.
Nagasaki	39	700.0 (8.0)	0.38	2.87	1.75	0.36	-2.95	1.84	-0.01	0.07
Sasebo	19	741.8 (18.0)	0.50	3.86	1.18	0.45	-3.99	1.12	0.11	0.12
Hakata	19	805.4 (46.0)	-0.35	4.12	1.77	0.93	-4.89	1.69	0.10	0.14
Yamaguchi	19	900.3 (145.0)	-0.59	4.43	1.60	0.63	-6.76	1.47	-0.13	0.19
Onomichi	19	990.0 (139.0)	0.33	2.27	1.67	0.56	-7.08	0.81	0.11	0.10
Takamatsu	20	1029.6 (156.0)	-0.33	3.81	1.15	1.12	-5.48	3.11	0.19	0.23
Kobe	200	1400(200)	-	-	0.44	1.11	-10.04	3.81	0.11	0.39

(M. and S.D. means each mean value and standard deviation value)

CHACLE and PMT are suitable for ASF correction.

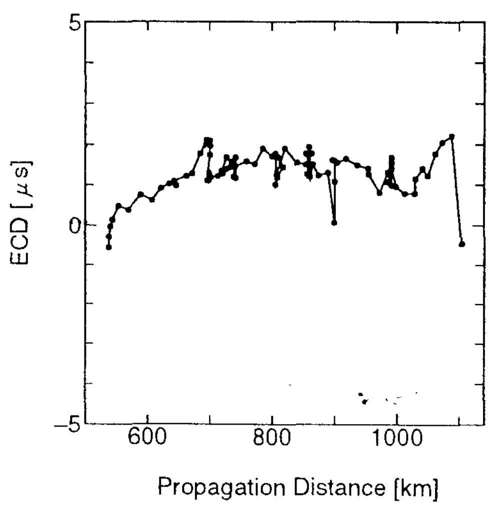

Figure 9: ECD variation vs. propagation distance

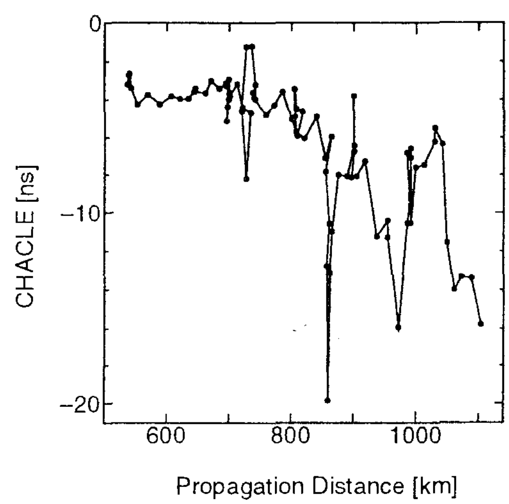

Figure 10: CHACLE variation vs. propagation distance

3.3 ASF effect of CHACLE

To verify that CHACLE has an effectiveness for ASF correction, it is necessary that the sea water path and land path effects of this measure should be introduced. The distance characteristics of three different propagation path showed before section had two different gradient for propagation distance as follows,

Table 2: Results of CHACLE correction

	No. of data	Measured CHACLE	SF Correction		ASF Correction	
			Predicted	Residual	Predicted	Residual
Mean	86	-6.46	-4.48	-1.98	-5.77	-0.69
S.D.	86	3.69	0.82	3.16	1.84	2.64

(S.D. means the standard deviation value)

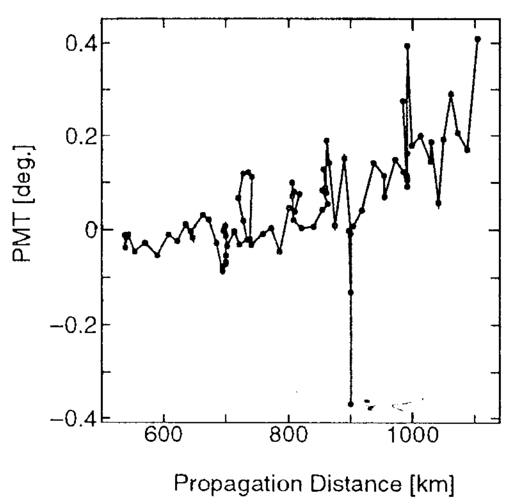

Figure 11: PMT variation vs. propagation distance

$$\frac{\partial(CHACLE)}{\partial(Dist.)}|_{\sigma=5.0} = -0.0055$$

$$\frac{\partial(CHACLE)}{\partial(Dist.)}|_{\sigma=0.02} = -0.025$$

$$\frac{\partial(CHACLE)}{\partial(Dist.)}|_{\sigma=0.005} = -0.058 + 0.000047 \times (Dist.)$$

The each conductivity (σ) = 5.0 and 0.02 mean sea water and the agricultural land (or freshwater) respectively. Then we use each gradient to estimate ASF effect of at each path. Fig.12 shows the effect of SF and ASF correction on CHACLE. In this figure, SF means the result of correction that was supposed all sea path, and ASF means the results that was supposed mixed (sea and land) path. Moreover Tab.2 shows the results of statistical evaluation for these corrections. It is clear that ASF change of CHACLE is estimated effectively. This result means that CHACLE will be able to use the ASF correction of Loran-C time difference. Because PMT has the same property as CHACLE, it will be use same correction too.

4 Conclusion

To improve the absolute accuracy of Loran, one of the most useful technique is to estimate the ASF value and correct it, then some method had been developed. At present the most popular method of that is to use the ASF correction table. We have been developing another method that used to some pulse distortion measures. In this paper, it is shown that CHACLE has the most useful characteristic to correct ASF value experimentally. As we can't record the GPS daa unfortunately, in this experiment the comparison between δTD value and pulse distortion measure was not shown.

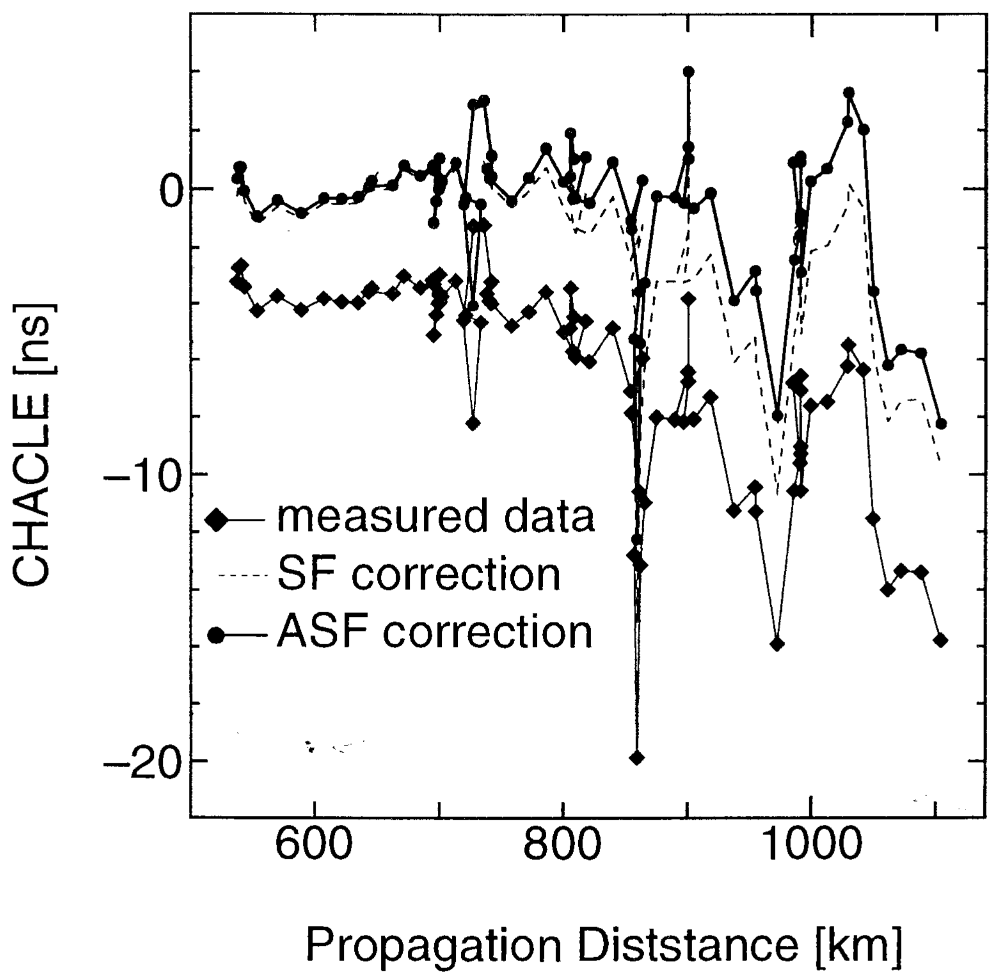

Figure 12: correction on CHACLE

Acknowlegement

The author wish to express my thankfulness to Prof. Yuichi Miyoshi of KOBE Univ. of Mercantile Marine for many helpful suggestions and to staff of our labs. for help.

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Mapping Additional Secondary Factors for the Northwest European Loran-C Chains

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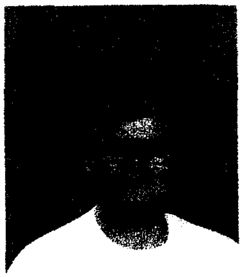
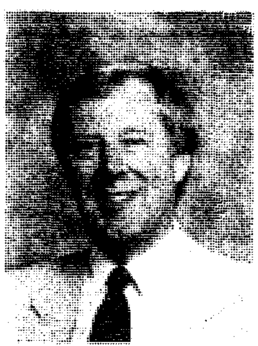
University of Wales, Bangor, United Kingdom



Dr. Paul Williams was awarded the degrees of BSc(Hons) in Electronic Engineering in 1990 and PhD in 1994 by the University of Wales, Bangor. He developed his interest in radio-navigation systems during 1995/96 when he worked as a Post-Doctoral Research Fellow at Manchester Metropolitan University on a project concerning the calibration of the fixed errors of Racal's Hyperfix system. Since June 1996 he has been employed at the University of Wales on the Demonstration Phase of the "Mapping ASFs for the Northwest European Loran-C System" project.



Prof. David Last holds a Personal Chair in the University of Wales and is Head of the Radio-Navigation Group at Bangor. He was awarded the university degrees of BSc(Eng) at Bristol, England, in 1961, PhD at Sheffield, England, in 1966 and a DSc by the University of Wales in 1995. Prof. Last is a Board Member of the International Loran Association, a Fellow and former Council Member of the Royal Institute of Navigation, a Fellow of the Institution of Electrical Engineers and a Chartered Engineer. He has published many papers on navigation systems, including Loran-C, Decca Navigator, Argos, Omega, Marine Radiobeacons, GPS and DGPS. He has acted as a Consultant on radio-navigation and communications to companies and to governmental and international organisations. He is an instrument-rated pilot and user of terrestrial and satellite navigation systems.

ABSTRACT

Loran-C receivers measure time delay differences in the signals they receive, compute differences of distance, and hence determine the user's position. The conversion from time to distance requires knowledge of the signals' velocities, which differ from seawater values when propagating over land. Precise positioning requires the delays of land paths to be accurately mapped, a procedure traditionally entailing expensive and time-consuming marine surveys. The resulting data, in the form of additional secondary factors (ASFs), may be stored in Loran receivers.

The authors, working under contract to the Co-ordinating Agency Office of the Northwest European Loran-C System (NELS), are investigating the feasibility of calculating ASFs from knowledge of ground conductivity values and adjusting the resulting data using sparse measurements only. These techniques, devised in North America a number of years ago, can now take advantage of the availability of GPS for position measurement and precise time transfer. In addition, the possibility of minimising the degree of specialised surveying by the use of automatically-operating equipment installed on ferries, buoy tenders, and other ships of opportunity is being investigated.

The NELS system, with its four Loran chains, operates under Time-of-Emission (TOE) control, so encouraging the use of modern receivers that work in cross-chain and master-independent modes or that combine Loran measurements with GPS pseudo-ranges. These

operational techniques demand Time-of-Arrival (TOA) ASFs which are substantially more difficult to measure than traditional Time-Difference (TD) ones. The research programme this paper describes seeks to determine the degree to which the novel techniques specified above can be employed to map ASFs across the 8 million square kilometres of the NELS coverage area in an efficient and economical manner.

1. INTRODUCTION

1.2 The Northwest European Loran System

The Northwest European Loran-C System (NELS) contains nine transmitter stations arranged in four chains (Fig. 1 and Table 1). Four stations, Bø and Jan Mayen in Norway, Ejde on the Faeroe Islands and Sylt in Germany were former United States Coast Guard (USCG) installations, transferred to their host nations on 31 December 1994. Lessay and Soustons were existing French military stations. The other stations, Vaerlandet and Berlevåg in Norway and the proposed station at Loop Head in Ireland, are new installations. NELS is controlled by a Steering Committee with representatives from the six member nations, Denmark, France, Germany, Ireland, The Netherlands and Norway. Non-member, but interested, parties such as the United Kingdom contribute as observers. To implement decisions taken by the Steering Committee, a Co-ordinating Agency Office has been established by the Norwegian Defence Communications and Data Services Administration (NODECA) acting on behalf of the Royal Norwegian Ministry of Fisheries. Each member nation has set up a National Operating Agency (NOA), an organisation which implements Loran-C policy and operations for that nation.

GRI	Master	Secondaries
7001	Bø	Jan Mayen, Berlevåg
9007	Ejde	Jan Mayen, Bø, Vaerlandet, Loop Head
7499	Sylt	Vaerlandet, Lessay
6731	Lessay	Loop Head, Sylt, Soustons

Table 1 NELS chains.

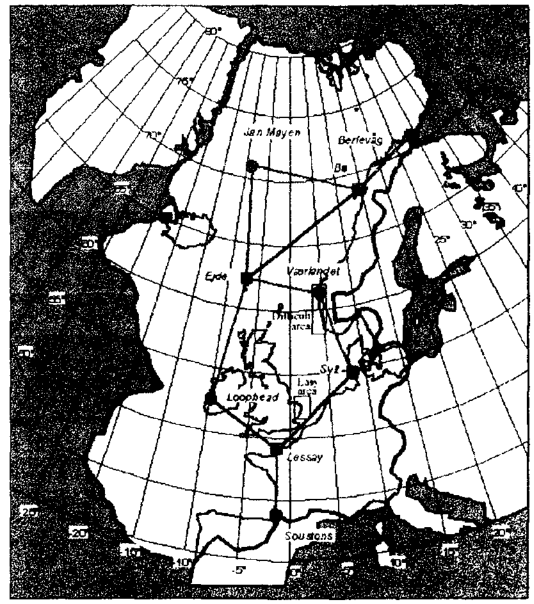


Fig. 1 Coverage area of NELS. Sea-trial areas are marked with rectangles.

1.3 Mapping ASFs

Loran-C receivers calculate their positions conventionally by measuring the differences in the times of arrival of pulsed signals from pairs of transmitters, so establishing hyperbolic lines of position. The speed of the ground-wave signals forming the components of each time difference varies according to the type of surface over which the signal travels; the key parameter is the electrical conductivity of the surface. Signals travel most slowly over ice, deserts or mountains, a little more quickly over good farming land and most quickly of all over sea-water. Further, velocity varies with distance from the transmitter in a complicated manner.

Loran-C receivers assume in the first instance that the signals they receive have travelled over sea-water paths. They use the USCG *Salt-Model* [USCG94] to compute their positions. The Salt Model assumes that the velocity of a signal travelling over sea-water consists of two components:

- The *primary factor velocity,* or velocity in the earth's atmosphere. This is determined by the speed of light (299,792,458 ms^{-1}) and index of refraction of the atmosphere, defined by the USCG as 1.000338.

- The *sea-water 'Secondary Factor versus Distance'*, the additional delay due to the signal's travelling over sea-water. The USCG employ the curve from NBS 573 [JOH56] that corresponds to a conductivity of 5000mS/m.

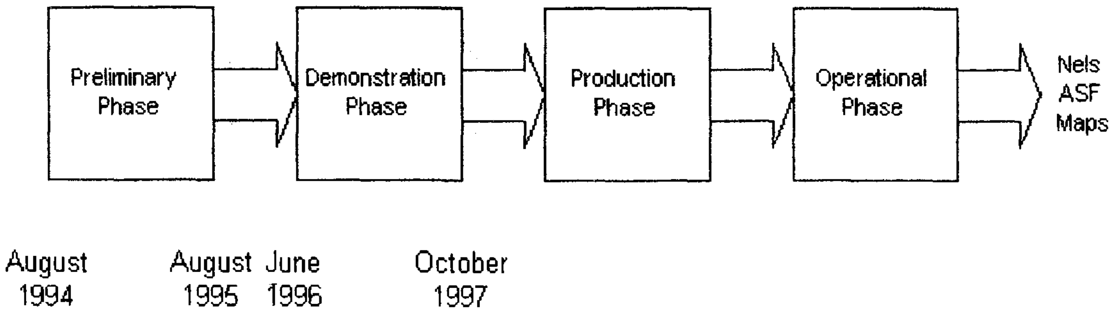


Fig. 2. The four phases of the Mapping ASFs for NELS project.

At this level, receivers know nothing of land masses. It is necessary, therefore, to determine the extra delays due to the presence of land along the transmission path if the published absolute accuracy of Loran-C (0.25 nautical miles or 463 m) is to be met. These land delays are the Additional Secondary Factors, or ASFs.

The simplest way to map ASFs is by measuring them using a survey vessel, or land vehicle. One measures the true position using surveying methods and the position determined by a Loran receiver; the differences are the ASFs. This is how it used to be done, but the method is slow and expensive. To cover an area the size of NELS could take as much as 1000 days and cost $5M. It would be more cost-effective if one could replace data measured in this way by ASFs computed from knowledge of the conductivity of the ground. The basic principle of the proposal for mapping the ASFs of the NELS area which we are exploring is to model the ASFs as far as possible, then calibrate the resulting values using a sparse set of measurement points. Further, to the maximum extent possible, these measurements will be collected by an automatic measuring system installed on ships sailing their normal routes.

2. HISTORY OF THE PROJECT

The main aim of this programme of research is to develop and validate a cost-effective way of mapping the ASFs of NELS. Developments in the computer prediction of ASFs during the early 1980s in the US and Canada [SPEIGHT82] [GRAY80], while not wholly eliminating the need for surveying, greatly reduced its contribution. We are attempting to extend their work, taking advantage of the most accurate position and time measurements available from GPS and employing automatic measuring equipment operating unattended.

The project is being conducted in the four phases shown in Fig. 2. The principal aim of the Preliminary Phase, carried out by the University of Wales and completed in August 1995, was to explore the feasibility of the proposed approach. It also specified the requirements for the Demonstration Phase and outlined the Production and Operational Phases. The subjects studied in the Preliminary Phase were the principles of ASF prediction, techniques for measuring ASF data automatically, and the use of GPS for precise time and position measurement. This Phase also laid down the principles for validating the results, recognising that ASFs are safety-critical data. Briefly, the recommendations for further development stemming from the Preliminary Phase covered the following work areas: arrangements for using GPS to measure position and time of arrival; modelling ASF predictions; methods for combining ASF predictions with measured ASF data; and the choice of publication format for the ASF data.

In the current Demonstration Phase the work has been split into a hardware and a software component. The University of Wales is responsible for demonstrating the feasibility of modelling ASFs, calibrating them using measured data and storing the results in a convenient publication format. Geometrix, a Norwegian company specialising in radio communications and navigation equipment, are responsible for demonstrating the ability to measure TOA ASFs. Their equipment, currently the size of a desktop PC, will eventually be further developed so that it is suitable for unattended operation on ships that travel around the NELS area. If this approach proves feasible, the cost to the National Operating Agencies of calibrating the ASFs will be greatly reduced, by eliminating the need for survey ships with their specialised manpower.

The Demonstration Phase is a proof-of-concept operation. If successful it will demonstrate, and also quantify the success of, the process of modelling ASF values and calibrating those values using measured data. The modelling and measurement operations will cover two test areas: a so-called *easy area,* which is essentially smooth, and a *difficult area* with the additional problem of mountainous terrain. The measurement programmes in these two areas will record data at many more points than will be the case in gathering calibration data once the system has been developed and validated. This very detailed data will be used to optimise the algorithms employed in the computer ASF model being developed. Technical recommendations and resource estimates for the Production and Operational phases will be produced at the conclusion of the Demonstration Phase.

If the Demonstration Phase is successful, a decision will be made to proceed to the Production Phase in which the hardware and software for mapping the NELS ASFs will be produced. The measuring equipment will be made user friendly and capable of unattended operation. The software for modelling ASFs and combining them with measured data will be further developed and validated. The scope of the model will be expanded from the Demonstration Phase test areas to the full NELS coverage area. The work plan for the Operational Phase will be revised and updated and cost estimates prepared. In the Production Phase there will be considerable emphasis on the quality control of the ASF mapping methodology.

In the Operational Phase the measuring equipment will be sent into all areas for which NELS NOAs are responsible. The ASF data will be processed, either country-by-country or by a central bureau .

Originally, the Production and Operational Phases were intended to run consecutively (as in Fig. 2); however in late 1996 NELS decided that, because the need for ASF data was becoming urgent, the two phases should run in parallel, as far as practicable. Thus, software development and survey planning will take place alongside the initial surveys – and benefit from the added data and experience they provide.

3. TYPES OF ASF

Certain types of Loran receiver operate in the *circular mode* rather than the conventional hyperbolic mode. They measure the *Times of Arrival* (TOAs) of the signals, and create lines of position which are circles around the transmitters. The ASFs such receivers required are *time-of-arrival ASFs;* that is, the ASF of the paths from the individual Loran stations. ASFs produced previously have almost always been *Time Difference (TD) ASFs*, that is, the ASF components of the time-difference measurements between the signals from pairs of stations that generate hyperbolic TD lines of position.

Table 2 summarises the ASF requirements of various types of Loran-C receiver. It was in order to facilitate the more advanced modes of operation that the decision was taken in developing NELS to employ Time-of-Emission (TOE) chain control, rather than the traditional Service Area Monitor (SAM) technique. If receivers are to take full advantage of TOE control, they require TOA ASFs. TD ASFs can, of course, be calculated by differencing pairs of TOA ASFs. Further, the model for computing ASFs works station-by-station and so generates TOA ASF. Thus TOA measured ASF are required to calibrate the results. Although it is possible for the model to compute TD ASFs. When calibrating them using measured values it is impossible to ascribe the total delays to the two paths that contribute to them. For all these reasons, TOA ASFs are much more attractive to those modelling, calibrating and publishing ASF data.

However, TOA ASFs have one major disadvantage; they are very much more demanding to measure than TD ASFs. A receiver that measures the times of arrival of Loran signals is vulnerable to errors because of the uncertain time delays between the antenna and the time measurement point. TD receivers eliminate these errors since they are common to the two times of arrival the differences of which are calculated. A TOA receiver requires some means of determining and eliminating these receiver delays. Further, the times of arrival must be measured against some precise absolute time reference. The expense and inconvenience of carrying caesium standards prohibit their use for this purpose in the proposed automatic ASF measurement system. Finally, in order to compute TOA ASFs, the TOEs of the Loran pulses from the transmitting stations must be known with equal precision, and against the same time reference, as the TOAs.

These problems were identified and analysed during the Preliminary Phase. Several companies in Europe had developed TOA receivers. One, Geometrix, claimed to have a TOA measurement package sufficiently small and light to encourage the expectation that it could form the basis for an automatic receiving package. The time reference it employed, however, was GPS. Because of the effects of Selective Availability, the precision of the resulting TOA measurements – of the order of hundreds of nanoseconds – was insufficient for ASF use. It was realised, however, that since the ASF data was not required real time, it would be possible to correct the SA (and certain other) time errors post-mission, using single-point precise orbit and time data. A proof-of-concept trial showed that this technique could yield time precision of the order of a few nanoseconds. The Time of Emission data required for ASF use is collected routinely by the NELS control centre at Brest, France. It remained only to align the time reference at Brest with GPS time for all the elements of a potentially successful measurement package to be in place.

Mode of Operation		ASF Requirement
Stand-alone repeatable mode		Not required
Single-chain hyperbolic		TD only
Stand-alone independent mode	Cross-chain	TOA
	Master-independent	TOA
Land mobile		TOA, but at base station
Loran-C to check GNSS integrity		TOA preferably
Loran-C to enhance GNSS availability and continuity	Integration of positions	GNSS-derived ASFs possible
	Integration of pseudo-ranges	TOA
Eurofix	DGNSS broadcasts	Not required
	Other modes	ASFs required as above

Table 2 ASF requirements of various types of Loran-C receiver.

The TOA ASFs to be measured may be thought of as the small differences between the Times-of-Flight (TOFs) of the signals from a transmitter to the receiver and the corresponding values calculated using the Salt Model, that is, assuming an all-sea path. The TOFs are themselves the differences between the TOA and TOE values recorded:

$$TOF = TOA - TOE$$

TOA ASFs are then computed from the TOF data by:

$$TOA\ ASF = TOF - T_{Vp} - T_{SF}$$

where T_{Vp} is the primary velocity delay, the extra delay imposed on the signal over the speed of light in a vacuum when the signal propagates through Earth's atmosphere,. It is computed from $\frac{C}{\eta}$ where C is the speed of light in vacuum and η is the refractive index of the atmosphere. T_{SF} is the Secondary Factor delay, the extra delay imposed on the signal due to its propagating over sea-water.

4. ASF MODELLING

The authors have written a suite of computer programs to compute maps of TOA ASF values. The programs calculate the values at each point in large arrays of points uniformly spaced in latitude and longitude and covering the area of interest. The conductivity variations along the Great Circle path from a transmitter to each array point in turn are determined and a *path conductivity profile* created. The source of the conductivity data is primarily the digital database, derived from [CCIR88] and other sources, developed at the University of Wales and used previously for predicting the coverage of the NELS system. For ASF modelling, however, the points at which the path crosses coastlines need to be known more precisely; this information is extracted from the World Vector Shoreline Database [DMAWVS88]. The modelled ASF of the path is then computed using the Millington-Pressey algorithm [MILL49] [PRESSEY52] and published Secondary Factor delay curves.

The process just described assumes a smooth inhomogeneous Earth. In ground-wave propagation the signal hugs the surface of the ground. Where the path crosses elevated ground, and especially mountains, additional delays are experienced. The effects are very complex to analyse. As a first approximation it may be assumed that the additional delay is that due to the additional path length corresponding to piece-wise linear paths from the transmitter to the receiver across the mountain – the length of a piece of string stretched tightly from the one to the other. Fig. 3 Shows the effect of the additional path length, over the horizontal distance to the vessel, when the vessel is near a cliff. Delays of this nature were first observed near Vancouver by the Canadian Hydrographic Service [MORT78], and the extra path length theory has been used successfully by the present authors to calibrate the UK Hyperfix system.

The Bangor ASF model employs the Digital Terrain Elevation Data Level 1, a database of precise terrain data published by the US National Imagery and Mapping Agency. The data is approximately equivalent to the contour information on a 1:250,000 scale map. Sample points are approximately 100m apart. The Bangor model computes the additional delay of each path that crosses elevated terrain, having first determined whether the terrain variations are sufficient to cause significant delay.

5. TEST AREAS & SEA TRIALS

The Demonstration Phase sea trials have been conducted in an *easy area* and a *difficult area* (Fig. 1). The easy area, off East Anglia, part of the coastline of the UK, enjoys paths from four transmitters along which there are no significant additional delays due to terrain variations. Sailing routes were designed to allow ASFs to be measured along paths radial to various transmitters. The ship followed these routes out to sea from close to the shoreline, allowing the so-called ASF coastal recovery effect to be explored. This effect is a gradual reduction with distance from the shore of the ASF built up over a land path. The ship also sailed along tracks circumferential to a transmitter at various distances from the shore, so allowing in-shore and off-shore ASF values to be compared. The trial took place in May 1997, ASF data being collected using the Lessay, Soustons, Vaerlandet and Sylt stations.

The difficult area was chosen to display the effects of terrain variations. The test region, on the west coast of Norway (Previous Fig.), is characterised by a complex coast-line, fjords, and mountainous cliffs – the area is probably the most difficult within the NELS coverage! The sea trial was conducted in April 1997, ASF data being collected using the BØ, Vaerlandet, Ejde, Jan Mayen and Sylt stations. Sailing routes were designed to demonstrate the effect of irregular terrain on the delays of the transmitted signals, particularly the sudden changes in ASF as the vessel passes large mountainous islands and travels along fjords.

At the time of writing the authors are awaiting the data recorded during the two sea trials. The data sets will contain post-processed GPS positions, times, and TOF values. Built into the test programme are a series of periods when the survey vessel was at static location in harbour or at sea. The records for these periods will allow the stability of the data to be assessed independent of the vessel's motion, and its repeatability to be determined over the period of the trials. Also included are test manoeuvres designed to reveal any dependence of the TOA measurements on the vessel's orientation with respect to the paths from the transmitters.

6. ASFs GENERATED BY THE MODEL

ASFs have been modelled for the *easy* and *difficult* survey areas. Fig. 4 shows the map of Sylt ASFs. Fig. 1 shows the transmitter location, ENE of the easy area. The paths to most of the sea areas lie solely over sea water, with ASFs of less than 20ns contributed solely by the

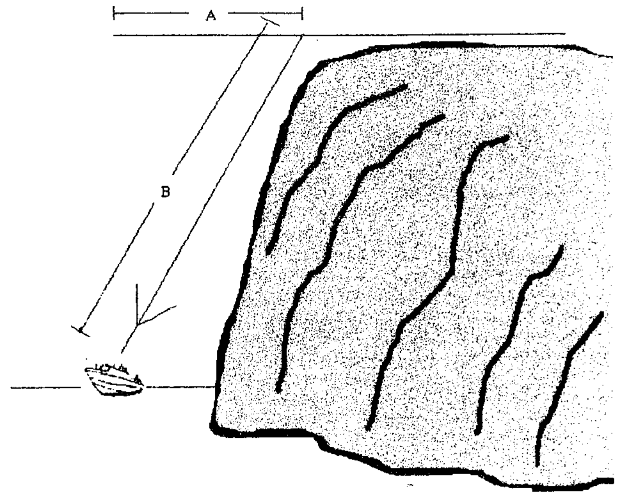


Fig. 3. The extra delay, over the horizontal distance to the vessel from the transmitter, is approximated by the extra path length (B-A).

short land paths between the Sylt station and the shore of the island on which it stands. ASFs can be seen building up once the signal has crossed the coastline. The maximum value is 490ns. Fig. 5 shows the ASFs of the Lessay signals which vary from 400ns, for paths largely over sea, to 1.4μs where there are long land paths. An example of the coastal recovery effect may be seen off the northern coastline of the East Anglian peninsula.

Fig. 6 is a map of the ASFs of the Ejde throughout the difficult area, predicted by the model. Ejde lies to the west of the area and the ASFs off-shore are again close to zero. The combination of the extremely low land conductivity of Norway and the additional delays due to its mountains leads to the rapid build up of the ASF which reach a maximum value of 3μs.

7. CALIBRATION OF MODELLED ASFs USING MEASURED DATA

In an ideal world ASF maps would be produced by the computer model alone. Unfortunately, the model is incapable of producing results of sufficient accuracy. The principal limitations are the inadequate precision of the ground conductivity data and the use of one-dimensional empirical techniques for computing the ASF values (see Section 6).

The calibration process assumes that the measured data is the truth and adjusts the model (or the data it produces) to fit the measurements [SPEIGHT82] [ENGE88]. The ASF model generally predicts the shape of the ASF surface fairly accurately, leaving the calibration process to minimise bias errors. The approach we are adopting initially is to force-fit the results of the model to match the measured data. An alternative principle, which may be investigated later, is to adjust the parameters such as ground conductivity, employed by the model so that the results and data agree.

Also being developed are techniques which extend the validity of measured data points over the maximum area, so maximising the separation between adjacent points at which measurements must be taken. Such techniques include the use of distance weighting methods and more sophisticated techniques based on understanding of the propagation characteristics of low-frequency radio signals and their resulting ASFs.

The performance of the calibration process will be quantified, and the density of calibration points required minimised, using the data collected in the Demonstration Phase sea trials.

8. LIMITATIONS OF THE PRESENT MODEL

The methods used for determining ASFs at Bangor are one-dimensional approximations [SAM79] employing a database of ground conductivity values. These methods are straightforward, but have limitations:

- Propagation is assumed to take place along infinitely narrow Great Circle paths from the transmitter to the receiver.
- Conductivity variations perpendicular to the propagation path and refraction effects at conductivity boundaries are ignored.
- Signals travelling over sea paths parallel to an adjacent coastline are known to accrue ASFs, which these methods fail to model.

In addition, the Millington-Pressey algorithm produces results which mimic the coastal recovery effect but it does not model the phenomenon accurately. The model we have adopted initially is at best a first-stage approximation of the complex propagation of signals over irregular terrain.
The authors have held discussions concerning these techniques with Makarov & Pylaev of the Institute of Radiophysics, St. Petersburg, Russia, workers who have great experience in the subject [GORSHENEV81] [PROSCURIN81] [GLUMOF90] [PYLAEV91]. It is hoped that a collaborative programme of research can be organised, aimed at generating the most precise ASFs possible, so minimising the requirement for measuring ASFs in the NELS area.

9. ASF DATA PUBLICATION FORMAT

During the Preliminary Phase, Loran receiver manufacturers were asked to specify their preferences for the format in which the NELS ASF data should be published. The preferred method was in grid format. ASF storage in the receiver needs to be compact and efficient. Options include arrays, with densities that are uniform, or non-uniform to allow greater detail in coastal areas where ASF values change most rapidly. An alternative approach is to model the two-dimensional ASF surface for each station using a two-dimensional polynomial representation. Changing between one publication or storage format and another is a fairly straightforward computational task.

10. SUMMARY

The NELS ASF mapping project is being conducted in four phases. The principal objective of the current Demonstration Phase, due for completion in the near future, is to demonstrate an ability to predict ASFs by computer and calibrate the results using sparse measured data., the results being stored in a convenient and economical format. This phase is also designed to generate technical requirements and resource estimates for the subsequent Production and Operational Phases. The NELS programme is based upon the use of TOA ASFs. The model used in the Demonstration Phase employs widely-accepted techniques capable of further development. Two field trials have been conducted employing a novel approach to the challenging problem of measuring TOA values and, at the time of writing, the results are awaited

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Q: I see better results over land by ignoring Millington's method and doing a direct calculation.

A: Yes, you will, as long as there are not land-water interfaces.

Q: What about seasonal effects?

A: We have to characterize how rainwater is absorbed by the various land areas., and we have to look at changes in seawater salinity, for example.

Q: Is ECD related to ASF?

A: The same parameters seem to be at work in both cases. See an ILA paper [from Prof. David Last] about 3 years ago relating the two.

Q: I note that changing ASFs changes waypoints previously recorded!

A: That is not a real problem in Europe. There are not many users. Remember, loran is brand-new in Europe!

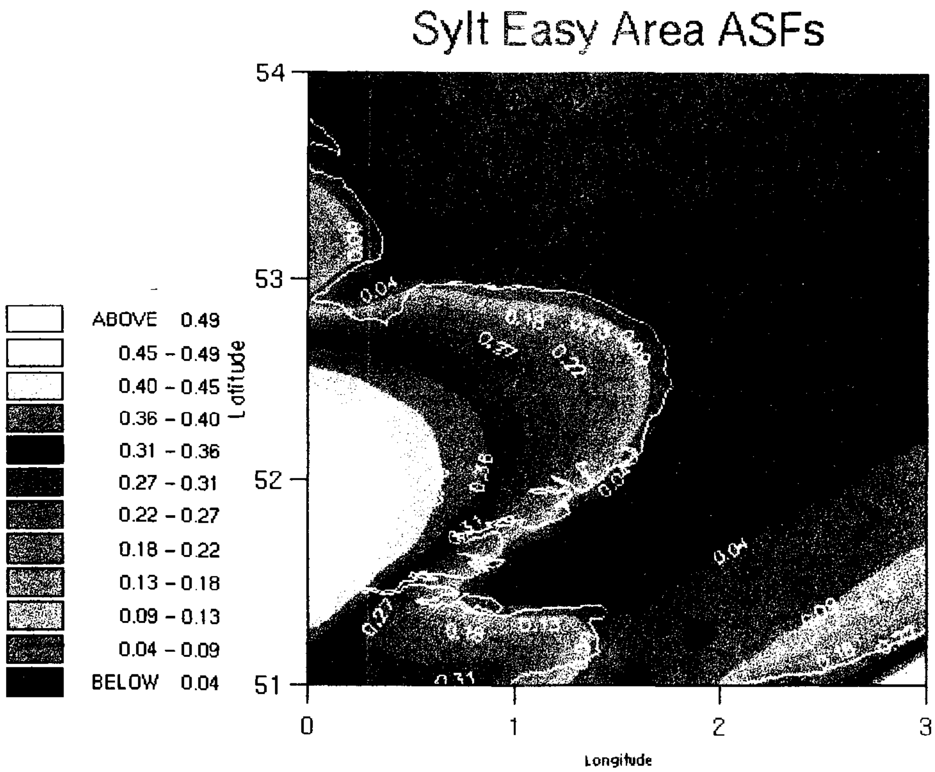

Fig 4. Sylt *easy area* modelled ASFs. The station lies ENE of the test area (Fig. 1)

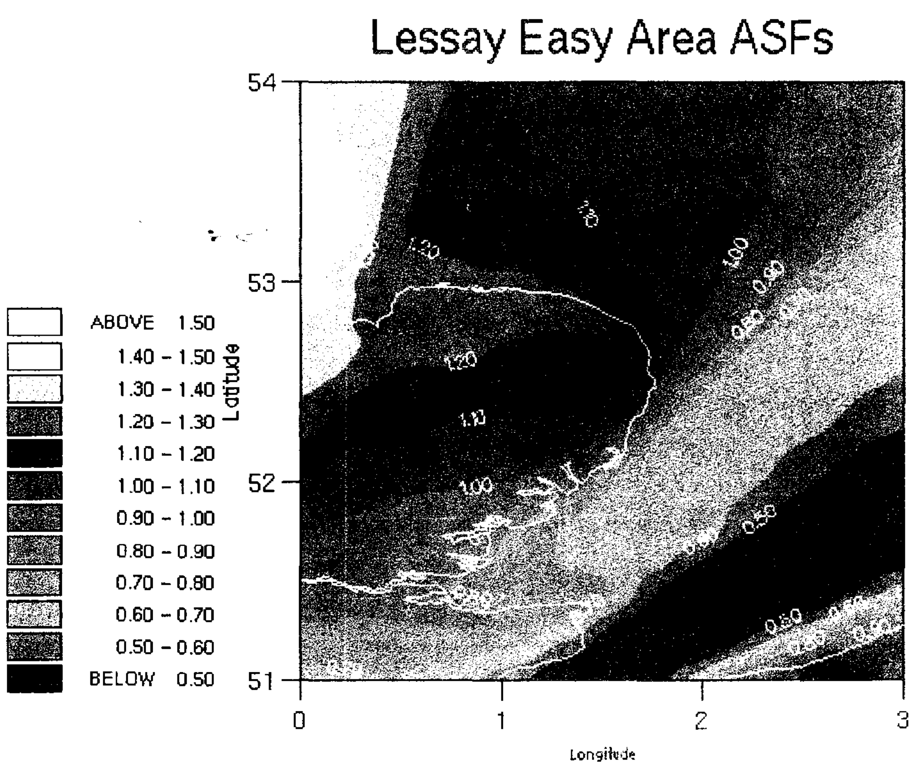

Fig 5. Lessay *easy area* modelled ASFs. The station lies WSW of the test area (Fig. 1).

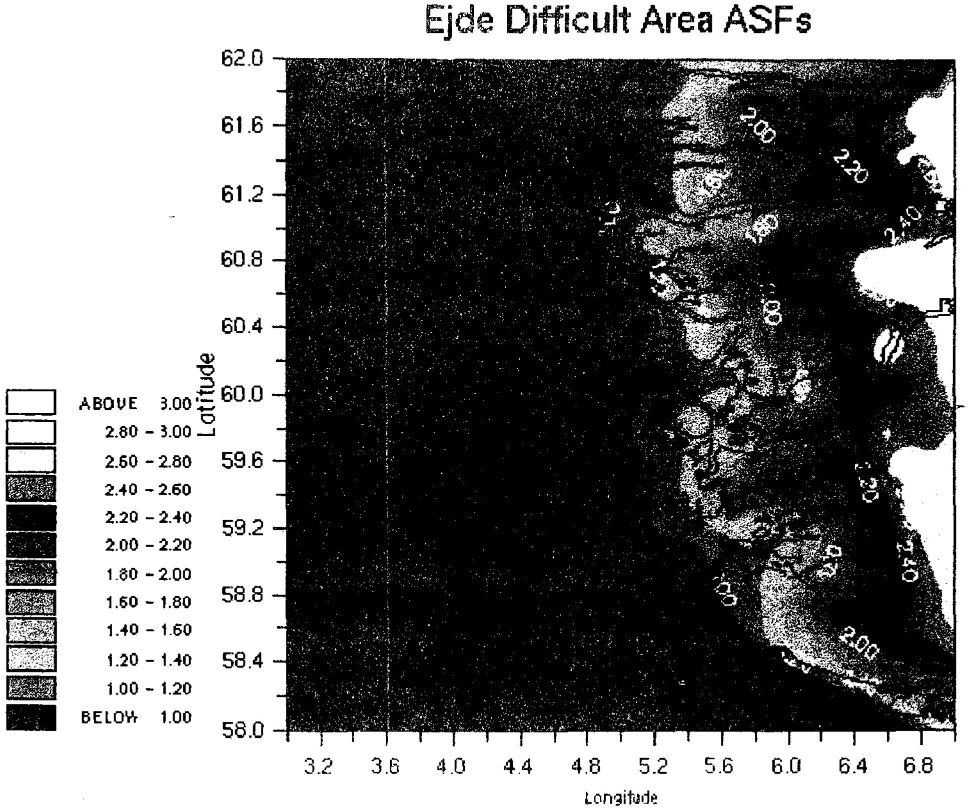

Fig 6. Ejde *difficult area* modelled ASFs. The station lies W of the test area (Fig. 1).

UTC SYNCHRONIZATION SYSTEM

by William F. Roland
Megapulse, Inc.

BIOGRAPHY

Bill Roland is a long-time participant in all aspects of Loran. He brings a unique mix of government service, business experience and international contacts to the WGA. He is a 1956 graduate of the USCG Academy and received a Masters in Electronics Engineering from the U.S. Naval Postgraduate School in 1963.

In thirty years of U.S. Coast Guard service he was Commanding Officer of a Loran-A station in the Philippines; System Engineer for the installation and operation of the Southeast Asia Loran-C chain; and Section Commander for the Northwest pacific and Commando Lion Chains. He has also served as Loran-C Branch Chief and as Commanding Officer of the USCG Electronics Engineering Center at Wildwood, NJ. Additionally, he was System Development (Loran-C) Branch Chief and Electronics Engineering Division Chief at Coast Guard headquarters.

He retired from Coast guard service in 1986 and remained in Hawaii for six years. While in Hawaii he managed power plant system sales for an industrial sales organization until an opportunity came up to join Megapulse as Vice President for Program Manger. In October, 1992 he was named President of Megapulse, Inc.

ABSTRACT

The UTC Synchronization System (USS) is a unique computerized system developed to significantly improve Loran-C time synchronization. The USS functions include high precision synchronization of Cesium Standards (CS) to a reference source, which may be either the GPS constellation master clock, or (by using GPS time transfer techniques) a primary time reference station. The Loran-C signal is then controlled to assure that the Loran-C epoch is precisely synchronized with the defined time-of-conicidence (TOC) for the operating rate. After system initialization and the CS has settled, the Loran-C epoch synchronization will be within ±8 nsec.

The purpose of Loran-C synchronization is to provide a regional precision time and frequency reference distribution service, and to permit precision integration of GPS and Loran-C radionavigation service. This results in navigation service availability two orders of magnitude better than can be provided with either Loran-C or GPS alone. Other recent advances in Loran-C utilization add the capability of differential correction and integrity messaging services for both navigation services.

OPERATING CONCEPT

The GPS constellation clock is maintained to within 15 nsec of UTC as defined by the US Naval Observatory Master Clock [1]. The constellation clock is the mean of all the individual satellite clocks in the constellation. GPS timing receivers provide a 1PPS output which is synchronized to the mean instantaneous time of the satellites being tracked. Because not all satellites can be tracked simultaneously, and because of the variations of selective availability and ionospheric effects, estimates of the actual GPS master clock epochs must be derived from long term (2 to 5 day) averages of the difference between the GPS timing receiver output and the local reference. Only a cesium standard is sufficiently stable to permit such long term averaging. In fact, all Loran-C transmitting stations are equipped with two cesium standards, making it possible to modify a station for GPS timing synchronization, without expensive refitting.

The USS uses two computers each equipped with a precision time interval counter card, to make measurements of the difference between each of two GPS timing receiver's 1PPS and the associated cesium standard every six seconds. The computers check the data for anomalies (and provide fault actions for such conditions), and then generate one minute averages which are stored for record purposes and for generating cesium control data. The one minute averages for a two to five day period (the period is selected at setup) are processed to create a linear least squares estimate (LLSE) of the cesium's end of period time offset (epo) and mean frequency offset for the period (mfo). The corrected frequency offset (corfo) is the algebraic sum of the current cesium frequency offset and the mfo. The closing frequency offset (clofo) is the algebraic sum of the corrected frequency offset and the additional offset required to reduce the epo to zero in 48 hours. The frequency offset computations are made and commands sent to the cesium's microsteppers once daily, at 0000 hours. This ideally results in the epo being reduced to one half its previous magnitude each day, asymptotically approaching zero epo and zero clofo. The corfo then equals the GPS master clock frequency, and the cesium standard is synchronized. The standard deviation of the day-to-day epo's is less than 5 nsec. If a Primary Time Reference Station is to be the reference for time control, then data on the PTRS-GPS is used to compute the correction for each measurement of CS-GPS. The correction is added to each six second observation and the resulting combined error measurement used to compute corfo, epo and clofo.

EQUIPMENT

The USS timing control rack (TCR) is designed to be installed at a Loran-C transmitting station in close proximity to the timing equipment. The TCR takes signals from the CS and the Loran-C timer for the purpose of measurement and control computations. It then controls the frequency of the CS to synchronize it to the external reference, and monitors the Loran-C time-of-transmission to assure continuing precise signal synchronization to the CS. This is accomplished in such a way that the transmitter timing equipment functions are unchanged from operation without the USS, and therefore, equipment failures in the USS do not directly effect Loran-C signal availability or timing accuracy. See Figure 1.

The TCR consists of two sets of Timing Control Computers (TCC). Each set is associated with one of the two timers on the Loran-C station. A TCC set includes a GPS timing receiver, an IBM-compatible PC, a CS timing signal distribution amplifier and an uninterruptable power supply. Each TCC receives Loran-C timer PCI triggers synchronized to the antenna current, and CS 10MHz and 1PPS signals, from the existing station timing equipment. In the TCR, there is only one set of keyboard, mouse and video monitor, with a selector switch which permits them to be assigned to either TCC.

The USS also includes a Watchstander Monitor Computer (WMC) which operates as a network workstation for both of the TCCÆs, which are each considered servers for operating system purposes. The WMC is also an IBM-compatible PC with network interface, dial-up modem, keyboard, mouse, video monitor, UPS and printer.

OPERATING SYSTEM

The operating system is Windows NT, version 4.0. The network may be setup using Eithernet cards or using RS-232C and the remote access server (RAS) function of the operating system, depending on the existing site communications wiring. NTÆs security functions are used to limit control parameter access to only those with administrator or maintenance user-names and passwords. The startup routines are set, so that on power-up, the user logon is automatic and the application software starts, without operator intervention.

APPLICATION SOFTWARE

The TCC application software consists of the TCC Monitor the TCC Measurement System and the TCC Maintenance Service. The TCC Measurement System runs continuously at the highest priority, makes all timing measurements, computes CS control commands, analyzes cesium and Loran-C timing errors and makes data available to the display software for video display, alarms, and reports. The TCC Monitor provides for the display of data at the TCC and provides the various alarm functions. The display is shown below.

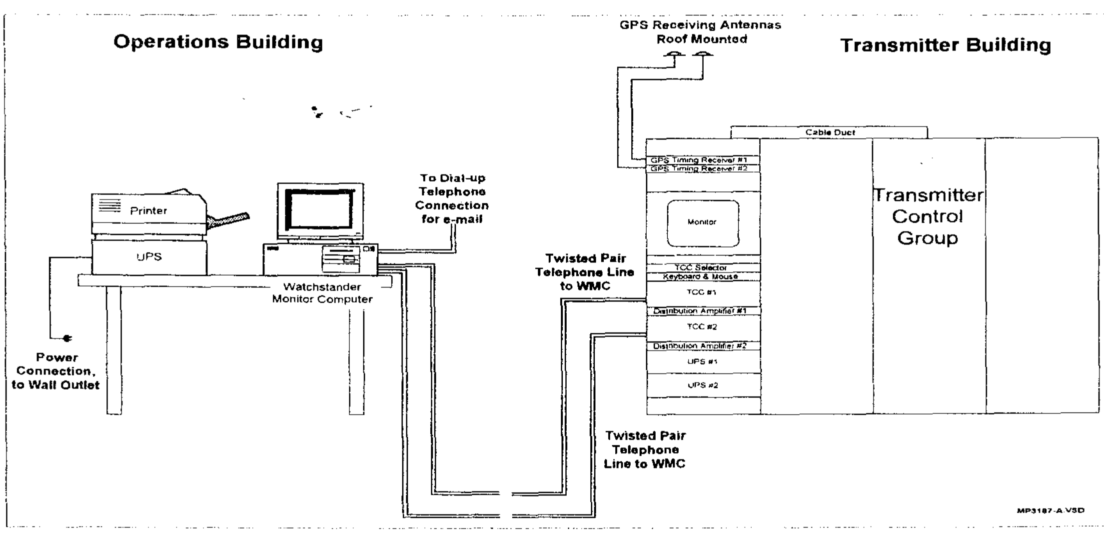

Figure 1. General Layout of UTC Synchronization System Equipment

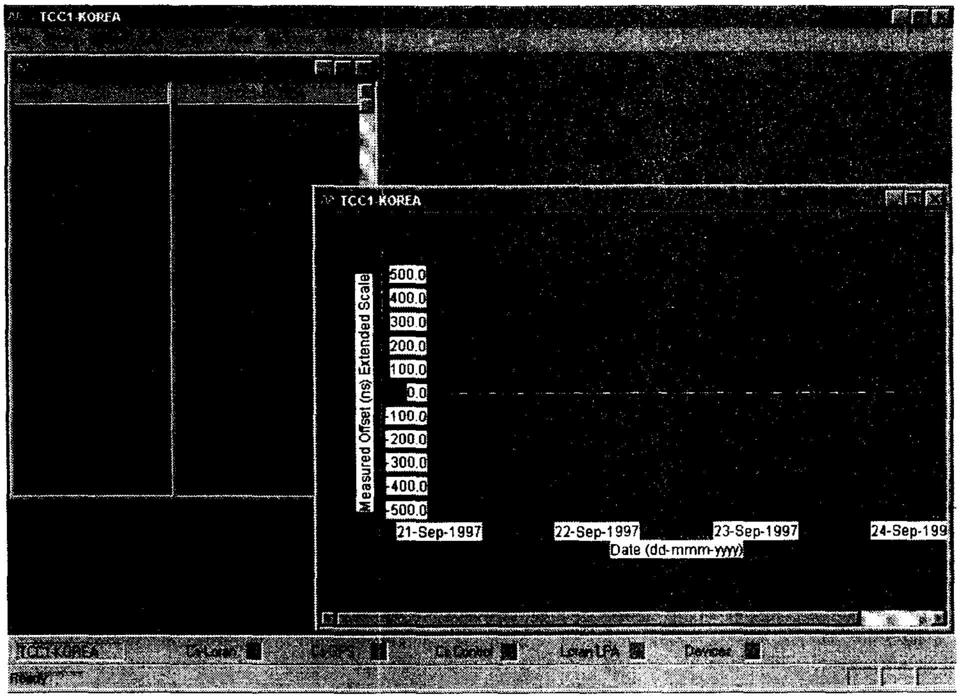

Figure 2. TCC Monitor Screen

The data displayed includes the current 6 second Cs-GPS (or Cs-Reference Station) error, the past 1 minute average error, the average error over the number of days currently used for averaging (in this case, 3 days), and the number of outliers observed this day. Outliers are error measurements which exceed the outlier threshold (300 nsec here), and are used to detect faulty equipment operation. The next group of data are observations of the Loran-C time of transmission error, including the current 6 second measurement, the previous minute average, the previous day average, and the number of outliers. The outliers are considered any measurements over 50 nsec. In the third group of data, the current observation of reference station data, slope and intercept, the cesium offset observed at the end of the previous day, as computed from data observed over the previous three days, the corrections to the cesium standard required first to reduce the rate of change of errors to zero (slope correction) and second to reduce the end of period offset to zero in 48 hours. The net cesium offset command is displayed next followed by the actual command accepted by the cesium. The last two displayed data items are the recommended Local Phase Adjust, to reduce any transmitted phase errors, and the status of devices, such as the GPS timing receiver, cesium standard, and communications devices.

The graph is a continuous set of 4 hour running averages of the one minute averages over the past three days, showing in this case that the cesium offset error is slowly being reduced by the control software. The graph scale may be changed to ±50 nsec full scale.

At the bottom of the screen are five alarm lights, which draw the operator's attention when there is an alarm condition. Green means no alarm, yellow is warning, orange is alarm, and red is critical alarm.

Note that the TCC's are designed to operate without operator intervention. All necessary information is relayed to the Watchstander Monitor Computer, where the operator is expected to take action when an alarm is displayed.

The TCC Maintenance Service screens are shown in Figures 3 through 10. The program is available to make changes to the operating parameters, such as cable delays and error levels for various alarm conditions. Also the TCC Graphical User Interface Maintenance screen is available to change the number of days on the graph and the running average period. Note that some parameters require that the software be restarted to change the displayed information. Restarting the software will restart the measurement program, which will require allowing at least 3 days for the computation of the cesium slope and offset to be valid for control. Future software versions will remove this limitation.

The Watchstander Monitor Computer application software receives data from each TCC once every six seconds, with additional data sent for one minute averages and for daily data. The six second data provides for alarm decisions and for communications link testing. The WMC displays the data from the TCC's and provides graphs of the performance of the system. Additionally, the WMC includes the Internet services needed to retrieve the reference station data on the GPS constellation clock. The operator establishes the Internet link and downloads the data set. The WMC software detects the downloaded data by its file name which includes the date. The WMC then computes the new slope and intercept, and sends the resulting data to the TCC's. The WMC also provides daily reporting services which summarizes events in the TCC's, and also includes a printout of the graphic plot of system performance.

The design is such that the operation of the TCC's is not dependent on the WMC. If communication is lost, the WMC waits for the service to be restored, and retrieves the data belatedly. If the WMC is shut down, no data is lost, but on restart, the graph and display only show newly retrieved data.

OPERATIONAL PERFORMANCE

The TCC's each measure and control a Cesium Standard and monitor the time of transmission of the Loran-C signal to assure that it remains synchronized to the Cesium Standard. The two operations are separate, in that

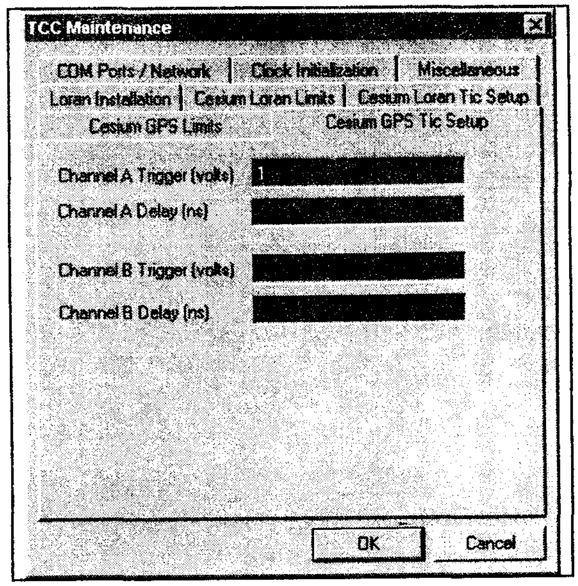

Figure 4: Cs-GPS TIC Setup

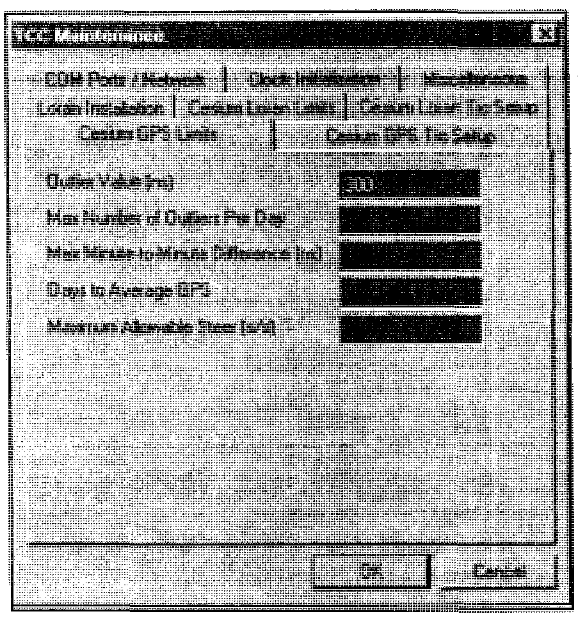

Figure 3: Cs-GPS Limits

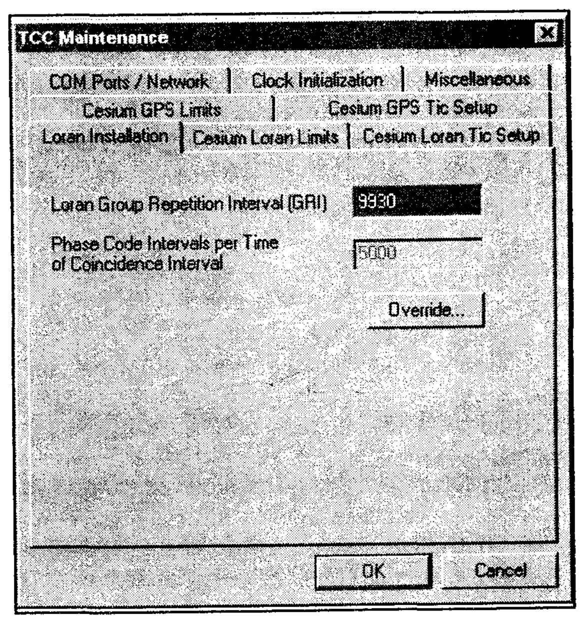

Figure 5. Loran Installation

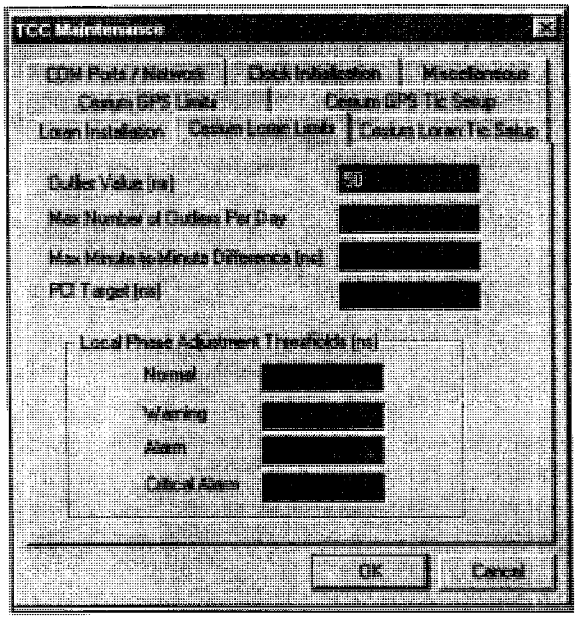

Figure 6. Cs-Loran Limits

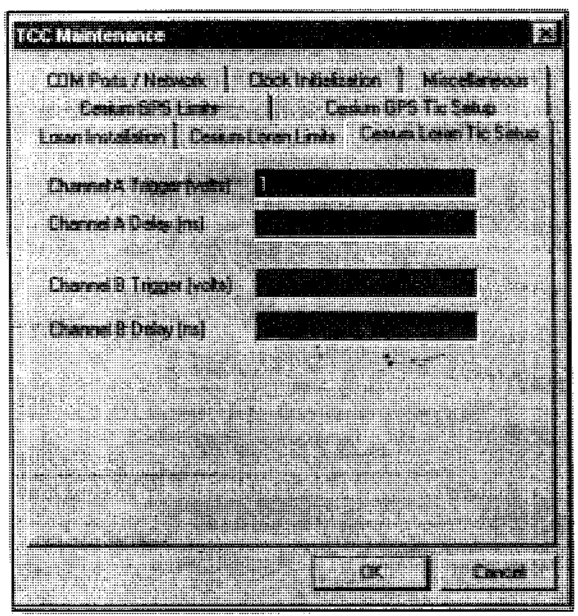

Figure 7: Loran Installation

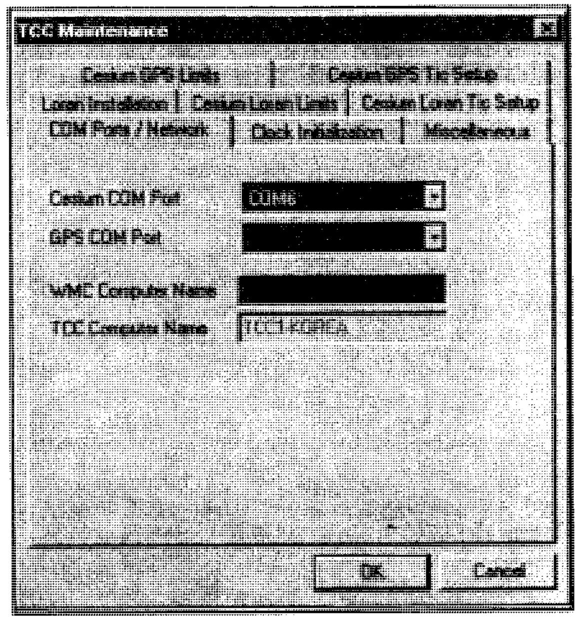

Figure 8. CommPort & Network Setup

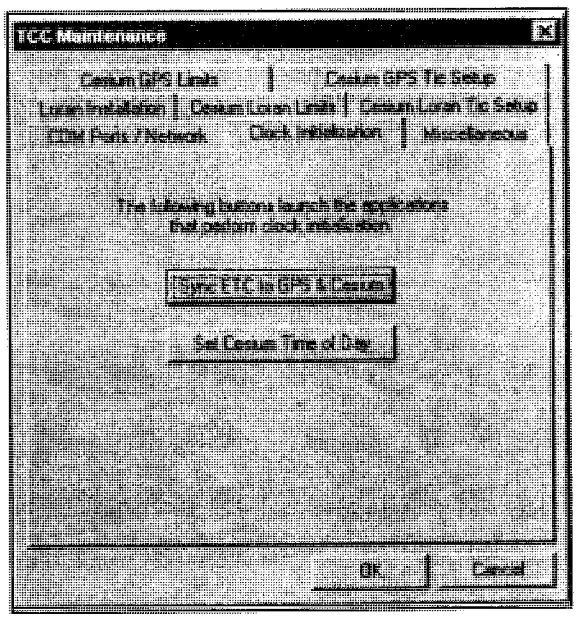

Figure 9. Clock Initialization

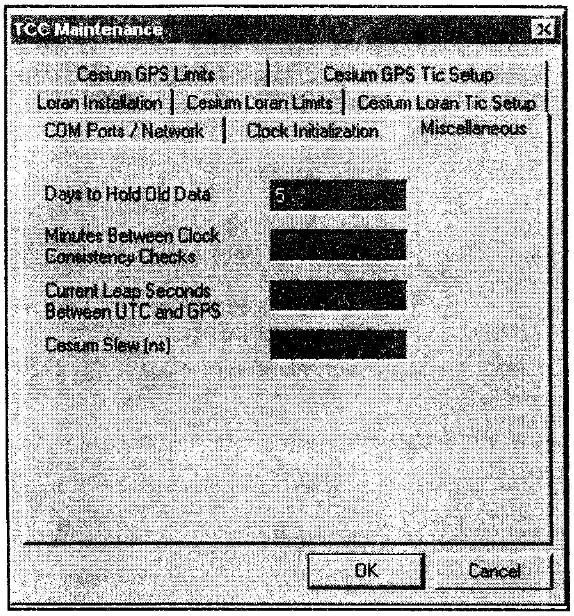

Figure 10. Miscellaneous Settings

the control of the Cesium is carried out without need for the timer, and the Loran-C signal monitoring with respect to the Cesium is done without concern for the operation of the synchronization to the external standard. There are numerous alarms to notify the operator of the loss of functions, but they do not interfere with the other operations.

Each of the TCC's operate independently of each other, including even the use of separate Uninterruptable Power Supplies. This permits complete servicing of either TCC or its associated timer without effecting the operation of the other.

The synchronization of the Cesium Standard to an external standard, such as KRISS or USNO, is accomplished by continuously measuring the offset between the CS and the GPS signal, and correcting the observed offset for the predicted offset observed at the primary reference site. If no primary reference site is identified, the synchronization is to the GPS master clock. The CS frequency is steered by the offset errors so as to minimize both the time and frequency offsets. After settling, the system will synchronize the CS to within 8 nsec of the external reference.

The TCC also compares a timing reference from its associated timer, and determines the Loran-C offset error to within about 2 nsec. The measurement is compared to various error thresholds, and when the error exceeds those thresholds, advises the operator of the error and recommends LPAÆs to correct to error. If in any 6 second measurement the TCC detects a timer jump, it immediately initiates blink, or advises the control operator to initiate blink and/or to change timers, depending on the operating doctrine.

Chain control character changes somewhat, in that if the USS is installed at the master station, the secondary stations immediately notice any changes in the operating frequency of the master station CS's. As a result, there are generally additional LPA's required at the secondary stations. These can be minimized by making changes in the secondary station cesium standards which cause them to experience the same frequency offsets as the master, and allowing them to track the master station closely, without excessive LPA's. Should the USS be installed at the secondary stations as well, the need for LPA's will be reduced to a minimum, and may even be eliminated, depending on the chain control scheme utilized.

In general, chain communications will be significantly reduced by UTC synchronization, bringing with it a substantial reduction of operating cost. The USS has established a new standard of performance for Loran-C systems which will greatly improve service to the users of both radionavigation and timing applications. The USS also allows the development of integrated GPS and Loran-C user equipment.

PROCESS DETAILS

- Time Conventions

Within the USS, time is defined by three different conventions: Coordinated Universal Time (UTC), International Atomic Time (TAI), and GPS time. UTC and TAI are identical clocks in that their 1 seconds epochs are coincident. However, UTC is adjusted by inserting leap seconds at times designated by the international time coordinating body, BIPM in Paris, France. By agreement, the UTC and TAI clocks were coincident on 1 January 1958. Since then, as of 1 July 1997, there have been 31 leap seconds, resulting in TAI being 31 seconds ahead of UTC. This is significant because Loran-C time is defined such that all Loran GRI time references were conidident with the 1PPS of 00:00:00 1 January 1958. The Loran-C rates are governed such that all future conicidences of GRI time references and 1PPS are based on the TAI time.

To further complicate the time references, GPS time is reckonned from the UTC time of 00:00:00 on 6 January 1980, at which time there were 19 leap seconds difference between the TAI and UTC clocks. GPS time is defined such that the GPS clock reference is offset from TAI by 19 seconds, and there are no leap seconds applied to the GPS clock.

The USS measurement program reads the GPS time and the UTC time from the GPS Timing Receiver. Within the TCC computer there is a special clock card (Event Timer Card, ETC) which uses the cesium standard 10 MHz frequency input to assure stability and synchronization with the CS. Further, the 1PPS of this ETC clock is reset to be coincident with the 1PPS from the CS. This internal clock is set to read TAI. Because this clock is on the computer bus, it is read by the computer within 1 millisecond of the time of request. Hence the software can accurately time events in the GPS Timing Receiver and Cesium Standard, allowing the clocks to be set relative to each other. Requests for time readout from the GPS receiver are timed by the ETC to assure that the readout data is correctly associated with a particular TAI second. Clock consistency between the GPS, CS and the ETC is checked regularly and an alarm condition is set, directing switch timers, when there is an error.

- Date Conventions

Dates and time tags within the USS are recorded in Modified Julian Date (MJD). MJD is the date convention used by the various timing authorities in reporting GPS observations. MJD is based on the astronomers Julian Date(JD) method of dating events over long periods, with a range of 7,900 years. MJD has a range of 100,000 days, or 273 years. 1 July 1997 is MJD 50,629, leaving about 130 years before roll-over is a concern. Calculation of the time of occurrence of Loran-C epochs must be done with microsecond resolution of periods of time beginning forty years ago. MJD provides the easy method. Dates and time are expressed in MJD with the fractional part of a day being represented in the decimal part of MJD. Twelve decimal digits to the right of the decimal point accurately define times to within a microsecond. For example, 15:41:29.123456 on November 15, 1997 is expressed as:

$$\begin{aligned} MJD &= 50766 + 15/24 + 41/1440 + 29.123456/86{,}400 \\ &= 50766.653809299259 \text{ MJD} \end{aligned}$$

Whether the time is UTC, TAI or GPS depends simply on the notation of the original time. If the time is TAI, it is converted to GPS by subtracting the fractional day equivalent of 19 seconds:

$$19 \text{ sec} = 19/86400 = 0.000219907407 \text{ day}$$

- Primary Time Reference Station Data

PTRS data is reported regularly and is generally available on the Internet. Among the data reported are MJD and time-of-day time tags for the mid-point of a summary data point of the observation of a single satellite or of the mean of the observable constellation. The period of observation is generally 13 minutes. The computed Ref - GPS is the data to be used by the USS. Assuming the observations are normally distributed about the mean value of the GPS constellation clock, and noting that the rms value of the reading is on the order of 100nanoseconds, a minimum of 1000 data points is necessary to attain an estimate of the true value of the mean Ref - GPS and the slope (frequency offset) between the Ref and GPS. This requires a minimum of 2 weeks of data (78 points per day * 14 days). The USS calls for a one month data set to be used, with the data set being up dated as frequently as weekly.

The PTRS data is used to predict the real time difference between the Ref and GPS. The prediction is then used to correct the USS observations to synchronize with the PTRS. If no PTRS data is available, or if it is desired to synchronize directly to the GPS clock, then Ref - GPS is set to zero. See Figure 11 for the timing diagram for a single measurement.

MEASUREMENT PROCESS

The USS measures the time between the CS 1PPS and the next occurring GPS 1PPS, and the next second measures the time betweent the CS 1PPS and the Loran-C PCI (time reference) from the Loran station timer. The measurements are corrected for the various delays in the physical devices, to compute a single error (e). This data is checked for alarm conditions and then mathematically processed as described below to control the CS.

- Timing Diagram

Figure 11 represents the relative timing of various epochs occurring around one UTC second. Epochs are defined by the transitions of various digital waveforms and in the case of the radiated signal, by the 6th REF epoch from the timer.

The CS-GPS time interval counter(TIC) starts on the 1PPS(CS) epoch and stops on the 1PPS(GPS) epoch. This is a relatively large interval, and since the measurement accuracy should be within 1ns, the TIC clock must be within 1 part in 10^7. This accuracy is achieved by using the CS 10MHz as the TIC clock. Note that the cable delays are included in the computation, as well as the computed PTRS offset. The Cesium Slew is the offset to which the CS is steered. The steering is independent of the operation and status of the Loran-C timer.

The CS-Loran time interval counter starts on the 1PPS(CS) epoch and stops on the PCI(Timer) epoch. This interval is nominally 10 usec but actually occurs at 10 usec only on a Time-of-Coincidence (TOC) second. This results from the fact that the Loran PCI is only sub-synchronous with 1PPS. On seconds other than TOC seconds (un-TOC seconds), the offset between 1PPS(CS) and PCI(Timer) will be a multiple of 20 nsec plus the nominal 10 usec offset. The time between TOC seconds and the pattern of un-TOC second offsets is a function of each specific GRI. Since the computer makes measurements at regular intervals (set to 6 seconds in this implementation), the computer must compute the expected offset for the measurement time. The computer displays the difference between the nominal 1PPS(CS)-PCI

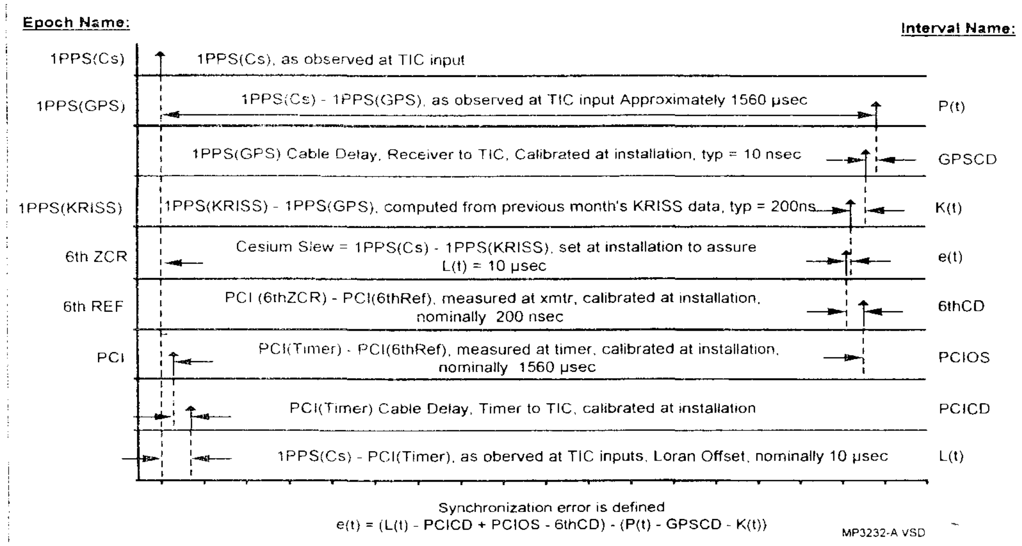

Figure 11 USS Timing Diagram

and the measured value. The PCI can only be incremented by 10 or 20 nsec, dependending on the LPA resolution of the timer in use. Therefore, to reduce the difference to zero, the Cesium Slew and nominal 1PPS(CS)-PCI are adjusted to move the PCI to exactly the correct time.

MATHEMATICAL PROCESSES

- Estimating Cesium Standard Errors

After the error is measured and checked for alarm conditions, one minuteÆs worth of data are averaged from 10 samples taken every six seconds, beginning 27 seconds before the minute to 27 seconds after the minute. The average is associated with the time tag for the minute. When a full day of data has been collected (after 23:59), it, along with data from some number of previous days, is merged in linear least squares fit algorithm. The algorithm estimates the mean frequency error for the period and the end-of day offset between the CS and the Ref. The number of days used in the algorithm is selectable. The recommended setting is three days including the current dayÆs data, which provides 4320 data points. This number of data points results in an expected standard deviation of the measured error of about 1 nanosecond. Note that the measured error may have other error sources which are greater, eg PTRS data errors, ionospheric errors, multipath, site position errors, cable measurement errors etc. Constant terms of the error can be removed by one-time use of an external reference.

- Cesium Steering

Computation of the required steering command for the CS is done in two steps. First, the estimate of mean frequency error is added to the current commanded frequency offset, with the proper sign to reduce the frequency error to zero. This is the corrected frequency offset (corfo) mentioned above. Then the end of period offset (epo) in nanoseconds is used to compute the closing frequency offset (clofo) needed to close the epo to zero in two days. The clofo is algebraically aded to the corfo. Since the steering computation will be repeated in one day, the epo is expected to be reduced by only 50% in that period. The clofo computation will then be repeated for the reduced epo, and the clofo will be less. With this process, the epo asymptotically approaches zero, with minimum disturbance to the users of the Loran-C signals.

It is noted that when the USS is first installed, and CS steering is introduced at a master station, the secondary stations will note an increased LPA activity. This is normal, and after the master station CS has settled, the steering commands will be relatively insignificant (on the order of 1 or 2 parts in 10^14. At this time, the secondary station CSÆs, assuming they are not using the USS, should be steered to reduce LPAÆs to net less than one 10 nanosecond LPA each day. Note further that when control is based on the æsystem area monitorÆ (SAM) concept LPAÆs frequently occur based on day and night effects which generally net to zero. So care should be taken to only steer the CS for the net LPAÆs.

- Loran-C Signal, Time-of-Transmission Control

The USS, as currently implemented, measures the time of the PCI trigger from the timer. This trigger is directly synchronized to the cycle-comp sampling trigger. The cycle-comp sampling trigger samples every transmitted pulse and adjusts the delay through the transmitter such that the mean time of transmission of the signal is the time of the cycle-comp sampling trigger. Therefore, having measured the exact offset of the PCI trigger with respect to the cycle-comp trigger, the measurement of the time of the PCI trigger provides the USS with exact knowledge of the mean time-of-transmission of the signal.

The time interval counter provides the capability to gate the input to permit direct measurement of the time of the zero-crossing of a specific pulse in a group of eight. This alternative has the advantage of being capable of direct measurement of the transmitted pulses. However, it has pitfalls which cause us to reject such measurement. First, a pulse must be selected on which to make measurements. Since there are small variations in the delay of individual pulses in a group, the pulse selected should be that pulse having the reference zero-crossing closest to the mean. This is not a constant in the below 10 nanosecond range, but varies with relationship to a dual rate signal, with respect to blink and when the pulses are modulated, such as with Eurofix. By allowing the cycle-comp servo to average the times of the individual pulses, the USS sees the same mean time of transmission of the pulses as would a receiver.

ALARM PROCESSES

Every measurement is tested for alarm conditions and an appropriate alarm status is set. Next the one minute averages of CS - GPS and CS - PCI are tested for alarm contitions to a more stringent tolerance. Also consecutive measurements and averages are tested to even more stringent standards. Alarms conditions are set for out of tolerance averages, and for consecutive out of tolerance averages. The software is arranged to permit the setting of alarm levels at the time of installation. Figure 4 shows the TCC Maintenance GUI interface and the alarm levels which may be set.

SUMMARY

The UTC Synchronization System has been in an operation installation for three months, and has proven its reliability and ease of operation. The concept of direct, continuous control of the Cesium Standard has shown that very tight UTC synchronization is possible, greatly increasing the number of applications for the Loran-C service.

Future developments will include further improvements in the application software functionally, including direct control of Loran transmitter LPA's and automatic blink. The hardware will be more closely integrated with a new timer and transmitter interface which will reduce the cost and size of the transmitter control unit.

REFERENCE

[1] *"Time Transfer via GPS at USNO"*, Klepszynski, W. and Miranian, M., U.S. Naval Observatory.

Expectations for Cycle 23

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~~Joe Kunches~~

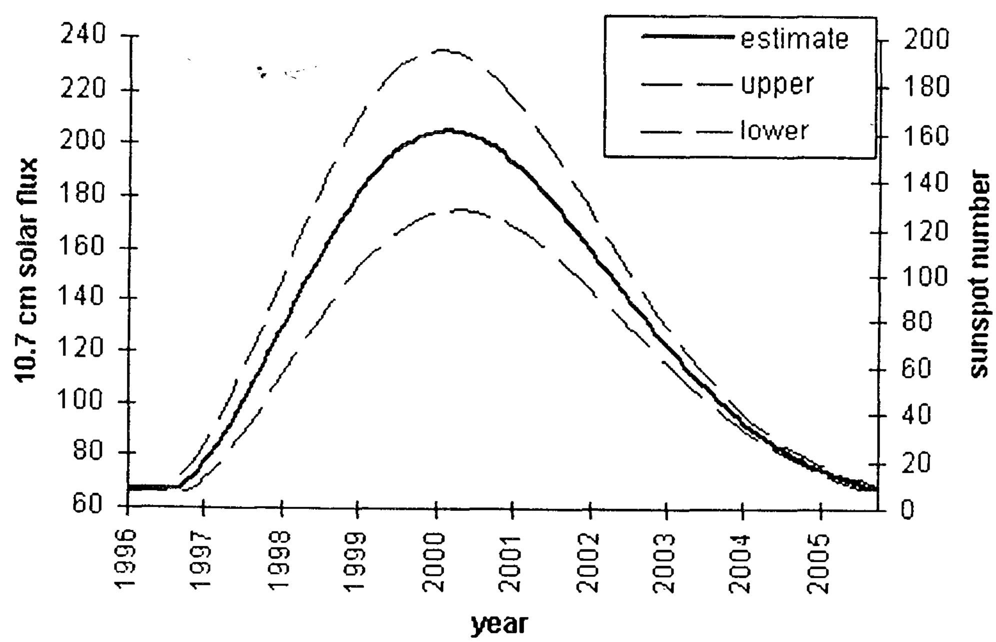
Space Environment Center
Boulder, Colorado

ILA 26th Annual Technical Symposium, Ottawa
October 6-9, 1997

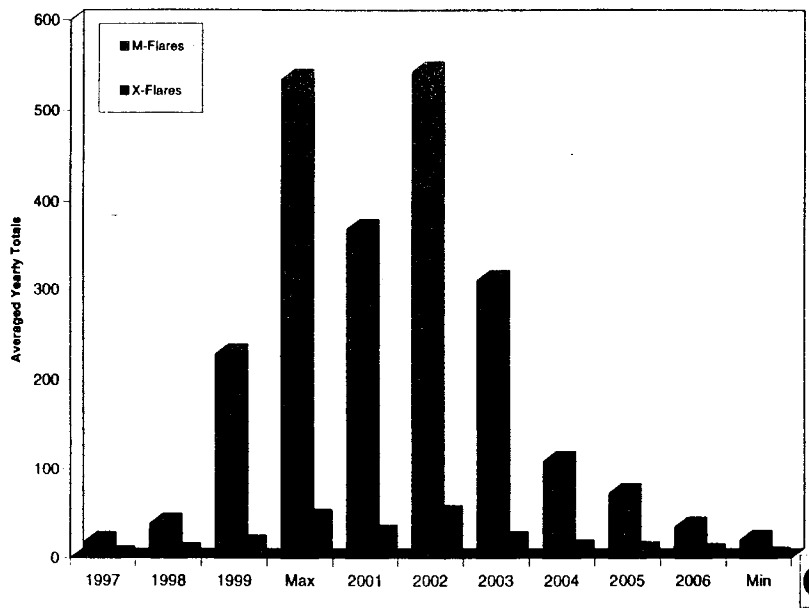
NOAA Space Environment Center

Expectations for Cycle 23

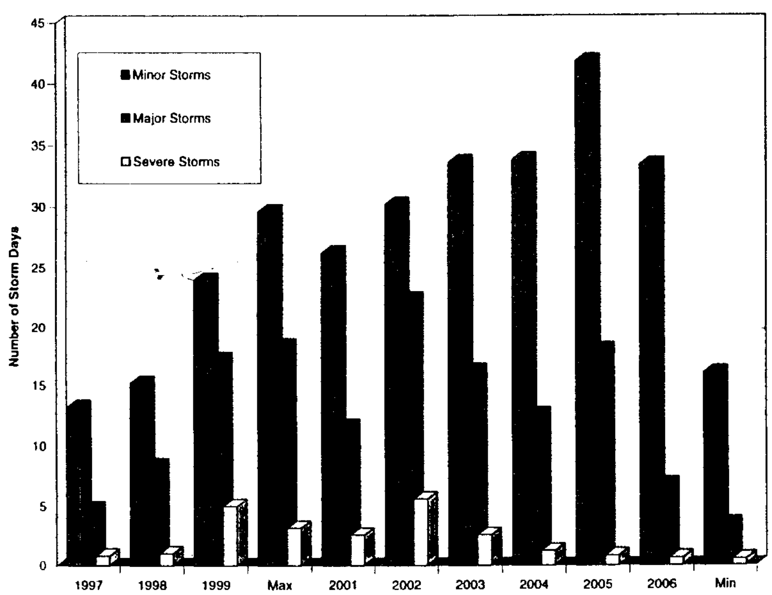
1. (Graph of sunspot number, 10.7 cm flux vs. year). Cycle 23 began in October 1996 (revised from an earlier estimate of May 1996). Activity is now increasing and the prediction is for a sunspot number of 160, slightly larger than the last cycle. Maximum should occur near the year 2000.
2. (Graph of Projected Class M & X Flares for Cycle 23). Using statistics from the last 2 cycles, and averaging by the number of occurrences for year 1, year 2, etc., average rates of occurrence can be determined. M & X class flares will affect Loran on the dayside of the earth. Look for 2000 & 2002 to be active years.
3. (Graph of Geomagnetic Storm Days, averaged over last 3 cycles). Both numbers of days, as well as level of disturbance, increase monotonically through 2000. These events can have a large effect on the ionosphere, both for Loran as well as GPS. Major and Severe storms are the ones that really impact navigation systems.
4. (Graph of Projected Proton Events, averaged over the last 3 cycles). These events, also known as Polar Cap Absorptions (PCA's), will average one per month near solar maximum. PCA's have a big effect on Loran and GPS at high latitudes.
5. (Conclusions). Pretty self-explanatory. One can know of the current situation by logging on to the web site, calling the forecaster, or calling the voice recording which is updated every three hours.



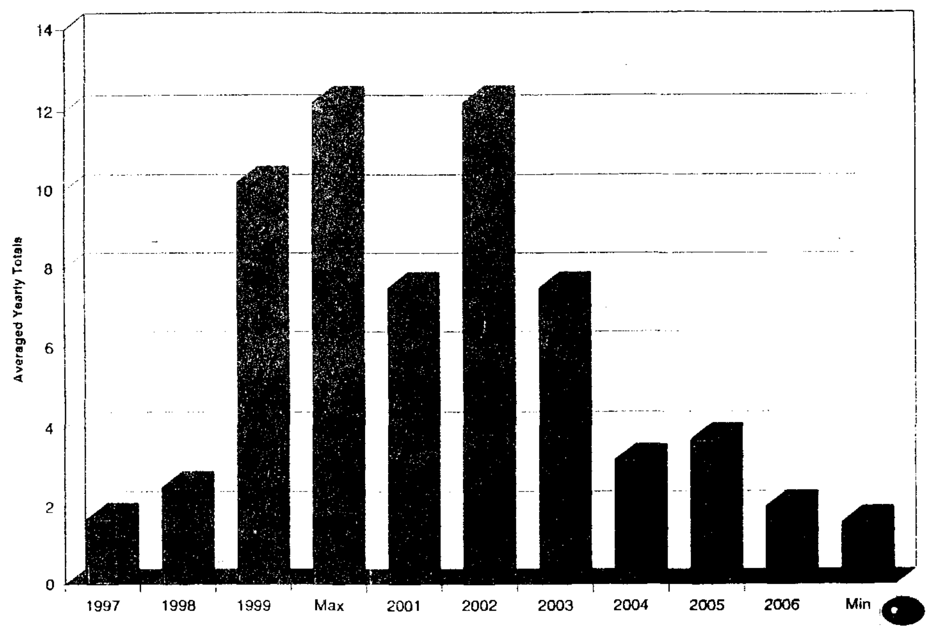
Projected Class M and X Flares for Cycle 23



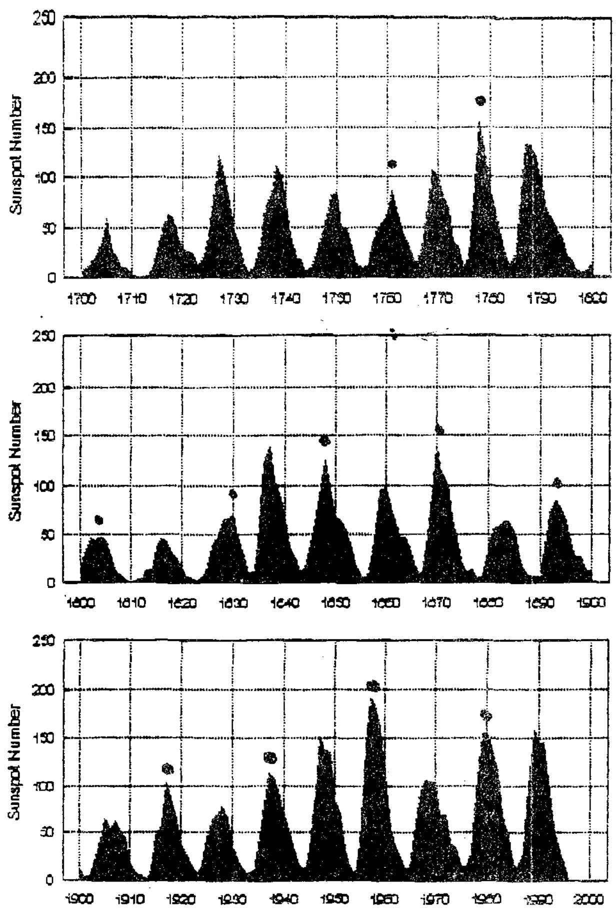
Projected Geomagnetic Storm Days for Cycle 23



Projected Proton Events for Cycle 23



ANNUAL Sunspot Numbers: 1700-1995



Conclusions

- Cycle 23 began in October 1996.
- Latest estimates are for it to be similar to, but slightly larger than, Cycle 22.
- Flares, Geomagnetic Storms, and Solar Proton Events will impact both ground-based and satellite systems.
- To know of disturbed conditions:
  - http://www.sec.noaa.gov
  - (303) 497-3171 (Space Weather Operations)
  - (303) 497-3235 (Voice Recording)

NOAA Space Environment Center

Session 8: Eurofix

Session Chair: LCdr Charles Schue
USCG Loran Support Unit

Session 8: From left; Charles Schue, Durk van Willigen, Dirk Kügler, Arthur Helwig, Gerard Offermans

Eurofix DGPS Service Through The Sylt Loran-C Transmitter: Static and Dynamic Test Results
Arthur Helwig, Gerard Offermans, Durk van Willigen, TU Delft
(Presented by Arthur Helwig)

Performance of Eurofix in Land Applications in Germany
Dr. Dirk Kügler, Avionik Zentrum Braunschweig; Dr. Volkmar Tanneberger, Bosch/Blaupunkt; Arthur Helwig, Gerard Offermans, TU Delft
(Presented by Dirk Kügler)

Regional-Area Augmentation Concept for Eurofix — Reducing Spatial Decorrelation Effects through Multi-Station DGNSS
R. F. van Essen, Gerard Offermans, Arthur Helwig, Durk van Willigen; TU Delft
(Presented by Gerard Offermans)

Future Eurofix Services
Durk van Willigen, Arthur Helwig, Gerard Offermans, Edward Breeuwer; TU Delft
(Presented by Durk van Willigen)

Eurofix DGPS service through the Sylt Loran-C transmitter: static and dynamic test-results

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BIOGRAPHY

Arthur W.S. Helwig and Gerard W.A. Offermans received their M.Sc. degree in Electrical Engineering from the Delft University of Technology in 1995 and 1994 respectively. Currently, Mr Helwig is working on "general digital receiver concepts for integrated navigation receivers" and Mr Offermans on "datalinks for differential navigation" in a 4-year Ph.D. research program at the same university.

Dr Durk van Willigen heads as a professor in radionavigation a research team of staff, Ph.D. and M.Sc. students in the Department of Electrical Engineering at the Delft University of Technology. This group focuses on integrated navigation systems. Finally, Dr Van Willigen is the president of Reelektronika, a small privately owned consultancy on radar and radionavigation.

ABSTRACT

The existing Loran-C infrastructure may with some minor changes become a very powerful augmentation system for GNSS. By additional modulation of the Loran-C pulses a long range data channel can be established which enables broadcasting of DGNSS correction data and integrity information to GNSS users. The applied additional three-level modulation is fully balanced so it has negligible influence on the basic Loran-C positioning accuracy. Since 1989 Delft University has been working on this system called Eurofix [1].

The user can expect DGNSS accuracies of better than 5 metres (95%). As long as DGNSS performance is good the ASF values of the Loran-C propagation can continuously and accurately be updated by the precise DGNSS positions. During periods of poor GNSS reception in urban canyons, highly calibrated Loran-C may take over. So, the Eurofix system offers the user very good DGNSS service, external GNSS integrity and improved radionavigation availability. In January 1997 the German DoT allowed implementation of Eurofix in the Sylt Loran-C station on experimental basis. The paper highlights some on-air static measurements and mobile experiments of Eurofix carried out in France, Germany and Switzerland.

1 - INTRODUCTION

A well-known problem of satellite positioning systems is the poor penetration of L-band radio signals in urban environments. The signals are often either blocked or reflected by man-made structures. The low-frequency Loran-C signals propagate quite differently from GNSS signals in built-up areas. As the wavelength (3 km) is long compared to the size of constructions, Loran-C signals are not easily blocked or reflected. However, due to large man-made structures phase alterations of the 100 kHz signals may be experienced. Surprisingly, the effects are different for the Loran-C electric field and magnetic field.

Low-frequency signals propagate along the earth's surface slightly different than in free space. Due to the limited conductivity of water and soil the signals experience an additional propagation delay. The delay due to sea water known as the Secondary phase Factor (SF) can easily be taken into account in Loran-C position calculations. The conductivity of ground or fresh water is even less than for sea water and strongly varies with different types of soil. This results in an extra delay, the so called Additional Secondary phase Factor (ASF). If the receiver contains a database with ground conductivity figures or ASF corrections for the total Loran-C coverage area, the system's absolute accuracy can be improved. Research carried out by the USCG Academy [2], by Megapulse, Inc. [3], at the University of Wales and at Delft University of Technology indicates that the H-field not only better penetrates in deep city canyons but it also shows less deviations from the modelled ASF properties than the Loran E-field.

As the Loran-C datalink offers DGNSS correction data, the user might use the accurate DGNSS position to continuously calibrate the estimated Loran-C position and build up his own correction database [4]. This calibration can be done much more accurately than possible with the best known ASF tables. This offers the unique possibility to use calibrated Loran-C whenever GNSS becomes unavailable. So, the combination of GNSS and Loran-C offers three important advantages:

- Differential GNSS service through Loran-C
- Improved availability and continuity by using calibrated Loran-C
- External integrity

This is in strong contrast to DGNSS services currently operational. These services only supply DGNSS correction data and sometimes external integrity. The continuity and availability of the total system depend on the continuity and availability of the basic GNSS and the DGNSS correction data service. Whenever one of the two systems fails precise position determination is no longer possible.

Section 2 outlines the Loran-C datalink. Choice of modulation, DGNSS message format and Forward Error Correction will be briefly discussed. In Section 3 the Eurofix reference station implementation in the Sylt Loran-C transmitter is addressed. Some static measurements at Delft and dynamic test results of a mobile test run in France, Germany and Switzerland will be presented in Sections 4 and 5.

2 - LORAN-C DATA TRANSMISSION

The Eurofix system is an integrated navigation system consisting of GNSS and Loran-C. The Loran-C pulses are additionally modulated to carry differential correction data and integrity information to the Eurofix users. They can apply the corrections to navigate with high accuracy. When DGNSS is available, the accurate position will be used to calibrate Loran-C. If DGNSS fails, the user can continue navigation with accurate Loran-C positioning (10-20 m).

As Loran-C is a navigation system in itself, the transmission of information is restricted by Loran-C navigation requirements and parameters. The additional data modulation onto the Loran-C signal shall not influence normal Loran-C operation. Therefore, the following restrictions are imposed on the use of the Eurofix datalink:

- The blinking service must be preserved, which excludes the first two pulses of each Loran-C group of Eurofix modulation.
- The modulation is not allowed to induce tracking biases, which requires a balanced type of modulation.
- The modulation index must be kept small in order to prevent an undesirable loss in tracking signal power.

Based on these requirements, a pulse position modulation with a 1 μs modulation index is chosen. Only 6 out of 8 pulses per group will be modulated and the modulation is always balanced on a per GRI basis. The application of 3-level modulation (a 1 μs advance, a prompt or a 1 μs delay) leaves a possible 7 bit of information per GRI [5]. With Loran-C GRI's varying between 40 ms and 100 ms, the raw bit rate available for data transmission ranges from 175 to 70 bps.

Normal Loran-C users only experience a slight signal loss of 0.79 dB [5]. Future Loran-C receivers, which have knowledge of the Eurofix modulation, can easily compensate for the applied modulation, once the pulses are demodulated. This will cancel the signal loss completely. Note that the influences of Cross-Rate interference and blanking, phenomena inherent to the choice of the Loran-C signal structure, cause larger signal degradation.

Earlier publications [5,6] describe the Eurofix datalink in more detail.

DGNSS message format

The differential information is sent to the user in an asynchronous message format. The use of standard RTCM type-1 messages requires too much time to transmit a complete set of corrections. To keep data latency within acceptable limits, a minimum RTCM type-9 compatible message of 56 bits is applied, Table I. Unfortunately, the parity used in the RTCM messages does not suffice in the aggressive Loran-C environment of Cross-Rate interference and high ambient noise levels. Therefore, a different error correcting strategy is chosen. However, as standard and commercially available DGNSS receivers must be facilitated, the received Eurofix data is converted into a standard RTCM type-9 message.

Forward Error Correction

To ensure reliable broadcast data communication through Loran-C, Forward Error Correcting codes are applied. These codes provide an effective means to correct occasional errors (improved datalink availability) and validate the decoded data (integrity) at the cost of an increased message overhead. Figure 1 shows the

TABLE I. EUROFIX MESSAGE FORMAT (BASED ON RTCM TYPE-9 CORRECTION [7])

Function	Number of bits	Resolution	Range
Message type	3		8 types of messages
Modified Z-count	13	0.6 seconds	0 - 3599.4
Scale factor	1		
UDRE	2		4 states
Satellite ID	5		32 satellites
Pseudo-Range Correction	16	0.02 or 0.32 m	±655.34 or ±10,485.44 m
Range Rate Correction	8	0.002 or 0.032 m/s	±0.254 or 4.064 m/s
Issue of Data	8		
Total:	56		

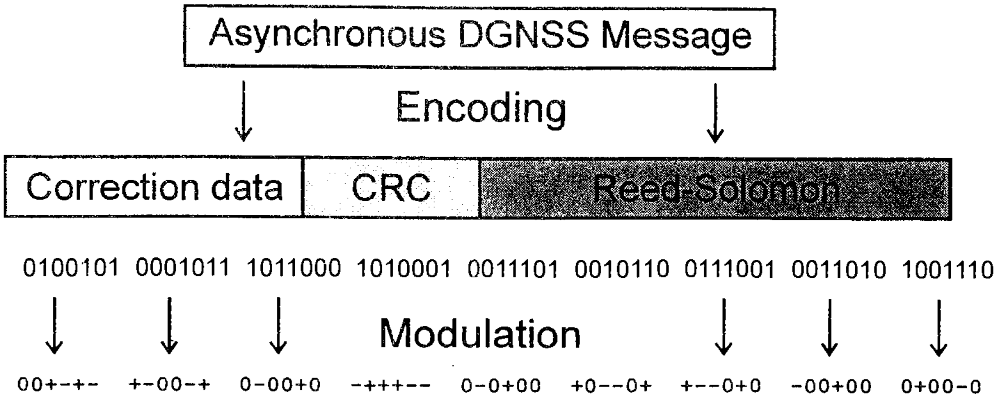

Figure 1. Encoding and modulation for the Loran-C data communication.

modulation and encoding currently used to transmit data via Loran-C. In Eurofix the message integrity is ensured by a 14-bit Cyclic Redundancy Check (CRC), while the Reed-Solomon code ensures datalink availability for stations up to 1,000 km. Each 56-bit message (8 GRI's of 7 bits) is protected by additional Reed-Solomon parity GRI's. In recent experiments messages contained in 20 and 30 GRI's have been tested. Depending on the Group Repetition Interval (40-100 ms) of the Loran-C station the effective datarate of these schemes will be 70-28 bps and 47-19 bps, respectively.

3 - Implementation of DGPS Service at the Sylt Loran-C Station

On February 5th,1997, Delft University installed a DGPS reference station at the Sylt Loran-C transmitter site (Germany) on an experimental basis. From that date on RTCM compatible differential corrections have been broadcast throughout Europe on the Sylt Secondary rate 8940. Corrections for all satellites in view are broadcast at an update rate of once every 2.7 seconds per satellite (30-GRI message at 89.40 ms). Since September 23rd, 1997, Sylt operates as a Secondary in the new French chain 6731. The slightly lower GRI number increased the update rate to once every 2.0 seconds. When also the Master rate of Sylt (7499) will be used for data transmission, the correction update rate will be even further improved. Apart from providing RTCM type-9 corrections across Europe, the reference station can also broadcast Integrity messages and Emergency Broadcast ASCII Messages.

The reference station consists of an industrial PC with a 12-channel NovAtel GPS receiver. On average 8.7 satellites are in view at the reference station site, Figure 2. The antenna is located on the roof of the office building located 100 m from the transmitter. The antenna is placed

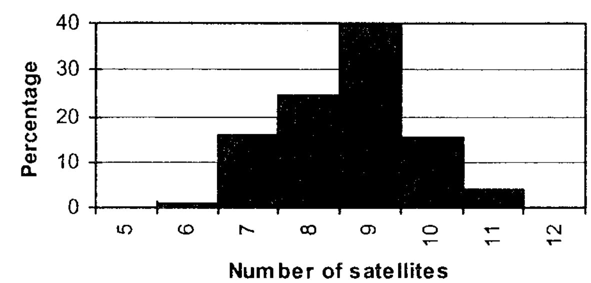

Figure 2. Number of satellites visible at Sylt over 24 hours, (average 8.7).

in a choke ring to reduce low elevation multipath errors. The code multipath errors measured did not exceed 50 cm. Figure 3 shows the set-up at the Sylt station.

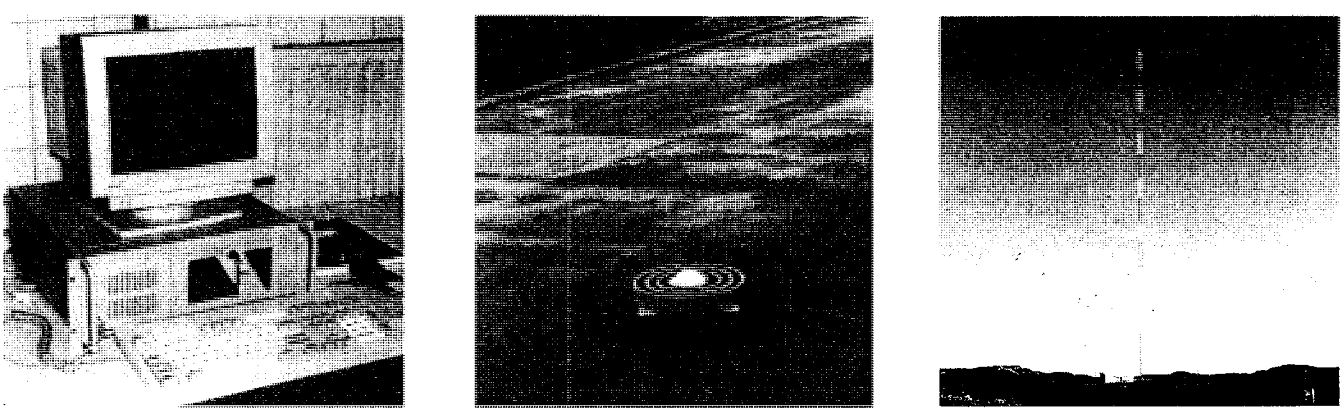

Figure 3. Reference station PC, GPS antenna and Sylt Loran-C transmitter.

The reference station can be remotely controlled by Delft University to allow maximum flexibility in testing the system. Tests with different coding strengths (and thus different update rates) can be scheduled, and modulation on/off time can be controlled. Until now the Loran-C monitor stations at Brest (France) and Bø (Norway) have not reported any degradation of the Loran-C signal quality due to the Eurofix modulation. Therefore, the test period which initially was restricted to two months is prolonged indefinitely.

4 - Static Test Results

Since the beginning of the experimental Eurofix transmissions from the Sylt Loran-C station, the quality of the transmitted data has been constantly monitored at Delft University. The Eurofix datalink was tested using different amounts of Forward Error Correction (FEC), and the influence on the resulting DGPS position was measured.

The overall quality of the DGPS service via the Eurofix datalink is a function of the following parameters:

- Integrity of the messages
- Availability of the datalink

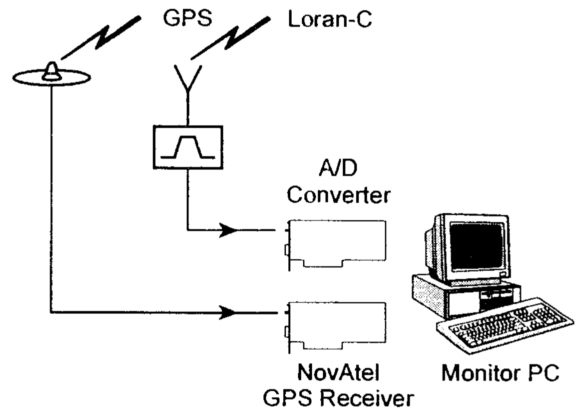

Figure 4. Eurofix monitor at Delft University.

- Accuracy of the DGPS positioning.

During the measurements not a single DGPS message was lost (100% datalink availability). Furthermore, no CRC failures on the messages were found either. Due to the relatively long baseline between Delft and Sylt, some spatial decorrelation errors would be expected.

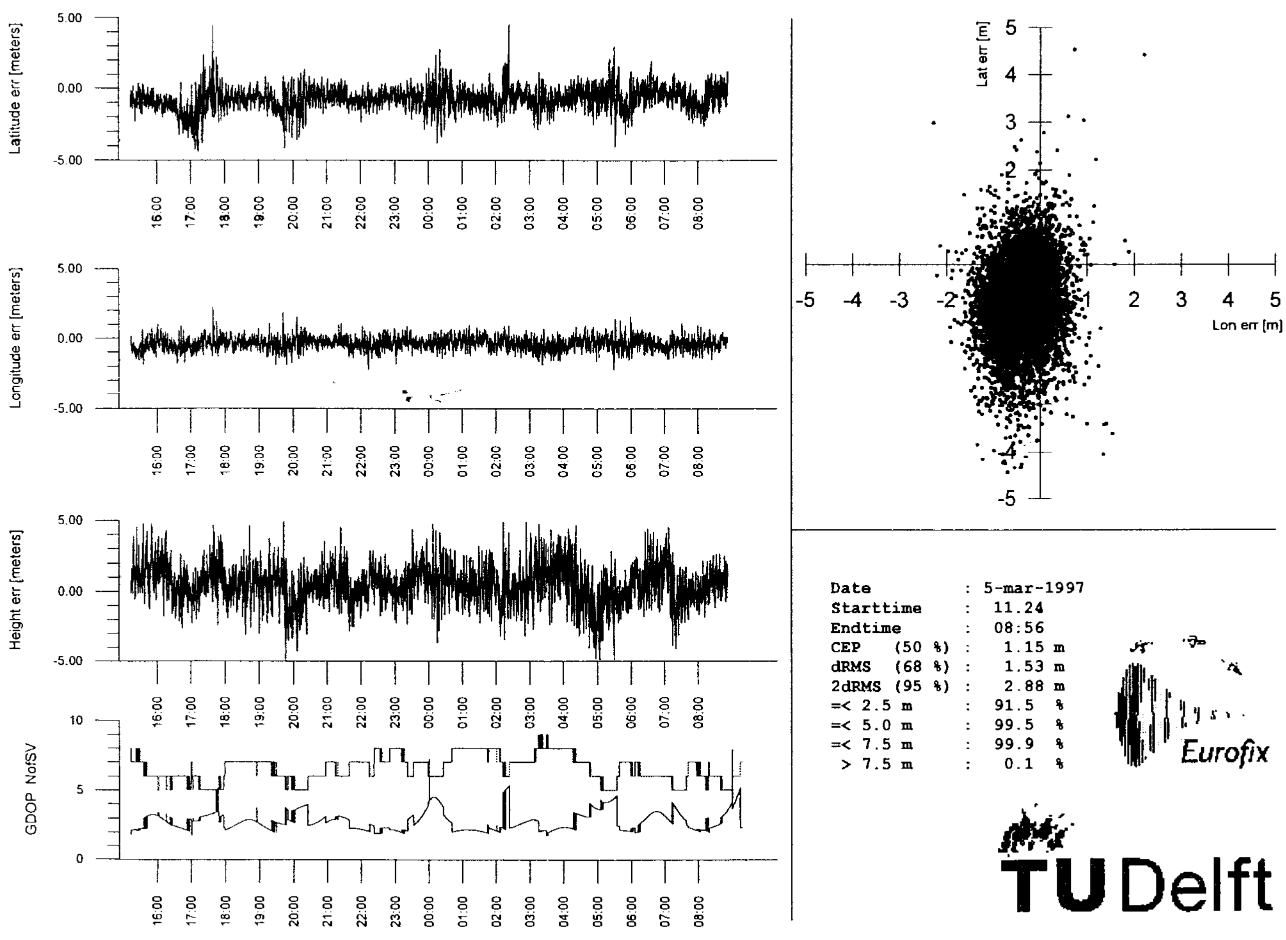

Figure 5. Static test results using a 30 GRI (21 bit per second) datalink, 5/6 March 1997.

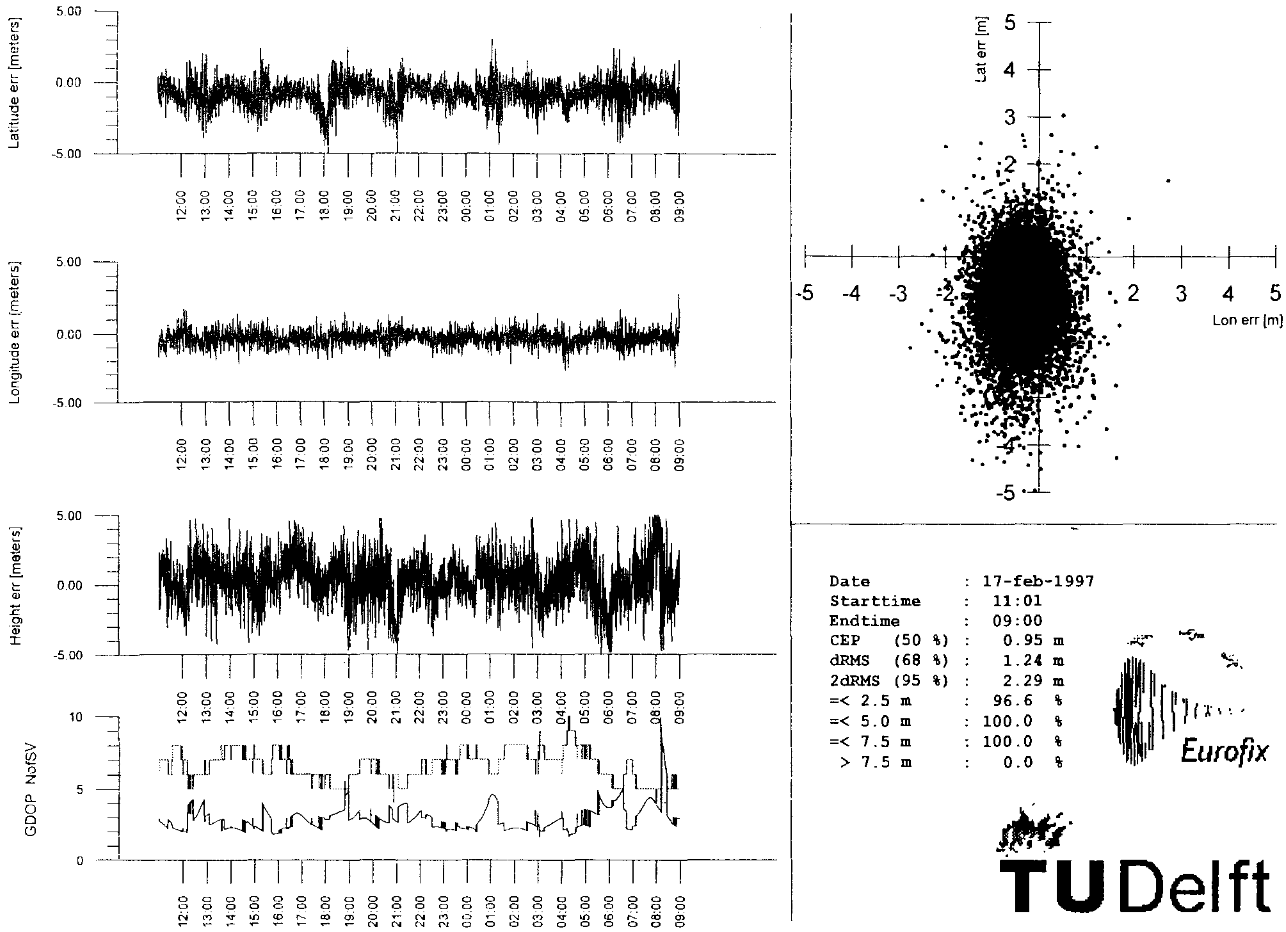

Figure 6. Static test results using a 20 GRI (31 bit per second) datalink, 17/18 February 1997.

Measurement set-up

An experimental measurement set-up has been built at Delft University to monitor the Eurofix DGPS transmissions from the Sylt Loran-C station (400 km baseline). The equipment consists of the following components, Figure 4:

- A 486 DX 100 MHz PC
- A 12 channel NovAtel GPS PC board
- A 12 bit, 400 kHz A/D converter board
- A NovAtel GPS antenna with choke ring
- A Loran-C E-field whip antenna with bandpass filter

The Eurofix modulated signals are received using the E-field antenna, then, after being bandpass-filtered and amplified, they are sampled at 400 kHz (quadrature sampling) with the A/D converter board. The processing of the signals involves the demodulation of the pulses and the Reed-Solomon decoding of the DGPS messages. When the message is retrieved, it is converted into a standard RTCM type-9 message which in turn is fed to the NovAtel GPS card. The GPS card outputs a position fix once every second.

For further information about the Eurofix receiver design the reader is referred to Helwig et al. [6].

Test results

One of the parameters of the Eurofix datalink is the amount of Forward Error Correcting code that is applied to the DGPS correction messages. If more FEC is added, the range over which a user can still successfully decode the messages will increase; however, the update rate of the messages will decrease resulting in larger position errors. DGPS positioning results using two different amounts of FEC will be presented. During both runs, all of the messages were successfully decoded and used.

The test results of the first measurement are shown in Figure 5. During this 22 hour run, one DGPS correction (56 bits) was packed into 30 modulated GRI's (2.7 seconds), resulting in a 21 bps datalink. In the figure at the left bottom, the GDOP and number of Space Vehicles are shown. Note that, on average, the number of Space Vehicles is somewhat low and the GDOP is fairly high. It is believed that, if these values were better (by using a better place for the user GPS antenna), the resulting accuracy would be better. As can be seen from the plots, the 95% error is 2.88 metres.

The test results of the second measurement are shown in Figure 6. During this 22 hour run, one DGPS correction (56 bits) was packed into 20 modulated GRI's (1.8 seconds), resulting in a 31 bps datalink. The latency for all messages is somewhat decreased due to the higher datalink bandwidth. As a consequence, the DGPS positioning errors are slightly less than in the previous figure. The 95% error is 2.29 metres, with no errors above 5 metres.

With the recent change of GRI for the new Lessay chain, the update rate for a 30-GRI message will be only 2.0 seconds (30*67.31 ms = 2.02 s). Results for static measurements using this new GRI will probably correspond to the results presented in Figure 6.

Note that in both cases there appears to be an offset on the average position. This is believed to be the effect of spatial decorrelation over the baseline of 400 km. Such offsets could be mitigated if the DGPS corrections from multiple Loran-C stations were used simultaneously in a Networked DGPS solution. This is called a Regional Area Augmentation System (RAAS) concept [8].

Summary

This section has shown the measurement results of on-air Eurofix transmissions over a baseline of 400 km. The datalink availability was 100% in both measurements presented. The positioning error increases if a higher amount of FEC is used; however, even with DGPS messages packed in 30 modulated GRI's, the resulting 95% error is still limited to about 3 metres. The effect of spatial decorrelation over the baseline Sylt-Delft (400 km) can be seen from the plots as an offset of the average position. The results presented here with corrections generated at the Sylt reference station correspond to earlier results of real-life simulations [6,9].

Figure 7. Measurement van of the Dutch Survey Department.

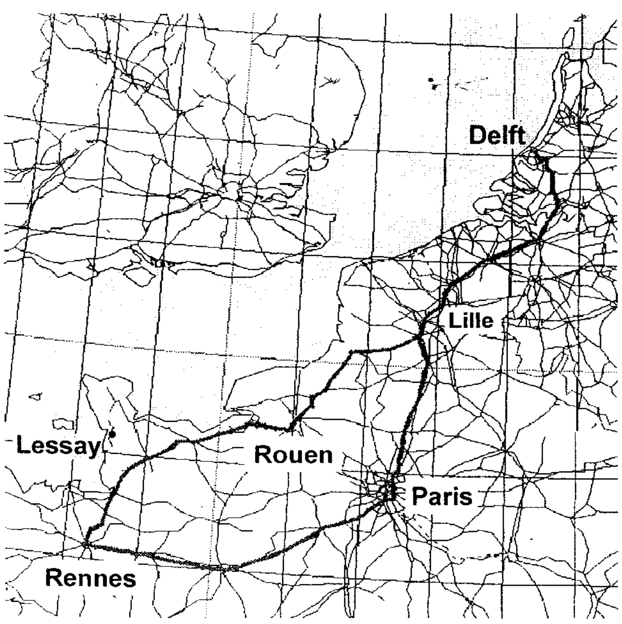

Figure 8. Route of the 1st measurement campaign.

5 - DYNAMIC TEST RESULTS

The previous section showed the DGPS performance of the Eurofix system statically. Good static datalink availability on 400 km from Sylt can easily be achieved. So, to evaluate the datalink performance dynamically two mobile measurement campaigns were undertaken. A first measurement campaign was set-up from Delft to Normandy, France in March 1997. The purpose of these tests was to evaluate datalink behaviour in dynamic environments and to determine the Eurofix coverage extremes, which were estimated at about 1,000 km.

A prototype Eurofix receiver comparable with Figure 4 was mounted in a measurement van of the Dutch Survey Department, Figure 7. Both an electric field and a magnetic field antenna were used during the trials. Tests were done on highways as well as on country roads. No serious tests in urban environment were undertaken.

Figure 8 shows the route travelled from Delft to Normandy, Table II gives the distances to Sylt at specific locations along the route. Generally speaking the performance of the datalink was good. Messages were only occasionally lost while driving under highway crossings and power- or telephone lines, Figure 9. Even with severe Cross-Rate conditions near the Lessay Loran-C transmitter in Normandy with signal strengths 20 dB higher than Sylt's signals the datalink was still available.

TABLE II. DISTANCES FROM SYLT

	Sylt
Delft	406 km
Lille	580 km
Rouen	770 km
Paris	780 km
Lessay	930 km
Rennes	1050 km

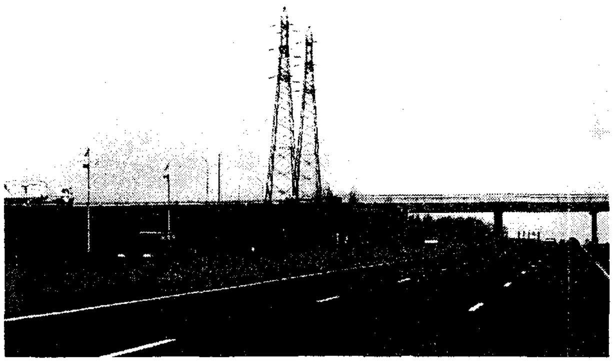

Figure 9. Example of difficult environment for Loran-C reception.

In August 1997, a second measurement run was conducted with the purpose to verify the results from the first run and to compare the Loran-C electric field with its magnetic field under dynamic circumstances. Also, Loran-C and Eurofix signal availability was tested in difficult mountainous environments. Figure 10 shows the route of the second campaign, Table III lists some waypoints and their distances from Sylt.

TABLE III. DISTANCES FROM SYLT

	Sylt
Delft	406 km
Luxembourg	597 km
Basel	809 km
Annecy	1003 km
Beaune	900 km
Stuttgart	673 km
Bonn	461 km

Two Eurofix receivers were installed hooked onto a magnetic field antenna (Megapulse LLA-3) and an electric field whip antenna, respectively. The output of the receivers was recorded for post-processing and fed into a standard RTCM type-9 capable GPS receiver. The van also contained a Locus LAD Loran LRS-III receiver for Loran-C signal availability evaluation purposes.

By running the two Eurofix receivers simultaneously, the performance of the electric field and the magnetic field receivers could be compared under exactly the same conditions. The following observations were made:

- Under open terrain conditions, both receivers performed well. Only highway crossings and power lines occasionally induced the loss of messages. Depending on the direction of the highway crossing in respect of the signal's direction, the magnetic field signal component could still be present while the electric field disappeared.

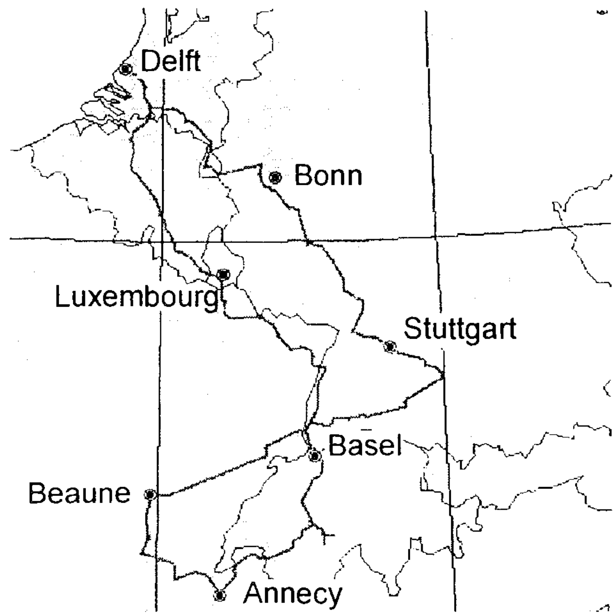

Figure 10. Route of 2^{nd} measurement campaign.

- As the terrain became more hilly, the differences in performance of both receivers became more apparent. Obviously, the Loran-C electric field suffers more from signal attenuation due to hills and mountains than the magnetic field components. In these cases, the magnetic field receiver clearly outperformed the electric field's, Figure 11a/b.
- Deep in the valleys of Switzerland, where mountains are in excess of 3,000 m high, the magnetic field signal components from Sylt (at 900 km) were also lost, Figure 11c. In many cases, however, the signals from the Lessay transmitter (at 750 km) could still be received, depending on the direction towards the transmitter and the heading of the mountain-ridge. When Eurofix is implemented in all NELS Loran-C stations, the service will still be available.
- As the mountains attenuate the received signals excessively, the man-made noise will become dominant (train, cable-car installation). At some locations, the signals could not be found even after long integration times (Locus receiver).

Once the terrain became more open again, both receivers performed well again. Even in Annecy at a distance of 1,000 km from Sylt, the Eurofix service was still available, reconfirming the large coverage range.

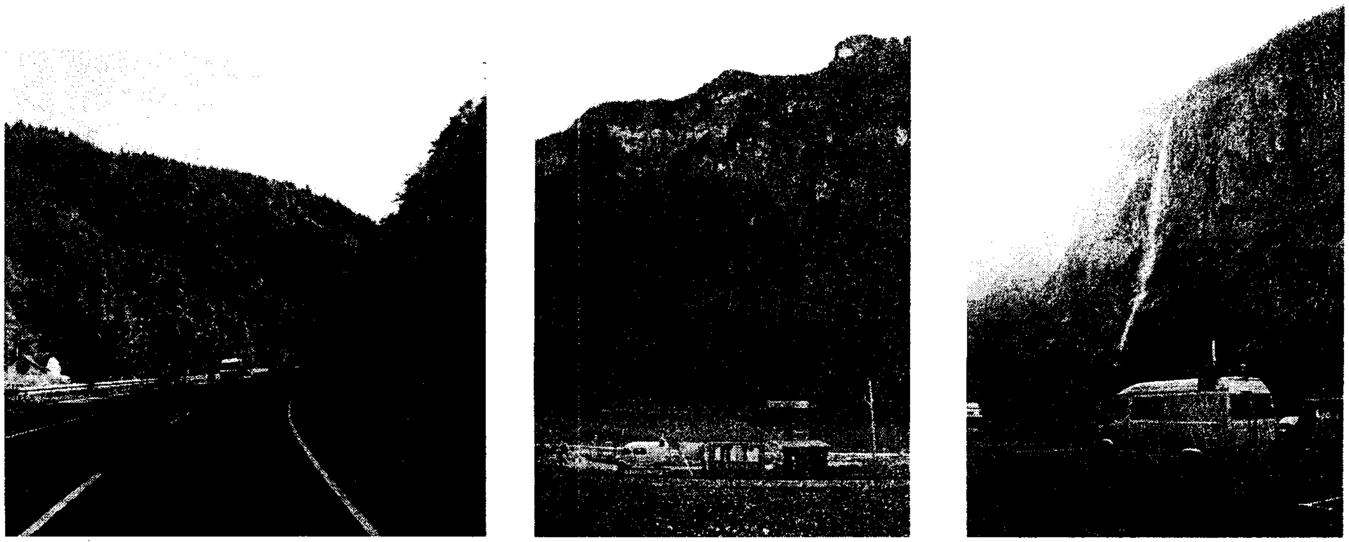

Figure 11. a) Hills of Schwarzwald in Germany, magnetic field receiver worked well, electric field receiver deteriorated performance.
b) On the road to Grindelwald, Switzerland, magnetic field receiver still worked, electric field receiver failed.
c) In Lauterbrunnen, Switzerland, both receivers failed.

6 - Conclusions and Further Work

This paper has outlined the possibility for Loran-C to augment GNSS. By additional modulation of the Loran-C signals differential corrections and possibly other messages can be broadcast to users up to 1,000 km.

The Eurofix implementation at the Sylt Loran-C transmitter in Germany is described. Both static and dynamic test results were satisfying and corresponded with earlier simulation results. Accuracies of better than 3 metres (95%) can easily be obtained. The measurement campaign in France has shown good datalink reception at distances up to 1,000 km. Even under severe Cross-Rate conditions the datalink was still available. The measurement campaign in Switzerland reconfirmed earlier Eurofix performance results. It also showed some areas of difficult Loran-C reception.

When all Loran-C stations in Europe will be modified to broadcast differential corrections the accuracy can be even improved. Furthermore, if in dual-rated stations both rates are used for data transmission, the correction update rate will be drastically increased, reducing temporal decorrelation effects.

The static tests showed a slight bias in the measured position due to spatial decorrelation. These effects can be reduced by employing a Regional Area Augmentation concept. If more stations can be received, the user can calculate a networked differential correction which will better correspond to the range error encountered at his location.

Further work

Until further notice the Sylt transmitter keeps broadcasting differential information. Delft will continue to collect data on the operation and performance of the Eurofix service.

The next step in the project is the implementation of Eurofix in other NELS Loran-C transmitters to provide a standardised, large coverage DGPS service over Europe. Regional Area DGPS concepts can be implemented to improve accuracy, integrity and availability. Recently, a plan supporting this implementation is presented to the NELS Steering Committee.

Finally, Delft will be involved in new Eurofix datalink- and integrated Loran/DGNSS receiver design and development.

Acknowledgements

The authors would like to thank the German Department of Transportation, especially Mr C. Forst and Mr E.O. Huß for making the Eurofix installation at Sylt possible. We further like to thank the Survey Department of the Dutch Ministry of Transportation for their funding and support throughout the project.

Megapulse, Inc. modified the timer of the Sylt transmitter and provided us with a magnetic field antenna. Their contribution to the project and the extensive support for many years is gratefully acknowledged.

A special word of thanks to Dr D. Kügler of Avionik Zentrum Braunschweig, Prof. J.D. Last of Bangor University, Prof. F. van Graas of Ohio University and Mr J. Beukers for their technical help and political support.

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Presented by Arthur Helwig - Eurofix at Sylt

Q: At 1000 km did it give perfect results?

A: There were no errors

Q: The effect was about +/- 1 microsecond?

A: Yes

Q: Can you say more about the bias and its relation to spatial decorrelation?

A: Post processing the data indicates if you use corrections generated at one point to provide improvement at another point, the bias and the direction are predictable.

Q: What is the cost for the demodulator?

A: We have only experimented. No hard prototype.

Comment from the floor: There's essentially no hardware cost; only software. If you're sampling the pulse anyway, you've got the Eurofix data already. You might have to have more hardware to put it into RTCM electrical format and transmit it to a user, but that's all.

Q: How did you determine the actual degradation of the loran signal strength with Eurofix running?

A: Degradation could not be seen at 1dB resolution. The 0.79dB figure follows from the energy calculation.

Comment from the floor: When we worked on the Clarinet Pilgrim communications link, you could only see the effect of the added data channel if the basic signal were very clean.

Performance of Eurofix in Land Applications in Germany

Dr. Dirk Kügler, Avionik Zentrum Braunschweig; Dr. Volkmar Tanneberger, Bosch/Blaupunkt; Arthur Helwig, Gerard Offermans, TU Delft
(Presented by Dirk Kügler)

The text of this paper was not available at the time of publication; interested readers are invited to contact the author.

Q: In your scatterplot a bias is noted. What is the explanation?

A: Bias at 350 km was not identified. There may have been a survey error. It's within a couple of meters.

Q: What receiver?

A: Trimble

Q: Where was the loran antenna?

A: The antenna worked mounted under the car. There was some offset, but it was functional.

Q: What about after the test phase? Will there be an operational installation now, a launch customer?

A: We have thought of it. There is no stoppage in the testing; the signals are on the air. There's an implementation plan under way. There is the "chicken and egg" problem. Manufacturers say they could do receivers easily, but they need some stable system promise to get started ... and vice versa.

Regional Area Augmentation Concept for Eurofix

Reducing Spatial Decorrelation Effects through Multi-station DGNSS

R.F. van Essen, G.W.A. Offermans, A.W.S. Helwig and D. van Willigen
Delft University of Technology, The Netherlands

BIOGRAPHY

R. Frederik van Essen, Gerard W.A. Offermans and Arthur W.S. Helwig received their M.Sc. degree in Electrical Engineering from the Delft University of Technology in 1997, 1994, and 1995 respectively. Currently, Mr Van Essen is employed by KLM Royal Dutch Airlines. Mr Offermans is working on "datalinks for differential navigation" and Mr Helwig on "general digital receiver concepts for integrated navigation receivers" in a 4-year Ph.D. research program at the same university.

Dr. Durk van Willigen heads as a professor in radionavigation a research team of staff, Ph.D. and M.Sc. students in the Department of Electrical Engineering at Delft University of Technology. This group focuses on integrated navigation systems. Also, Mr Van Willigen is the president of Reelektronika, a small privately owned consultancy on radar and radionavigation.

ABSTRACT

Eurofix is an integrated navigation system, which combines Differential GNSS and Loran-C. The Loran-C system is used to transmit messages which contain differential corrections for GNSS by additional modulation of the transmitted signals. It has been shown that reliable data transmission with Loran-C stations up to 1,000 km distance is feasible. The differential corrections are generated by a DGPS reference station located at the Loran-C transmitter site, providing single DGPS to all users within the datalink range. Unfortunately, single DGPS corrections suffer from spatial- and temporal decorrelation, degrading the differential performance with increasing distance from the reference station.

It can be shown that for most of the Eurofix service area, data transmissions from more than one Loran-C station can be received simultaneously. By using the information from the differential corrections received from all stations instead of only one, overall navigation performance can be improved, this is called networked DGPS.

This paper focuses on a specific implementation of regional area networked DGPS (NDGPS) called Eurofix RAAS. Spatial decorrelation and augmentation systems as a means to counter this, will be outlined. As a test case the performance of Eurofix with RAAS is simulated with a post-processing test set-up using real-life GPS data. Single DGPS and NDGPS performance results are presented. It will be shown that using Eurofix RAAS, navigation performance and integrity can be increased.

I. INTRODUCTION

The Eurofix integrated navigation system consists of differentially corrected GNSS and Loran-C/Chayka. As Chayka is very similar to Loran-C and Glonass to GPS, this paper will focus on Loran-C and GPS. In Eurofix, Loran-C signals are additionally modulated with differential corrections for GPS without any significant degradation in Loran-C navigation performance

The coverage of the Loran-C system currently includes the full CONUS, north-west Europe, the Mediterranean and large parts of Russia, Japan and China. This means that the area that can be supplied with DGPS data is quite large. In Eurofix, each Loran-C transmitter acts as a single, local DGPS reference station, transmitting differential corrections to users within datalink range. The range of the Eurofix datalink has been shown to be at least 1,000 km [1]. By providing single DGPS corrections over such large areas Eurofix serves as a Wide-Area Augmentation System for GPS.

While the single differential technique can greatly reduce biases in GPS observations, it is based on the basic premise that the primary error sources of the system are spatially correlated with those measured at the reference station. While this is true for short distances from the reference station, the error sources decorrelate as distance increases. A remote user will not be able to sufficiently reduce the primary error sources in his GPS measurements by using the differential corrections computed at the reference station, reducing DGPS navigation accuracy.

The error due to spatial decorrelation has been estimated at about 0.4 metres per 100 km separation from the reference station [8]. With a typical user always being within distances of 600 to 800 km from a DGPS station this would lead to a spatial error of about 3 metres. This is under the assumption that there is no intentional ephemeris error due to SA.

With a datalink range of about 1,000 km, Fig.1 shows that, over most of north-west Europe, it is possible to receive more than one Loran-C/Chayka station. In fact over

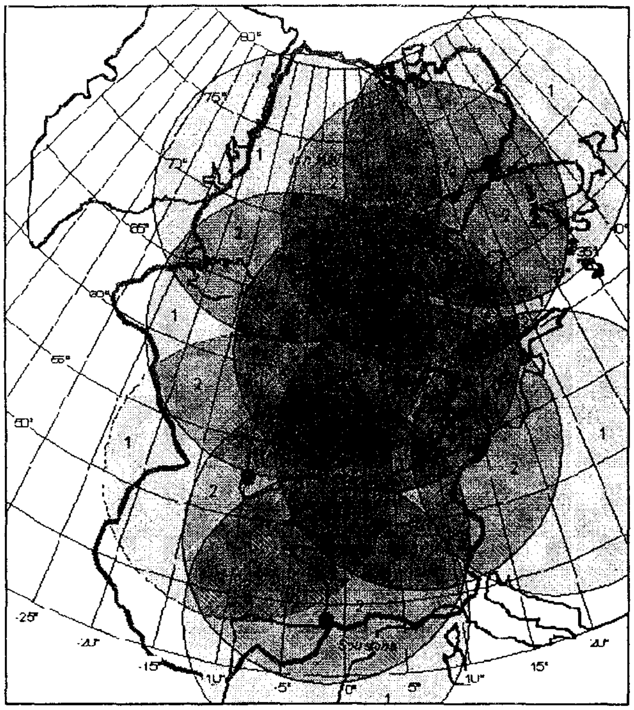

Fig.1 Approximate Eurofix datalink coverage (range ≈ 1,000 km). Numbers indicate number of stations within range.

most of the European land areas and the North Sea, it is possible to receive three or more stations, enabling more reliable DGNSS reception.

To improve integrity and accuracy even further, the Eurofix stations could be incorporated in a network. A network of a few reference stations can already provide a broad area with accurate differential corrections that should almost be comparable to local differential GPS [4, 10]. Networked DGPS also has the potential to be more robust, since it is able to detect and recover from equipment failure in one of the reference stations.

A concept of networked extended differential GPS, known as RAAS (Regional Area Augmentation System) is best suited for Eurofix. In the usual RAAS configuration, a communication network is needed to connect all stations for exchange of locally determined pseudorange corrections. With Eurofix, this network is not necessary. All stations broadcast directly to the Eurofix user. This provides the user with the option of autonomously deciding how he wants to use the received differential GPS corrections (PRC's); either as single DGPS corrections or as a networked correction.

Theoretical research by Jin [2] has shown that regular RAAS-networks spanning a typical Eurofix region leave only very small remaining errors. The performance of the RAAS-network depends on the number of reference stations used in the network solution. With at least three stations, decorrelation in both latitude and longitude direction can be compensated. With two stations the spatial error remains only minimal on the baseline, with normal LAAS degradation in the direction perpendicular to this baseline.

This paper details the mathematical processing that is required to implement RAAS networking in Eurofix and it describes the research work that was done to simulate the behaviour of a Eurofix RAAS using real-life data from the International Geodetic System of GPS reference stations.

II. DGPS Accuracy Limits

When assuming that accurate differential corrections at a reference station can be calculated, there are two general factors that limit the achievable DGPS position accuracy; temporal and spatial decorrelation of the DGPS correction data.

A. Temporal Decorrelation

Temporal decorrelation is mainly caused by the data latency of the communication link. This latency should be less than the time span over which pseudoranges change either due to unpredictable Selective Availability (SA) or because of variation in the ionospheric and tropospheric delays. Offermans and Helwig [1] have shown the temporal decorrelation error in Eurofix to be approximately 1.5 m.

B. Spatial decorrelation

The main spatial decorrelation errors are ephemeris errors and variations in the ionospheric and tropospheric delays. Jin [2] investigated the non-linearity of these spatial decorrelation errors over distances up to about 1,000 km. For three reference stations, well-spread over the area, and applying linear interpolation and smoothing techniques, Jin found for areas of 500 by 500 and 1,000 by 1,000 kilometres the remaining errors as listed in Table 1:

Table 1 Remaining effect of ephemeris errors, ionospheric delays and tropospheric delays after application of networked differential corrections, three reference stations

Network	Remaining errors (m)		
Size	Eph.	Ion.	Tro.
500x500 km^2	0.07	0.17	0.23/0.1*
1,000x1,000km^2	0.14	0.23	1.82/0.1*

* results using a tropospheric model

The following assumptions have been made

- satellite ephemeris error = 10 m
- ionospheric delay = 4.5 m (vertical, at reference)
- elevation = 15° (at reference)*
- Δ-elevation = 2°/100 km (at reference)
- tropospheric delay = 4.5 m (vertical, at reference)
- Δ-height = 80 m (between reference and user)

* note: in the later to be explained RAAS simulations, this elevation mask has often been used to recreate the conditions as used in this theoretical work.

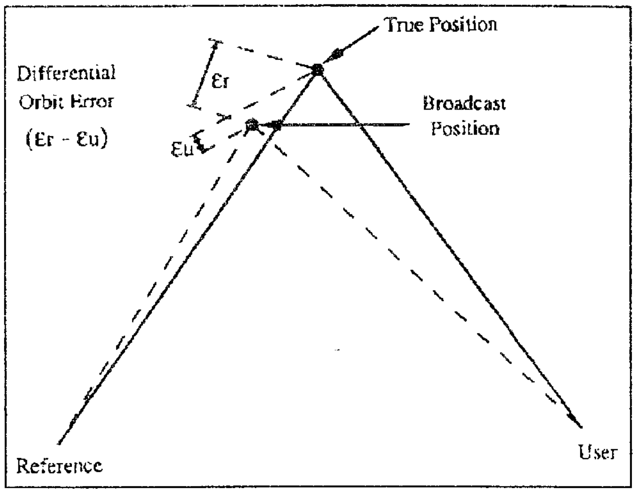

Fig.2 Ephemeris errors depend on the viewing angle.

EPHEMERIS ERROR

The satellites' orbits (ephemeris) are measured by the US Department of Defence and then broadcast by the GPS satellites. Under Selective Availability, the orbit parameters are purposefully misreported to cause a controlled navigation error for the user. With incorrect orbit parameters, both the reference, and the user will compute an incorrect satellite position. Although user and reference will have identical errors in computed satellite position, they will have slightly different errors in their respective computed ranges because of differences in viewing angles (see Fig.2)

As the separation between the reference and user becomes larger, so does the difference in viewing angle and the difference between the computed range errors. The navigation error caused by satellite position error is highly correlated between viewers and very linear in nature, i.e. the error is roughly proportional to the distance from the reference station.

IONOSPHERIC ERROR

As the GPS signal travels through the ionosphere, it experiences a delay. This delay can either be measured with a receiver that is capable of dual frequency code measurement, or it can be modelled. Unlike range error due to orbit parameter error, which behaves very linearly over large distances, the ionospheric error is subject to occasionally quite non-linear behaviour. Long-distance spatial decorrelation studies by Kobluchar indicate correlation distances in thousands of kilometres. Typical decorrelation ranges are 200 km (disturbed conditions) to 1,000 km (normal conditions) [4].

TROPOSPHERIC ERROR

The tropospheric delay of the GPS measurement is an unwanted delay in the code and carrier data introduced by the troposphere, which extends from sea level to approximately 50 km altitude.

The total delay can be divided into a dry and wet component. The dry component, which accounts for about 90% of the total delay, can be reasonably well modelled without any meteorological data. The wet component on the other hand, requires measurements of the local weather conditions along the line-of-sight for maximum accuracy. All tropospheric models are good above 15 degree mask angles.

For navigation networks, with hundreds of kilometres between reference stations, tropospheric error is more or less uncorrelated, and hence considered to be reference station unique. No exact function describing the variation over the coverage area can be constructed.

Table 2 Typical values for some GPS errors [3]

Error source	Typical Range Error	DGPS (Code) Range Error <100 km Ref-station
SV Clock	1 m	-
SV Ephemeris	1 m	-
Selective Availability	10 m	-
Troposphere	1 m	-
Ionosphere	10 m	-
Pseudo-range noise	1 m	1 m
Receiver noise	1 m	1 m
Multipath	0.5 m	0.5 m
RMS Error	15 m	1.6 m
Error * (PDOP = 4)	60 m	6 m

Typical values for the GPS errors that involve DGPS are listed in Table 2.

III. AUGMENTATION SYSTEMS

Augmentation systems consisting of networks of reference stations are based on the fact that an absolute pseudorange correction (PRC) can be defined for each satellite as a function of user location. A map of this function can be constructed, with the "iso-PRC" contours much like isobars on a weather map

As outlined by Loomis [4], the object of the network is to measure the PRC's at a few points, the reference stations, and construct an "iso-PRC" map (Fig.3) for each satellite. Because the ionosphere and the line-of-sight to the GPS satellites continuously change over time, this map would have to updated frequently; a heap of maps. In order to be able to take into account as many variations as possible in the PRC function, the reference nodes should cover as large an area as possible, with their spacing being dictated by the range over which the PRC function varies by large amounts and unpredictably.

LAAS DGPS

The reference stations, which may be co-located with the Loran-C transmitters in the Eurofix system, provide cor-

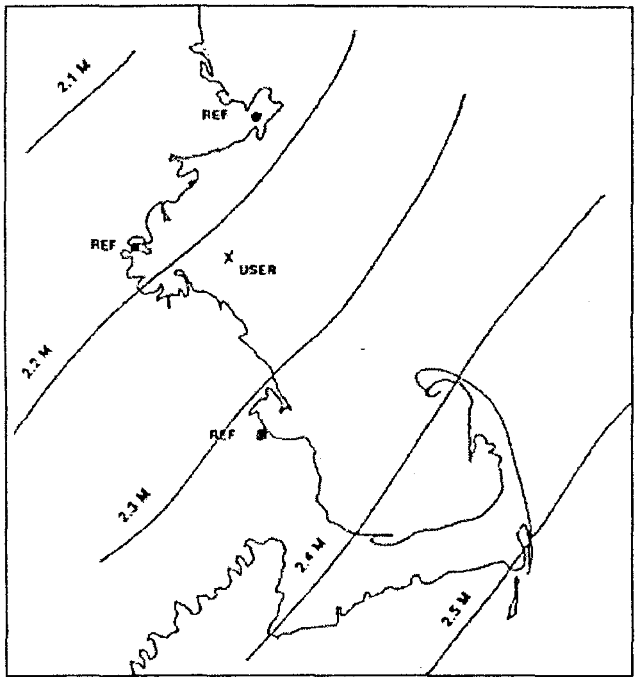

Fig.3 ISO-PRC's for each satellite.

rection data from a single reference point to users within the Eurofix datalink range. The navigation performance a user gets by applying this data depends on the temporal and spatial decorrelation between monitor and user. At best, without any spatial decorrelation, the maximum accuracy is dictated by the Loran-C datatransmission speed [8]. Generally a usable range of about 100-200 km is assumed for LAAS systems. Assuming it would at all be possible to implement such a system, even at sea, one would, by gross estimate, still need more than 60 reference stations to cover the total Eurofix service area.

Several reference stations would have to be linked to each of the Loran-C transmitters, and corrections from all of the linked stations would then have to be transmitted via the (on average) 30 bps datalink capability of the Loran-C signal, giving rise to serious delays and temporal decorrelation.

Clearly, these problems are not easily solved and a system like this with its infrastructural requirements would be very costly to implement as well. At the same time, users would be dependent on the corrections provided by only one reference station at a time.

It seems logical to assume that both efficiency and integrity will be improved if one could use corrections from not one, but multiple DGPS sources; by creating a network of reference stations. When using networked DGPS, there are two basic strategies to improve the differential corrections at a user site :

1. *Estimate the components* that make up the total GPS error and model their variation over the service area (WAAS).
2. Model the *variation of the total GPS error* over the service area using several (Extended (range) DGPS) reference stations.

WAAS

Wide-Area Augmentation System (WAAS) uses 20-30 reference stations at large distances apart [5]. These reference stations transmit their corrections to one or more master station(s) which are then able to estimate corrections for the various GPS error components and their variation over the total service area.

Due to its long baselines WAAS is able to extract ephemeris errors using triangulation. Ionospheric delays are measured by dual frequency receivers and tropospheric delay is modelled using temperature measurements and measurements of the humidity and barometric pressure [6]. Both ionospheric and tropospheric corrections are estimated using complex models [7].

Because individual error components are modelled over the total service area, navigation performance no longer depends on user position. Rather an average navigation performance over the total service area is realised. By combining the information from all the reference stations, continental-wide DGPS integrity is offered.

Because of the need for information processing at a master station, a large, reliable and costly infrastructure is required. Also high-speed datalinks are required to transmit corrections for all satellites in view in the total service area (such as e.g. satellite links), making this approach especially unattractive for Eurofix with its existing Loran-C infrastructure.

RAAS

The other, and simpler network strategy, that does take advantage of the existing transmitter network, is the combination of measurements from several reference stations surrounding the user (Regional) and the user applying a weighted (least-squares) average of the differential corrections from each of the reference stations (Common View Network [4]). No attempt is made to estimate the individual GPS error components. PRC's are merely weighted together, providing a first-order approximation of the variation of the PRC's in the region surrounding the user [8, Fig.4].

By letting the user compute his own weighted correction the need for a, costly, ground network can be eliminated, as is the case with the current single DGPS Eurofix system. Because a user can use more than one reference station and the fact that faulty corrections from one reference station are smoothed by the others in the averaging operation, integrity is improved. When reception of one of the reference stations is lost, Regional Area Augmentation will serve as a backup against total DGPS loss.

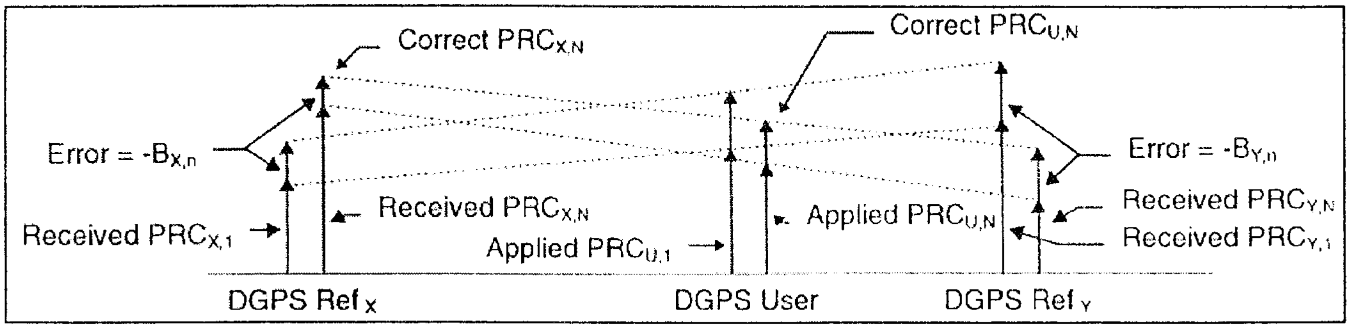

Fig.4 The derivation of the pseudorange corrections at the user's site by linear interpolation of the corrections obtained from two Eurofix reference stations.

A Regional Area Augmentation System like this offers average navigation performance away from the reference stations and even local area performance when moving close to one of the reference stations. Fig.4 illustrates the calculation of a user correction from interpolation of the surrounding corrections.

Due to the short baselines it is not practical to estimate ephemeris errors in a regional area network. Further improvements could be found in modelling the variation of the iono- and troposphere over the service area (differential ionosphere [9]).

Theoretically, a hybrid version of both the regional system and local DGPS could also be implemented. Close to a transmitter (according to a set range threshold) corrections from a single transmitter could be used while switching to a networked regional mode farther away. A disadvantage of this Mixed Area system would be the loss of integrity protection when using the single station DGPS as in the LAAS case.

IV. EUROFIX RAAS

The RAAS system for Eurofix is similar to the common view network described by Loomis. It is assumed that the differential user will navigate only with satellites visible to all the reference nodes. Obviously, the larger the region that is spanned by the network, the more difficult it becomes to find 4 or more satellites that qualify.

Since the common view network area is relatively small, one can assume that the PRC's are basically a linear function over the area. Over a regional area , this assumption would certainly be accurate for orbit error and reasonable for a single-frequency ionospheric model and may perhaps extend to tropospheric models as well. This assumption may be stretched a little in the case of very low elevation satellites [4].

WEIGHTED AVERAGE

The PRC that the common-view Networked DGPS (NDGPS) user applies is a weighted average, or blend, of he PRC's from the reference nodes. The weights for the average are determined solely by the relative geometry of the user and reference nodes (Fig.5). If the user is close to one of the nodes, of course the data from that node is more highly weighted [4,10].

The weighting coefficients can either be determined analytically or statistically [4]. The three weighting coefficients a_1, a_2, and a_3 for a three node network can be determined analytically by solving the three equations

$$\phi = \sum (a_i) \cdot \phi_i \tag{1}$$

$$\lambda = \sum (a_i) \cdot \lambda_i \tag{2}$$

$$1 = \sum (a_i) \tag{3}$$

with ϕ = user latitude and λ = user longitude.

The error introduced by each monitor receiver is thus diluted by its weight, so that if, for example, the weights were all equal, then each monitor receiver error would be diluted by a factor of $1/n$. But since the errors are uncorrelated, the standard deviation of their sum is $1/\sqrt{n}$; thus, the standard deviation of the total error due to the monitors is decreased by a factor of $\sqrt{n}$ from that of one monitor [10].

It is healthy practice to include more than three nodes in the network. Using least squares analysis techniques, the extra data can be used for checking the linearity assump-

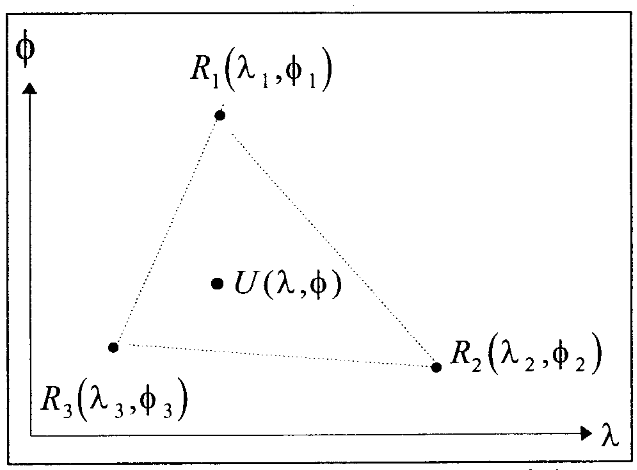

Fig.5 Calculating the correction weights using relative geometry of the stations.

tions and to check for reference station failure. Also, the extra stations can provide protection against equipment failure.

When implementing the above weighting method in Eurofix, it should be realised that the number of stations that can be received may vary, as will the processing required.

Assume that at n_r reference stations n^s satellites have been simultaneously observed and the PRC ∇^i_j $(i = 1,\ldots,n^s; j = 1,\ldots,n_r)$ and its rate of change have been computed at each of these reference stations. By means of the Loran-C transmissions, all the PRC's are transmitted to the user. Jin [2] has shown that in an area occupied by the n_r reference stations, although the PRC will not be the same for all of the n_r reference stations, it can be regarded as a linear function of x and y. The above result of equations 1-3 can therefore be expressed as

$$\nabla^i_j = \nabla^i_1 + a^i_1(x_j - x_1) + a^i_2(y_j - y_1) \tag{4}$$

where now x and y are the latitude and longitude coordinates in the WGS84 system. The parameters a^i_1 and a^i_2 are coefficients of a plane. It follows from (4) that for a DGPS network with three reference stations, we have

$$\begin{bmatrix} \nabla^i_2 - \nabla^i_1 \\ \nabla^i_3 - \nabla^i_1 \end{bmatrix} = \begin{bmatrix} \Delta x_2 & \Delta y_2 \\ \Delta x_3 & \Delta y_3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{5}$$

or

$$\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \Delta x_2 & \Delta y_2 \\ \Delta x_3 & \Delta y_3 \end{bmatrix}^{-1} \begin{bmatrix} \nabla^i_2 - \nabla^i_1 \\ \nabla^i_3 - \nabla^i_1 \end{bmatrix} \tag{6}$$

where $\Delta x_j = x_j - x_1$ and $\Delta y_j = y_j - y_1$

This method is extremely simple to retrofit to existing DGPS installations, as all the network-specific algorithms are contained in the user receiver.

Weighted Least-Squares

For the case of four or more reference stations, the same procedure can be followed by using least-squares techniques to solve the over-determined set of equations:

with $G = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \\ \vdots & \vdots \\ x_r & y_r \end{bmatrix}$ the coefficients become:

$$\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \left(G^{\mathrm{T}}G\right)^{-1} G^{\mathrm{T}} \begin{bmatrix} \nabla^i_2 - \nabla^i_1 \\ \nabla^i_3 - \nabla^i_1 \\ \nabla^i_4 - \nabla^i_1 \\ \vdots \\ \nabla^i_r - \nabla^i_r \end{bmatrix} \tag{8}$$

Instead of using least-squares techniques, it would also be possible to use an extra parameter a_3 and the extra equation, to model the effect of e.g. height variations. While this approach makes sense for small networks with a large height variations, it is a poor solution for Eurofix. The long baselines and the relatively small variations in height over the service area (bad VDOP) will make the Eurofix network correction very susceptible to reference station deviations. Instead of a smoothing effect, it has been noticed in simulation that this can lead to large jumps in the navigation solution and significant loss of performance.

Projection

In case only two reference stations can be received, network corrections can only be modelled over the baseline between the two reference stations. Perpendicular to this line, the spatial decorrelation error grows with the same amount as in the conventional LAAS mode. The user differential correction can be written as:

$$\nabla^i_j = \nabla^i_1 + a^i_1 \cdot p_j \tag{10}$$

with a^i_j being the gradient of the differential correction over the line connecting the two reference stations;

$$a^i_1 = \nabla^i_2 - \nabla^i_1 \tag{11}$$

and p_j being the factor of the projection of the users position onto the line connecting the two reference stations;

$$p_j = \frac{\begin{bmatrix} \Delta x_2 & \Delta y_2 \end{bmatrix} \begin{bmatrix} \Delta x_j \\ \Delta y_j \end{bmatrix}}{\begin{bmatrix} \Delta x_2 & \Delta y_2 \end{bmatrix} \begin{bmatrix} \Delta x_2 \\ \Delta y_2 \end{bmatrix}} \tag{12}$$

with $\Delta x_j = x_j - x_1$, $\Delta y_j = y_j - y_1$.

In RAAS, the difference in PRC's between reference stations j and 1 for a particular satellite does not include the satellite clock bias. It is, therefore, only a function of the difference of ephemeris errors, tropospheric delays, ionospheric delays and receiver clock biases between these two stations, and so are the parameters a^i_1 (and a^i_2). Second, the difference of receiver clock bias included in $\left(\nabla^i_j - \nabla^i_1\right)$ has the same effect on a^i_1 (and a^i_2), $i = 1,\ldots,n^s$, for all satellites, thus it will only result in a bias in the estimate of the receiver clock bias of a user. It will not affect the estimate of user positions.

SYSTEM ASPECTS

In general not much design effort has been put into RAAS-like concepts of extending the effective range of DGPS. This is because such a system is inefficient from the standpoint of frequency allocation because multiple DGPS data streams are used, requiring several times the single DGPS communication bandwidth. Since Eurofix is uniquely based on the existing Loran-C infrastructure, cost aspects of implementing a data-transmission structure is not an issue, making RAAS very well suited for Eurofix.

There are two points to be made about RAAS-type common view-systems that distinguish them from wide-area systems. First the common-view system needs no synchronisation between the reference node clocks. Whatever the individual reference clock errors are, they are averaged into the pseudorange corrections to form a blended "network clock" using the same weights that are used to blend the PRC's. The NDGPS user clock error is relative to the blended clock, just as the DGPS user clock is relative to the DGPS reference station clock. Second, because the area of coverage is relatively small, there is no need to try to separate the satellite clock error from the satellite radial error (or more exactly, line-of-sight error). Consequently, the satellite position is not fully determined by the common view network [4].

V. RAAS TEST SET-UP

SIMULATOR

In order to test the proposed Eurofix RAAS system a Windows-test bed DGPS Engine has been created.

This test bed consists of three integrated parts.

1. <u>Differential Corrections generator</u>. Generating differential corrections from code-based pseudorange measurements at a specified reference station position.
2. <u>RAAS network vector generator.</u> Applies the weighted (least-squares) network algorithm as described in the previous section to calculate a PRC for a given user location.
3. <u>GPS Navigator</u>. Calculates user position from user pseudorange data using:
    a. no corrections at all (stand-alone GPS)
    b. single DGPS corrections from one reference

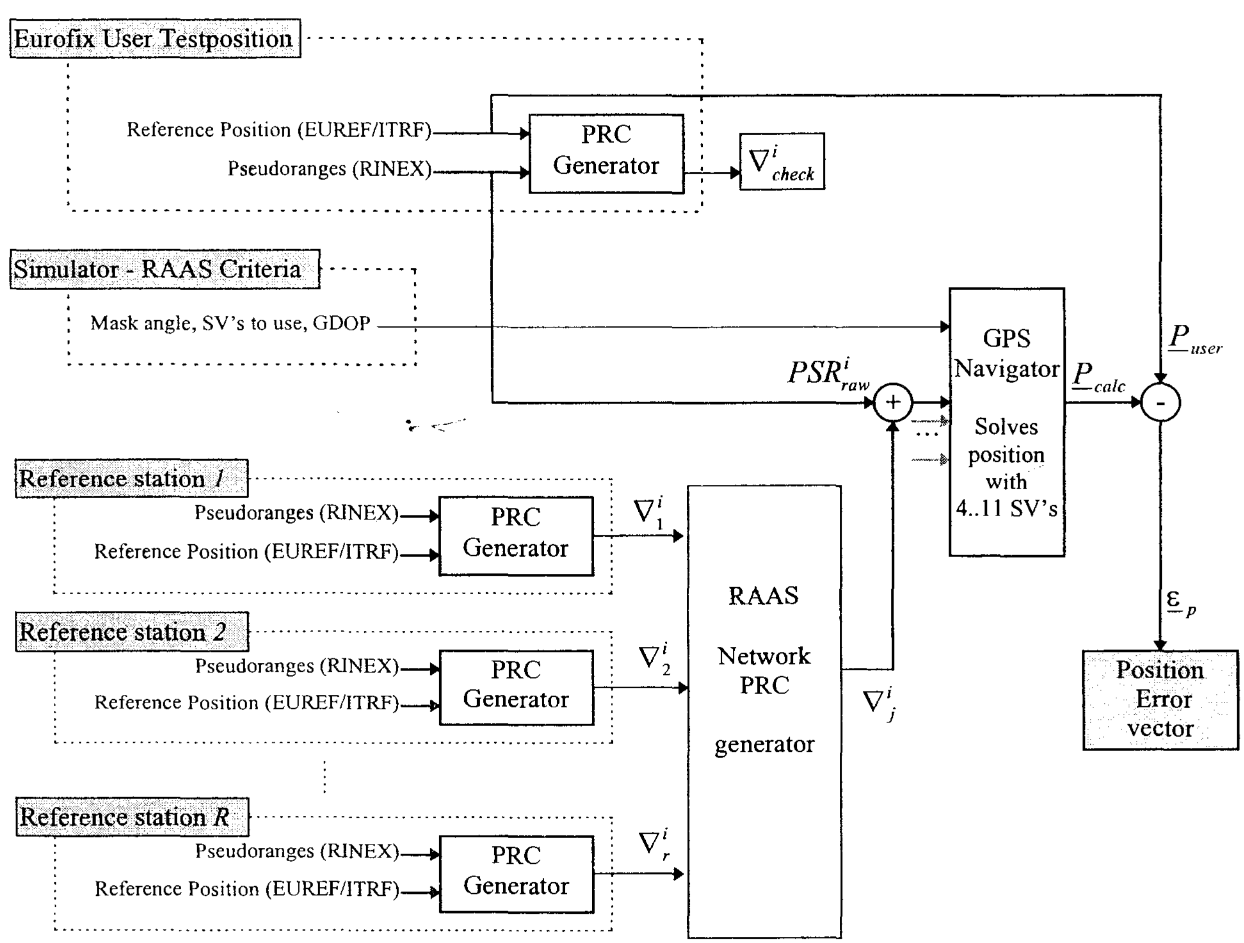

Fig.6 Functional diagram of the RAAS test-bed.

station (standard Eurofix)

c. networked DGPS from two or more reference stations

The *Navigator* includes options for

- specifying the maximum number of satellites to use (preferably all),
- the masking angle for elevation (in order to e.g. use only satellites higher then 15 degrees above the horizon) and
- the maximum acceptable GDOP.

No code-smoothing techniques have been employed when generating the differential corrections.

Fig.6 shows the functional diagram of the test set-up.

GPS DATA

For simulating spatial decorrelation, it is essential to have access to GPS measurements taken at different locations over the Eurofix service area, all at the same time instance. To solve for this problem in the simulation raw GPS data are used from the international geodetic system (IGS). This system is made up of reference stations world-wide which continuously log raw GPS data at 30 second intervals. All navigation data from the GPS satellites is logged as well as one or more observables (code, carrier, Doppler). Data from the reference stations is distributed in the Receiver Independent Exchange (RINEX) format and is available via special servers on the Internet in datafiles comprising one whole day of logdata.

REFERENCE SITES

Since only errors due to spatial decorrelation are to be investigated, it was decided to try and minimise unwanted errors by careful selection of the reference sites that would provide GPS data. A selection of 14 IGS fiducial sites (Fig.7) was made using the following criteria:

- known, exact and trusted position (EUREF)
- stable clock (atomic standard)
- datafiles adhere strictly to RINEX specification

Using the exact location of a reference station is very important for DGPS to work, for any survey errors will translate directly into user position offsets. Stable clocks are not strictly required for synchronous DGPS processing, therefore the requirement for an atomic clock will be dropped in further simulations. Since receiver clock errors apply to all PRC's from a particular reference station they will be solved in the GPS Navigator. Only when an asynchronous scheme is used, such as is the case when using the slow Loran-C datalink, the clock error should remain (extremely) stable during the time the correction data for all satellites are broadcast.

In Eurofix a system is used whereby the receiver clockbias is estimated by averaging all satellite PRC's [8]. To be as close to true Eurofix as possible, the same technique is also implemented in the RAAS test bed as an option. In the simulator this technique serves as an analysis tool; scaling

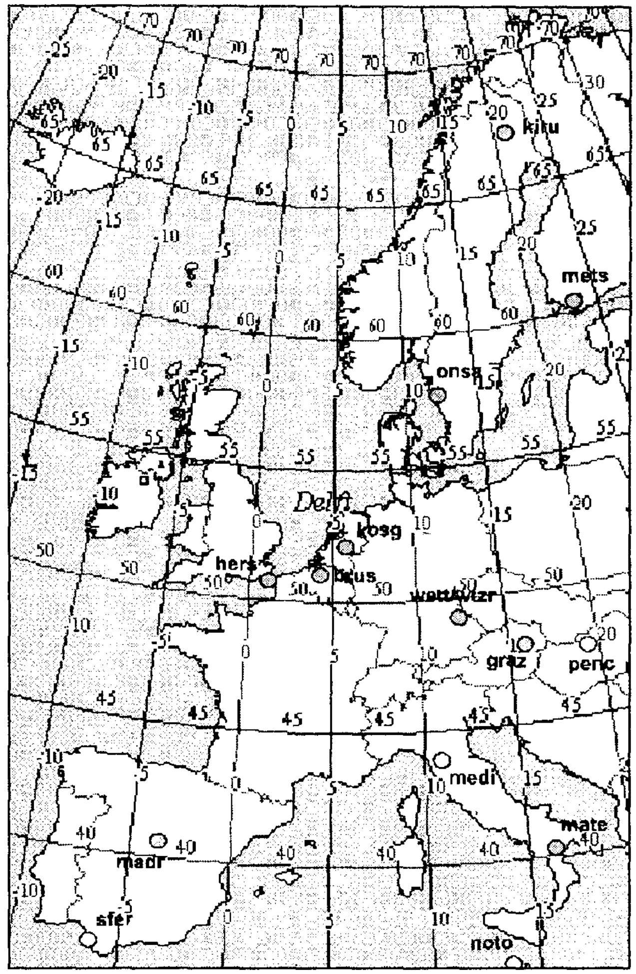

Fig.7 Selected IGS Stations with atomic clocks and fiducial positions.

the PRC's of the different reference stations to the same order of magnitude, making comparisons easier.

In selecting constellations of reference sites for the simulations, those sites have been chosen that have baselines between stations that are comparable to Eurofix/Loran-C baselines.

OUTPUT

To verify the calculated networked PRC's, one of the IGS stations is selected as user position with one or more other stations serving as reference stations. Logs are created with the user's stand-alone GPS solution, single-DGPS solutions for each reference station at the user site and if applicable the users position when applying the network vector PRC.

VI. TEST RESULTS

NOISE

Before investigating spatial decorrelation, it is useful to get an impression of the positioning performance of the simulator, using a short baseline (little spatial decorrelation). Fig.8 shows the noisy nature of the GPS solution when

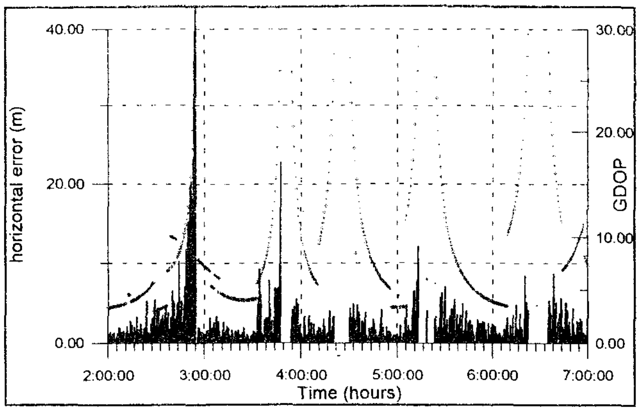

Fig.8 Noisy Single DGPS solution when using first 4 common satellites (at 183 km from reference station) Missing data (gaps) are epochs with less than 4 common satellites. Plus-signs indicate value of GDOP (same axis).

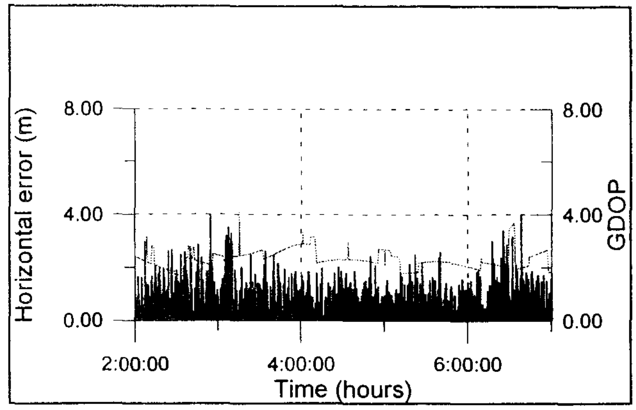

Fig.9 Single DGPS solution when using all available common satellites (same GPS dataset as Fig.8). Line indicates GDOP values.

using only the minimum required set of 4 satellites to solve the position.

Because of the 30 second interval it is difficult to use code smoothing techniques to lower noise levels. Fortunately, as can be seen in Fig.9, using all available satellites in the GPS solution significantly improves performance, reducing standard deviation fivefold (from 3.26 m to 0.70 m) and the average by 50% (from 2.12 m to 1.12 m.).

At the expense of availability, further improvements can be made by applying selection criteria; setting upper limits to the usable Dilution of Precision and lowest elevation angle (Fig.10). Recall that as mentioned before setting elevation masks has also been adopted by Jin in his theoretical work on networked DGPS. So this selection technique should improve similarity between actual simulator results and the theoretical ones.

SPATIAL DECORRELATION

To investigate the effect of spatial decorrelation, single DGPS solutions over varying baselines were calculated. Fig.11 shows a typical case using long (1,000 km) baselines.

If there were to be perfect spatial correlation between the single DGPS reference station and the remote user location, all position dots would be right in the centre (0,0) of the grid, namely exactly on the user's true position. Due to

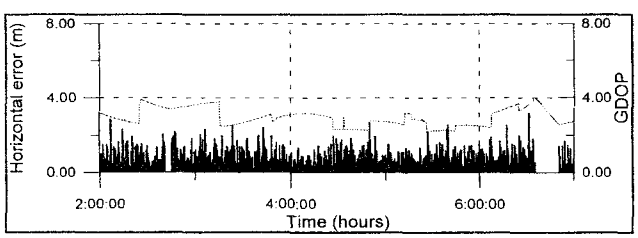

Fig.10 Single DGPS solution when selecting only satellites that meet criteria. Selection of data based on elevation of more than 15 degrees. and epoch GDOP < 4 (Same GPS dataset as Fig.8) Line indicates GDOP values.

receiver unique errors as e.g. multipath and receiver noise a certain spread is inevitable, but as these errors are uncorrelated they should not cause an average offset.

There are two effects that are assumed to be a possible cause the observed offset:

1. Spatial Decorrelation
2. Survey errors in the location of the reference site. (i.e. an erroneous reference position is used in calculating differential corrections)

Since differential GPS positioning relates the users position to the reference station (which is assumed to have a precise knowledge of its position), survey errors will directly translate into navigation errors (offsets) at a user. To prevent this from happening very precise geodetic co-ordinates (EUREF) have been used in the RAAS simulator. The sur-

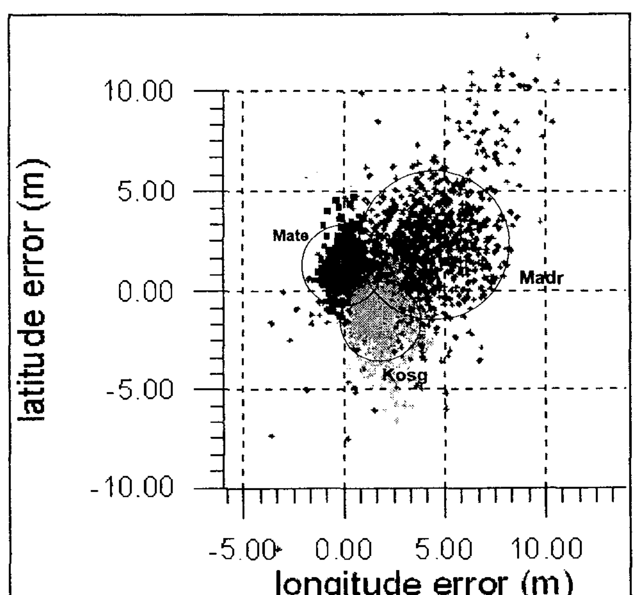

Fig.11 Single DGPS errors with Graz as user station and Kosg, Madr, Mate as references (data selection criteria applied).

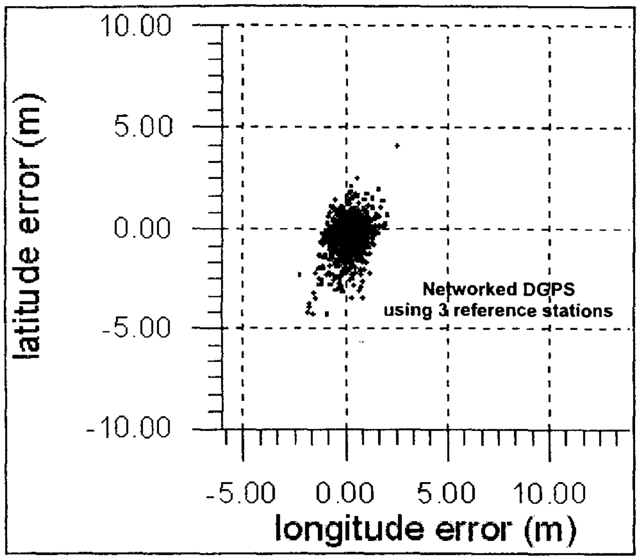

Fig.12 Networked DGPS error using same stations as in the case study of Fig.11.

veying error in the positions for all stations used in this paper should thus be less then a few centimetres.

This leads to the conclusion that the observed offsets in Fig.11 can only be caused by spatial decorrelation.

To evaluate the proposed RAAS network DGPS it is not absolutely necessary to know the exact size of the error caused by spatial decorrelation. It is just possible to compare the performance of the various networked position solutions to the single DGPS solutions.

RAAS NETWORK DGPS

Using the three single DGPS reference stations from the previous case, a networked DGPS is generated, the results of which are plotted in Fig.12, as well as listed in Table 3.

Table 3 Positioning results Single DGPS and 3 reference Network DGPS

Positioning	NDGPS	Kosg	Madr	Mate
Average	0.930 m	2.332 m	4.763 m	1.33 m
Std.dev.	0.668 m	1.007 m	2.513 m	0.632 m
95%	2.320 m	4.329m	9.574 m	2.381 m

It can be seen that the network performance is better than any of the individual single DGPS reference stations. Although, there is not much difference between the single DGPS performance of Mate, a user would not have known which station to use best. It is only in these simulations that a 'best' reference station shows up. The network has the added bonus that it always gives good performance without any need for reference station selection.

A similar result is obtained using another set of reference stations. This time four reference stations are used to obtain a RAAS networked DGPS result with baselines up to 1,000 km. (Table 4)

Table 4 Positioning results Single DGPS and 4 reference Network DGPS at user-node Kosg

Position	NDGPS	Hers	Brus	Onsa	Wett
Average	1.269 m	2.327 m	1.187 m	2.534 m	2.362 m
Std.dev.	1.174 m	2.131 m	0.920 m	2.442 m	2.677 m
95%	3.106 m	5.542 m	2.834 m	7.557 m	5.675 m

In this case, the nearby station Brus has just a bit better performance compared to the network solution. The reason being the rather bad performance of the Hers station which is also relatively close by. This is the result to be expected with applying an averaging operation to obtain the network corrections. Still the smoothing effect of the network on the 'bad' data is such, that if a user had selected any of the other reference stations, performance would have been worse than the current network DGPS solution.

Results for different user stations but using the same network of reference stations as in the first network example (Fig.13, Table 5), show that for stations within the edge formed by the reference stations, the average offset in user position is within metre-level and 95% values are within 2 metres.

The station with the large(std) errors is Onsa, 700 km away from the nearest network reference node and outside the edge of the area circled by the reference nodes. The maximum distance between Onsa and a reference station is 2215 km., a distance unobtainable using the Loran-C datalink, resulting in often very poor numbers of observable satellites. Still its 95% error is within 5 metres.

Table 5 NDGPS Positioning error for users at different locations using the same 3 network reference nodes

Station	Brus	Graz	Onsa
Average	0.827 m	0.930 m	1.929 m
Std.dev.	0.558 m	0.668 m	1.422 m
95%	1.898 m	1.797 m	4.758 m

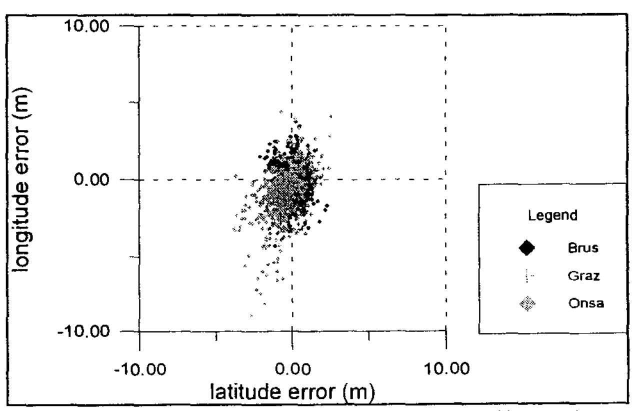

Fig.13 Position error for NDGPS users at different locations using the same 3 reference stations.

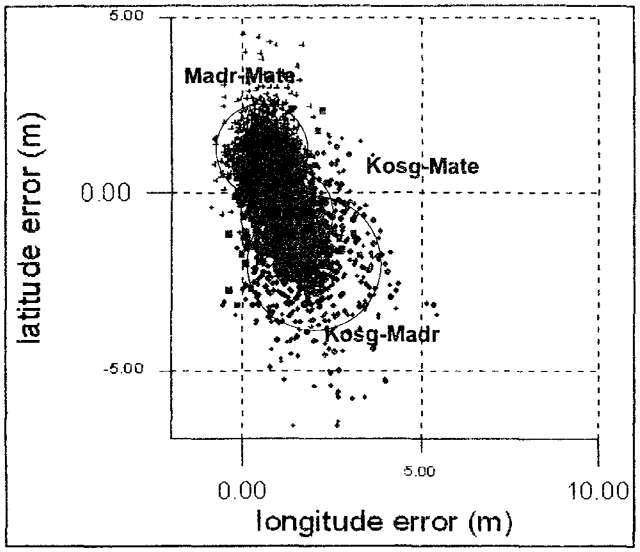

Fig.14 NDGPS/RAAS performance using only 2 reference stations to calculate network solution (various baselines).

Finally, Fig.14 shows three network solutions for a user at Graz using a network of two reference stations to calculate a correction. Each of the pairs forming a network has been marked on the figure. On the IGS-station map it can be seen that the baselines of Madr-Mate and Kosg-Madr are almost perpendicular to each other. Since a network with two stations can only compensate using a gradient along its baseline, this results in the first network to compensate using a northing gradient and the latter to compensate using an eastbound gradient. Since neither of the two has its baseline close to the user position, this should in both cases result in a marked residual error (offset). As can be seen this is the case. The third network consisting of reference stations Kosg and Mate has a baseline that both comes relatively close to the user position and which has a baseline which is diagonal to both others giving it a gradient that compensates for both the variation in latitude and longitude. One should therefore expect on the basis of the RAAS network theory, that the Kosg-Mate network should best be able to compensate in this case with a network solution which is between the offsets of the two others. This is exactly what happens in practice as the figure shows.

VII. CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

This paper has shown the feasibility to implement a wide-area augmentation system for Eurofix and that a regional area common-view system is best suited for this. Algorithms for using regional augmentation of Eurofix using two, three or more reference stations have been proposed. A method and implementation of simulating the RAAS system using real-life GPS data was shown and the first simulator test results were presented. Based on the noisy nature of the supplied data, input limits had to be imposed to lower the noise level of the simulation results, trading availability for quality.

The following observations can be made about the proposed RAAS system for Eurofix.

Eurofix RAAS:

- indicates in simulations that, within typical Eurofix navigation ranges of less than 1,000 km:
  - –metre-level accuracy is obtainable where three or more Eurofix stations can be received *(large part of NELS coverage area, see Fig.1)*
  - –metre-level accuracy is obtainable over the baselines between two reference stations.
- does not degrade the performance of Eurofix compared to the 'standard' LAAS system; at ranges less than 200 km from a reference station RAAS performance is equal to LAAS
- adds integrity monitoring capability
- smoothes irregular PRC's
- makes use of the existing Loran-C infrastructure
- needs no additional hardware or communication networks to be installed
- is easy to upgrade (user software only)

Extensive checks and the simulation results indicate proper operation of all software, which means a system is now in place to validate the RAAS system with extensive simulation over long periods of time.

FURTHER WORK

Apart from further validating the existing RAAS proposal, it should be possible to improve upon the current 'simple' linearity assumption for the variation of the gradients.

Currently no attempt has been made to extract ionospheric- and tropospheric delay. Using models for these errors, theory suggests [2] that even better differential corrections could be obtained at a user position.

To make visible, the improvements that are to be implemented, it is very desirable to obtain better GPS data to serve as input for the Eurofix RAAS simulator with :

1. a much smaller sampling interval (a few seconds or less), smoothing techniques could then be used to lower the current noise level in the current code-based positioning algorithm.
2. a much higher density in reference stations locations. Having more reference stations will enable a more detailed picture of the behaviour of the PRC-error over the coverage area and the creation of "virtual Eurofix", a network with identical geometry to the Loran-C chains, in post-processing.

The current assumption is one of a fixed reception area for the Eurofix stations. Since it is unlikely that in practice one could receive a station all the time in this coverage area, further studies could investigate the availability of the signals and techniques to counter the effects of sudden loss of reception of data from a reference station.

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Q: Can you explain the bias which is correlated and in the direction of the user?

A: I think it has to do with different viewing angles between station and user.

Comment from the floor: Satellite signals coming to the reference station and to the user travel through different tropospheric and Ionospheric environments ... It gets difficult to understand because there are so many satellites, directions, etc.

Author: We have no good answer right now. We're working on it.

Comment from the floor: Ionospheric and Tropospheric delays are always positive.

Comment from the floor: Maybe it's that all the satellites go the same way, or are asymmetrical in azimuth coverage.

Author: For a 2000 km spacing, the elevation difference for a satellite can be as much as 20 degrees.

Future Eurofix Services

Dr. Durk van Willigen, Arthur W.S. Helwig, Gerard W.A. Offermans & Edward J. Breeuwer
Delft University of Technology

BIOGRAPHY

Dr. Durk van Willigen heads as a professor in radionavigation systems a research team of staff, Ph.D. and M.Sc. students in the Department of Electrical Engineering at the Delft University of Technology. This group focuses on integrated navigation systems. Finally, Dr. van Willigen is the president of Reelektronika, a small privately owned consultancy on radar and radionavigation.

Arthur W.S. Helwig and Gerard W.A. Offermans received their M.Sc. degree in Electrical Engineering from the Delft University of Technology in 1995 and 1994, respectively. Currently, Mr. Helwig is working on 'general digital receiver concepts for integrated navigation' and Mr. Offermans on 'datalinks for differential navigation' in a 4-year Ph.D. research program at the same university.

Edward J. Breeuwer got his M.Sc. degree in Electrical Engineering in 1991 from the Delft University of Technology. He has conducted his M.Sc. research on GPS multipath partly at the Avionics Engineering Center of Ohio University at Athens, Ohio. Mr. Breeuwer almost finished his Ph.D. research program on 'integrated navigation' at Delft University of Technology. He is currently with Reelektronika and working for Eurocontrol in Paris.

ABSTRACT

Since February, 1997, Eurofix is initially operational at the Loran-C station at Sylt (Germany). The tests carried out show a very reliable system which gives an accuracy of better than 3 meters (95%) at 400 km from Sylt. A short message service (SMS) is operational since July 1997. Successful static and dynamic tests have been executed in France, Switzerland and Germany up to distances of 1,000 km from Sylt.

The paper describes the public acceptance and political problems that Loran-C faces today. Suggestions in respect of additional services are given to improve the added value of the Loran-C system. It is rather easy to use Eurofix in a Regional Area Augmentation System (RAAS) mode. It is only the receiver that must be capable to perform the RAAS calculations; the Eurofix transmitters remain fully autonomous. In this mode the temporal and spatial decorrelation decrease while the reliability of the navigation functionality significantly improves.

Finally, a short comparison is made between performance and costs of Eurofix and WAAS or EGNOS.

CURRENT STATUS OF EUROFIX

The Loran-C transmitter at Sylt (Germany) is transmitting Eurofix DGPS correction data since February 1997. A Eurofix receiver is installed at Delft University, at a distance of about 400 km from Sylt, to monitor the Sylt transmissions and to remotely control the Eurofix data transmissions. The achieved horizontal position accuracy at Delft is better than 3 meters (95%). Fig. 1 shows a typical scatter plot as measured at Delft. Since the start of the transmissions the Eurofix system at Sylt proved to be very reliable.

In July 1997 a Short Message Service (SMS) has also been activated at Sylt. From the site at Delft short messages can be sent to Sylt via the public telephone network. These messages are then broadcast at the earliest possibility after finishing the current message being transmitted. This delay will take at most 60 GRI which equals 6 seconds for a GRI of 9999. The length of a single message is limited to 56 bits. Longer messages can be broadcast by using multiple 56 bit long messages. If more than one message is delivered to the station, a priority control mechanism must decide which one will be sent first.

Further tests of the Eurofix transmissions have been conducted in France, Switzerland and Germany. A van equipped with two Eurofix receivers and signal analysis tools has been used. The signals have been monitored at distances up to 1,000 km from Sylt. Helwig et al. further report on this [1].

HOW TO CONTINUE?

During its April-'97 meeting held in Voorburg, (Netherlands) the NELS (Northwest European Loran-C System) Steering Committee decided in principle to implement Eurofix in NELS. An Implementation Working Group guided by Mr. Christian Forst has been asked to write an Implementation Plan to be presented at the Steering Com-

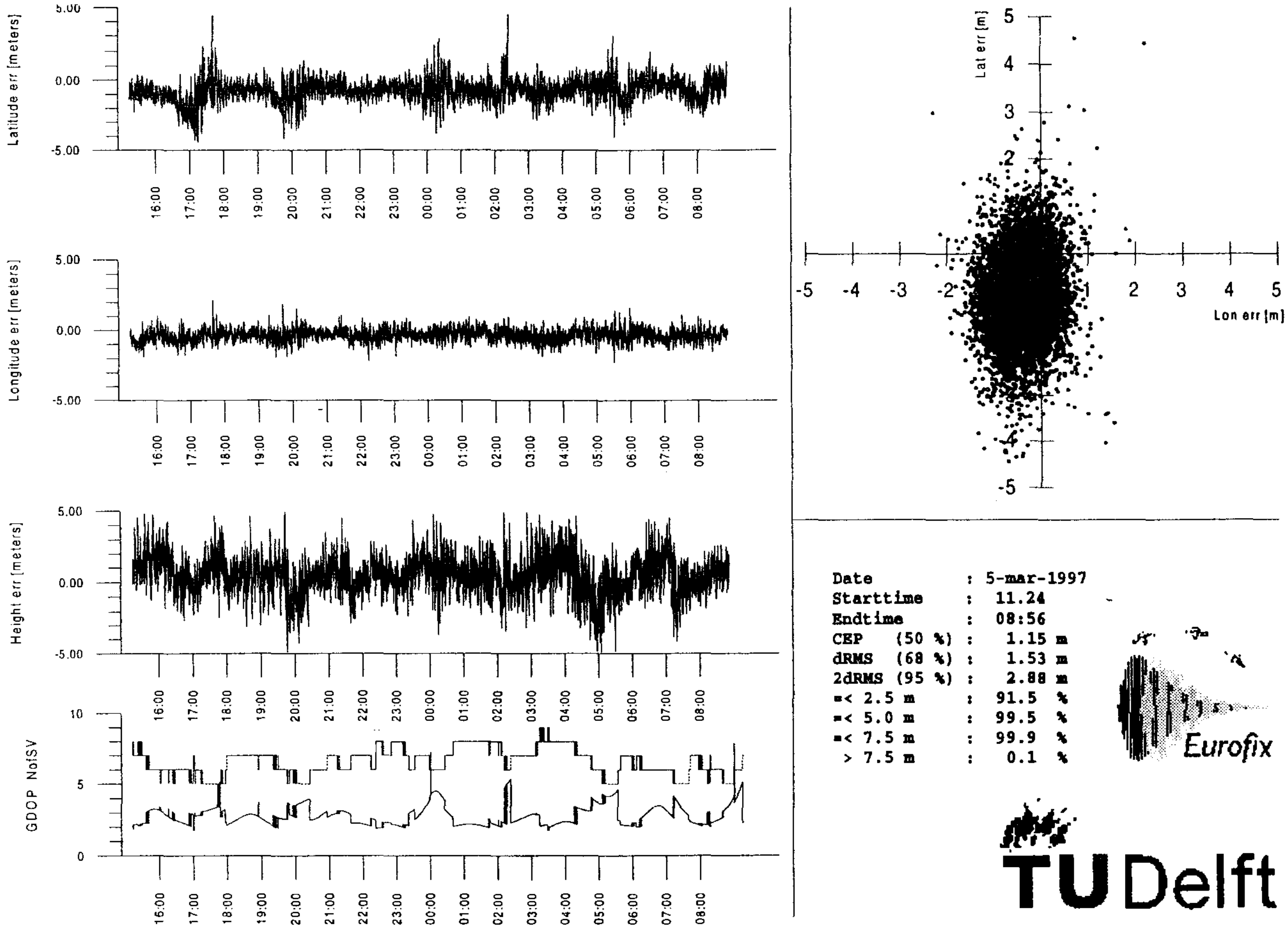

Fig. 1 - Static test results using a 30 GRI (21 bits per second) datalink, 5/6 March 1997

mittee meeting in Oslo on 28-29 October 1997. This committee must then decide how to continue. We hope of course that the Initial Operating Condition will be continued and that the Full Operating Condition will be achieved soon.

It is noted that the NELS initiative might be an important signal to Russia, Asia and the United States concerning the continuation of Loran-C after the year 2000.

As no low-cost and high-performance Loran-C or Eurofix receivers are currently available, the Steering Committee also decided to ask Mr. Terje Joergensen (head of the NELS Coordinating Agency) to set up a consortium for the design and production of such receivers. Four different types of receivers are foreseen:

- Basic Loran-C receiver which operates in the traditional way. However, this type must meet certain specification in respect of accuracy under typical European interference conditions.
- OEM Loran-C receiver that can be integrated with commercially available GPS receivers. The integration may be either on the position level or, more advanced, on the raw data level [2].
- Eurofix datalink receiver to be used for DGPS correction data reception only. This type will not process the measured Loran-C range data. This receiver is a direct substitute for the current IALA Radio Beacon receivers, however, with a substantial longer range.
- High-end Eurofix receiver which has the largest capabilities to achieve maximum accuracy and reliability. It runs in the DGPS mode as long as both GPS and Eurofix are available. In this mode it continuously calibrates the received Loran-C ranges in order to compensate for any error in ASF estimation [3].

To maximize the usability of such receivers its cost, size and power consumption must be kept very low. The DGPS data output is fully compatible with the RTCM SC-104 Type-9 format.

COMMERCIAL ISSUES

Loran-C is, unfortunately, generally received by the public with skepticism. Its performance in respect of absolute accuracy and acquisition time is not as good as that of GPS, and Loran-C is therefore typically seen as one of granddaddy's systems. Unfortunately, it must be agreed that many Loran-C receivers are indeed slow, bulky, costly and incapable to integrate with GPS. And meanwhile the public is still convinced that GPS works anywhere and always. As nobody likes to be seen with an old-fashioned system, the integration of Loran with GPS is psychologically somewhat difficult!

In the US and also in Europe we observe very different situations in respect of Loran-C receiver availability and the number of users. We see many users in the US, but the FRP of 1996 states that the Loran-C transmissions will stop by the year 2000 [4]. In Europe the Loran-C network is still expanding, but there are very little users which may raise concerns to the governments [5,6]. So, the governments, the users and the manufacturers all have different reasons why few receivers are currently available. The governments want to see more users; the users would like to have receivers capable to operate in Europe, and, finally, the manufacturers need guarantees for the continuation of the Loran-C transmissions to obtain an adequate return on investment in research and development.

POLITICAL ISSUES

The Global Position System GPS is the US-embraced navigation aid which offers large economic benefits to the US industry. Due to its initially DoD funded receiver design the US industry got a unique commercial head-start with respect to Europe and Asia. So, there could be a good reason for the US to discourage any radionavigation system that might endanger the rolling GPS ball. Such endangering systems are for example Loran-C, Omega, VOR/DME, ILS and MLS. Keeping this in mind one can more easily understand the reasoning of many US-government decisions on radionavigation.

Therefore, the idea must be strengthened that Loran-C offers substantial possibilities to make GPS even better than it is already today. It may help to improve the continuity of the navigation functionality which may help to counteract the single-point failure character of GPS. Such failures already became evident during periods of radio interference wherein GPS is almost helpless. Bond [7] has reported this at the October 1997 Air Traffic Control Association meeting at Washington on October 2, 1997. Many other papers on this subject have been published. It is this single-point-failure character of GPS that is repeatedly ignored, at least in public, by almost any official US organization.

It is interesting to note that the popular DGPS radio beacon system gives excellent accuracy and external integrity. However, as both systems must be up and running to achieve this improvement, it will inevitably be at the cost of availability and reliability. Integration of Loran-C and GPS offers improved availability and reliability but will not lead to a higher accuracy or integrity. The basic accuracy of Loran-C may hardly help to improve the SPS accuracy and RAIM performance of GPS. The maximum gain in the integration of Loran-C and GPS can be obtained by using Eurofix and external integrity. Then we have DGPS with adequate RAIM performance, and a continuous calibration of Loran-C by using accurate DGPS positions.

During outages of GPS, the highly calibrated Loran-C will bridge the gap with good accuracy as long as the Loran-C propagation velocity does not change too much.

To change the public opinion in respect of Loran-C's granddaddy aureole a number of initiatives should be taken:

- Convert the 80,000 general aviation Loran-C users into a group that requires better accuracy and integrity performance than GPS in its SPS mode can give today.
- Revitalize the public awareness that the 'navigation tax money' could probably be used more efficiently than is done today.
- Inform the GPS community in the appropriate magazines like GPS World, Aviation Weekly and Space Technology, and boating magazines about what is really going on in the GPS and Loran-C areas.
- And finally, continue to exercise the above given actions at full power for many years to come.

NEW SERVICES

To keep systems at the highest level of performance possible it is necessary to regularly come up with new capabilities of such systems. A number of real improvements can be implemented in the foreseeable future:

- Add SMS capability to the Eurofix transmissions in order to offer the GPS users full integrity services that comply with IMO and ICAO's en-route, NPA and possibly CAT-I requirements. The CAT-I capability, however, needs substantial further research.
- The SMS function might also be used as an emergency communication network during major communication infrastructure breakdowns due to earth quakes, power failures, flooding, loss of timing for telecommunications, etc.
- Add GLONASS correction and integrity data to the Eurofix transmissions.

- Implement dual-rate for data latency reduction
- Implement RAAS for spatial decorrelation and further data latency reduction, and for enhanced reliability.

The integrity of the Eurofix DGPS data and its broadcast is monitored on three different levels. First, the integrity of the pseudoranges and range-rates is analyzed. If an integrity alarm occurs the broadcast of the type-9 message of that particular satellite gets the highest priority. Next, the Eurofix transmissions are received at the reference station by a Eurofix receiver and the decoded data are compared with the generated data. Finally, the received data are also fed into a DGPS receiver and its position output is compared to the known surveyed position of the DGPS reference antenna. If an integrity threshold at the reference site is exceeded an integrity message will be released within at most 60 GRIs, always less than 6 seconds. If Eurofix is used in a Regional Area Augmentation Service (RAAS) mode this alarm time will be even less.

As already stated above, it is important to add differential GLONASS services to Eurofix. This will enlarge the potential user group. The absence of Selective Availability in GLONASS makes the additional load on the Eurofix datalink less than 10% of its total DGNSS capacity.

The adding of DGLONASS is not only interesting for availability reasons. It is maybe even more important for political reasons. The GLONASS addition makes satellite navigation less American and therefore more acceptable for the non-US parts of the world. It must be noted that GLONASS is expected to play a key role in the European GNSS-1 EGNOS design.

REGIONAL AREA AUGMENTATION SYSTEM - RAAS

Normally, RAAS configurations are based on a fast communication network between the reference stations and the master control station. The master station communicates the corrections to the users. As the Eurofix user will generally receive two or more Loran-C stations such a communication network is now entirely superfluous. It is the Eurofix user who computes the RAAS correction data for the GPS receiver.

To understand the RAAS capabilities of Eurofix more easily one must realize that the SA disturbances on the measured pseudoranges are identical for all GPS receivers at the Eurofix reference stations and at the user position. So, if the Eurofix stations are broadcasting LAAS corrections, all data correction messages will basically contain the same SA range corrections. However, LAAS-type corrections do not only contain SA components. These stations send corrections that are compiled of SA errors and of iono (I), tropo (T) and ephemeris (E) errors. ITE errors are sensitive to spatial decorrelation and are therefore basically different at all reference sites. Fortunately, the ITE errors vary only slowly with time which makes it possible to integrate the estimated errors to reduce the measurement noise.

Fig. 2 shows in the upper left part the time-variant values of the total emitted correction of reference station 1 while station 2 is shown at the upper right, both for satellite 1. The user is somewhere between these two stations. By applying a weighted average of the data received from the two stations the user obtains more accurate corrections than by simply applying the LAAS correction from either station. The transmissions of the Eurofix stations are basically asynchronous which makes the determination of the weighted average rather inaccurate due to SA. The horizontal axis shows the organization of the time multiplex structure of the type-9 correction data transmission. By storing a number of received corrections a second-order approximation of the curve of the correction data can be determined. This approximation makes it possible to find time-identical values of correction data of all received Eurofix stations. The horizontal lines connecting time-synchronous pseudorange correction values shift vertically due to the influence of SA. However, these lines will also rotate because of changes in the partly spatial decorrelated ITE values at the positions of the reference stations. These rotations vary rather slowly, so averaging is allowable. Therefore it is also allowed to extrapolate the attitude of the connecting lines to the present time. The variations in SA and ITE for another satellite will probably vary, as is shown in the lower part of Fig. 2 .

Summing up, the correction for the user position is found by taking the total LAAS correction for a particular satellite from the most recently received station and then add to this value the spatial correction term determined from the slope of the connecting line and the distance to the station. Note that the best situation will be achieved with three Eurofix stations where we get a correction surface instead of a line [8].

An interesting point is that if a Eurofix station cannot be received anymore the RAAS position accuracy will slowly degrade to LAAS accuracy. The transition time from RAAS to LAAS values depends on the rate of change of the attitude of the ITE correction surface.

This Eurofix RAAS concept is currently under further investigation at Delft University. Very realistic simulations based on measured GPS data at European IGS stations have been carried out and show very interesting results [8]. Based on this analysis and the experience with Eurofix transmissions so far, a horizontal position accuracy better than with the current LAAS technique (3 meters / 95%), is expected to be achieved throughout the full RAAS operating area of Eurofix. If all NELS and SELS stations will be reconfigured to Eurofix the operating range is likely to cover the whole continent of Europe.

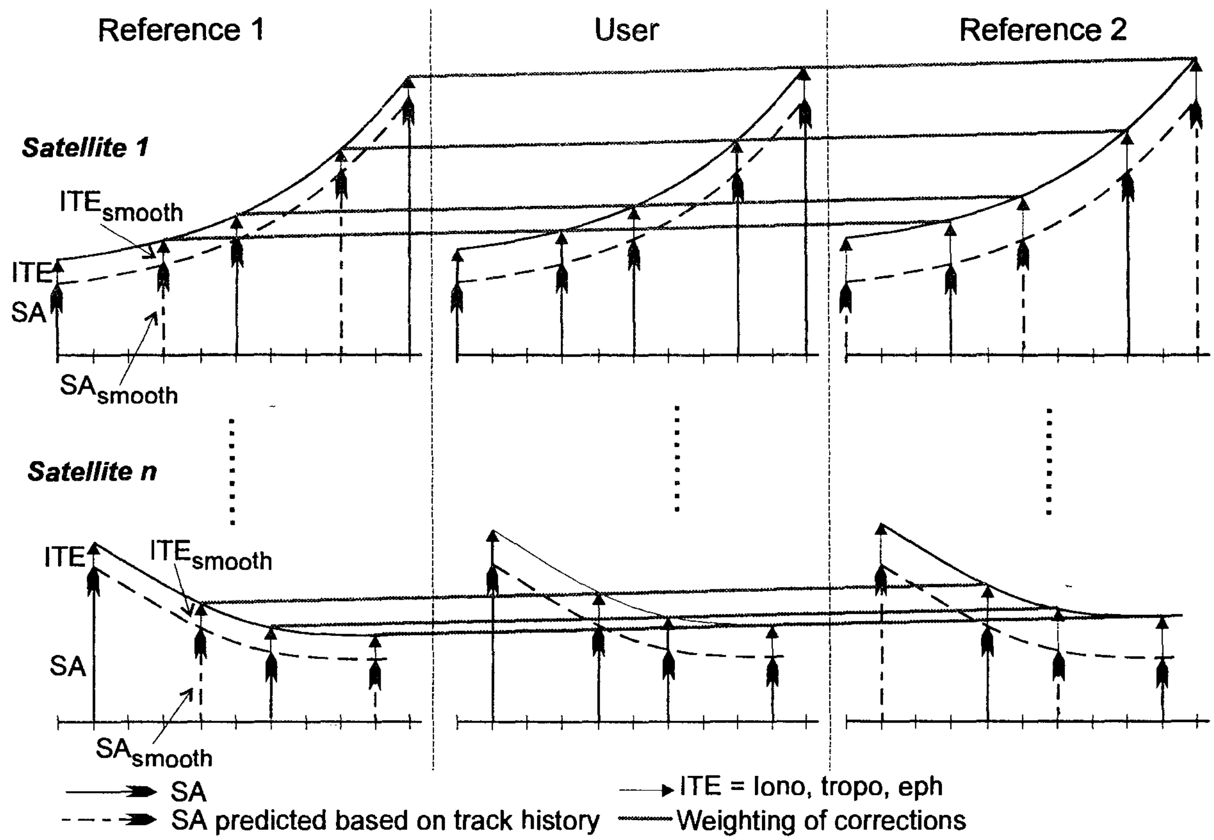

Fig. 2 - Eurofix RAAS mechanism to find linear approximated ITE corrections

CONCLUSIONS

It should be interesting to compare the performance and costs of two very different GNSS augmentation systems, WAAS and Eurofix. WAAS's specified accuracy goal is 7.6 meters (95%) in all directions while Eurofix RAAS may achieve 3 meter in the horizontal and better than 5 meters (95%) in the vertical direction. WAAS must fulfill the CAT-I integrity requirements regarding range limits and alarm time. Although, Eurofix is not tested for these requirements yet, it might be possible that comparable results are obtained. However, a major difference in reliability might be seen during thunderstorms where GPS and WAAS is expected to operate superior to Loran-C.

A very strong point of the Eurofix DGNSS service is its unique backup navigation functionality in case GPS or one of the Eurofix reference receivers fail. GPS failures can easily happen due to interference or due to shadowing the signals.

A very interesting issue for the tax payer is the enormous difference in costs of the two systems. Rudimentary comparisons show that Eurofix requires only about 1% of the investments required for WAAS. For all operations where the flight critical CAT-I numbers do not apply, Eurofix might be a very economic alternative for WAAS and EGNOS.

The required changes in the European Loran-C stations are minor and may be executed in a rather short time. If starting right now Eurofix will possibly be initially operational in 1998 and fully operational in 1999.

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Q: Eurofix was originally envisioned for marine, land, and potentially aviation enroute. Is precision approach new? Have you thought of 6 seconds time to alarm, etc.?

A: No

Q: Need to do that. We need precision approach.

A: It is not our first goal. In Europe we need Category 3 approcah guidance. Category I is not generally interesting.

Comment from the floor: I suggest you need to consider Category I since it is the goal in the US for a wide area system such as you propose. It's politically a problem not to do this.

Q: Could you transmit slowly carrying Iono, Tropo and Ephemeris (ITE) errors from each station for it and all its neighbors?

A: Takes more bandwidth, but we must retain the LAAS potential.

Comment from the floor: You do this, since each monitor still transmits its own ITE.

Q: Will you now publish this work more publicly?

A: We're a University; not allowed to do politics.

Comment from the floor: You are allowed to think the unthinkable, however...!

Future Eurofix Services

Dr. Durk van Willigen, Arthur W.S. Helwig
Gerard W.A. Offermans & Edward J. Breeuwer

Delft University of Technology

Current Status of Eurofix

- On air at Sylt (Germany) since February 1997
- Measured LAAS accuracy performance at Delft (450 km from Sylt) better than 3 meters (95%)
- Short Message Service operational since July '97
- No software or hardware failures detected since start of operation with the exception of one power failure
- Mobile tests conducted in France, Switzerland and Germany up to 1,000 km from Sylt

What to do now ?

- NELS Steering Committee asked Implementation Working Group (Christian Forst) to write a Eurofix Implementation Plan to be presented in Oslo on 28-29 October 1997
- We hope that NELS decides to give green light to implementation
- We want to continue the IOC of Sylt until FOC status of Eurofix in Europe has been established
- NELS initiative important signal to Russia, Asia and USA

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What to do now ? cont'd

- Terje Jørgensen (NELS) leads team to set-up consortium for the design and production of Eurofix/Loran-C receivers
- Various levels of sophistication of Loran-C receivers are to be designed
  - Basic Loran-C receiver
  - OEM Loran-C receiver to be embedded with GPS receiver
  - Eurofix datalink receiver
  - High-end Eurofix receiver

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Problems we face

- General scepticism towards Loran-C
  - Nobody wants Loran-C
    - Old fashioned granddaddy system
    - Slow starter and poor performer
  - GPS is far superior; works always and everywhere. So, integration with GPS is a non-issue
  - Current Loran-C receivers are indeed:
    - expensive (if high-performance)
    - slow (most)
    - bulky (many)
    - not suited for integration with GPS (most)

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Problems we face, cont'd

- Availability of sophisticated (OEM) software radio type receivers essential for continuation of Loran-C
- Potential receiver designers don't start as long there is no official commitment to extend Loran-C life
- At provider and user sides Chicken-and-Egg status
  - Governments: There are too few users
  - Users: There are no Loran-C receivers
  - Manufacturers: There is no guarantee for future Loran-C

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GPS as a US-commercial weapon

- GPS is the US-embraced navigation aid with large economic benefits to US industry
- It gives the US a unique commercial head-start with respect to Asia and Europe
- Therefore, all systems potentially endangering GPS are world-wide subject to US attack
  - Loran-C, Omega
  - VOR/DME, ILS, MLS, ...
- So, the navigation war is not really technical, it is political, military and economical

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Political and Publicity Actions

- Position Loran-C and Eurofix not as competitors of GPS but merely as a powerful aid to support GPS
- Radio beacons and WAAS give better accuracy and integrity at the cost of availability and reliability
- Integrated GPS/Loran-C offers improved availability and reliability than GPS only
- Eurofix offers improved accuracy, availability and reliability than GPS only

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Political and Publicity Actions, cont'd

- **Transform** the "Old-fashioned 80,000 Loran-C users" into a user group that requires high-performance GA navigation functionality that GPS cannot give today
- **Reform** the public awareness that navigation tax money may be used more efficiently than is done today
- **Inform** the GPS audience in appropriate magazines like GPS World, Aviation Weekly and Space Technology, and Boating magazines.
- **Continue to do so at full power !!!**

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New Services

- Add GPS Integrity messages to Eurofix
- Develop Eurofix/RAAS technology to accomplish:
  - Improved accuracy by reduction of correction data latency through dual-rate messaging and redundant Eurofix DGPS stations
  - Improved accuracy by reduction of spatial decorrelation
  - Improved reliability through redundant DGPS stations
- Add GLONASS correction and integrity data to Eurofix
- Add SMS broadcast to Eurofix datalink

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Integrity

- Integrity of broadcast differential information is monitored at the Eurofix reference stations by:
  - Monitoring of correction data
  - Monitoring of DGPS position
- If integrity threshold is exceeded an integrity message will be released within 6 seconds max
  - 2*30 GRI for LAAS and Single Rate
  - max GRI = 0.1 sec
- Integrity services may be expanded to GLONASS

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RAAS Technology Issues

- Eurofix RAAS technology is based on autonomous Eurofix Loran-C stations
- SA is identical on all Eurofix sites leading to faster correction data throughput to user resulting in better accuracy
- Iono, tropo and ephemeris (ITE) errors vary slowly with time. So, ITE values may be integrated to improve noise performance
- Redundant RAAS technology improves reliability of DGPS service through LAAS fallback mode

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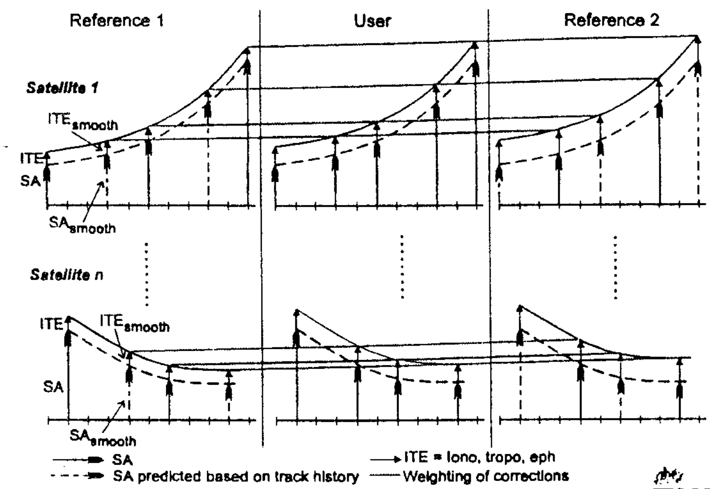
Eurofix RAAS Mechanism



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Adding GLONASS

- GLONASS does not suffer from SA
- Acceptable maximum data latency of GLONASS 10 times larger than of GPS
  - depends on iono and ephemeris variation, and ephemeris errors
- Adding GLONASS correction data to Eurofix will hardly influence DGPS performance
- GLONASS is key element of a European GNSS-1 using EGNOS
- GLONASS makes GNSS more worldwide acceptable

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Eurofix versus WAAS/EGNOS

- WAAS and EGNOS monitor stations are linked through high-speed telecommunication network
- WAAS and EGNOS determine iono, ephemeris and SA parameters in master control station
- Parameters are sent to user via GPS-like transmitter installed on GEO
- Unlike WAAS and EGNOS, Eurofix can back-up GPS navigation capability in case of GPS failures
- The emerging WAAS, EGNOS and MTSAT are not fully interoperable

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Eurofix versus WAAS/EGNOS, cont'd

- Eurofix operates in its coverage area like WAAS without the necessity for additional infrastructure
- Eurofix is limited to Loran-C/Chayka coverage areas
- Eurofix is much simpler than highly complex WAAS/EGNOS/MTSAT
  - Eurofix much less costly (expected 100 times less)
  - Eurofix contains less failure modes
- Accuracy and integrity performance expected to be similar to WAAS or EGNOS

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Potential Eurofix User Groups

- General aviation (generally regional operations)
  - Higher availability and integrity than with GPS only
  - Horizontal and vertical approach aid
- Marine
  - Eurofix gives increased reliability over GPS + differential service augmentation
  - Harbor-approach capability
- Land
  - Low-frequency Eurofix data signals can be received in cities and forests and do not suffer from shielding

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Conclusions

- Eurofix might be the reason to maintain Loran-C (and we like Megapulse !!)
- Current status of Eurofix indicates satisfactory performance over 1,000 km baselines
- Eurofix RAAS DGNSS and integrity capabilities probably comparable to WAAS, EGNOS and MTSAT, and maybe at 1% of costs
- Only Eurofix offers fall-back navigation capability if GPS fails
- That's all !! Thanks !!

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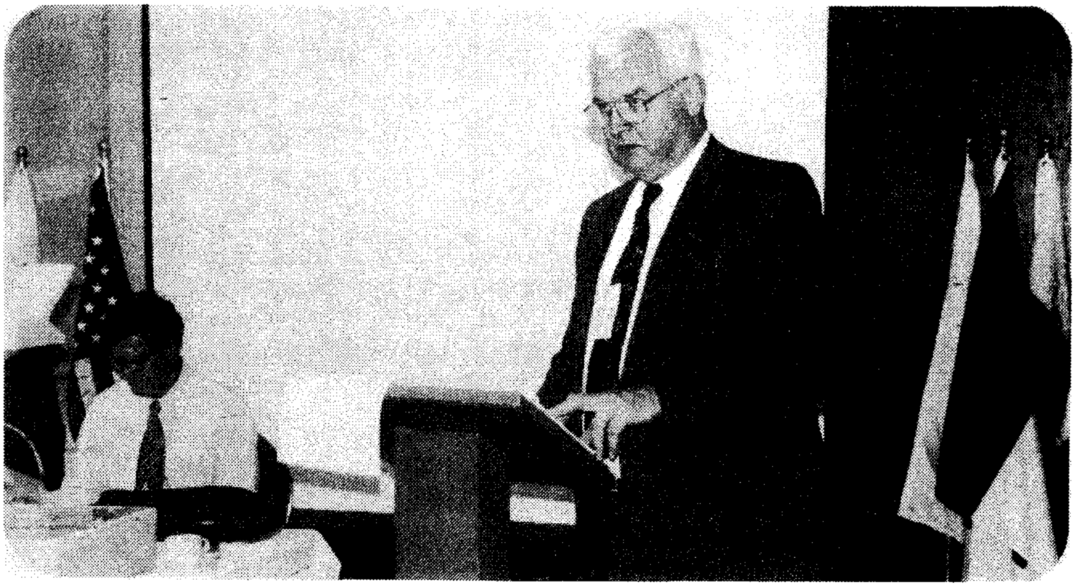
Session 9: ILA Working Groups Session

Moderators: William J. Brogdon, Jr., President, ILA
William F. Roland, Co-Technical Chairman



Session 9: ILA President Bill Brogdon, left, and co-technical chairman Bill Roland work on action items with convention attendees.

Various working groups were proposed, and convention attendees volunteered to pursue information and action items in those areas. In most cases, outputs from these efforts need to be made available to the Booz-Allen and Hamilton DOT Loran-C study, and to the upcoming 1998 Federal Radionavigation Plan User Input meetings.

- PDD Interpretation

We need a more clear picture of just what the President's Decision Directive means and what its likely effect on Loran-C as a partner with GPS will be. (Bill Brogdon, working with John Beukers)

- Land Users

Understand operations in tunnels, canyons, etc. Summarize Cap't Ben Peterson's three recent papers on this. Are there niches where only Loran/GPS can operate well? (Walt Dean)

- Why Loran is needed by WAAS, and how Loran and WAAS can cooperate.

We need to understand the synergy better, so we can sell it convincingly. (Durk van Willigen/David Last/Dirk Kügler)

- **Comments on Executive Summary of the FAA report to Congress**

  Coordinated set of comments on this report, which were requested by a DOT representative.

  (Bob Lilley to coordinate, with inputs from various ILA members and others)

- **Commercial Fishermen**

  This segment of the user community must be contacted for its inputs to the Booz-Allen and Hamilton study.

  (Ellena Roland will coordinate contacts, and initiate contacts in the northeast)

- **Loran-C Business Plan**

  We need a cost estimate and business plan for the future operation of the system. Discussed with the Canadian Coast Guard just how their costs are distributed. 1) people 2) power 3) communications Costs are less than USCG - less people, considerable effort to reduce power/communications costs also. Per-station cost per year about $250K Canadian compared with U. S. cost of $650,000. Continuing costs expected to descrease to $100K in Canada. We have a request from FAA sources to permit their review of such a plan (Bill Roland will write a "privatization" plan).

- **Weather Service**

  There are some big numbers (cost comparisons with GPS, benefits) related to weather-services use of Loran-C now that Omega is gone. We need to get weather interests talking with Booz-Allen and Hamilton.

- **Timing**

  Timing users tend to be competitive and secretive; we need to attract some of these users to the BAH study and FRP meetings, as their user numbers are very large.

  (G. Linn Roth)

Session 10: Resolution and Conclusions

Chairman: William J. Brogdon, Jr.
ILA President

Presentation, discussion and acceptance of the Convention Resolution and Conclusions

A draft Resolution was introduced and moved by President Bill Brogdon. During some 35 minutes' discussion and amendment, the resolution was finalized. The final document is included on the following pages:

International Loran Association
26th Annual Convention and Technical Symposium
October 5-9, 1997; Ottawa, Canada

Background

A year has passed since the 1996 ILA Convention and Technical Symposium held in San Diego, CA. During this period a number of events have taken place and some anticipated actions have not happened. It is worthwhile to review this activity or inactivity as the case may be. These are listed in no particular order.

Omega: In compliance with U.S. Department of Transportation policy as defined in the 1994 Federal Radionavigation Plan, the low frequency global Omega radionavigation system ceased operation on September 30, 1997.

Federal Radionavigation Plan: The 1996 Federal Radionavigation Plan was signed and was made electronically accessible in July of 1997. As of the end of September a hard copy was unavailable. Of significance is no change to the termination policy for Loran-C, VOR/DME and ILS. A User Conference for the 1998 FRP was announced for January 1998 in Long Beach, CA.

Eurofix: Live, on air tests of the transmission of differential GPS corrections using Loran-C transmissions (Eurofix) were conducted in Europe with successful results. Corrections to within 1-2 meters at ranges of 400-500 km were achieved.

GPS Vulnerability: The vulnerability of GPS from natural causes and from interference, both unintentional and intentional received substantial publicity. The ease with which GPS can be jammed and the ready availability of jamming devices became an issue of open debate.

Loran Congressional Language: The FAA plan required by Congress by March of 1996 has not been delivered. An unreleased draft became available and was criticized for its misleading and inaccurate statements. To provide the plan required by the later U.S. Coast Guard Authorization Bill, a contract was awarded to Booz Allen & Hamilton by the Department of Tranasportation. A user conference took place in September of 1997 in the Washington DC area.

NELS: The Northwest Europe Loran-C System Coordinating Office held a two day symposium and workshop in conjunction with a NELS Steering Committee meeting. This was considered a productive event and has led to some positive actions including the initiation of GPS/Loran receiver technology and the promotion of the NELS system.

Government Positions: Transportation Secretary Pena was replaced by Rodney Slater, FAA Administrator Hinson was replaced by Jane Garvey, and Assistant Secretary for Transportation Policy Kruesi is to be replaced. These and other government position changes may have an impact on DOT policy.

With this background, the International Loran Association at its 26th Annual Convention and Technical Symposium, at Ottawa, Canada issues this

Resolution

Noting that the 1996 Federal Radionavigation Plan adheres to the policy of total transition to GPS as the sole United States federally provided radio positioning system and continues to specify a termination date for the United States Loran-C service in the year 2000;

Noting also that the international Omega global radio positioning service ceased transmissions on September 30, 1997, the date published in the 1996 Federal Radionavigation Plan for discontinuing the Omega service;

Recalling that the Presidential Decision Directive concerning the civil national/international use does not specify GPS to be used sole-means or for there to be a termination or a transition plan from existing terrestrial radionavigation systems;

Recognizing the vulnerability of GPS service to interruption from natural causes and from unintentional and intentional interference, including jamming by rogue nations and terrorists;

Recognizing also loran technological advances that provide a data link for the transmission of GPS differential corrections (Eurofix), and in the development of combined Loran-C/GPS receivers;

Noting that GPS and Loran-C are dissimilar complementary systems exhibiting different weaknesses and failure modes, but that in combination they provide the availability and integrity that GPS alone cannot provide;

Noting also that GPS and Loran-C together provide the extremely reliable and traceable time and frequency references required by the communications and power distribution infrastructure and that Loran-C provides integrity to this service that GPS alone does not provide;

Whereas the language contained in Bills passed by the 104th Congress call for Loran-C system upgrades and operation beyond the year 2000,

Whereas the user community has overwhelmingly expressed its requirements that Loran-C service be continued beyond the year 2000,

Whereas having GPS as the only system to provide positioning and timing puts the United States critical infrastructure at risk,

Whereas the published termination date of the year 2000 is having a negative and deleterious effect on the international implementation of Loran-C technology,

Be it **RESOLVED** that every effort should be made to convince the United States government to revisit the loran termination date of 2000 and introduce appropriate language into the Federal Radionavigation Plan, the DOT Authorization and other pertinent legislation, to extend the Loran-C service indefinitely.

International Loran Association

STATEMENT OF RADIONAVIGATION POLICY

The International Loran Association (ILA) consists of organizations and individuals who advocate the continued implementation and use of the **LO**ng **RA**nge radio **N**avigation system Loran-C throughout the world.

Since its inception in 1972 as the Wild Goose Association, the ILA has followed the charter which states:

> ***"The International Loran Association (formerly the Wild Goose Association) was formed to provide an organization for individuals who have a common interest in Loran and who wish to foster and preserve the art of Loran, to promote the exchange of ideas and information in the field of Loran, to recognize the advances and contributions to Loran, to document the history of Loran, and to commemorate fittingly the memory of its members."***

While the Association's interest is loran and loran's development over the past 50 years, its current priority is the responsible implementation and use of Loran-C. In this context the ILA provides a technical forum for national and international loran related radionavigation issues.

In pursuing its advocacy role, the ILA acknowledges the presence of other long range or global radionavigation systems and recognizes that benefits accrue when these systems are used in concert.

The ILA supports the use of satellite or special purpose systems when employed within their technical limits. The Association is, however, opposed to, and will respond to pronouncements of "sole means" for a single system when these are detrimental to the orderly implementation of a mix of radionavigation systems.

The ILA is both technically and user oriented. In support of the User the Association advocates that all radionavigation systems for use by the civil sector have transmitted signal specifications and signal availability published in the Federal Register. Further the ILA advocates that dynamic notice of signal condition and availability are broadcast to users in a timely manner.

The ILA supports the position of the prudent navigator who requires the availability of more than one navigation system for navigating with integrity.

The ILA actively participates in the formulation of government radionavigation policy by providing comments and suggestions to the biennial U.S. government Federal Radionavigation Plan (FRP).

The ILA is sensitive to false and misleading claims of signal availability, performance and schedules for all long and medium range radionavigation systems and responds to such claims as appropriate.

The ILA recognizes that there is a substantial amount of development work to be completed with Loran-C as the system spreads to worldwide use and campaigns for the continued financial support of these activities.

ILA 26th Annual General Membership Meeting

Ottawa, Canada; Tuesday, October 7, 1997

President William Brogdon called the meeting to order at 0915.

Introduction:

President Brogdon reported on the recent meeting of ILA representatives with U. S. Coast Guard Rear Admiral Hull in Washington, describing the meeting as productive and a change in mood from previous USCG meetings. ILA representatives continue to communicate with members of Adm. Hull's staff.

ILA members were prominently in attendance and participation at the September user meeting held by Booz-Allen and Hamilton, contractor to U. S. DOT for the Congressionally-mandated study of Loran-C cost-benefit. There was good attendance by weather and timing interests in addition to the various transportation principals; many were impressed to learn of the critical timing needed for cellular phones, etc., and how Loran-C is working there on behalf of millions of users daily. Support for continued loran operation was expressed either in person or by letter from some previously untapped sources - Boat US, Motorola, the King Mackerel Tournament, Texas Shrimp Association, National Party Boat Operators and others. The study has not yet reached the commercial fishermen; efforts continue.

ILA Operations Center Move:

The move of the ILA Operations Center was announced formally; members should expect to receive mail from the new address at 741 Cathedral Pointe Lane, Santa Barbara, CA 93111. Ellen Lilley (and Bob, as her assistant) will continue to support this activity. New telephone and fax numbers, and e-mail and www addresses are published elsewhere in the Prodeedings document.

Finances and Membership:

The financial report consisted of a statement that the ILA is solvent and that membership is stable over the past few years. Aside from the usual expenses of running the Association, some expense was incurred to collect and provide data to the DOT study and to continue our contacts with the Coast Guard, the Administration and the Congress.

The 1997 ILA Election:

Officers:

President: Capt. Bill Brogdon	- re-elected - one-year term as president - director term ends 1998
Vice-president: Robert Wenzel	- term ends 1999
Treasurer: Carl Andren	- elected - to fill Bill Brogdon's 3rd year as director - term ends 1998
Secretary: Walt Dean	- elected - term ends 2000
Past President: Dale Johnson	- one-year term - ends 1998

Directors:

John Beukers	- term ends 1999
James Alexander	- term ends 1998
David Last	- term ends 1998
Ed McGann	- term ends 1999
Bill Roland	- elected - term ends 2000
Bob Lilley	- elected - term ends 2000
Mike Moroney	- term ends 1999
Durk van Willigen	- elected - term ends 2000
Marty Poppe	- Filling in for Olsen - term ends 1998

Appointed Directors:

President Brogdon solicited suggestions from members to fill the three appointed director slots.

[Subsequent to the Convention, G. Linn Roth, John Butler and William Polhemus were appointed.]

1996 Proceedings:

As members are aware, the 1996 Proceedings were delayed, but are now printed and will be mailed from Athens, Ohio immediately after the Ottawa convention. A preprint was provided to Booz-Allen and Hamilton for use in the ongoing Loran-C study, to make their data base as current as possible.

Location for the 1998 Convention and Technical Symposium:

France - Torsten Kruuse offered to work with us, from IALA? Their room accommodates 50, and may be crowded.

Most of the ILA activity has been focused on the US Congress and the administration. There is sentiment for a Washington-area meeting to emphasize our concern, but also for a European meeting where prospects for Loran-C are presently brighter. A policy change in the US affects other countries also.

Seattle was mentioned as an attractive U. S. site.

Bill Brogdon asked for suggestions during the meeting. The convention venue for 1998 will be decided at the Board of Directors' meeting on Thursday, October 9, at 12:30 PM. Interested members and guests are invited to attend.

Newsletter:

Mike Braasch, editor, has received newsletter materials from members and from the Board, and he has collected information outside the ILA also. The upcoming issue will focus on the Booz-Allen and Hamilton Loran-C study for the U. S. DOT.

General Discussion:

Bill Brogdon emphasized that data input for Booz-Allen and Hamilton (BAH) is an important need!

> BAH sees their job as analyzing others' data. We have said they should seek data! What is an anecdote, and what is data? Submitters should summarize a large paper when sending to BAH, to ease their work..
>
> Data input ends on 15 Dec, 1997, so BAH can write the report on time.
>
> ILA's Operations Center sent the last 10 years' Proceedings and a Coast Guard Loran Handbook, to provide BAH a technical resource.
>
> Linn Roth: Don't overcomplicate inputs to the BAH study - all we need is $17 million per year benefits.
>
> David Last: BAH will respond to inputs if they are credible -- maybe we need professional help in putting data together (a'la Larry Barnett as our Congressional worker).
>
> We need specific contacts: AOPA, Weather Service, timing users, boats, ECDIS. We just need to get benefits identified to exceed $17 million per year...
>
> We'll use Thursday morning at this Ottawa convention to work this data collection issue, rather than having the "debate" that was scheduled in the original program..

Congressional inputs are the key to short-term continuation - Larry Barnett and Linn Roth are very active.

The meeting was adjourned at 0845.

1997 Awards Presentations

ILA Awards Committee; Frank Cassidy, Chairman

Medal of Merit:

Professor J. David Last
University of Wales

President's Award:

Megapulse, Incorporated

Outstanding Service Awards:

Ellen G. Lilley
Executive Director of the International Loran Association

Frank Cassidy
ILA Awards Committee past Chairman

Dr. Robert Lilley
General Chairman, 1996 ILA Convention and Technical Symposium

John Beukers
Technical Chairman, 1996 ILA Convention and Technical Symposium

1996 Technical Symposium Best Paper Award:

"Integration of GPS and Loran-C/Chayka"

Dr. Dirk Kügler
Avionik Zentrum Braunschweig, Germany

Best Student Paper Award:

"GNSS and the New Loran: Global Partners for the Next Century"
Wen-Jye Huang
Avionics Engineering Center
Ohio University, USA

The International Loran Association

Medal of Merit

Professor J. David Last

In his position as Head of the Radio-Navigation Group at the University of Wales, Bangor, United Kingdom, Professor David Last has been instrumental in stimulating life into loran research in Europe. Acting in the capacity of both technical consultant and expert witness he has provided technical support and guidance on loran issues to many organizations including the General Lighthouse Authorities, the International Association of Lighthouse Authorities, the European Union, the European Group of Institutes of Navigation and to the Northwest Europe Loran-C System Coordinating Office. In his academic achievements Professor Last has guided students in pursuit of their Doctorates in the radionavigation discipline resulting in improved propagation models for loran and other low frequency systems. His published work on loran is extensive gaining him numerous awards and international acclaim. These accomplishments, together with his unique presentation skills, have earned Professor Last an international reputation for integrity and clarity in influencing future global radionavigation policy.

Presented this 8th day of October, 1997

Capt. William Brogdon, President

The International Loran Association

President's Award

Megapulse, Incorporated

The 1997 President's award is made to the Directors, Officers and Employees of Megapulse, Incoroporated in recognition of their long term, continuous and dedicated support of loran and for the outstanding technical contributions made to the worldwide Loran-C system.

Presented this 8th day of October, 1997

Capt. William Brogdon, President

The International Loran Association

Outstanding Service Award

This is to certify that

Dr. Robert Lilley

Avionics Engineering Center, Ohio University

by virtue of his contributions to Loran and the Association
as General Chairman of the 1996 Annual Convention and Technical Symposium

has significantly fostered the Aims and Purposes of
the International Loran Association

Presented this day the eighth of October, 1997 by
Authority of the Board of Directors

Chairman, Awards Committee

The International Loran Association

Outstanding Service Award

This is to certify that

John Beukers

Beukers Technologies

by virtue of his contributions to Loran and the Association
as Program Chairman of the 1996 Annual Convention and Technical Symposium

has significantly fostered the Aims and Purposes of
the International Loran Association

Presented this day the eighth of October, 1997 by
Authority of the Board of Directors

Chairman, Awards Committee

The International Loran Association
Outstanding Service Award

This is to certify that

Frank Cassidy

by virtue of his contributions to Loran and the Association as chairman of the Awards Committee from 1994 through 1997

has significantly fostered the Aims and Purposes of the International Loran Association

Presented this day the eighth of October, 1997 by Authority of the Board of Directors

Capt. William Brogdon, President

The International Loran Association
Outstanding Service Award

This is to certify that

Ellen G. Lilley

by virtue of her contributions well beyond her duties as Executive Director of the International Loran Association, through her dependable and careful work at the Operations Office, and through her valuable assistance at the Annual Conventions,

has significantly fostered the Aims and Purposes of the International Loran Association

Presented this day the eighth of October, 1997 by Authority of the Board of Directors

Chairman, Awards Committee

The International Loran Association
1996 Technical Symposium

Best Student Paper Award

"GNSS and the New Loran: Global Partners for the Next Century"

Wen-Jye Huang
Avionics Engineering Center
Ohio University, USA

Presented this day the eighth of October, 1997 by Authority of the Board of Directors

Chairman, Awards Committee

The International Loran Association
1996 Technical Symposium

Best Paper Award

"Integration of GPS and Loran-C/Chayka"

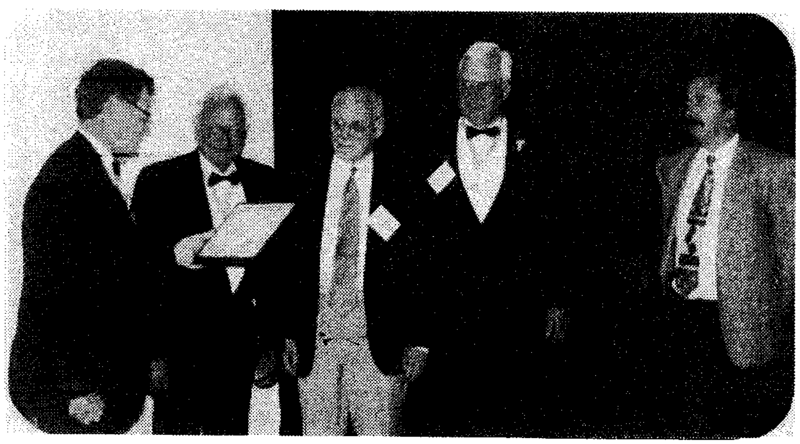
Dr. Dirk Kügler
Avionik Zentrum Braunschweig, Germany

Presented this day the eighth of October, 1997 by Authority of the Board of Directors

Chairman, Awards Committee

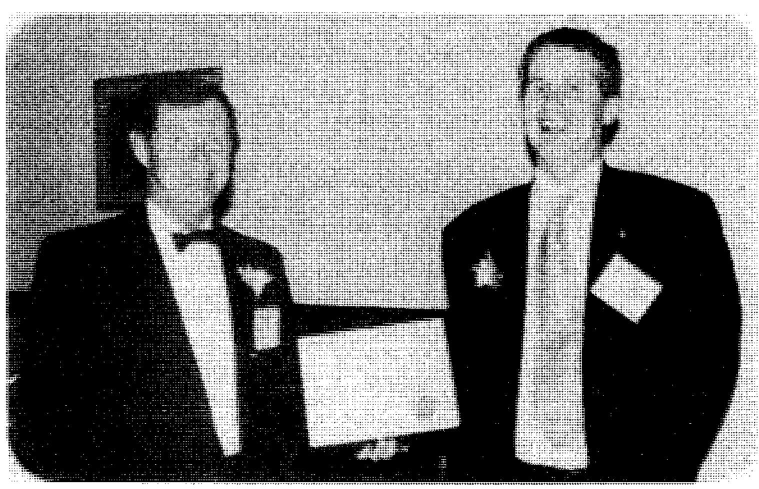
At the Convention Banquet, the Association presents awards earned during the year. Awards given in person this year:

Professor **J. David Last** receives the Association's highest award, the Medal of Merit, from President Bill Brogdon.



Officials of Megapulse, Inc. receive the President's Award. From left: President Bill Brogdon, **Paul Johannessen, Robert Rines, Bill Roland and Erik Johannessen.**

The 1996 Best Paper Award goes to **Dr. Dirk Kügler.**



Annual Banquet

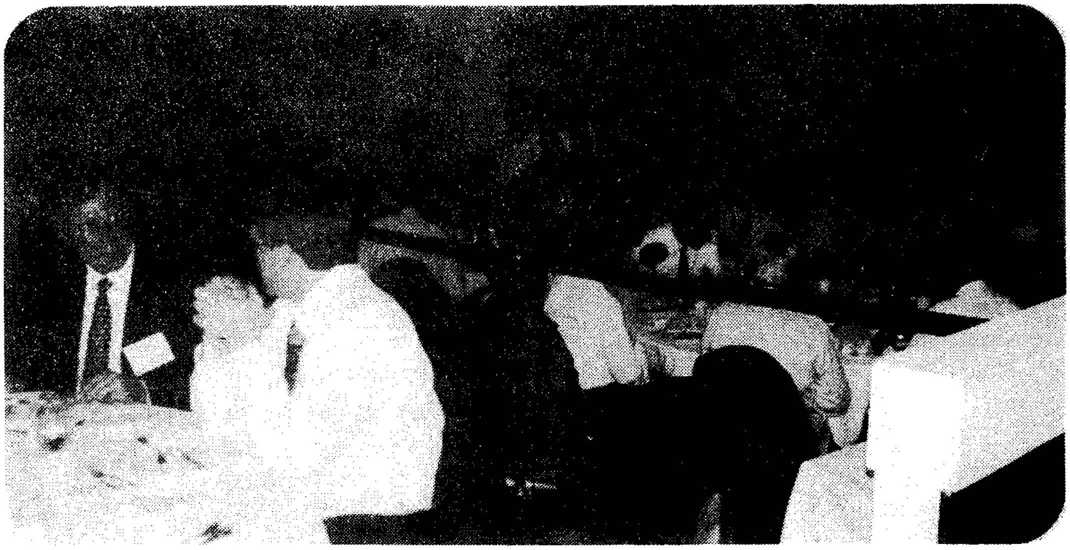
A highlight of the annual ILA Convention and Technical Symposium is the banquet. It is a time for both social and "shop" talk, reacquaintance with friends and for beginning new friendships. As you will notice from the photos below, from the banquet address and the awards presentations, the banquet is a busy time indeed!

Traditionally, the banquet affords the convention organizers an opportunity to say a few words. This time, Canadian Coast Guard's **David Waters** and his wife Jeannette worked long and hard to make the meeting a success. David offers his remarks...

And **Jeannette** adds some of her own. Unfortunately, these remarks were not recorded. Given David's expression, perhaps it's just as well!

The annual golf match involved two winners; it's just that Canadian Coast Guard's **Fred Forbes** (standing, left) used three fewer strokes than "Ninety-nines" pilot group's **Joyce Malkmes** (standing in photo below). Both had an opportunity to address the group; there was much discussion of "distraction factors" such as wind, sun, nearby jet aircraft and hot air balloons, in the appropriate and expected contexts, depending upon the speaker...

These photographs also document the members of the head-table contingent. From the left, Canadian Coast Guard's **John Butler**, convention chairman; **Ellena Roland**, Chair of the ILA Nominating and Elections Committee and convention registration collaborator; Megapulse, Inc. president **Bill Roland**, convention Technical Chair; **Jeannette and David Waters**; **Mrs. and Mr. John Redican**, **Ms. Nancy Weeks** of the "Ninety-nines" pilot group; **Joyce Malkmes**; and **Prof. Durk van Willigen**, Delft University of Technology. From the photos, it appears ILA President **Bill Brogdon** never sat down, but he was certainly at the head table also.



The banquet was served by the Ramada Hotel and Suites, to the enjoyment of the group. U. S. Coast Guard's **Capt. Jim Doherty** can be seen in the foreground, and readers with sharp eyes may see other familiar faces or haircuts.

One of the high points of each banquet is the awarding of the ILA Medal of Merit, the Association's highest honor. **Prof. J. David Last** is this year's recipient, and he offered some words to the group upon receiving the medal and accompanying plaque. The award is a serious one, given for David's significant contributions to the art and science of Loran-C; however, those who attended last year's 25th convention immediately recalled David's memorable banquet address on that occasion. An award-winner by itself! **Durk van Willigen**, **Joyce Malkmes** and **Bill Brogdon** react with pleasure.

(David was so moved, he later accepted the technical co-chairmanship for *next* year's convention!)

Then, the group was entertained and informed by **Mr. John Redican,** Director of Maintenance for the Canadian Coast Guard. The text of his address appears in the next section.

Banquet Address

Mr. John Redican
Director of Maintenance, Canadian Coast Guard

"Simply Geese"

My name is John and I know nothing about Loran-C. Now that is out of the way! Good evening, ladies and gentlemen. I must first explain how I come to be standing here tonight to give an after-dinner talk. David [Waters, Canadian Coast Guard], as most of you know, can be and is very persuasive. When he first asked me to do this, I realized that resistance was futile, and so here I am. I tried to explain that I knew nothing about Loran, nor did I know who the ILA was; he advised me that it was the new name for the Wild Goose Association. I told him I thought that was the militant wing of Ducks Unlimited.

I always used to wonder why David would belong to this group.

However, given my new enlightenment, I asked him what I should talk about, and he said, "Please yourself. Just make sure it's relevant, and not too long."

I would therefore like to address your Emblem tonight, the Wild Goose.

Firstly, we should look at why we have emblems. I belong to a rugby club and our emblem is a tree with a rugby ball in it and the Canadian flag and our motto is "Advance." It is probably not a good one because I cannot immediately relate to its meaning. Strength, I suppose.

One of the worst fights I was ever in whilst I was in the Navy surrounded an emblem. The Royal Marine emblem is a globe with the motto "per mer per terram" which was incorrectly translated by a sailor one night to be "By horse and by tram" and not "By sea and by land." The Royal Marine obviously took great exception to this mistake and the fight ensued. So emblems can and should be, important.

So back to yours, the wild goose.

For my sins, I am also involved with the Canadian Naval Reserve, and one of my duties is to instruct classes of senior ratings on leadership. The model I use is the goose. If you have heard this story, please bear with me because I think you will find I develop it a bit differently than most.

When geese migrate, using that incredible instinctive navigation system, they do so in a very special way. They take up the "vee" or "wing" formation. Now research has shown that this is deliberate and, in fact, is essential to the entire migration process. The lead goose is the only one which is giving it everything it's got, and the others behind are benefiting from the formation. This can be to the point that the following geese expend only 30% of the lead goose's energy. Also the honking that goes on is seen to be the encouragement for the lead goose from the followers. When the lead goose gets tired, another will move into the lead and take the strain. This brings me to the first point I want to make on this process, and that is not only is this a true team effort, but the skill demonstrated is the follower knowing when to become the leader.

I am sure that most of you are deluged with brochures and flyers from various organizations promising to make you a better leader, a world leader, etc., etc. Yet, how many companies want to turn you into a first-class follower?

In Greenlea's book on leadership, he purports that in order to be a good leader, first you must be a good servant. The understanding obtained from serving converts into skills needed for good leadership.

This is very true today. Our leaders do not have all the answers and need people, the followers, to be ready to step up and take the lead for issues -- to be ready to step in and say, "Let me take this one the next step," thus allowing our leaders to recharge their batteries.

So, the first lesson we can take from the emblem is that being a good follower or servant is important. When related to leadership, how does our fellow goose know when it is time to step up and take the lead? I am sure it is not when the lead goose drops from the sky exhausted. It is when it hears the cry from the leader to indicate it is time to change. I am not sure how this is done but I am sure the ability to listen plays a big part in it. The skill of listening is probably the most underestimated skill applied today. In any situation, the analysis of the problem will invariably boil down to a breakdown in communication. We than pat ourselves on the back for yet again arriving at this ever-present truth and go on our merry ways.

If we take the fundamentals of communication to be, "Is the message I want to transmit, the one that is received?" then the listening part is a good 50% of the equation, but we do not give it anywhere near that amount of recognition. It's not taught in schools.

The old saying, "The good Lord gave you two ears but only one mouth and, therefore, you should do twice as much listening as talking" is sadly not applied. The other one, "The good Lord gave you the ability to shut your mouth but not your ears" should be a hint, but is also not used. So if we go back to our goose, we can see that the ability to listen and interpret signals is very important.

So to recap, so far our goose has demonstrated that being a team player also requires us to take the lead when necessary and also to surrender the lead when new blood is needed. As a follower, we see the importance of being ever aware of the situation so you can step in and help the common cause. In the case of the geese, the cause is survival.

But we don't end there; the migration cannot take place without the participants exercising a degree of discipline. In such an important undertaking, chaos would result in failure since the structure of the migration formation is key to its success. So we now introduce a new element into what we can learn, and this is attitude. All the geese must have the attitude that what they are doing is important and vital to the success of the mission. In the case of the geese, to survive a few-thousand-mile trek over vast areas of land and sea, it is the attitude which is the key. In our daily lives, this is no different. Attitude is becoming one of the most important elements of a person's employability. Good engineers with lousy attitudes are no longer accommodated. So, if we can accept that a positive attitude is essential to all that we undertake, then it is another characteristic of your emblem the goose.

However, even given all of the teamwork from leaders and followers, and the right attitude, the mission will not be a success without the next element which is the need to prepare. The geese know by instinct that as the days get shorter and the leaves begin to turn after the first few frosts, it will be time to leave. In preparation for this, it is essential that they build up their strength for the journey. It is necessary for them to form up into the groups which will remain together for the entire journey; they form the team.

We term this preparation "planning" but it is no less essential to the success of one of our own initiatives that it is for the geese. We need to gather the team, and we need to ensure there is the synergy which will come from the attitude of those involved. In today's world, it is also necessary to be in the correct physical and mental shape to undertake today's tough projects, not unlike our models, the geese.

So the journey begins; the navigation systems are instinctive, but this in itself will not guarantee success. It is estimated that this year, over 100 million birds will migrate south, one of the largest migrations on record. There will be casualties. The geese who persevere will be the ones who reach their goal, and that is the final point for tonight. Perseverance is so very important in today's world. Set a goal and work toward it.

So to sum it up in looking at your emblem, the wild goose, I can say from a very personal perspective that it is important to be able to follow as well as lead. To know how to be a good servant will provide the tools necessary to be the good leader. It may seem strange to look upon the ability follow as a strength, but our goose model shows us it is.

The ability to listen and to make sense out of what we hear is vital -- to know when to step in and take the helm. In today's world no one person has all the answers. The importance of making sure what you are hearing is the actual message that is being sent cannot be overemphasized. In the case of our goose model, the message is when to take the lead, when it is safe to land, and so to fully contribute to the team by striving to be the best listener.

Attitude is also vital to success and involves willingness to be part of the team and provide the positive and constructive input. As someone much wiser than me said, "If five people around the table have the same opinion, then four are redundant." It is the "can do – will do" attitude which we can read into the goose model. Although many times we talk today about survival, we are talking about this in a corporate or organizational sense. Our friends the geese are looking at it from a much more realistic view; survival means life or death.

This reminds me of the simple way to clarify the difference between contribution and commitment. If you take a plate of eggs and bacon, the chicken makes a contribution but the pig makes a commitment. In today's business world, I think we need to make commitments to be successful. The last two points I think can be grouped together; preparation and perseverance are the ways to achieve the goal, be that personal or corporate. So a final recap for this evening: What can we take from the emblem of the ILA, the wild goose? Success requires us to be good followers ever willing to take the lead as part of the team. We need to enhance our listening skills to be able to fully contribute by understanding the messages we are being sent. Our attitude will be a significant factor in our ability to interact with others in this new world of team skills.

Preparation and perseverance in reaching the goal will be needed to be ultimately successful. If you need an acronym to remind you of all this, than FLAPP will fit the bill:

Follower
Listener
Attitude
Preparation
Perseverance

Thank you for listening; I hope that your meetings have been productive (and I am looking forward to getting David back into the *office*!). Again, thank you.

Convention and Corporate Association Sponsors

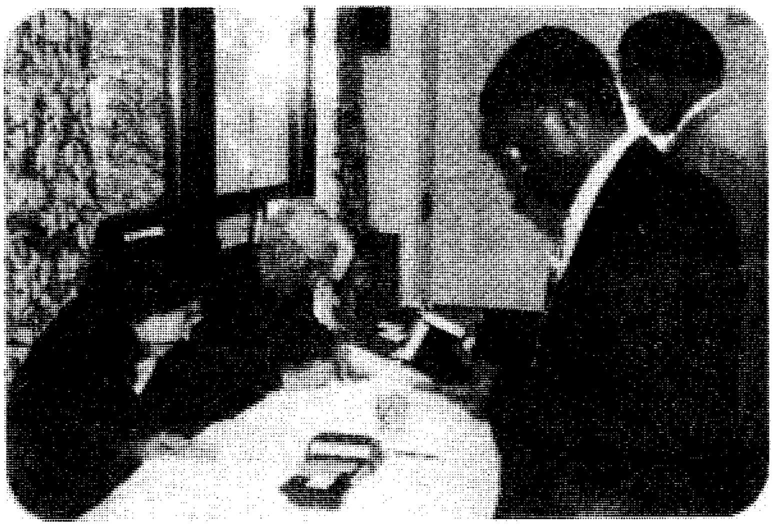
International Loran Association

Canadian Coast Guard (Host organization, 1997 Convention)

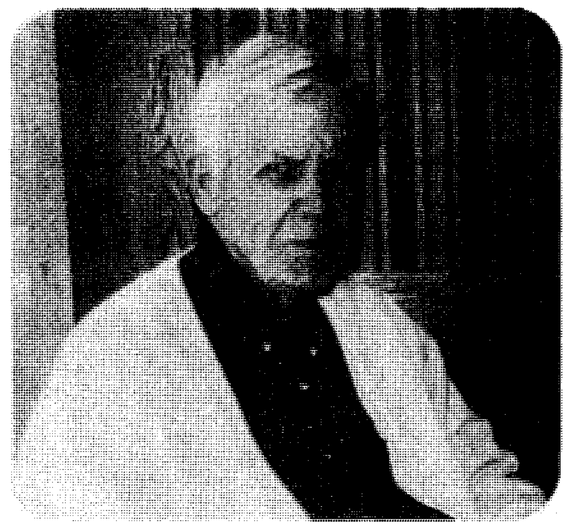
Commissioners of Irish Lights
FAA Architecture and Systems Engineering
Japan Association for Aids to Navigation
LOCUS, Inc.
Megapulse, Inc.
Morrow Aircraft Corporation
NDHQ
National Center for Atmospheric Research
Norwegian Defence Comm. Administration
Ohio University
Synetics Corporation
Telecom Solutions
U. S. Coast Guard
Volpe National Transportation Systems Center

Images from the 26th Annual Convention and Technical Symposium

It's not all work...

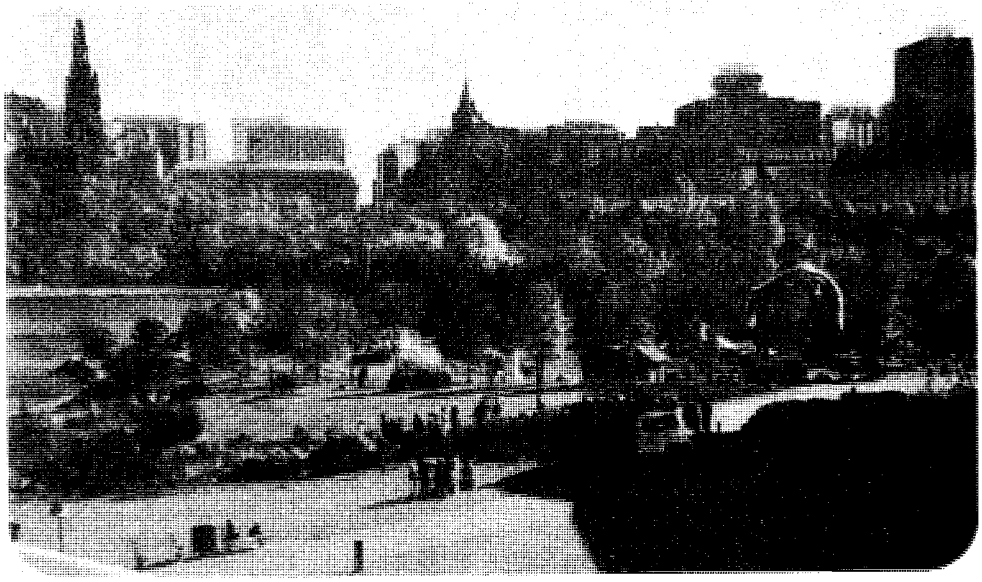


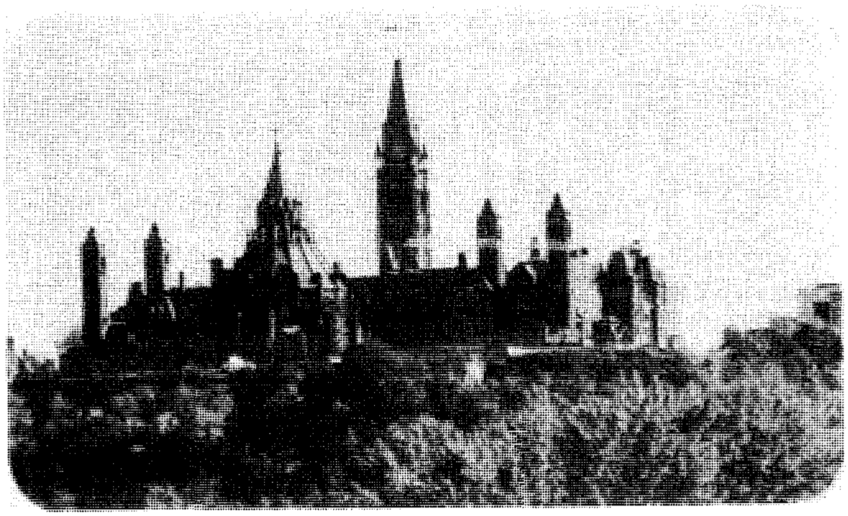
ILA Executive Director **Ellen Lilley**, and **Ellena Roland** register participants as the meeting gets under way.



Bill Polhemus came up from Vermont to work with the Board of Directors, trying to insure a long future for Loran-C.

"...and I see a day when there'll be Loran-C transmitters in every country in the world...!" Congressional Liaison **Larry Barnett** appears to have some encouraging words for Megapulse's **Paul Johannessen.**





The sights of **Ottawa** are impressive at any time of the year, and our meeting took advantage of truly beautiful fall weather.

Grace van Etten and **Joyce Malkmes** are among the boating crowd, on the canal through Ottawa.

From the top left: **Grace van Etten, Nancy Weeks, Astrid Johannessen**; and seated, **Joyce Brogdon** and **Joyce Malkmes** team up at the ILA evening reception.

ILA is truly international:

Italy's **Vito Minaudo** is flanked by Norwegians **Andreas Stenseth** and **Terje Jorgensen** in a discussion between meeting sessions,

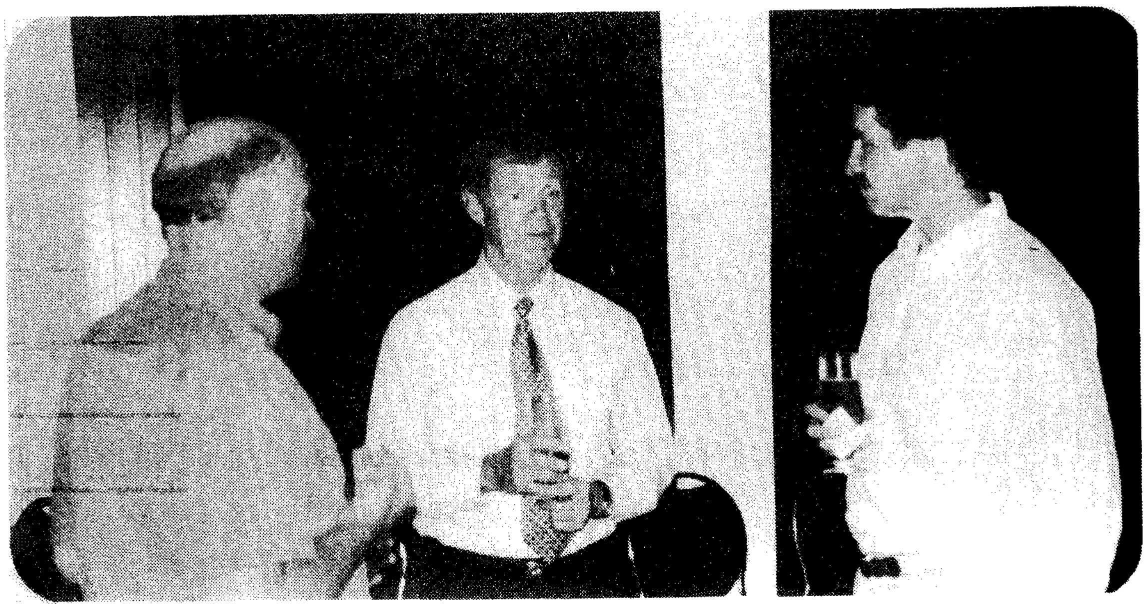
Germany's **Dirk Kügler** chats with **Erik Johannessen**, of Megapulse,

Durk van Willigen of The Netherlands talks with **Vito Minaudo**,

David Last of the University of Wales seems to be "closing his eyes" to comments from the U. S. Coast Guard's **Chuck Schue**; actually, the camera just caught him in a blink...

And ILA President **Bill Brogdon** compares notes with IALA's **Torsten Kruuse**.

Presidents three -- **Bill Brogdon** is cornered by Cambridge Engineering founder **Marty Poppe** and LOCUS President **Linn Roth**.



Technical Chairman **Bill Roland** claims to know how to relax after a long day running the meeting, with **Bob Lilley's** piano music.

International Loran Association

26th Annual Convention and Technical Symposium

October 5-9, 1997; Ottawa, Canada

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