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# Does Integration of GPS and LORAN-C Meet User Needs?

## *Some Different Approaches*

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# Why Integrate?

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- We need a better performance than either GNSS or LORAN-C/Chayka offers
  - GPS and SBAS experience shadowing and multipath in urban areas
  - SBAS' geo can't be heard in polar regions
  - LORAN-C's absolute accuracy inadequate
  - Lack of detailed ASF tables



# Q: Integration or Backing Up?

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- If GPS works fine then LORAN-C does not offer added value
  - Integration with LORAN-C does not improve GPS
- If GPS fails, then LORAN-C is the only backup radionavigation solution available
  - Integration with GPS doesn't make sense
- If SBAS works fine, then LORAN-C datalink not needed
- If SBAS fails, LORAN-C backup datalink needed



# Conclusion and Questions - 1

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- **Conclusion:** **Backing up** only pays if both systems do not fail **or** work at the very same time/position. If true then we get:
  - Improved availability for all user groups
  - Improved accuracy for all user groups
  - Improved integrity for all user groups
- **Questions:** **Integration** still needed?  
Yes, but ....
  - What do we mean with integration?
  - How can we integrate?
  - What is needed to integrate?



# Conclusion and Questions - 2

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- We need backup systems
- This backup function can most efficiently be achieved by integrating the systems, mainly in the receiver
- Integration of GNSS and LORAN-C in the classical way is not offering the service that many of us generally expect



# Backing Up GPS

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- GPS needs only LORAN-C backup if it fails
- How to determine it fails?
  - No signal: clear situation
  - Strong signal: unclear situation because
    - Signal can be loud and clear, but completely wrong due to multipath or jamming/spoofing
- Concluding question: When to raise the no-GPS flag?



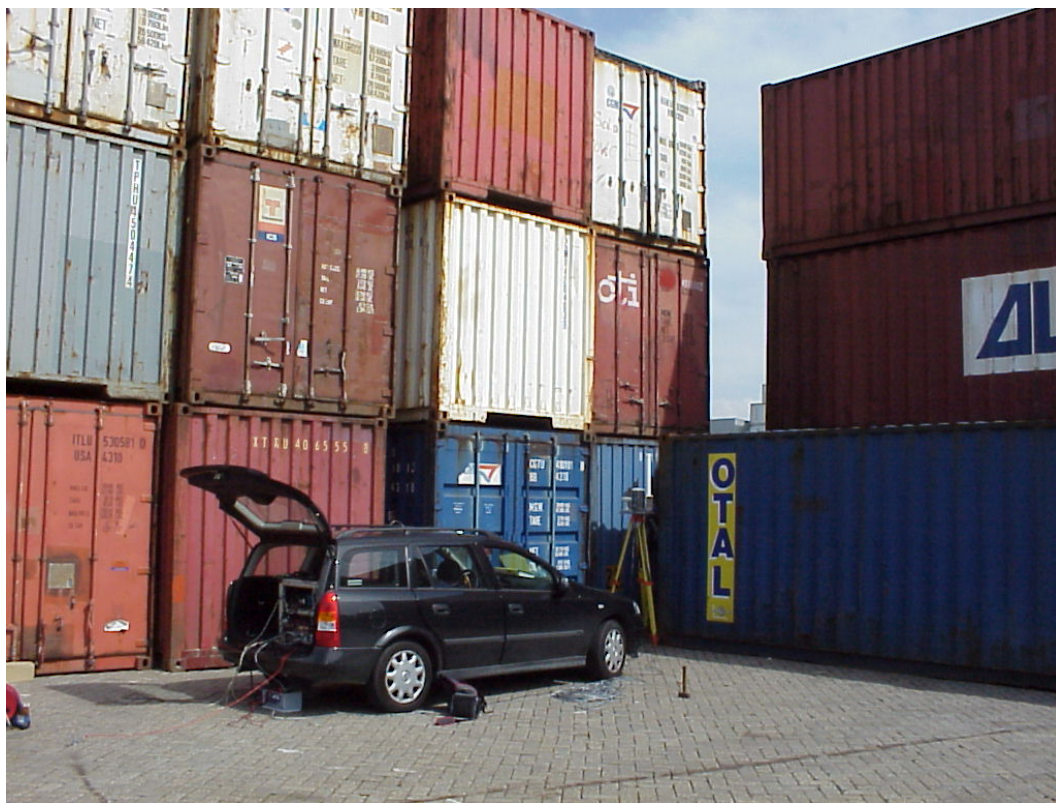
# GPS Backing Up LORAN-C

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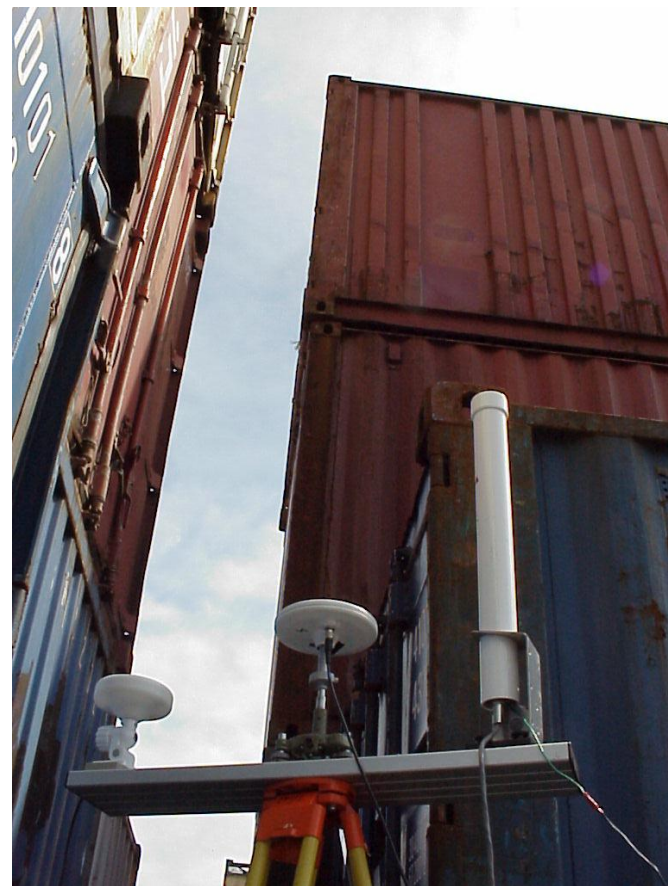
- LORAN-C needs calibration by DGPS prior to GPS disruption
- Calibration has two constraints:
  - DGPS must be good
    - Reliable flag-setting is essential
  - LORAN-C must be free of local propagation effects
    - ASF does not cause problems
    - Re-radiation is the bad guy

# A Nasty Example - 1

## Rotterdam Container Terminal

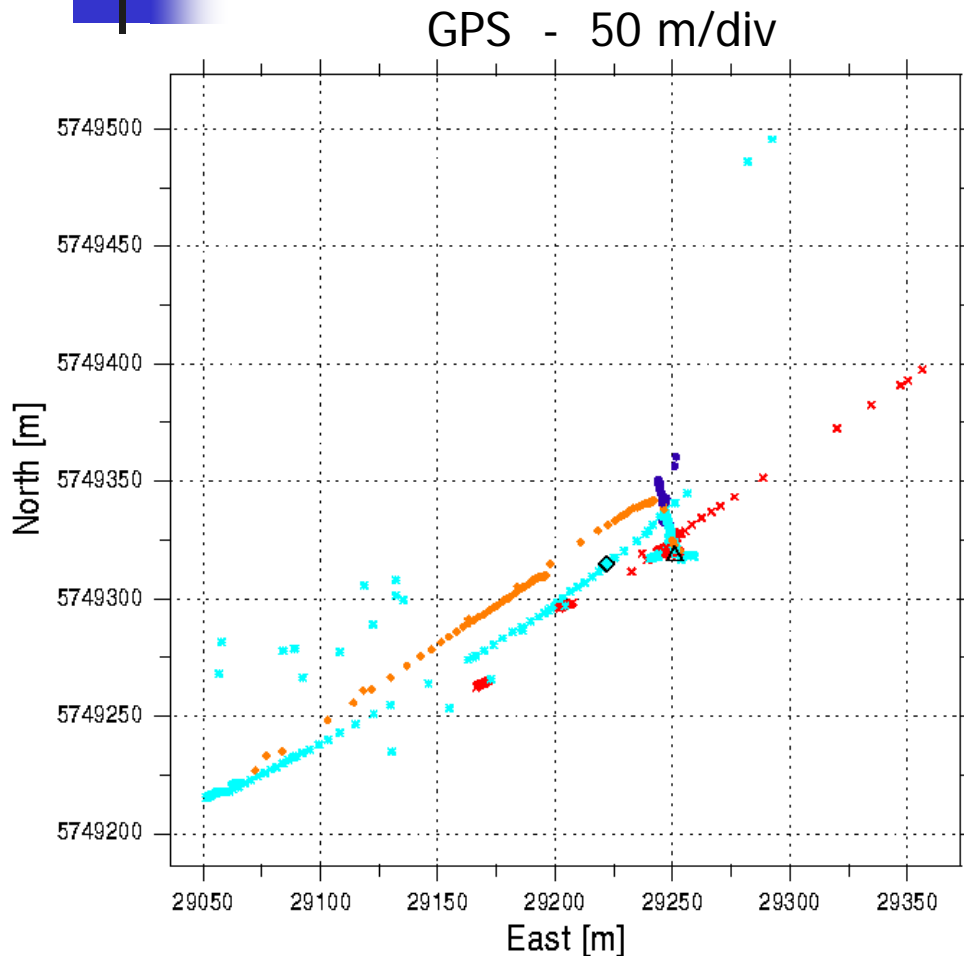


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GLORIA Tests by TCA Team

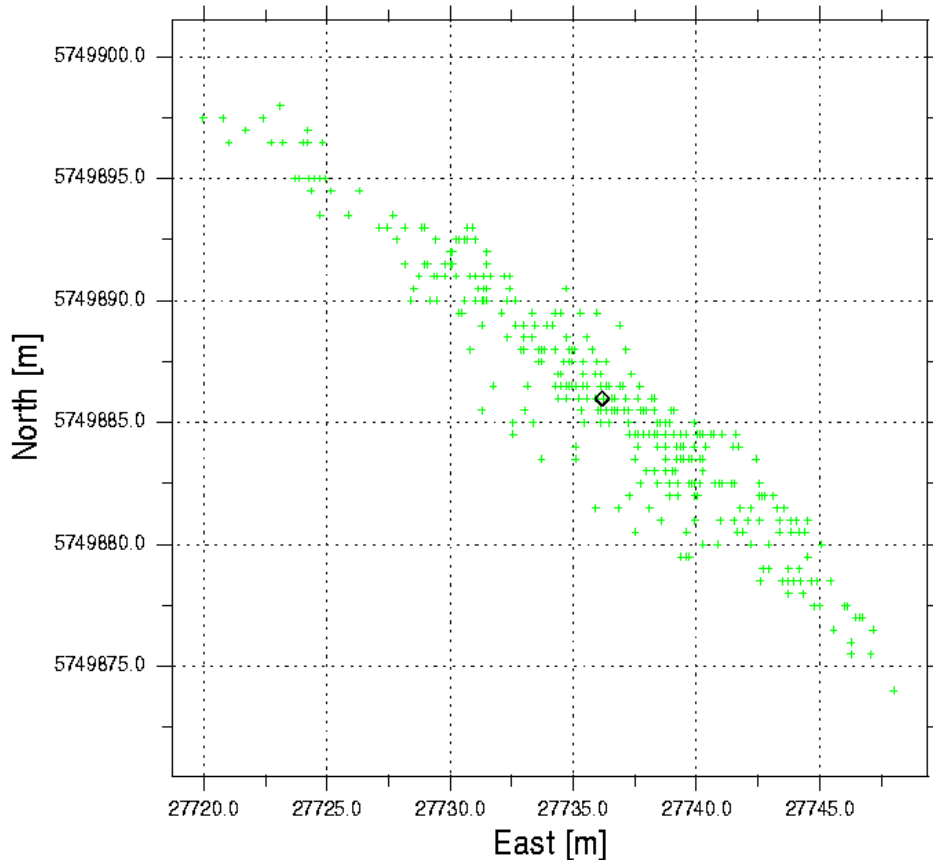
# A Nasty Example - 2



- Signals loud and clear....., but wrong pseudoranges
- Exact geometry not easily determinable by RX due to possible multipath
- Multipath detection and rejection hampered by short multipath de-tours
- RAIM is hard job!
- DGPS position only useful for LORAN-C calibration if:
  - Acceptable geometry
  - Proven free of multipath

# A Nasty Example - 3

LORAN-C / Lessay - 5 m/div



## Questions:

- Any re-radiation present?
- Re-radiation detectable?
- Rich re-radiation environment?
- Re-radiation history?
- Last calibration done in a re-radiation free environment?



# LORAN-C Datalink Backing Up SBAS

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- Two solutions:
  1. Backup SBAS datalink only:
    - a. Replace geo downlink by Loran-C datalink
  2. Backup SBAS functionalities:
    - a. Differential corrections
    - b. Integrity
    - c. Data from SBAS network or local ref station
- What are the differences and consequences for all user groups?



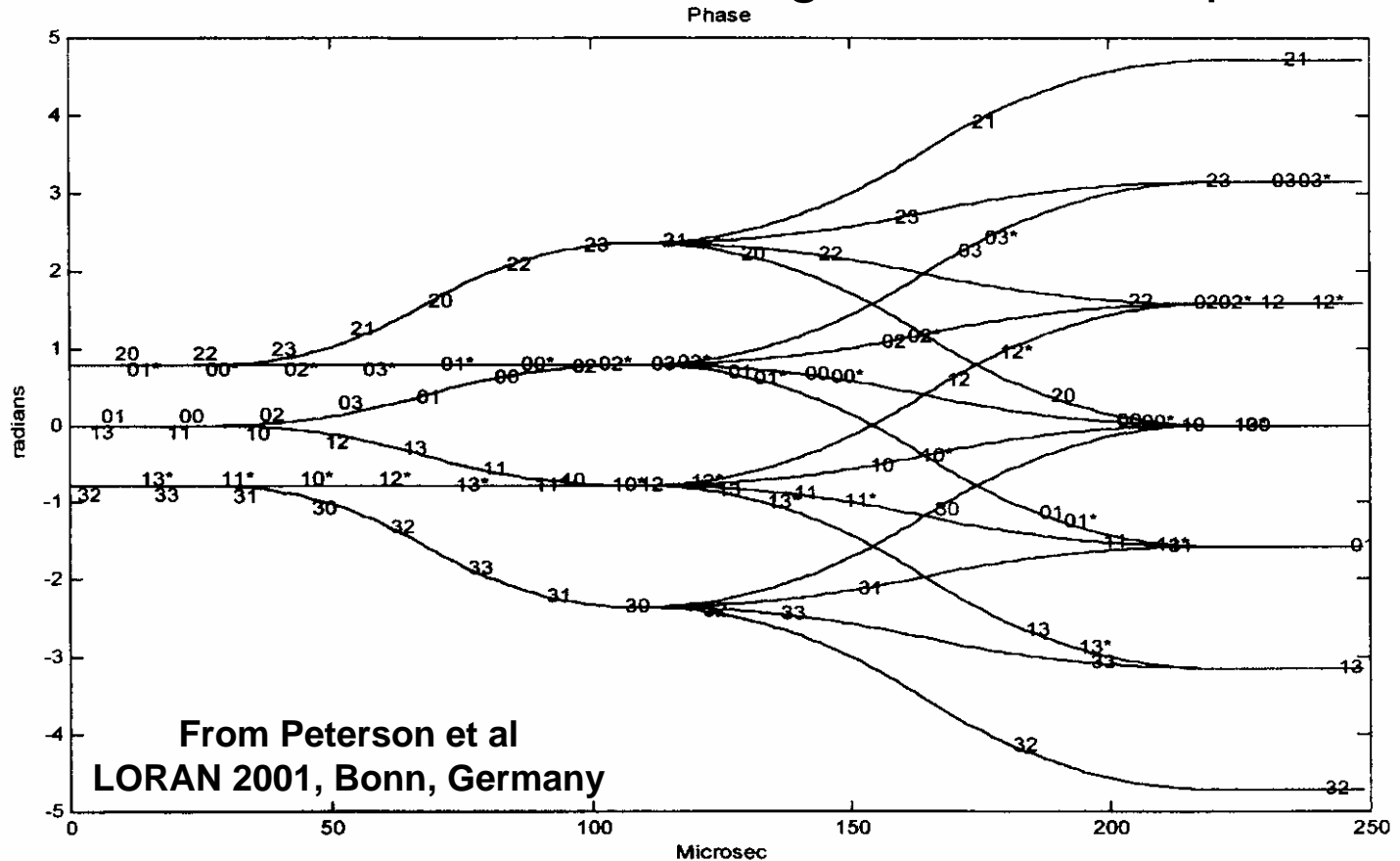
# Backing Up Geo Downlink

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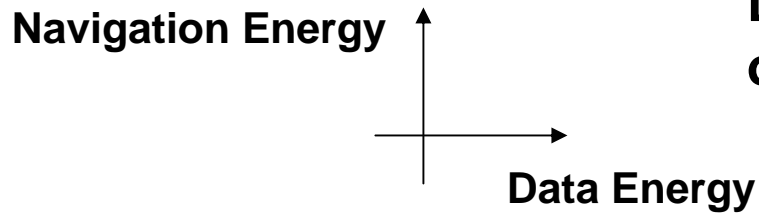
- Designed by **FAUST** Team
  - FAUST = **F**AA + **U**SCG + **S**tanford University
- Datalink bandwidth > 250 bps
- Successful Alaska flight trials
- Range TBD
- Significant change of pulse envelope
- Impact on total-pulse tracking
- Effects on legacy users TBD

# FAUST Phase Modulation Scheme 1

## Phase Modulation Along Pulse Envelope

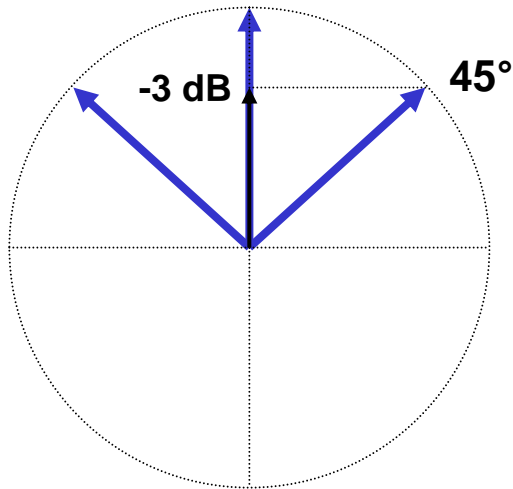


# FAUST Phase Modulation Scheme 2

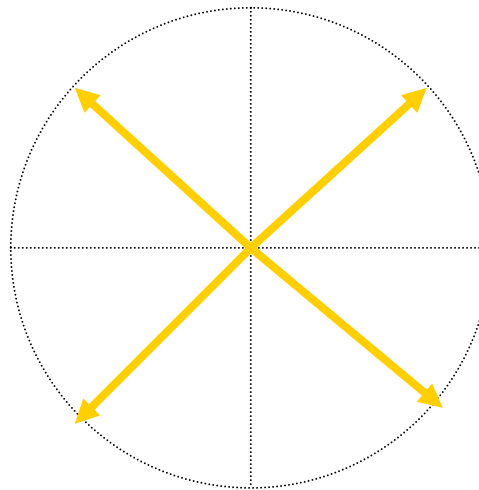


Loss in navigation energy depends on relative phase and occurrences

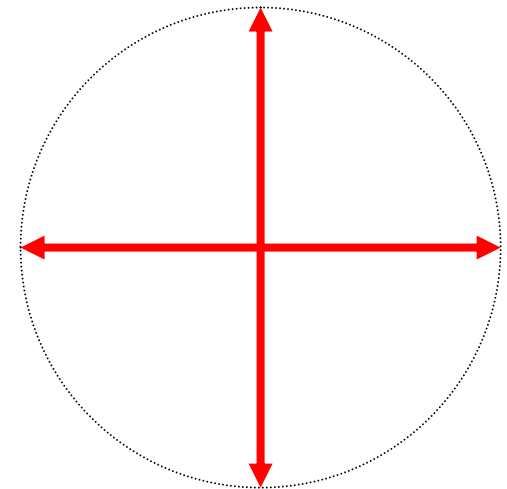
Leading Edge



Peak

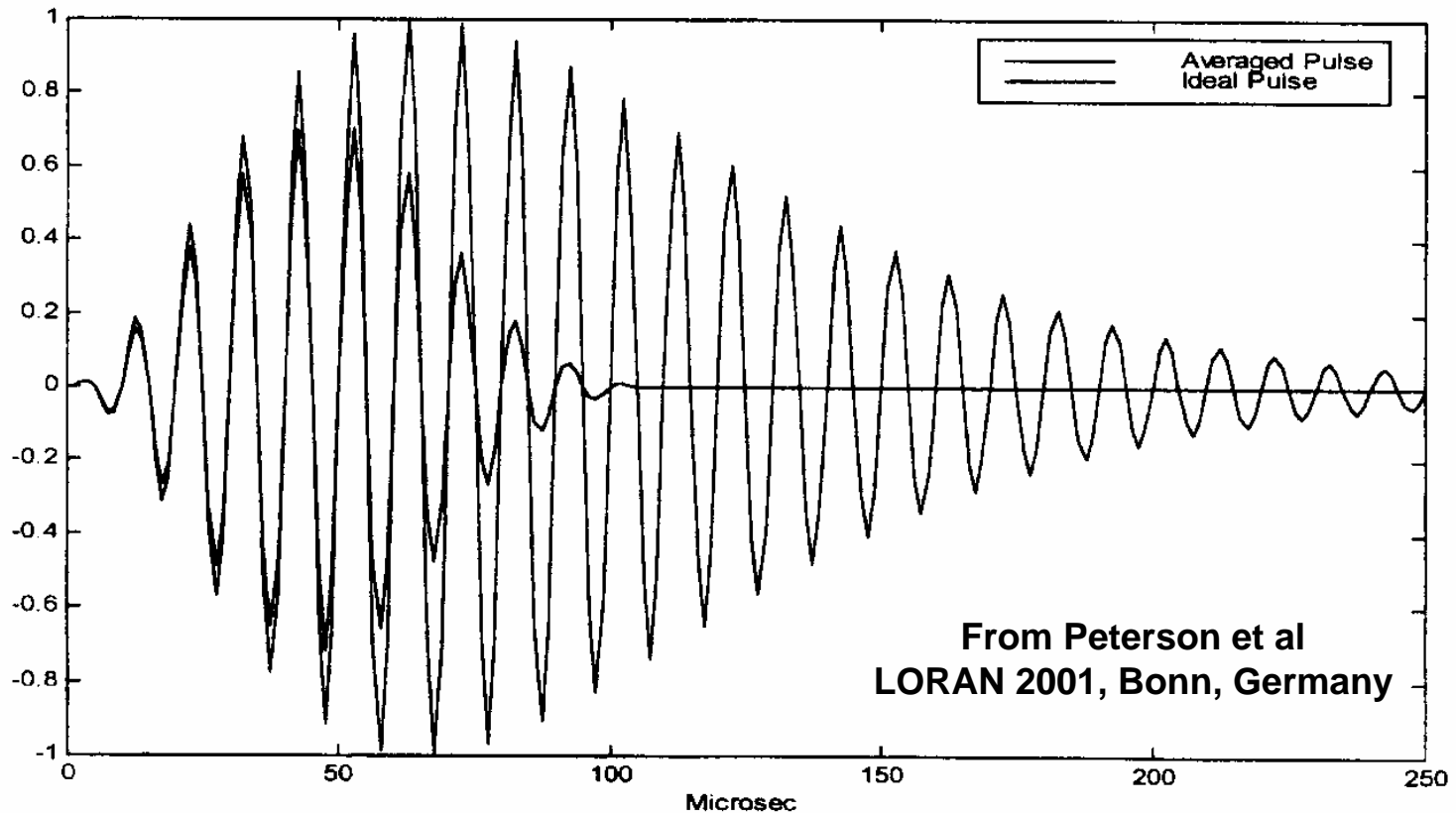


Trailing Edge



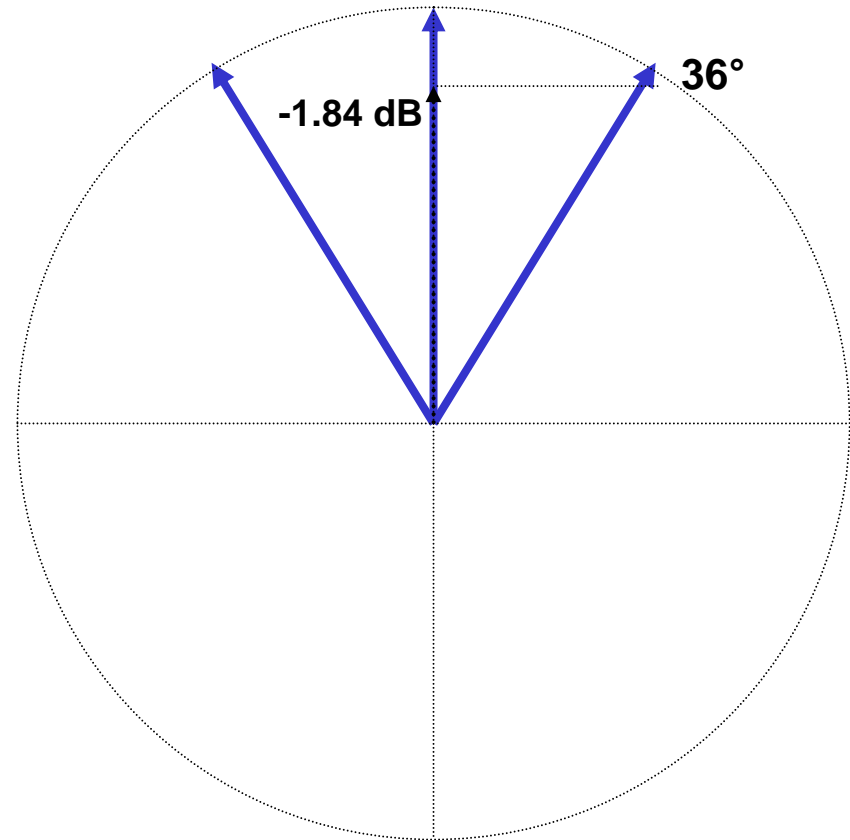
# FAUST Waveforms

Estimated Navigation Power Loss is  
6.2 dB relative to standard Loran-C, 5.4 dB relative to Eurofix



# Eurofix Phase Modulation Scheme

- Three-level time modulation over entire pulse  
-1, 0, +1  $\mu\text{sec}$
- Navigation energy loss over entire pulse = 0.8 dB
- Range Bias = 0



- Heavily wagging the tail is a very power-hungry exercise
- Therefore, birds do this just to impress their friends or enemies, but never do that to fly
- However, it is really a very high-tech tail biter



# FAUST - Eurofix Comparison - 1

	<b>FAUST</b>	<b>Eurofix</b>
Data rate per station	> 250 bps for dual-rated USCG stations	> 57 bps for dual-rated NELS stations
Range	??	≈ 1,000 km
Loss in navigation energy with leading edge pulse tracking	≈ 1.0 dB (estimated)	0.8 dB
Loss in navigation energy with full-pulse tracking	≈ 6.2 dB (estimated)	0.8 dB
Range bias	??	None
Multi-station reception	??	Yes
SBAS backup	Geo-broadcast	SBAS functionality
Influence on legacy users	??	Negligible



# FAUST - Eurofix Comparison - 2

	<b>FAUST</b>	<b>Eurofix</b>
<b>Service offered to</b>	??	≈ 250 Million Europeans South & North Korea incl. parts of Japan and China
<b>International status</b>	??	RTCM SC104 ITU-R M.589-3



# Aviation Requirements

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- Full autonomous LORAN-C receiver operation
- ASF data near runway to obtain high absolute accuracy
- High integrity and short time to alarm
- LORAN-C TOA transmissions or calibration for easy integration with GNSS



# Maritime Requirements

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- Full autonomous LORAN-C receiver operation
- ASF data to obtain high absolute accuracy
- High integrity and short time to alarm
- LORAN-C TOA transmissions or calibration for easy integration with GNSS



# Land-mobile Requirements

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- Extremely low-cost LORAN-C and GPS receivers
- Extremely fast re-acquisition after signal interruptions
- High availability at cost of integrity and accuracy
  - Total-pulse tracking allowed
  - GPS-aiding to re-acquire LORAN-C signal



# Timing Requirements

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- Full autonomous LORAN-C receiver operation
- LORAN-C TOE control or TOE calibration of SAM controlled transmissions via allocated Eurofix data channel (Russia and Far East)
- TOE linked to UTC or GPS-time

- FAUST

- High-speed LORAN-C datalink may backup WAAS geo-broadcast channel
- Simple concept
- Complex receiver

- Eurofix

- Medium-speed LORAN-C datalink may backup EGNOS navigation and integrity functionalities
- Slightly less simple concept
- Simple receiver



# Receivers

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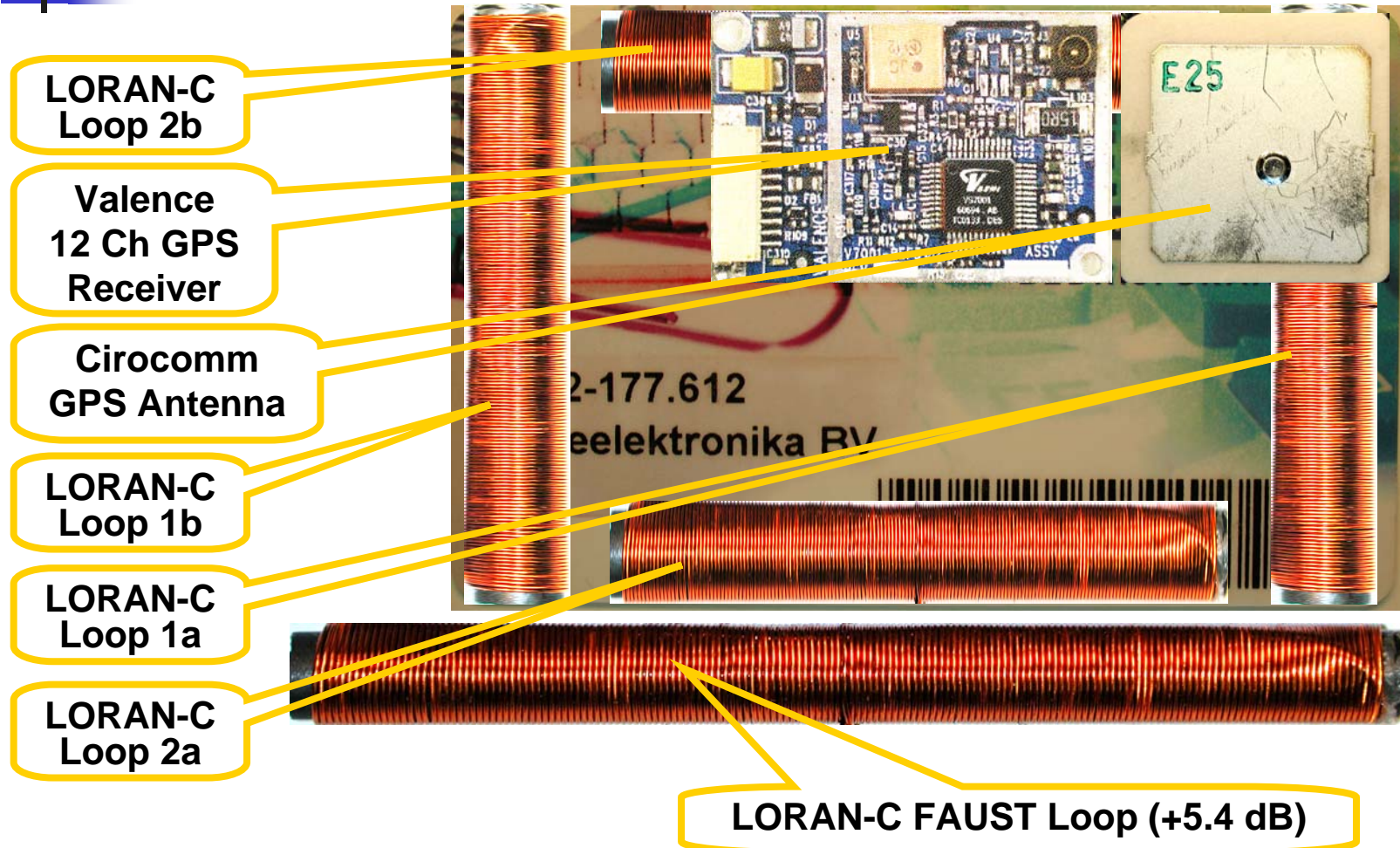
## GPS

- Widely available
- Very small
- Small antennae
- Low power
- Low cost
- Low-cost units show moderate performance
- WAAS available

## LORAN-C

- Hardly available
- Large
- High power
- Expensive
- High performance hardly available
- Old technology
- H-field antennae slowly emerging
- Eurofix available

# Receiver Hardware, hmm...





# LORAN-C Antennae

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- E-field antenna is relatively simple device and highly efficient
- H-field antenna is essential to land user but its design is specialist's job
- $SNR = LC / (N_{atm} + N_{ant} + CWI + CRI)$
- Minimize antenna size until  $N_{ant}$  approaches  $N_{atm}$  level
  - Smart receiver rejects CWI and CRI and therefore needs larger (lower noise figure) antenna
  - Simple receiver shows lower SNR, so smaller antenna can be applied
- FAUST-induced loss in LORAN-C power cannot be cured in the receiver if used at larger distances!!



# Conclusions on Receivers

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- GPS receivers ready to use
- LORAN-C receivers need complete rethinking
- LORAN-C receiver design is challenging
  - High levels of interference
  - Propagation issues like skywaves, CRI, CWI, re-radiation and local man-made noise
- LORAN-C receiver research needs funding like GPS got 20 years ago (400 M\$!)
- We must start NOW !!



# Final and Last Conclusions

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- GNSS needs LORAN-C and Chayka
- LORAN-C and Chayka need GNSS
- Integration of GNSS and LORAN-C is only solution for accurate and reliable radionavigation in the foreseeable future



# Tomorrow's Panel Discussion

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We are squandering our LORAN-C research forces and funds which slows down the development of receivers

So, it is in the interest of the entire navigation business to start a worldwide joint research to grab our changes in this narrow time slot

Should the aviation WAAS or the European land user prevail in the FAUST-Eurofix debate?