


A Miniaturized Loran H-field Antenna for Handheld Devices

David S. De Lorenzo, Morris Cohen, Jeff Chang, Sherman C. Lo, Umran S. Inan, Per K. Enge

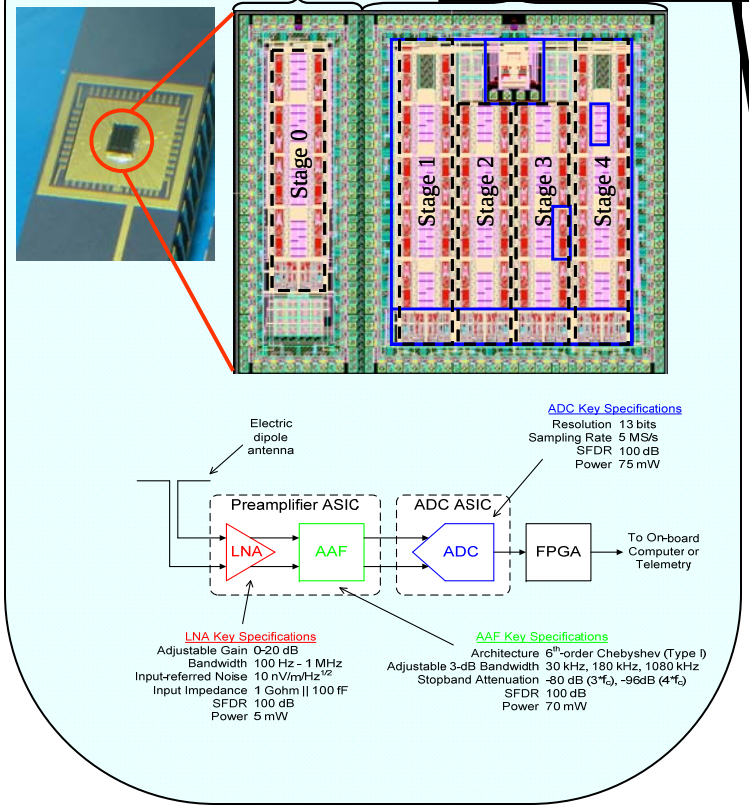
Technical Symposium of the International Loran Association
October 13-15, 2009
Portland, ME

Outline

- Background / Motivation
- Low Noise Amplifier Design
- H-field Antenna Evolution
- Live Signal Processing Results
- Next Steps
- Conclusions

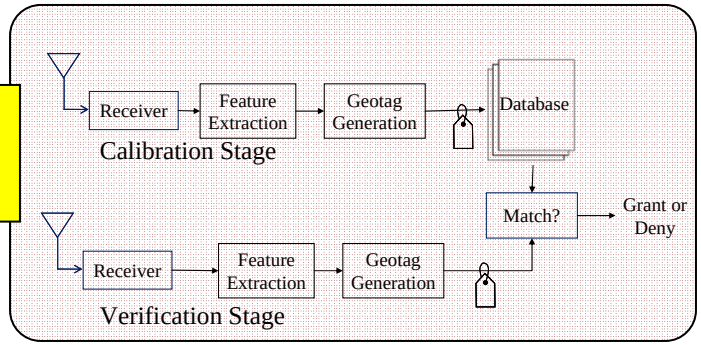
Enabling a Small Loran Antenna for Integrated Navigation Devices

Next-Gen Antenna & LNA for Small-form-factor eLoran (Stanford EE & AA)



Multi-sensor Integrated Personal Navigation Devices

Geo-security Applications

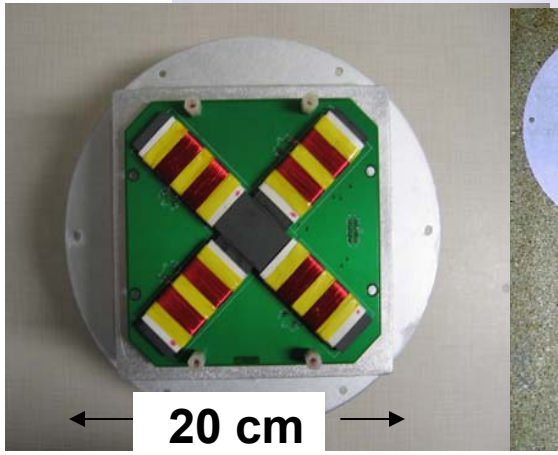


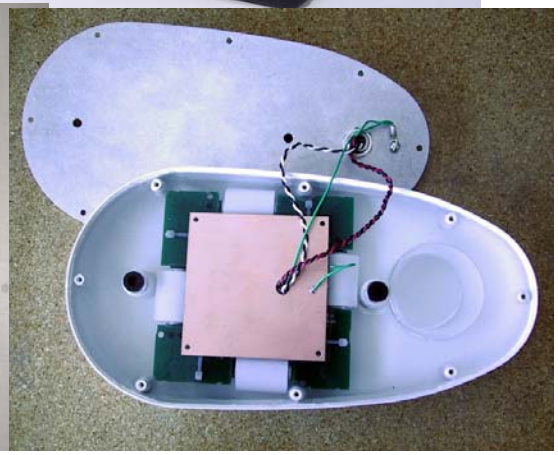
Enabling a Small Loran Antenna for Integrated Navigation Devices

- **Goal:** Enable Loran in next-gen PNDs
  - Meet form-factor, sub-system cost, and power consumption targets for handheld devices
- **Benefits:**
  - Improve navigation accuracy, availability, and integrity through multi-sensor integration (GNSS, eLoran, INS, etc.)
  - Enhance geo-security with jam- and spoof-resistance PNT
  - Unique capabilities (static heading)
- **Problems:**
  - Integration of Loran impeded by large antenna form-factor required to receive the 100 kHz RF signal
  - Small antenna sensitivities are limited by internal noise
- **Solution:**
  1. Develop an optimized LNA for the Loran band
  2. Demonstrate with a small-form-factor Loran antenna

Large Antennas Required to Receive 100 kHz Loran Signal

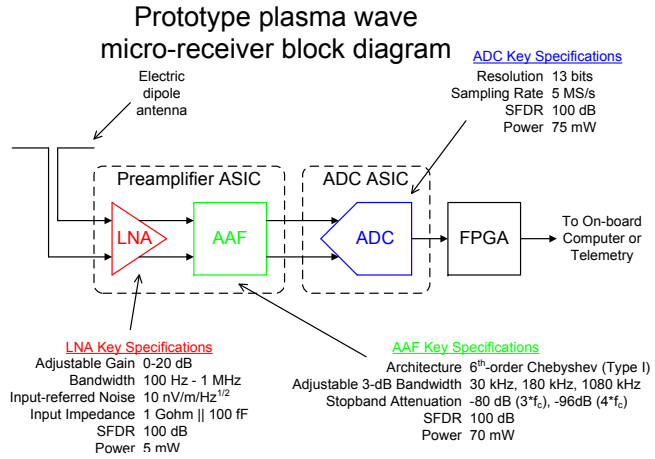
- Integration of Loran impeded by large antenna form-factors
- State of the art H field are getting smaller
- But current sizes and requirements are still not acceptable for PND

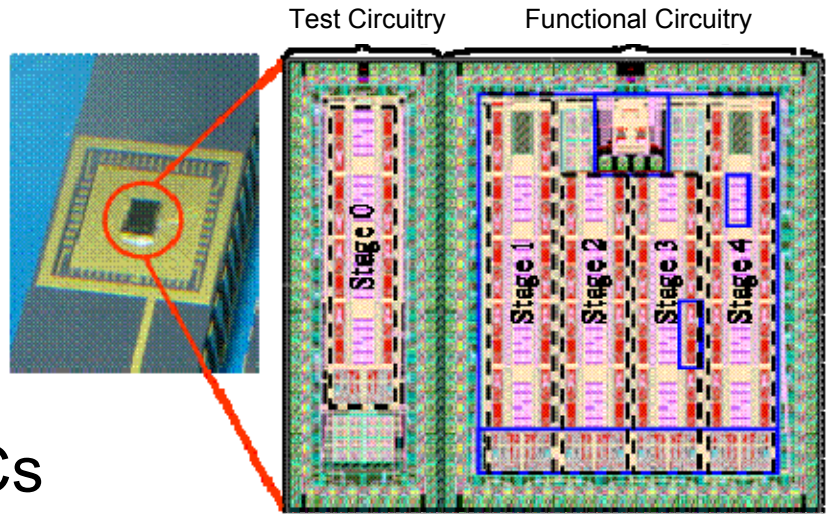




Fundamental Design Trade: Optimize the LNA to Reduce Noise

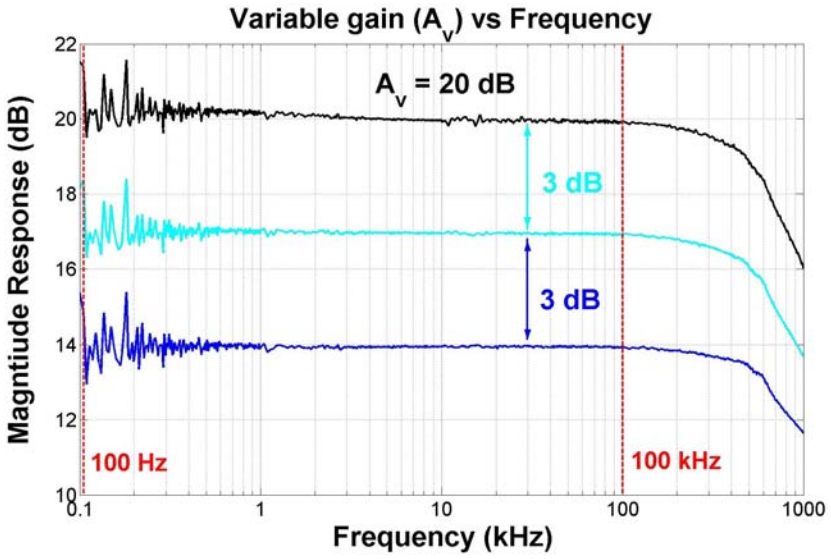
- Leverage (very) low-noise, low-power, high-linearity, wide-bandwidth, high-impedance LNA developed by Stanford EE STAR-Lab
  - Developed for low-noise space-based experiments
  - Current design bandwidth 100 Hz to 100 kHz
  - Low power draw
  - Have fabricated ~50+ ASICs

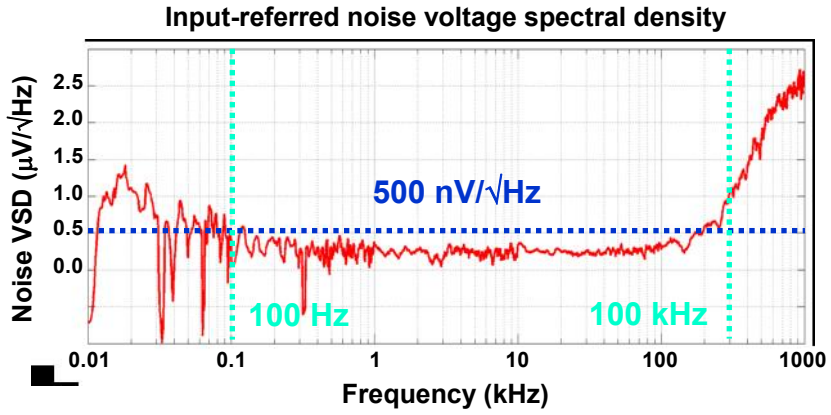




images courtesy: Ben Mossawir, Stanford VLF group

LNA Design & Measured Performance





Architecture

- Multiple series-series feedback loops:
  - High linearity
  - Immunity to component variation
  - High input impedance
- Flicker noise reduced via bipolar front-end devices

Measured performance

- Frequency domain
  - Flat passband up to 100 kHz
  - Accurate gain steps (14 – 20 dB)
  - Negligible flicker noise > 100 Hz
- Time domain
  - Linear gain achieved for 100 kHz input tone with A_v = 20 dB

images courtesy: Ben Mossawir, Stanford VLF group

Feasibility of Current LNA: Proof-of-Concept Calculations

- Internal noise calculation:

$$\underbrace{500nV/\sqrt{Hz}}_{\text{Input reference noise value}} * \underbrace{\sqrt{200kHz}}_{\text{LNA Bandwidth}} \cong 220\mu V$$

- Equivalent field strength:
  - Based on 0.05m antenna effective height

$$220\mu V/.05m = 4.4mV/m = 36.5dB\mu V/m$$

Compare this to the expected Loran field strength

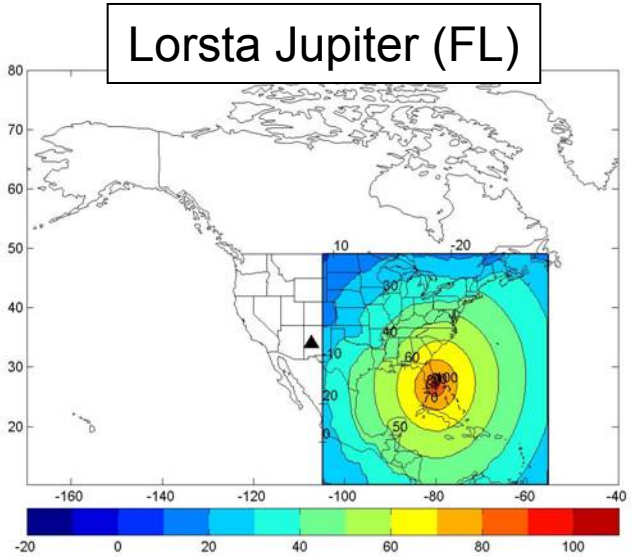
Feasibility of Current LNA: Loran Signal Strength Design Trades

- Expected Loran field strength:

$$\sim 30\text{-}110 dB\,\mu V/m$$

  - Assumes $\sim 1500 km$ range
  - Requires $\sim 80 dB$ dynamic range
- Atmospheric noise:

$$\sim 45\text{-}60 dB\,\mu V/m$$



- Feasible to build useful Loran antenna unit using this LNA design (equivalent field str $\sim 36.5 dB\,\mu V/m$)
  - Signal should be received at acceptable levels
  - Dynamic range is adequate

Optimized LNA: *Projections* based on Modified Design

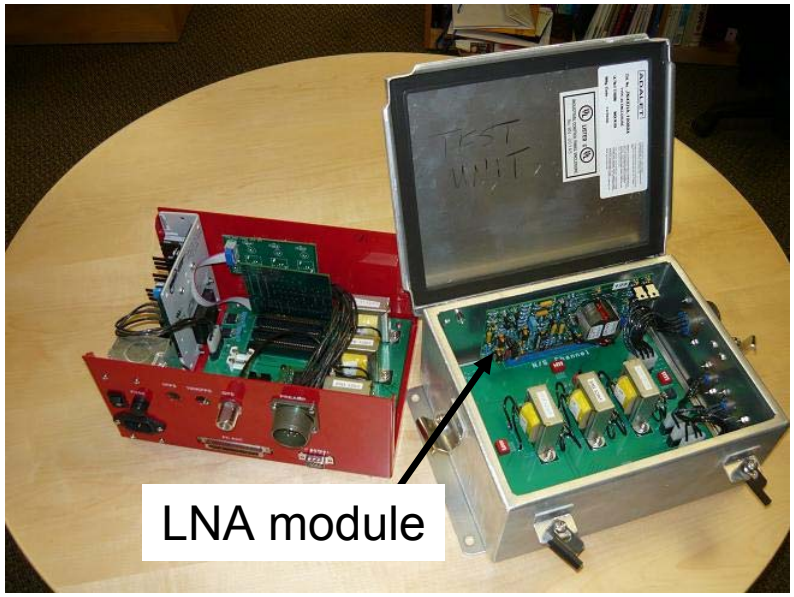
- Optimize LNA ASIC for Loran band
  - Band-pass rather than low-pass
    - 20 kHz bandwidth rather than ~200 kHz
  - Add a high-pass stage after LNA
    - Should not contribute much more noise (Friis' formula)
- Revised internal noise and equivalent field str:

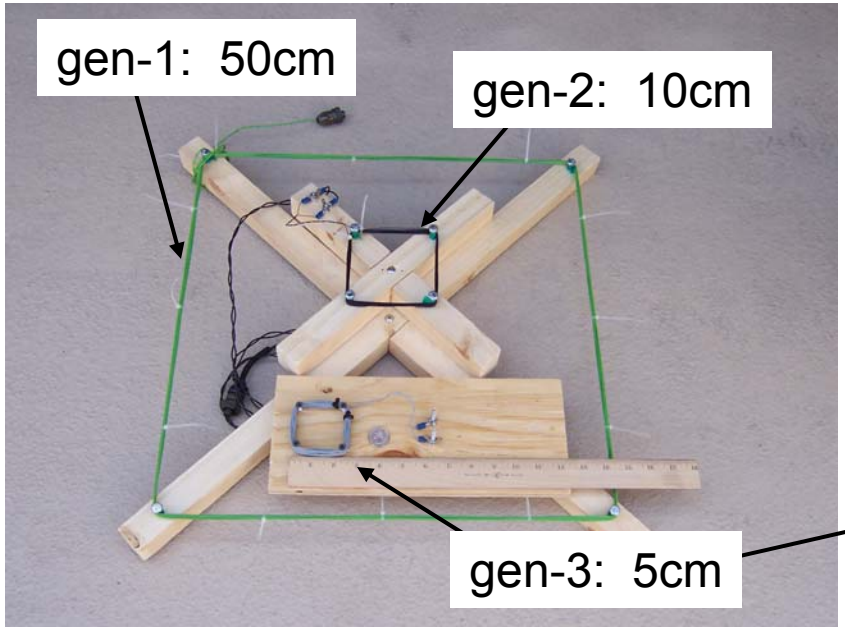
$$\underbrace{500nV/\sqrt{Hz}}_{\text{Input reference noise value}} * \underbrace{\sqrt{20kHz}}_{\text{LNA Bandwidth}} \cong 70\mu V$$

$$70\mu V/.05m = 1.4mV/m = 31dB\mu V/m$$

Integrate Baseline LNA with Small-form-factor Loran Antenna

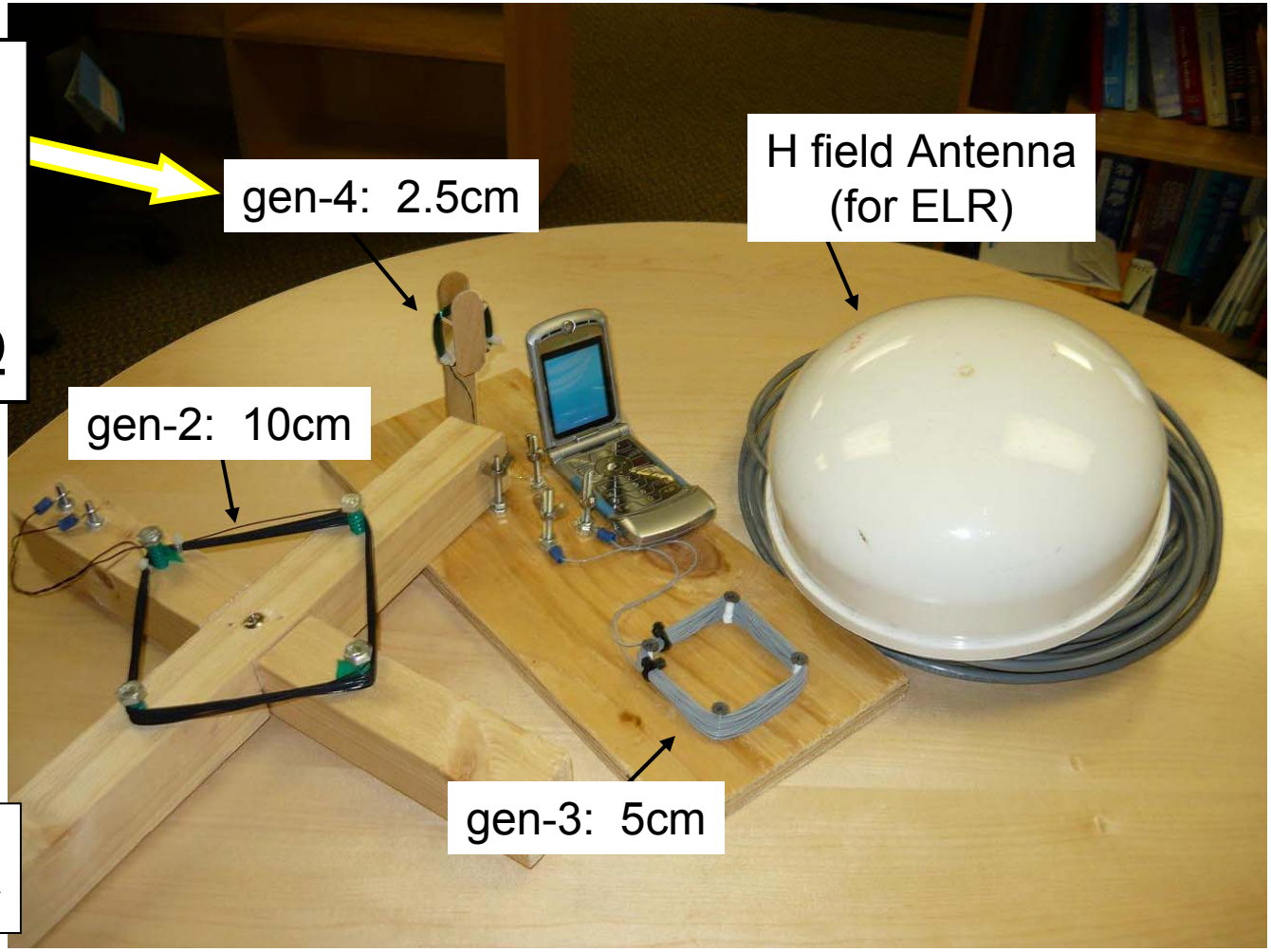
- LNA module and support electronics
- Antenna evolution





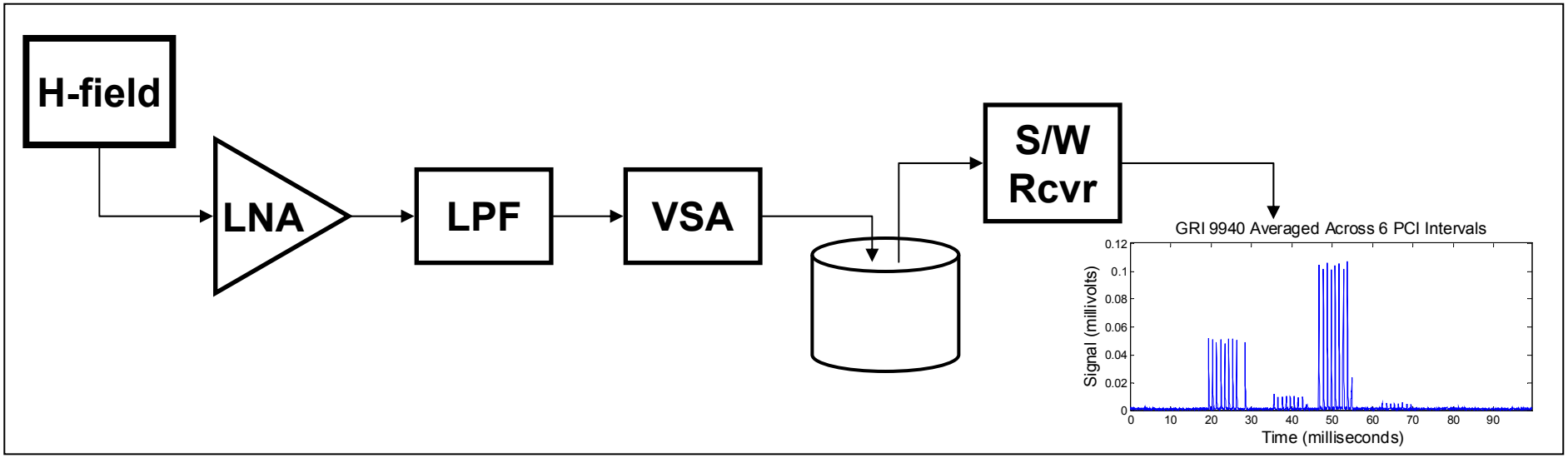
Next-gen Design: 2.5cm air-core H-field antenna

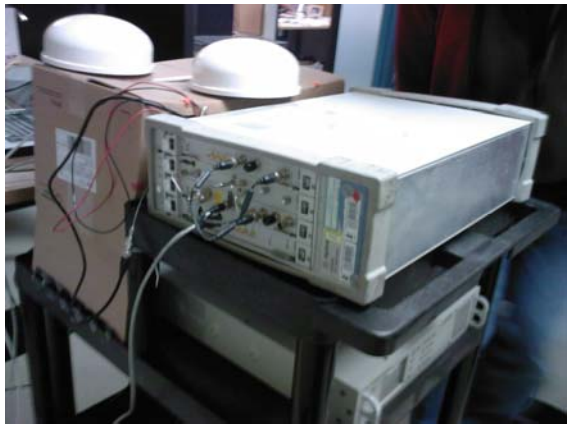
2.5cm square
26 AWG wire
74 turns
resistance 1Ω



Testing awaits some hardware repair issues

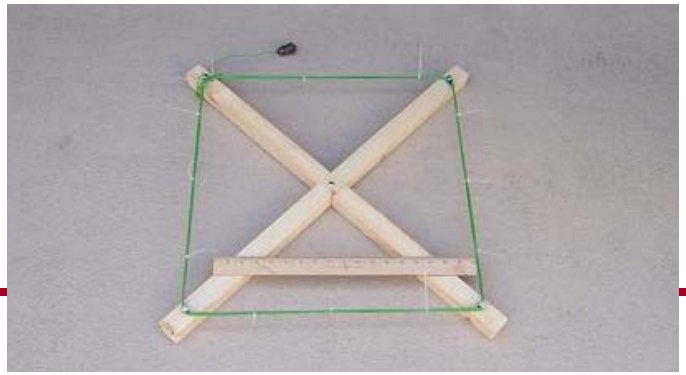
Loran Data Collection

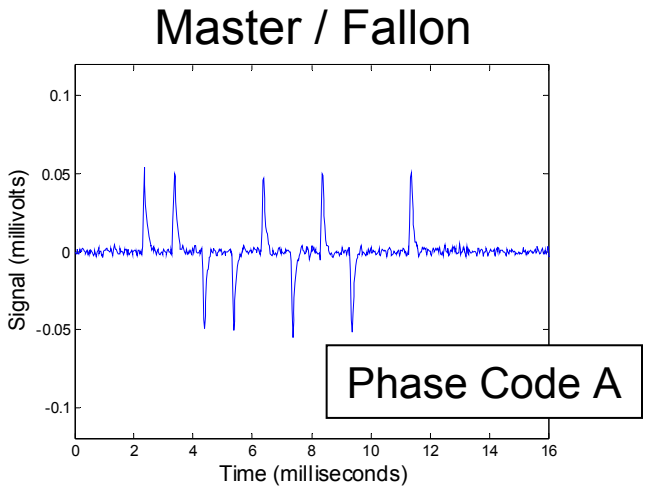


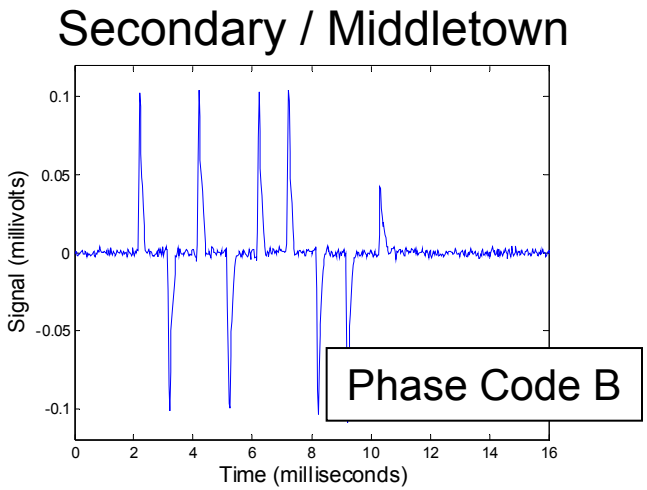


50cm (20 inch) H-field Antenna

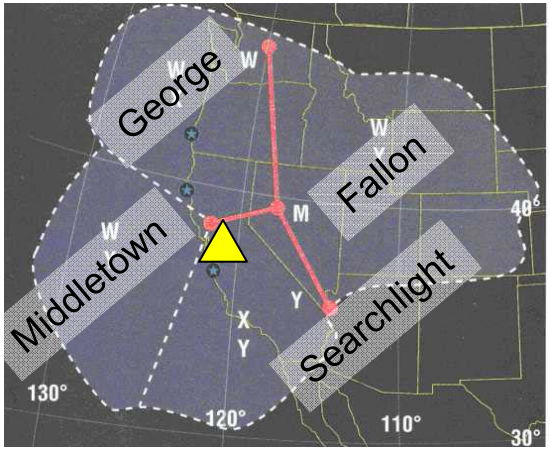
- Pulse sequence easily visible on signal analyzer
  - No averaging required
- Changing orientations reveals signal DOAs
- Antenna used to verify data collection system and signal processing







Loran West Coast Chain - seen from Stanford, CA -

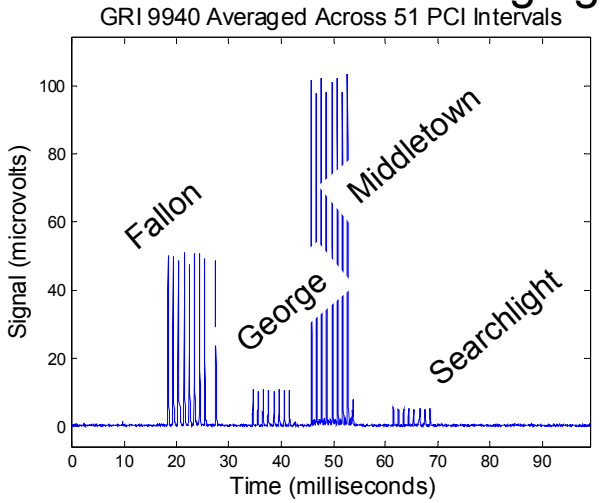


Outdoor data collection

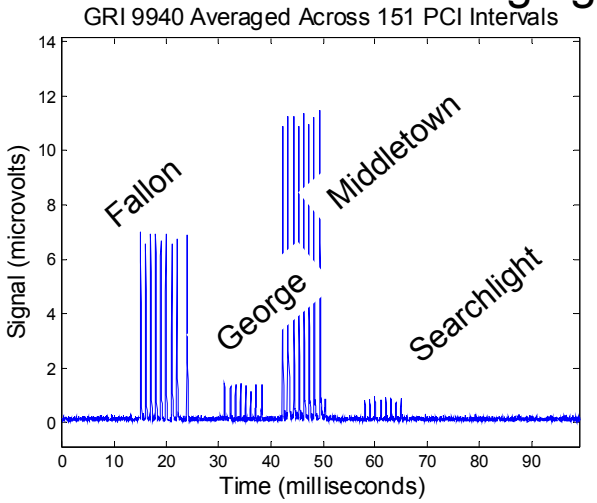
Large antennas easily process the available signals

5cm loop antenna requires fairly long averaging times

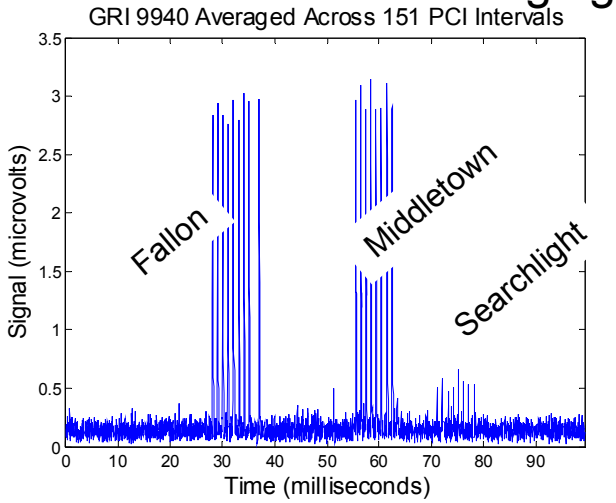
50cm H-field loop antenna
~10 seconds of averaging



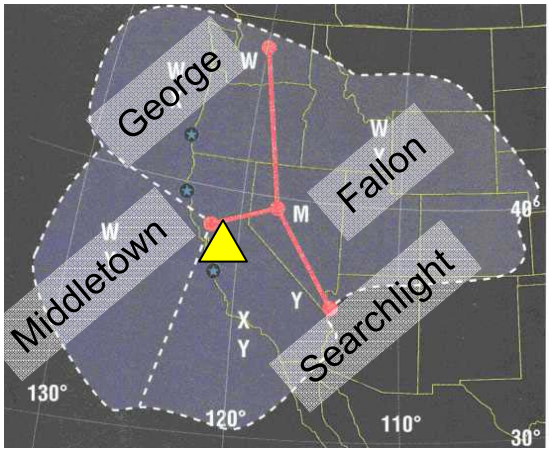
10cm H-field loop antenna
~30 seconds of averaging



5cm H-field loop antenna
~30 seconds of averaging



Loran West Coast Chain - Indoor Observation -

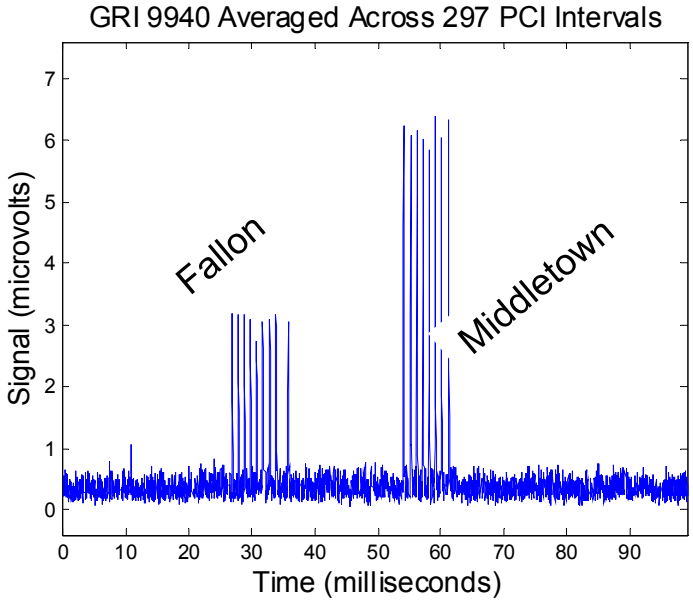


Indoor data collection

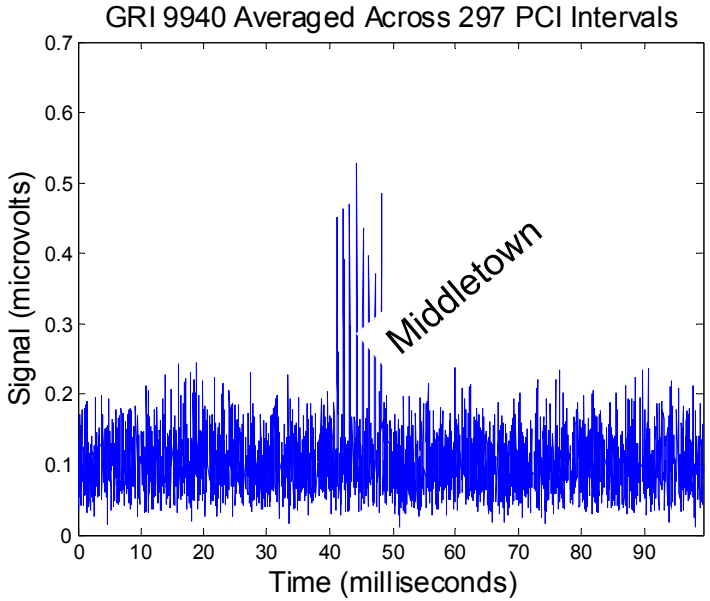
Signal attenuation is severe in the reinforced concrete building chosen for these tests

Testing with 5cm (2 inch) antenna

50cm H-field loop antenna
~60 seconds of averaging



5cm H-field loop antenna
~60 seconds of averaging



Conclusions

Received Signal Strength - µV					
Station	Outdoors			Indoors	
	50cm	10cm	5cm	50cm	5cm
Fallon	50	6.8	2.9	3.1	-
George	14	2.1	0.5	-	-
Middletown	210	27.1	17	7	0.46
Searchlight	8.5	1.3	0.9	-	-

- Reducing antenna size must focus on internal noise
  - Better LNA allows trade against antenna sensitivity
  - Long averaging times to combat low SNR
- Loran signals detectable both outdoors & indoors with smallest antenna size tested – 5cm H-field antenna
  - Timing and data services are enabled, but not indoor nav.
  - Possible excessive attenuation in reinforced concrete building
- Current analysis suggests improved performance with optimized LNA
  - Next antenna: 2.5cm air-core H-field
  - LNA: band-pass centered at 100 kHz

Acknowledgments & Disclaimer

- The authors gratefully acknowledge the support of the Federal Aviation Administration and Mitchell Narins under Cooperative Agreement 2000-G-028 and the Stanford Center for Position Navigation and Timing. We also acknowledge the help of Dr. Ivan Linscott and the STAR lab VLF group

- The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the U.S. Coast Guard, Federal Aviation Administration, Department of Transportation or Department of Homeland Security or any other person or organization.