THE UNIVERSITY OF TEXAS AT AUSTIN
RADIONAVIGATION LABORATORY

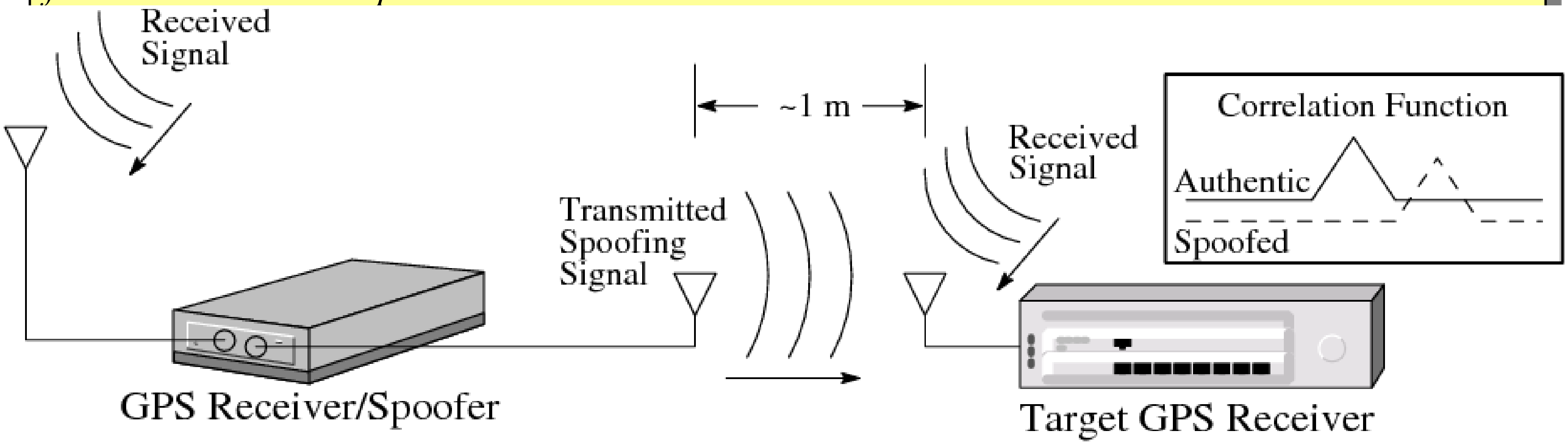
Assessing the Civil GPS Spoofing Threat

Todd Humphreys, Jahshan Bhatti, University of Texas at Austin
Brent Ledvina, Virginia Tech/Coherent Navigation
Mark Psiaki, Brady O' Hanlon, Paul Kintner, Cornell University
Paul Montgomery, Novariant

Spoofing Threat Overview

"As GPS further penetrates into the civil infrastructure, it becomes a tempting target that could be exploited by individuals, groups, or countries hostile to the U.S." -- 2001 DOT Volpe Report

- *"There also is no open information on … the expected capabilities of spoofing systems made from commercial components."*

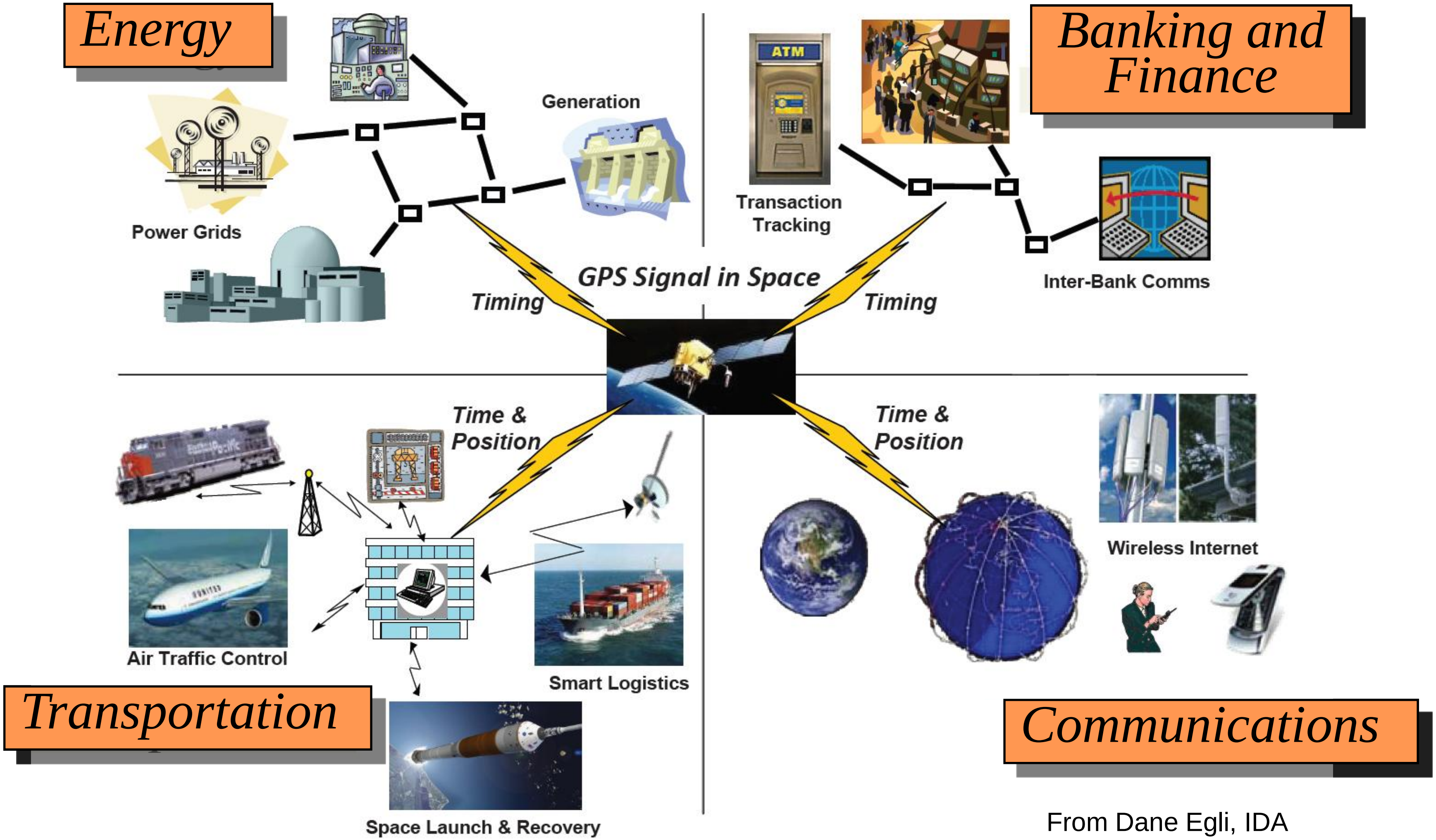


GPS World, July 2007

September 2008: Humphreys, Ledvina et al. present work on civil spoofer.

December 2009: Civilian GPS receivers as vulnerable as ever.

GPS: Dependency Begets Vulnerability



From Dane Egli, IDA

Suggested Spoofing Countermeasures

Suggested by Dept.of Homeland Security

- ~~Monitor the relative GPS signal strength~~
- ~~Monitor satellite identification codes and the number of satellite signals received~~
- ~~Check the time intervals~~
- ~~Do a time comparison (look at code phase jitter)~~
- Perform a sanity check (compare with IMU)
- Monitor the absolute GPS signal strength

Warner and Johnston, "GPS Spoofing Countermeasures," 2003
http:/www.homelandsecurity.org/bulletin/Dual%20Benefit/warner_gps_spoofing.html

<u>Other Suggested Techniques</u>

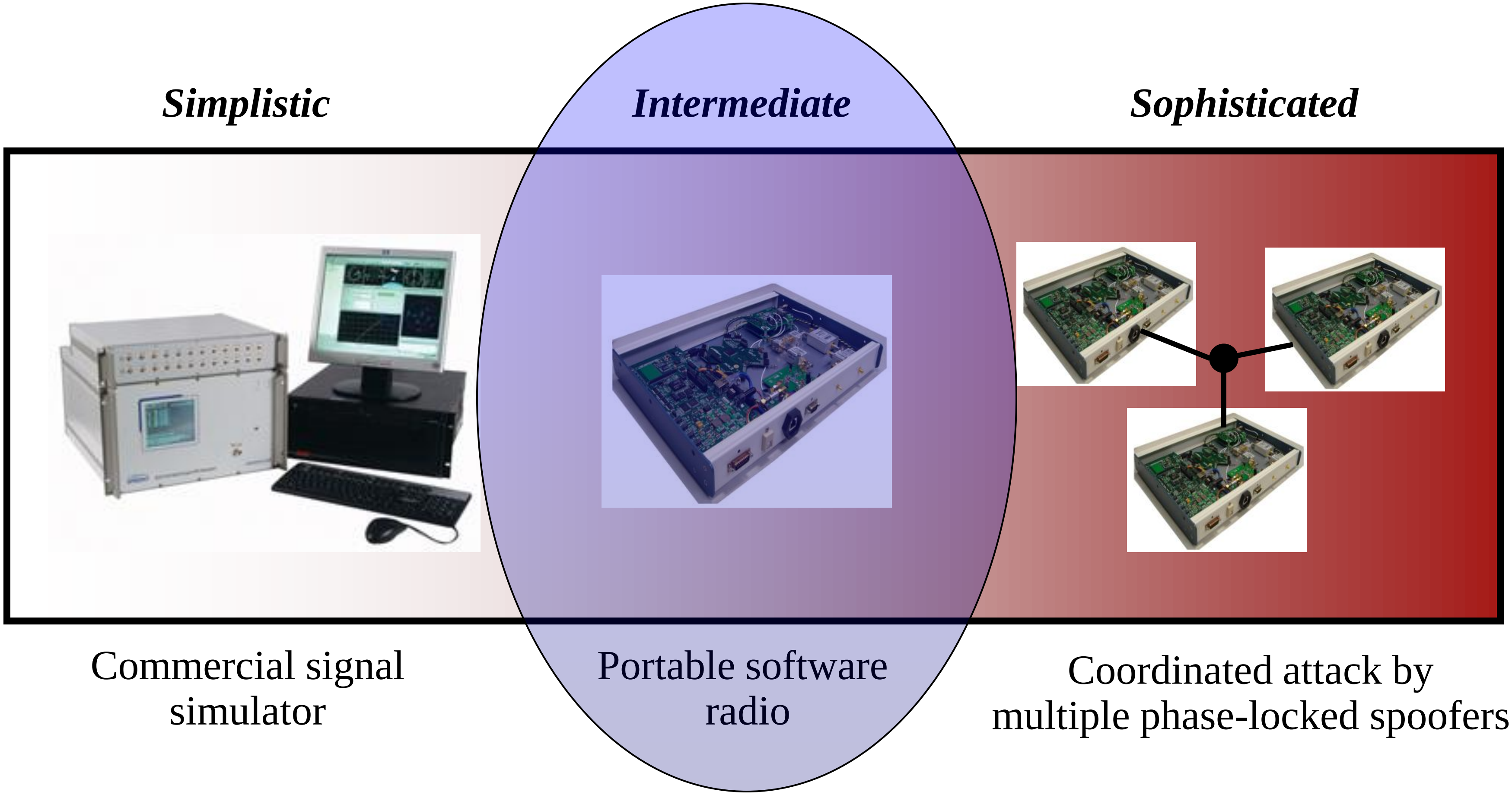
- Employ two antennas; check relative phase against known satellite directions

To accurately assess the spoofing threat and to design effective practical countermeasures, we concluded that it was necessary to go through the exercise of building a civilian GPS spoofer

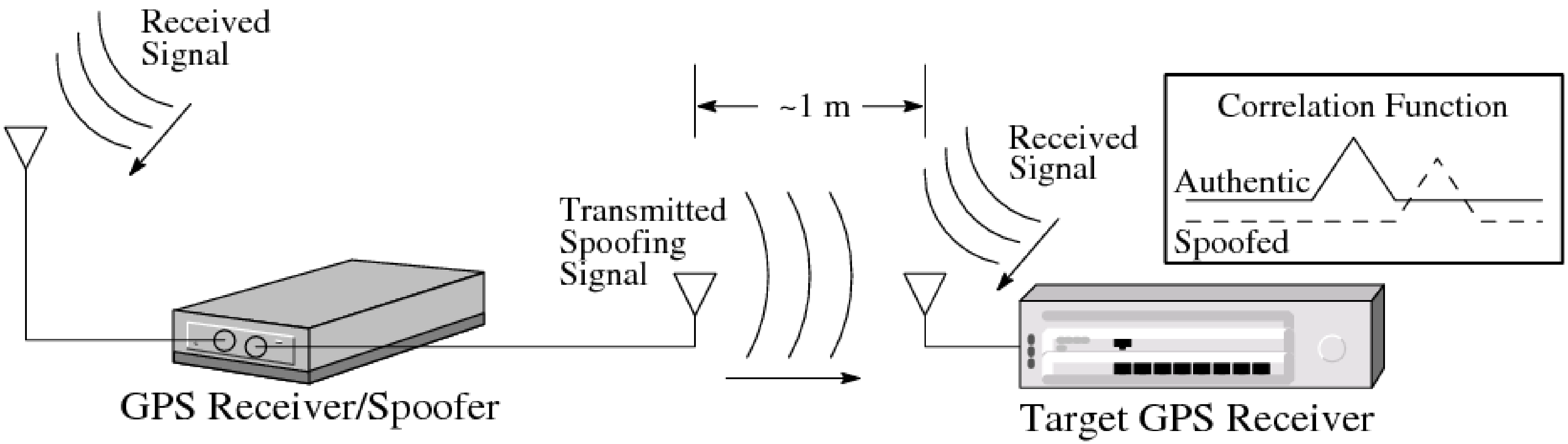
Goals

- Assess the spoofing threat:
  - Build a civilian GPS spoofer
  - Q: How hard is it to mount a spoofing attack?
  - Q: How easy is it to detect a spoofing attack?
- Investigate spoofing countermeasures:
  - Stand-alone receiver-based defenses
  - More exotic defenses

Spoofing Threat Continuum

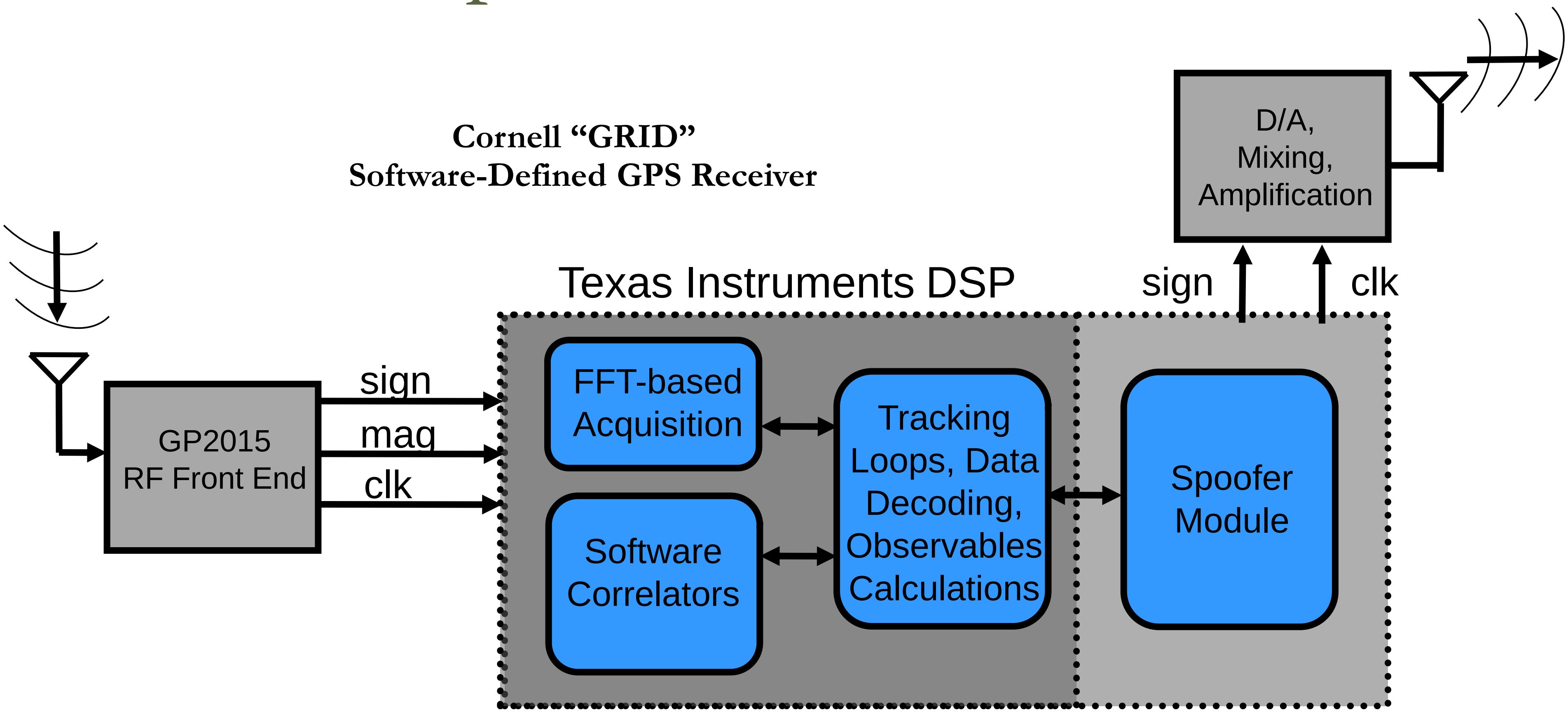


The Most Likely Threat: A Portable Receiver-Spoofer



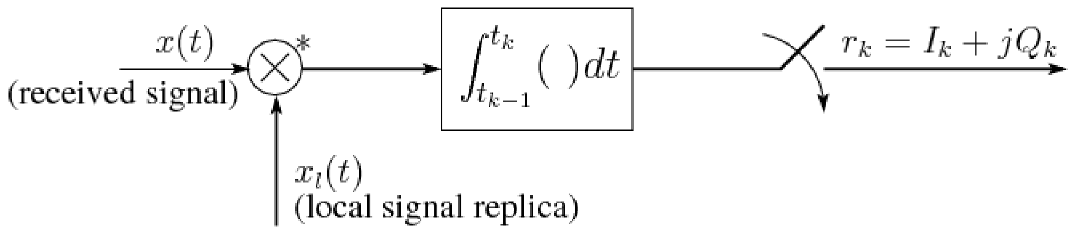
The portable receiver-spoofer architecture simplifies a spoofing attack

Receiver-Spoofer Architecture

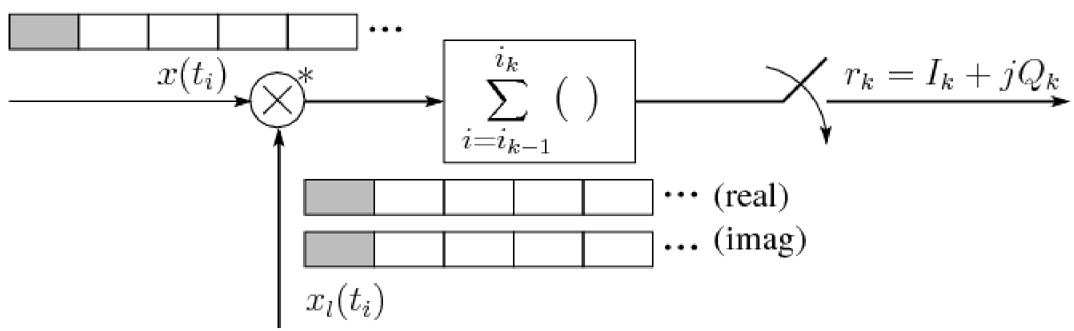


Signal Correlation Techniques (1/2)

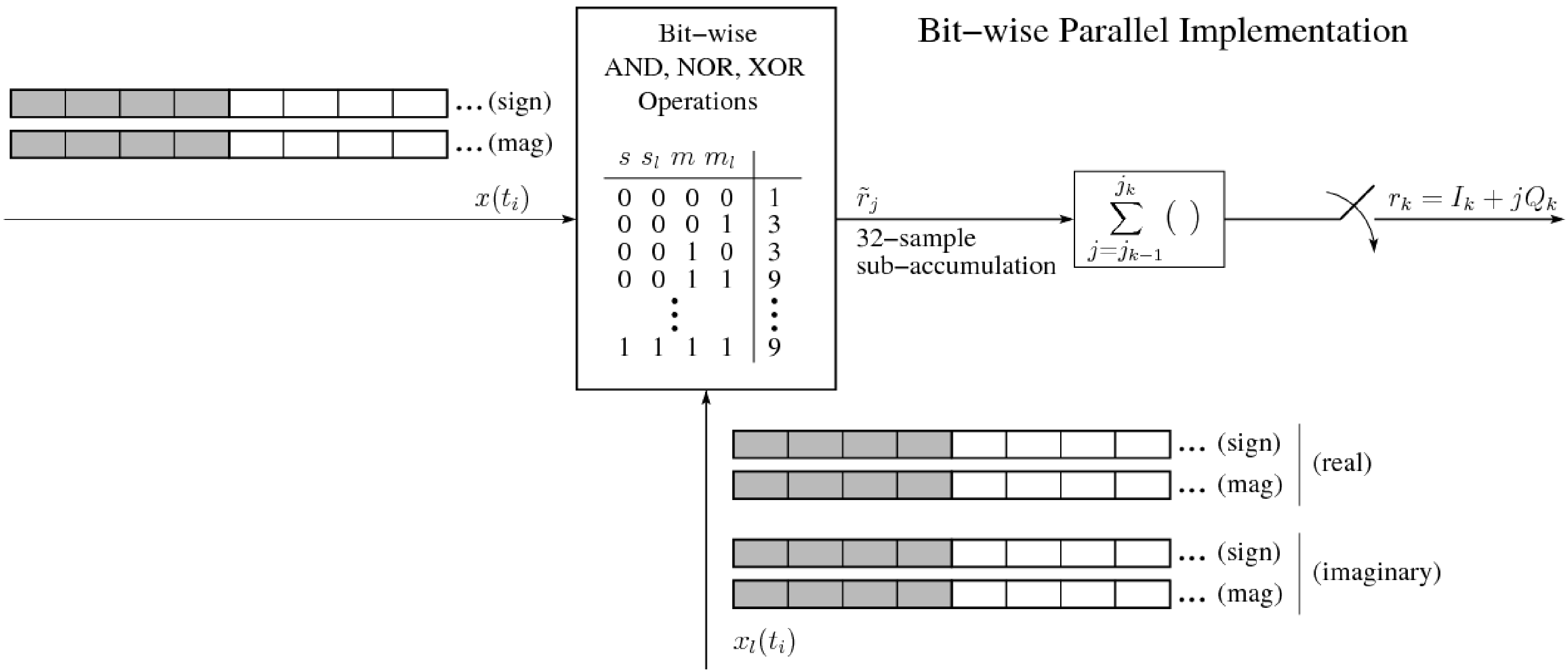
Standard Correlation Operation



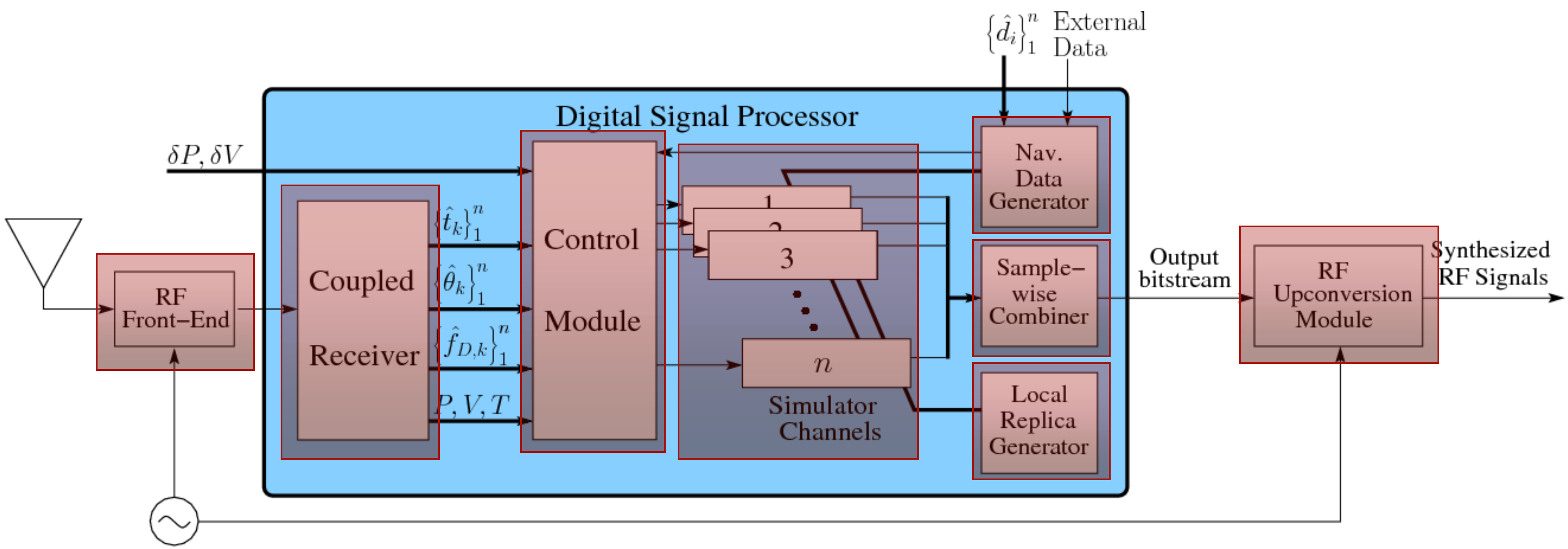
Byte–wise Implementation



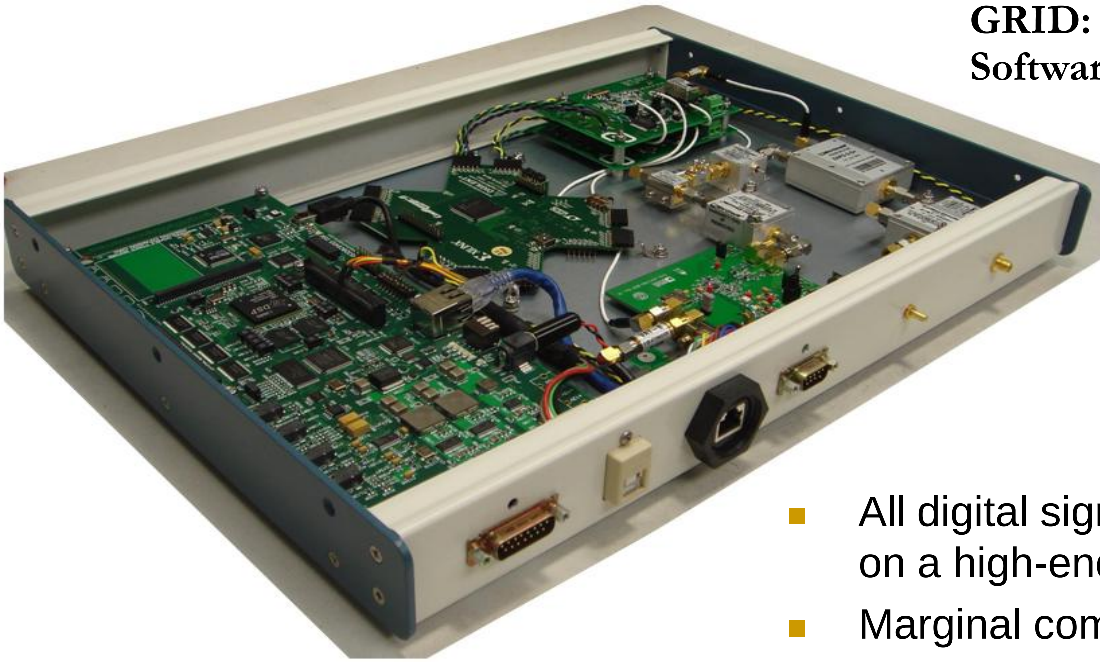
Signal Correlation Techniques (2/2)



Details of Receiver-Spoofer



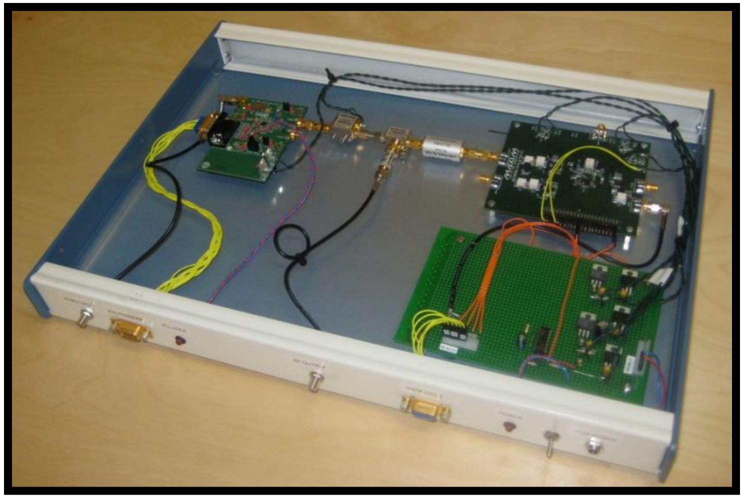
Receiver-Spoofer Hardware – DSP Box

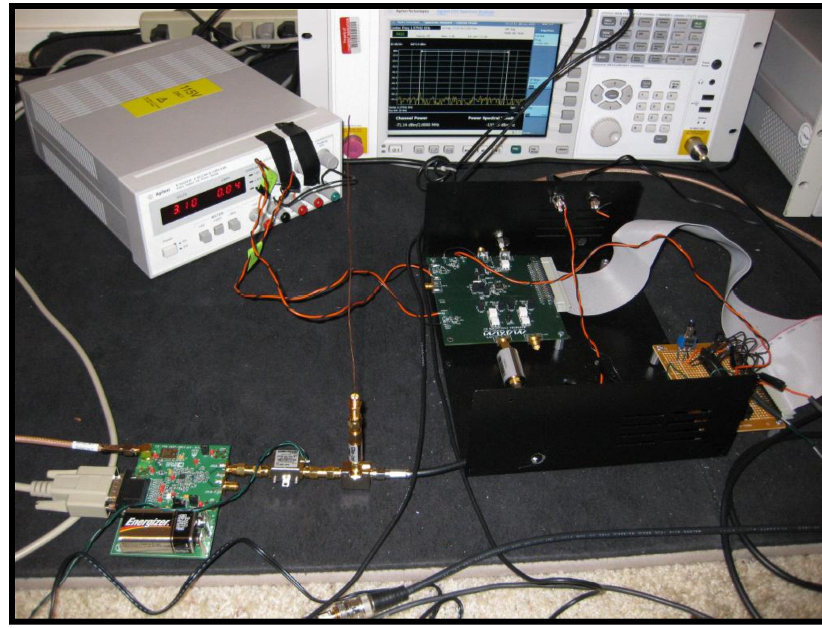


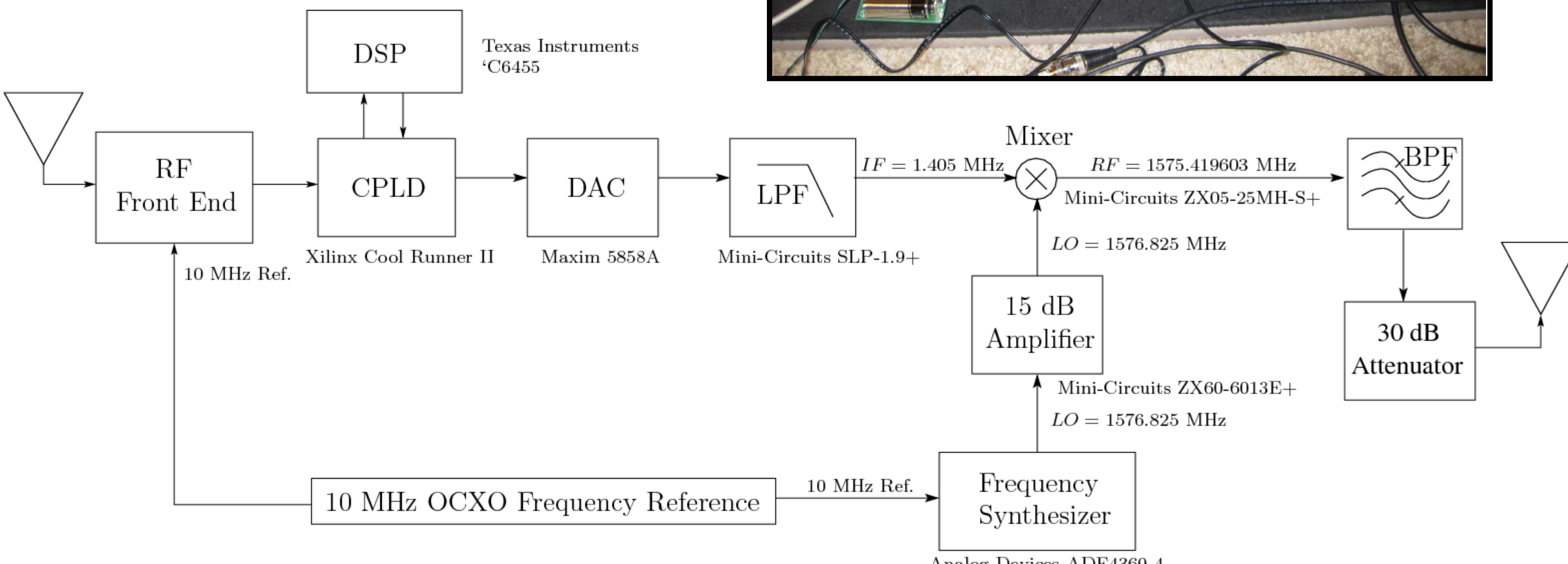
GRID: Dual-Frequency
Software-Defined GPS Receiver

- All digital signal processing implemented in C++ on a high-end DSP
- Marginal computational demands:
  - Tracking: ~1.2% of DSP per channel
  - Spoofing: ~4% of DSP per channel

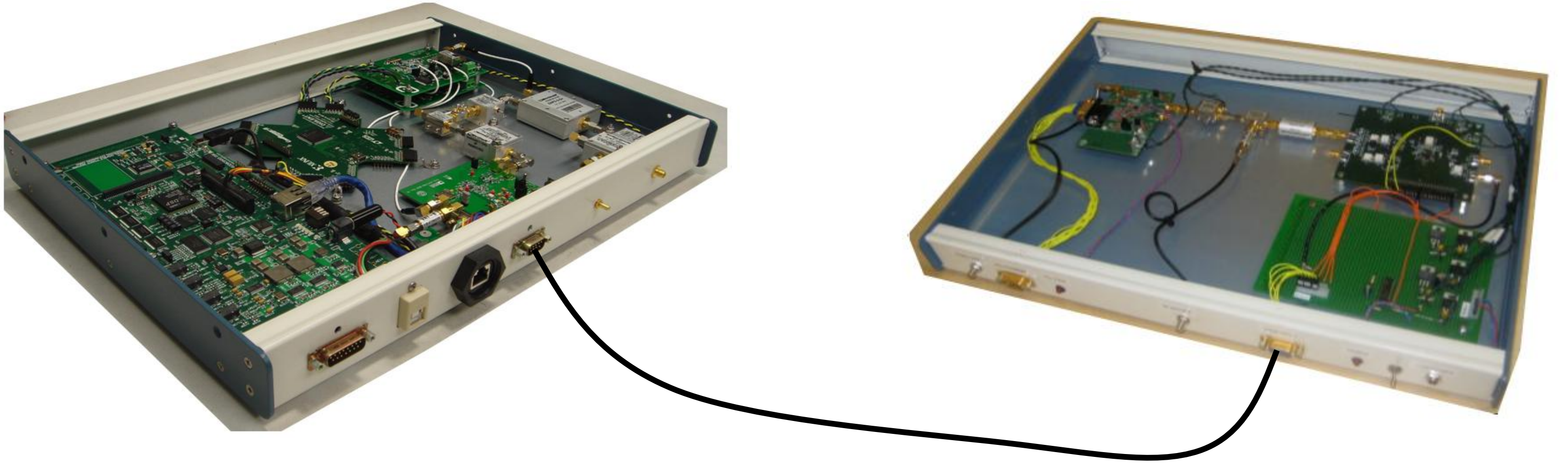
Spoofer RF Transmission Hardware







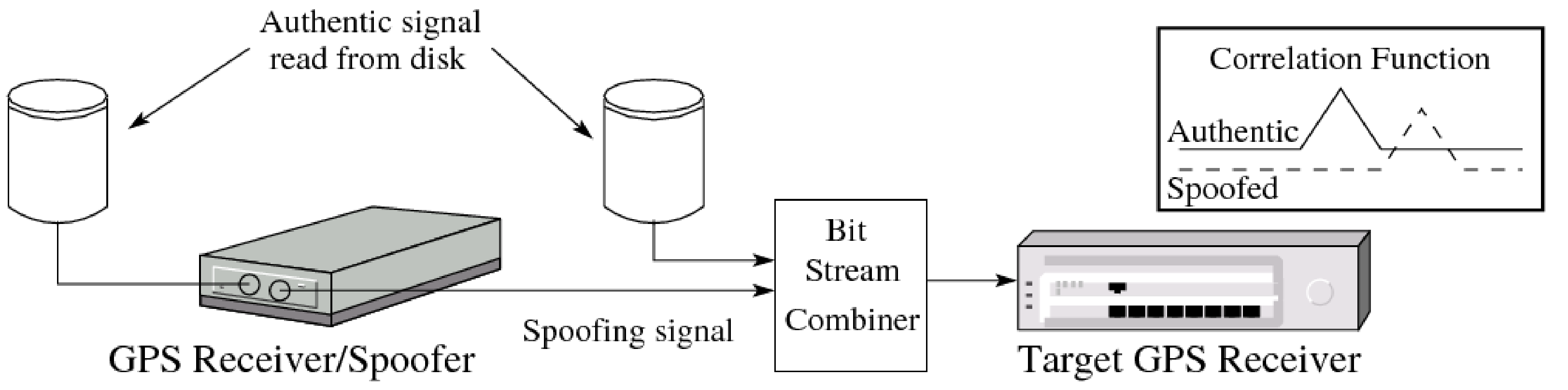
Full Receiver-Spoofer

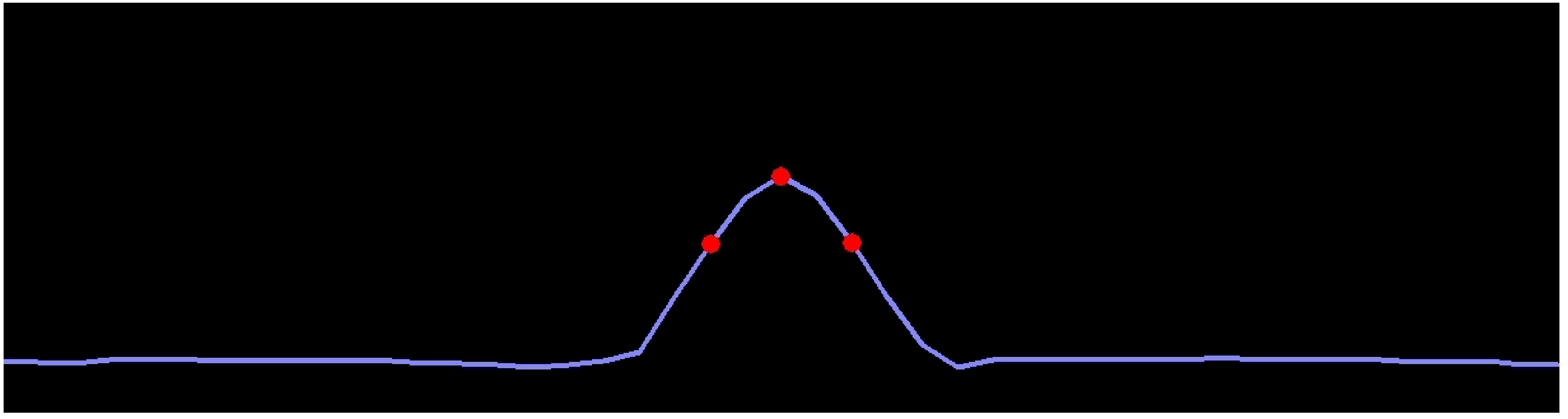


Full capability:

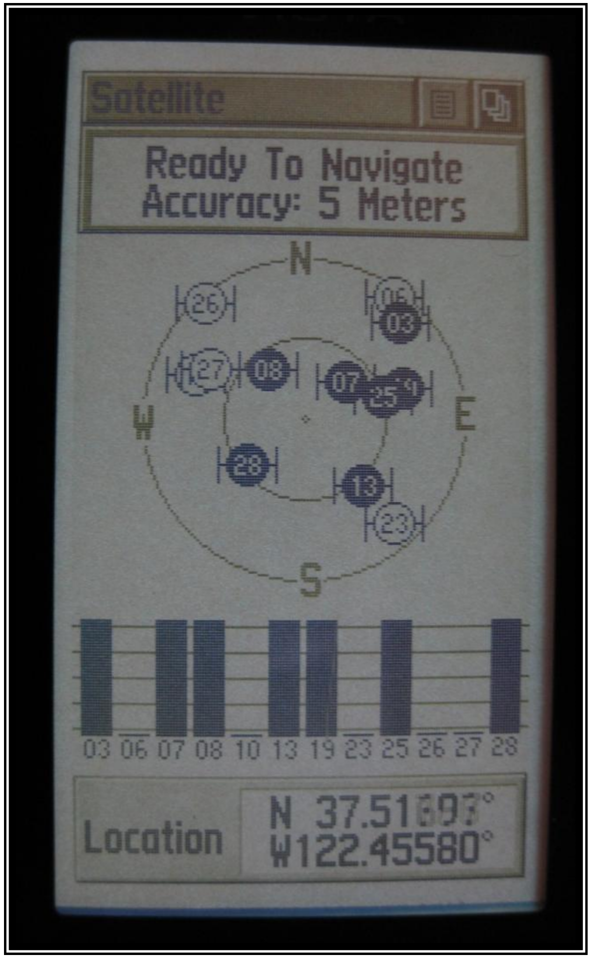
- 12 L1 C/A & 10 L2C tracking channels
- 10 L1 C/A simulation channels
- 1 Hz navigation solution
- Acquisition in background

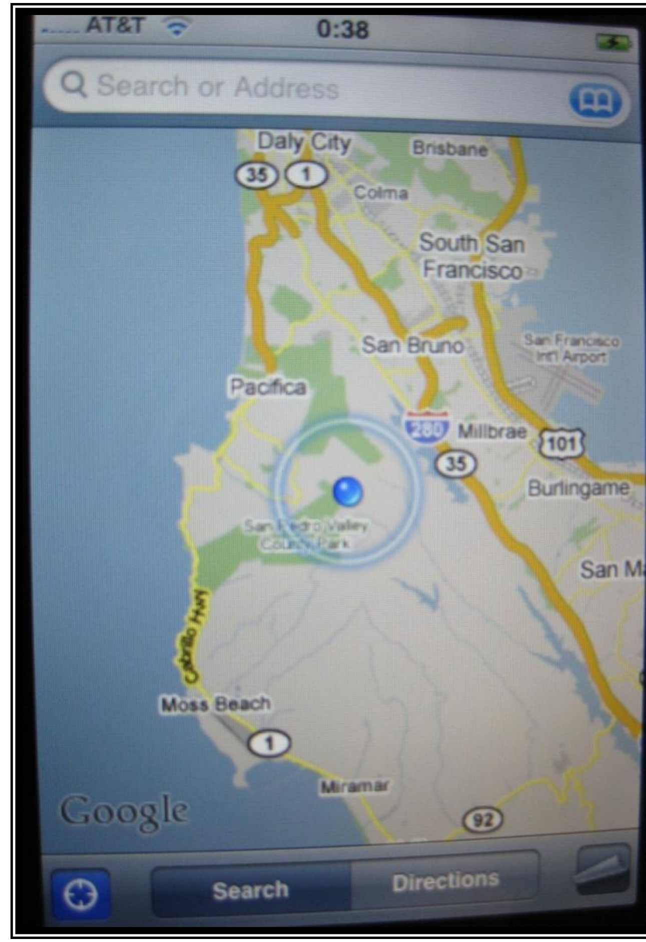
Spoofing Attack Demonstration (offline)



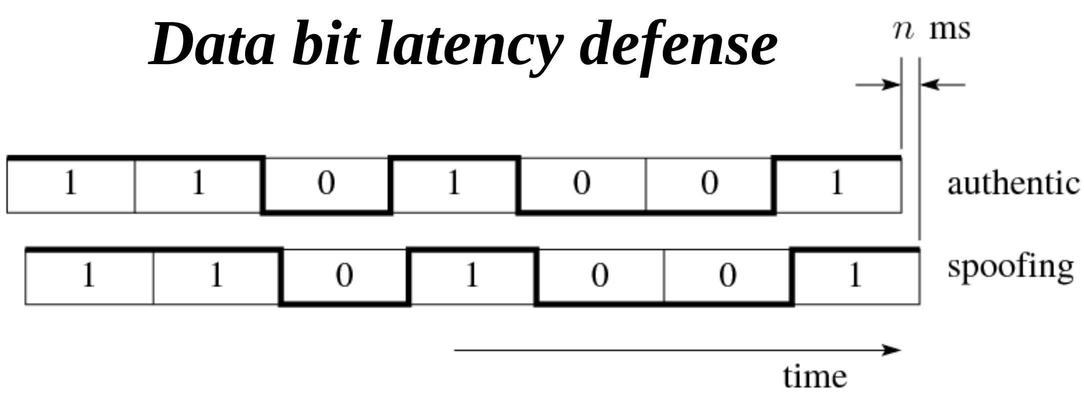


Spoofing Attack Demonstration (real-time, over-the-air)





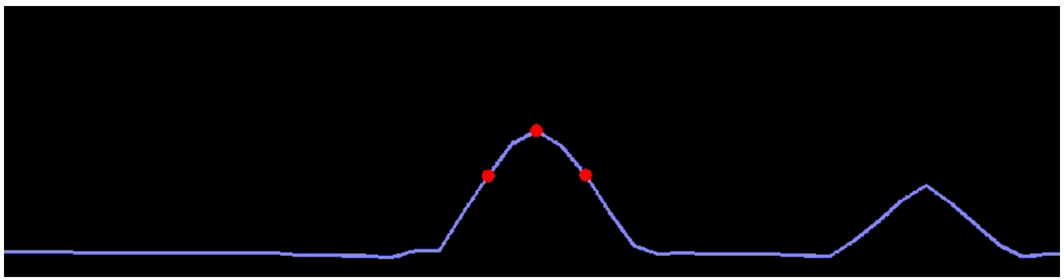
Countermeasures (1/5)



- Hard to retransmit data bits with < 1ms latency
- ***Jam first, then spoof***
- Jam-then-spoof attack may raise alarm
- ***Predict data bits***
- Hard to predict data bits during protected words and at ephemeris update boundaries
- ***Arbitrarily populate protected words, continue across ephemeris boundary with old data***
- No stand-alone countermeasure – must appeal to data bit aiding

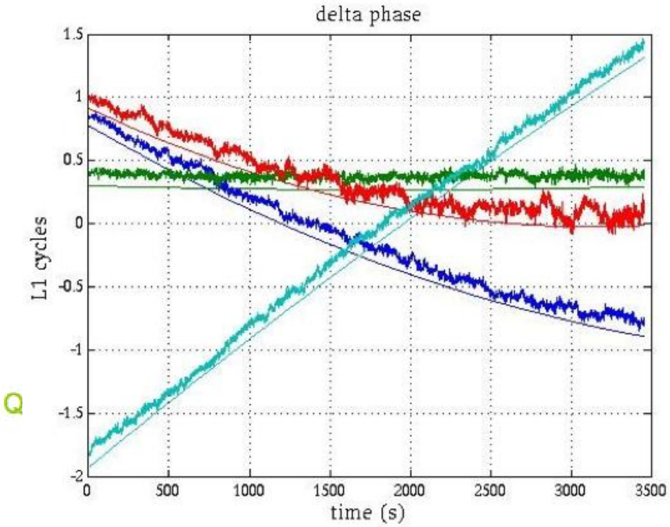
Countermeasures (2/5)

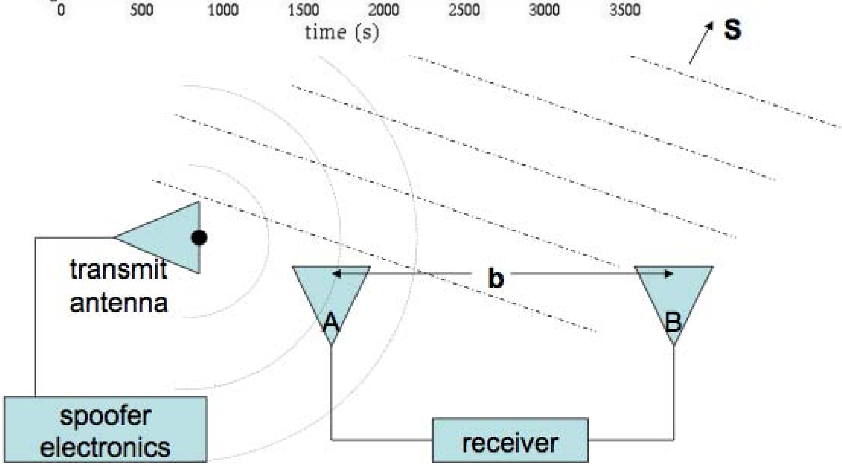
Vestigial signal defense



- Hard to conceal telltale peak in autocorrelation function
- ***Masquerade as multipath***
- Limits perturbation to < 1 chip
- ***Suppress authentic peak***
- Requires phase alignment for each signal at target antenna

Countermeasures (3/5) ***Multi-antenna defense***

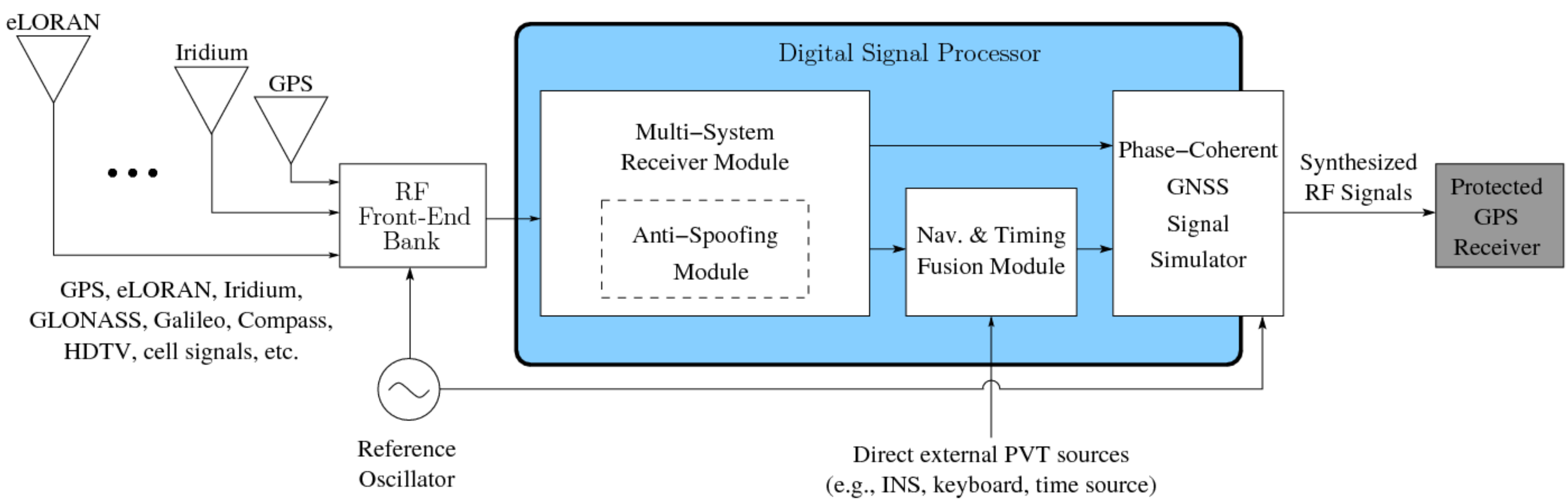




48 channel L1/L2 Quad Antenna

AutoFarm roof array with 146 cm baseline

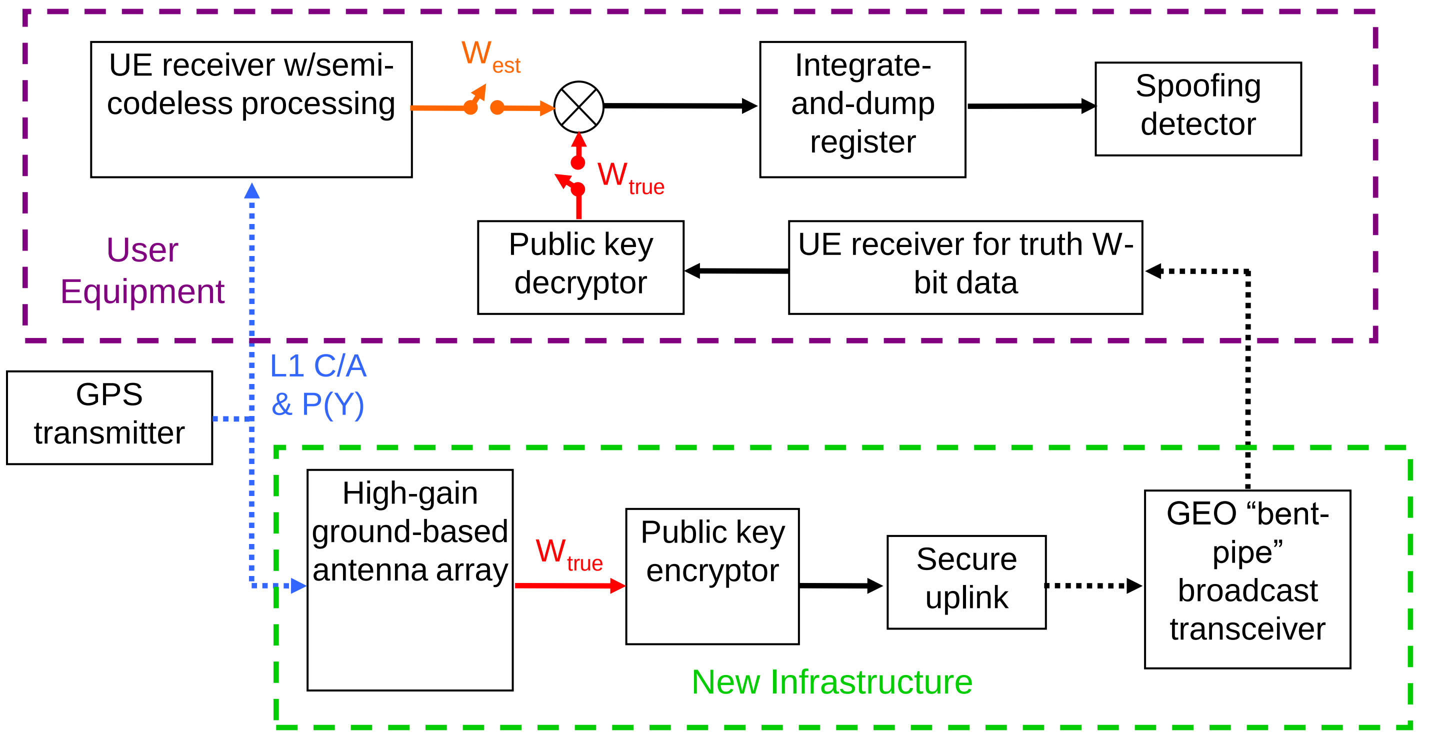
Countermeasures (4/5) ***Assimilative defense***



The GPS Assimilator modernizes and makes existing GPS equipment resistant to jamming and spoofing without requiring hardware or software changes to the equipment

Countermeasures (5/5)

Cryptographic defense based on estimation of W-bits



Findings (1/2)

- Bad news:
  - It's straighforward to mount an intermediate-level spoofing attack
- Good news:
  - It's hard to mount a sophisticated spoofing attack, and there appear to be inexpensive defenses against lesser attacks
- Bad news:
  - There is no defense short of embedding cryptographic signatures in the spreading codes that will defeat a sophisticated spoofing attack

Findings (2/2)

- Good news:
  - With the addition of each new modernized GNSS signal, the cost of mounting a spoofing attack rises markedly
- Bad news:
  - FPGAs or faster DSPs would make multi-signal attacks possible
- More bad news:
  - There will remain many single-frequency L1 C/A code receivers in critical applications in the years ahead

Are We Safe Yet?

- No. There is much much work to be done:
  - Characterization of spoofing signatures in full RF attack
  - Development and testing of more effective countermeasures, including stand-alone countermeasures and and network-based cryptographic countermeasures
  - Encourage commercial receiver manufacturers to adopt spoofing countermeasures