GNSS – eLoran combined receiver benefits for the mass market

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Biography

Philip G Mattos gained Bachelors and Masters degrees in Electronic Engineering from Cambridge, followed by Masters Degrees in Telecoms and Computer Science from Essex in 1977. He joined INMOS in 1979. INMOS was acquired by STMicroelectronics in 1989. He was made a Visiting Research Fellow at Bristol University, and awarded an external PhD on his GPS work in 1996.

Since 1989 he has worked exclusively on GPS implementations, and the associated RF front ends. He is now working on system level integrations of GPS, and on the Galileo system, while consulting on the next generation GNSS chips, including one-chip GPS (RF+digital), and high sensitivity GPS and Galileo for indoor applications.

Abstract

Benefits to the indoor sensitivity of GPS that can be achieved by deriving a time-sync from the building-penetrating low frequency LORAN signal are discussed, together with the minimal hardware needed to add a Loran RF to the existing GPS hardware, using the GPS dsp and CPU.

Introduction

GNSS and eLoran have well known benefits in terms of integrity, but there are further benefits where the high sensitivity GNSS receiver can operate to even greater sensitivity if it is able to have the precise clock from Loran, and benefits to the Loran implementation that high performance dsp (hardware and software) and a TCXO are available in the GNSS receiver.

The study arose from the observation that the hardware dsp circuitry of the GNSS chipset can equally well process Loran signals. This is achievable in the GPS generation of the chipset, by switching off the local prn code generation, which reduces the correlator to an integrator. This has the result of providing a precise NCO, mixer, integrator and carrier loop, with the now redundant code-phase setting being used to define the exact integration start time.

In the Galileo generation of the chipset, an even greater benefit can be found. Due to the memory codes used for Galileo, a new code can be written that matches the Loran waveform, optimizing for say 10 cycles during acquisition, then reducing to three cycles to eliminate skywave during tracking.

While LORAN penetrates buildings well, it suffers from interference and re-radiation that may diminish the accuracy. However as long as the time can be extracted at the microsecond level, from just one eLoran station, the GNSS receiver can operate in a much more sensitive mode, able to synchronise its integration periods to the 20ms data-bit in GPS, or to the 100ms (25 x 4ms) cycle of the secondary code in the Galileo pilot signal.

The use of a TCXO similarly allows many groups of the LORAN signal to be integrated. While software dsp of Loran signals has existed since the '80s, its integration has generally been limited to the clock accuracy, at least for the first station to be found. With the 0.5ppm TCXO available in the GNSS receiver, a 2 microsecond error builds up over about 4 seconds, setting the limit of integration. This is a huge improvement over the receivers of the '80s, where GRI+10ms, as needed to include two bursts, one A phase, one B phase, was difficult to achieve.

So provided suitable eLoran antennas can be developed for the mobile phone handset, which is the major indoor market, the GNSS-eLoran combined receiver can be built for only the extra cost of the 100KHz analogue section, and yield extra sensitive Loran, extra sensitive GPS, and also the ability to interwork with one Loran and two satellites for example, subject of course to recent calibrations of both propagation and receiver signal paths, done last time the receiver was outdoors.

1992

In 1992 I presented the paper shown below at the Wild Goose Association (pre-cursor to ILA) conference in Birmingham, UK.


AN ECONOMIC IMPLEMENTATION OF A COMBINED LORAN/GPS RECEIVER

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Figure (1): 1992 WGA Conference paper

At that time consumer navigation systems were confined to boats, and the market for Loran was in severe decline due to the ongoing expectation that GPS was just around the corner. However a combined GPS-Loran receiver could bridge the gap. At that time the benefits of the combination were very much in the direction of the

Loran….alone it could not afford a precise clock or powerful processor, however combined with a GPS receiver these were almost free, and the selling price for GPS receivers was significantly higher.

The 1992 architecture is shown below. As the software-GPS used a zero-IF at that time, even the analogue stages of the radio and the sampler could be re-used. At that time, my Loran implementation was also entirely software based.

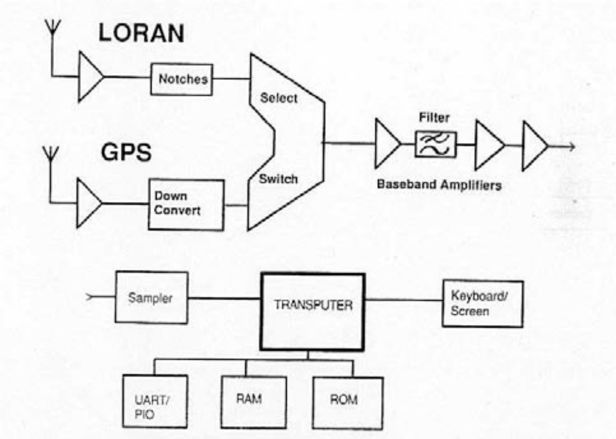

Figure (2) 1992 combined architecture proposal

Why now?

The new surge of interest in LORAN has been driven by a need for a redundant system to cover GNSS failures, particularly considering that all current GNSS systems use similar frequencies so can be jammed together, intentionally or accidentally.

Given the new interest, e-LORAN has added improved accuracy, and additional information over a data-channel. Loran penetrates buildings and shallow tunnels, due to its long wavelength (3km) it even works under water a little, while GPS deep indoors cannot read its signal modulation even to get coarse timing (seconds and milliseconds)

There are many levels of timing accuracy useful to GPS. It needs it to about 30 minutes to usefully use the almanac to determine which satellites are in view. It needs it to a few seconds to predict their Doppler shift and codephase, in order to minimise search time. These resolutions are usually not a problem as they can be achieved from a simple 32kHz watch crystal based RTC.

To operate without external assistance, ie neither time nor data, a simple GPS needs a signal strength of about -146dBm. Autonomous self assistance in terms of calculating ephemeris for the orbit data on the receiver itself [2] can remove this limit from the data point of view, and in this case only one satellite need reach this signal strength, to provide timing, the others being weaker.

With 10 millisecond accuracy, it can reach a sensitivity where although the bit error rate is too high to read the time, a statistical analysis of bit transitions can still determine time to an ambiguity of 20 milliseconds, so with the 10ms timing assistance, perfect time can be resolved.

For increased sensitivity GPS needs timing to 0.5 milliseconds, to switch to long coherent integration for acquisition sensitivity. This allows the 20ms databit period to be known in advance, with no need to find the databit edges in the field, even statistically. This allows operation with all satellites down to about -155dBm

The final step is to know time to much better than this, a few microseconds, so that instead of searching the full one millisecond codephase space, the receiver can limit its search window to a much smaller range. This range must cover both the time uncertainty, and the position uncertainty.

While most receivers are now fully parallel in acquisition, so this reduction of codephase space may not directly speed up acquisition, the reduction in the number of potential noise candidates in the peak-detect window results in a large reduction in the PFA, hence allowing an increase in sensitivity of up to 6 dB.

In Galileo, there is a similar effect that is much easier to handle. The pilot signal on E1-C has a secondary code on it that has a 4ms chipping rate. This destroys its usefulness as a pilot for the unassisted GNSS receiver.

However if the receiver can know time to better than 2 milliseconds, it can immediately predict the secondary code, yielding a perfect pilot signal that can be integrated coherently to the limits of clock stability and channel bandwidth.

This the realistic targets for time-sync from LORAN to assist GNSS acquisition are 0.5 milliseconds for GPS, and 2 milliseconds for Galileo.

As 100uS is easily achieved with e-Loran, even indoors, these targets are not pushing the LORAN technology, and its implementation is thus aimed at simplicity and economy, rather than precision. Note that reusing the GPS hardware DSP means that the LORAN signals are timed to the same master timebase as the satellite signals, which greatly simplifies the interaction of the two.

2008 Teseo

Now in 2008 GPS is implemented in a single device, sometimes one piece of silicon, sometimes two die, one RF, one baseband, in the same package. ST's implementation of the stand-alone GPS is Teseo, STA2058 as a baseband, ST8058 as RF+baseband in a single package. This has the advantage of two data input ports, designed to provide antenna diversity in automotive designs using two radios, one for satellites in front of the car, one for those behind, with antennas internal to the car.

While this feature has never been used by the car manufacturers, because they provide a roof antenna with omni-directional visibility, and would not pay for two radios anyway, it remains present on the chips.

As shown below, this can then be used one for the GPS radio, and one for the Loran radio, with the internal multiplexers programmed so that one channel is allocated to LORAN, all the others remaining for GPS.

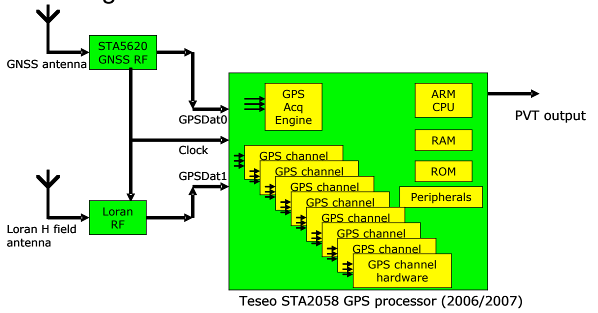

Figure (3) Teseo GPS architecture

Further detail of one channel is shown below. All channels are clocked from the same reference, and refer time to the same master timebase. As the clock is a 0.5ppm TCXO, useful integration of the LORAN carrier could be continued out to about one second, at least 10 x GRI, in order to achieve maximum sensitivity. To manage the coded phasing of the various pulses, the hardware would integrate over one pulse, with the software appropriately adding/subtracting the pulses to build a group, then integrating beyond for sensitivity.

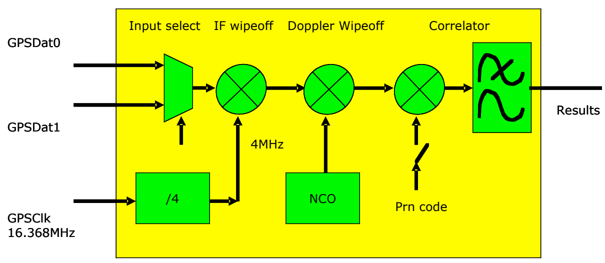

Figure (4) Teseo GPS channel

In LORAN mode, the prn generator is switched off, and the NCO is set to 100KHz to match the LORAN carrier. The accumulator then accumulates the LORAN energy, and delivers I/Q results from which the precise phase can be calculated.

There is a problem however, that the data input is expected on a 4.092 MHz IF. This means that the output of the LORAN receiver must be modulated onto a 4MHz carrier. With a one-bit signal at this point, it is achieved with an XOR gate driven from one quarter of the reference 16.368MHz clock.

On later Galileo versions, which have a 3-bit signal, the same can be achieved by modulating only the sign bit, as the signal is not coded in binary, but as sign and magnitude, where the coding for positive and negative values is symmetrical.

This modulation produces two copies of the LORAN spectrum, one above and one below the IF carrier. This is not a problem, as the final downconverter in the digital baseband is fully image rejecting, and will only select the upper sideband.

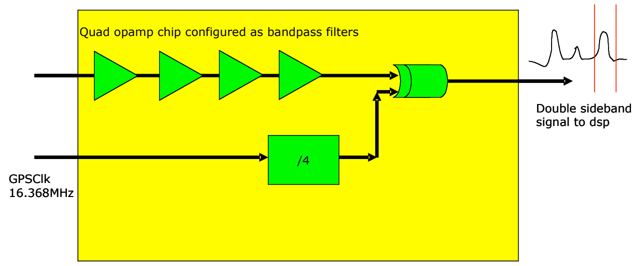

Figure (5) Loran RF with 4 MHz modulator

Loran RF

The LORAN RF is very simple, simply a quad op-amp configured as a low-Q bandpass filter. This is then front-ended with a high-impedance FET stage to avoid loading the antenna tuned circuit, though the loading is controlled deliberately to keep a wide bandwidth.

The low-Q, high bandwidth, and group delay must be carefully managed to ensure not only that a 100KHz carrier passes through correctly, but also to manage the pulsed nature of the signal with its special amplitude controlled envelope.

Narrow band filters will cause the receiver to miss the first half cycle of the LORAN signal, causing an error in the time calculation, and in situations with some near and some far transmitters, a position error also.

H-Field antenna

In the 1986 – 1992 design a normal E-field whip antenna was used. LORAN antenna technology has advanced since then and most receivers use an H-field antenna. This has advantages of size, but more importantly, is less sensitive to man-made electrical interference from neon lights, fluorescent tubes etc.

In our application, size is critical, so the magnetic core of the antenna is a surface mounted ferrite inductor, available in volume production for use in RFID tags. In order to increase the aperture, and thus the sensitivity, three of these are used, each tuned to 100kHz with a capacitor. Research continues as to the best level of coupling between the three. The Q of the main centre circuit is controlled by varying the bias resistor of the FET amplifier. Provision has been made to add a resistor on the other two circuits also.

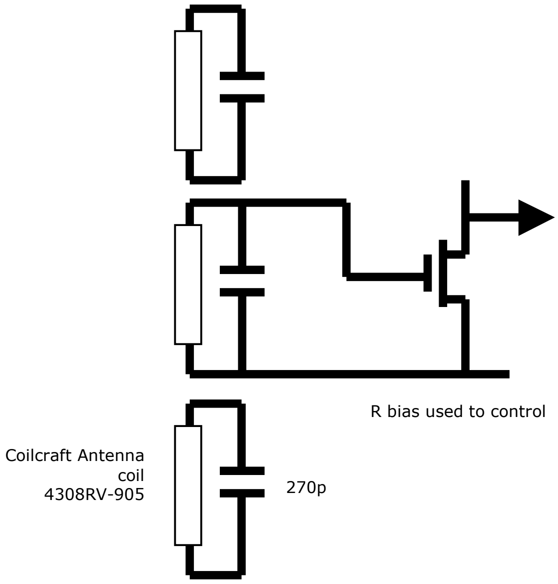

Figure (6) H-field antenna

Difficulties

Several difficulties have arisen mapping the successful 1980's LORAN design onto the 2008 GPS.

The extremely small dimensions of the GPS mean the oem expects the LORAN also to be very small, and all to fit in the mobile phone handset. This imposes major restrictions especially on the antenna. While the surface mount H-field design meets all these restrictions, it leaves difficulties of sensitivity, due to the very small aperture provided.

Additionally, new interferers have arisen since the 1980s. As the purpose of the design is to operate in buildings, it is necessarily near to man-made sources such as RFID-tags (the readers), id-card readers, and low-energy light bulbs which have proliferated widely. The standard fluorescent light bulb was always a problem and continues to be.

Using the GPS hardware for LORAN is excellent for envelope energy detection, and for reading the carrier phase of the entire pulse. However it is not so good for cycle detection or sky-wave elimination, as it naturally integrates for a one millisecond period. This will be solved in the Galileo version of the chipset, as the Galileo prn code is a memory code, and can be written by the software. Thus a code can be written that is active for just 3 cycles of the millisecond window, and this can be swept in the time (or codephase) domain to precisely identify the sky-wave free first few cycles of the LORAN signal.

There is one piece of bad news…. As the second data input for antenna diversity has not been used by the car manufacturers in the 7 years it has been available, it will not be provided on future versions. So the LORAN operations will have to be performed time divided with GPS, with an external multiplexer, on the Galileo versions of the chipset.

Signal availability

LORAN is available over North America, and the northern and central areas of Europe, with a Russion version extending coverage eastwards. However the E-LORAN version is only available on a few test chains currently. This is not a problem for the combined LORAN-GPS receiver, as all LORAN transmissions are based on a common timebase. Thus time can be derived even from the unmodernised chains due to the different rates on different chains.

However the E-LORAN version is preferable, as then, in compromised situations when only a single transmitter can be received, it can be identified correctly, and the appropriate time corrections made for emission delay and the users last known location.

Conclusions

A simple low cost way of adding a LORAN derived time reference to a GNSS receiver has been shown, giving vastly improved sensitivity to both GPS and Galileo receivers for deep indoor use.

Research continues into minimising antenna size versus performance and managing electrical interference in buildings.

Acknowledgements

ST GPS products, chipsets and software, baseband and RF are developed by a distributed team in:-

- **Bristol,** UK -DSP R&D, Software R&D
- **Milan**, Italy – Silicon implementation, algorithm modelling and Verification
- **Naples**, Italy- Software implementation and validation
- **Catania**, Sicily, Italy – Galileo Software, RF design and production

The contribution of all these teams to both product ranges is gratefully acknowledged.

References

[1] An economic implementation of a combined LORAN/GPS receiver, Philip Mattos, WGA 1992 conference, Birmingham UK

[2] Hotstart every time– compute the ephemeris on the mobile, Philip Mattos, IoN-GNSS2008 conference, Savannah Georgia.

[3]Teseo STA2058, STA8058 Datasheets, ST Microelectronics