THE UNIVERSITY OF TEXAS AT AUSTIN
RADIONAVIGATION LABORATORY

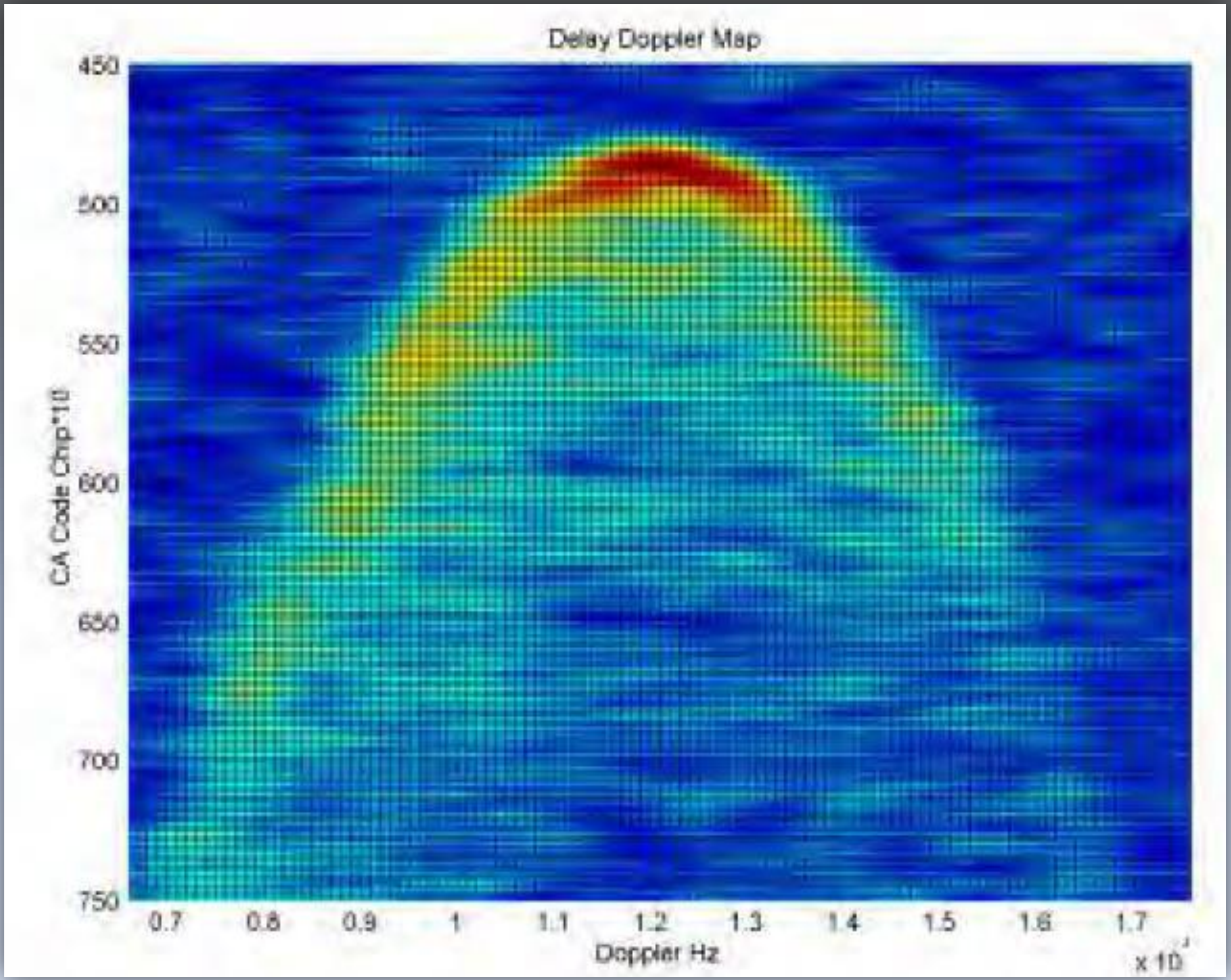
Toughening Techniques for GPS Receivers: *Navigation Message Authentication*

Todd Humphreys | Aerospace Engineering

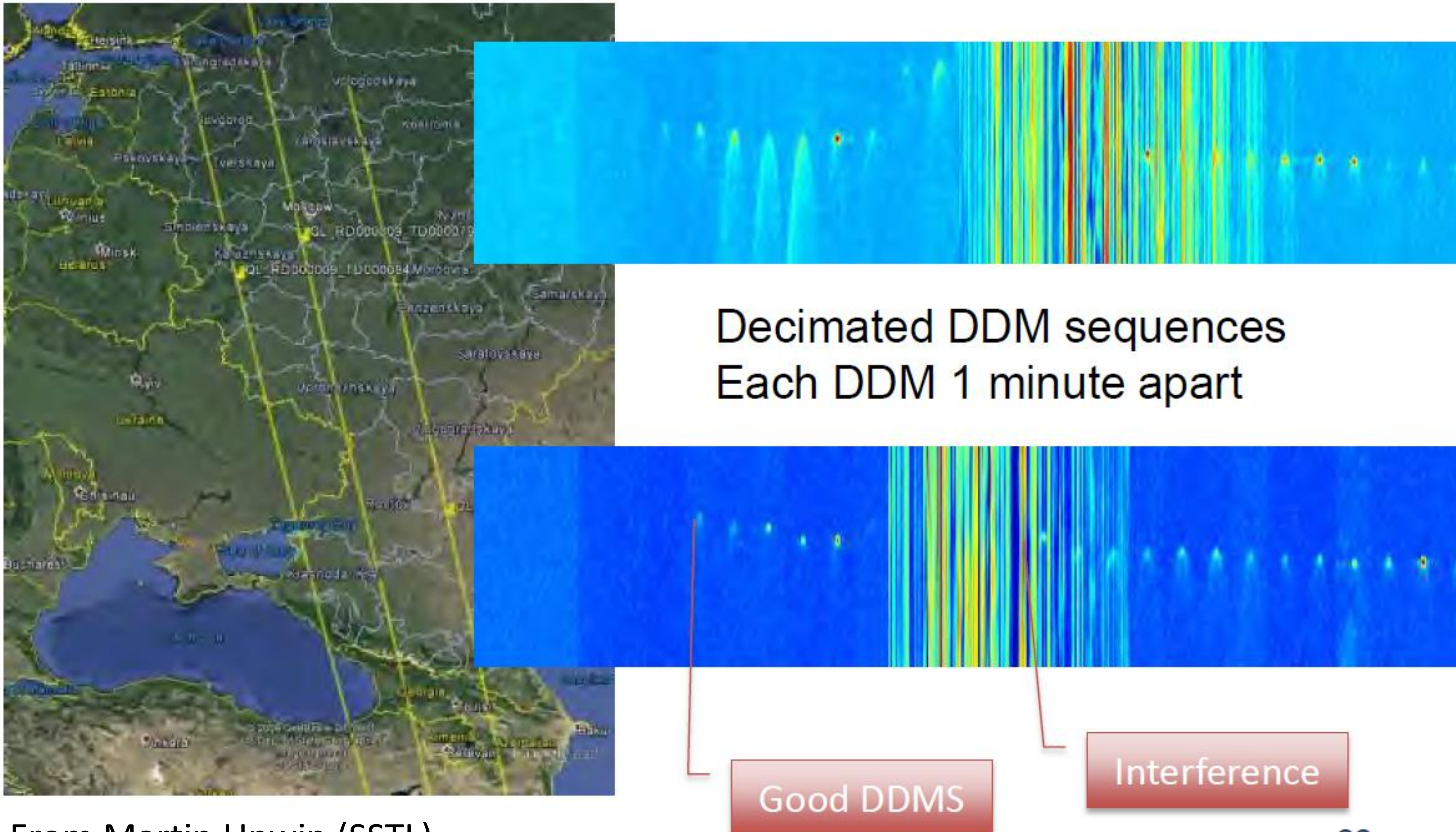
The University of Texas at Austin

PNT Advisory Board 15th Meeting | June 11, 2015

TechDemoSat-1, launched July, 2014
(SSTL, University of Surrey)



Delay-Doppler map used to measure sea state, detect ice edge, possibly measure soil moisture



From Martin Unwin (SSTL)

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Autumn 2014: DDMs over eastern Europe exhibit striping corruption. Cause: structured interference in GPS L1 band with structure similar to C/A code. Similar patterns manifest elsewhere around globe.

Civil GPS spoofing has been demonstrated in the laboratory and in controlled field tests; deliberate hostile spoofing has been detected in the wild.

At present, civil GPS spoofing is a rare, minor nuisance.

But experiments demonstrate that spoofing effects can be serious, especially for critical infrastructure.

Is the threat of civil GPS spoofing serious enough to warrant a change to the GPS signal-in-space?

Q1: How effective are receiver-side spoofing defenses?

Q2: How effective are SIS-side spoofing defenses?

Q3: By how much would such defenses increase receiver cost?

Defenses	Attacks							
	simulator	single-rx-antenna meaconing		Humphreys et al.		multi-rx-ant. meac.	nulling	
	unsync.	$d > 100$ ns	$d < 100$ ns	2008 [1]	SCER [2,3]	$d < 100$ ns	single-tx	multi-tx
conventional RAIM								
observables [4]								
NMA [5–7]								
RPM [8]								
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RPM + observables								
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SSSC [10]								
RPM + struct. power [11]								
spectral analysis								
IMU + carrier phase [12]								
multi-antenna [13,14]								
dual-rx corr. with P(Y) [15]								
symmetric-key SSSC [e.g., P(Y)]								


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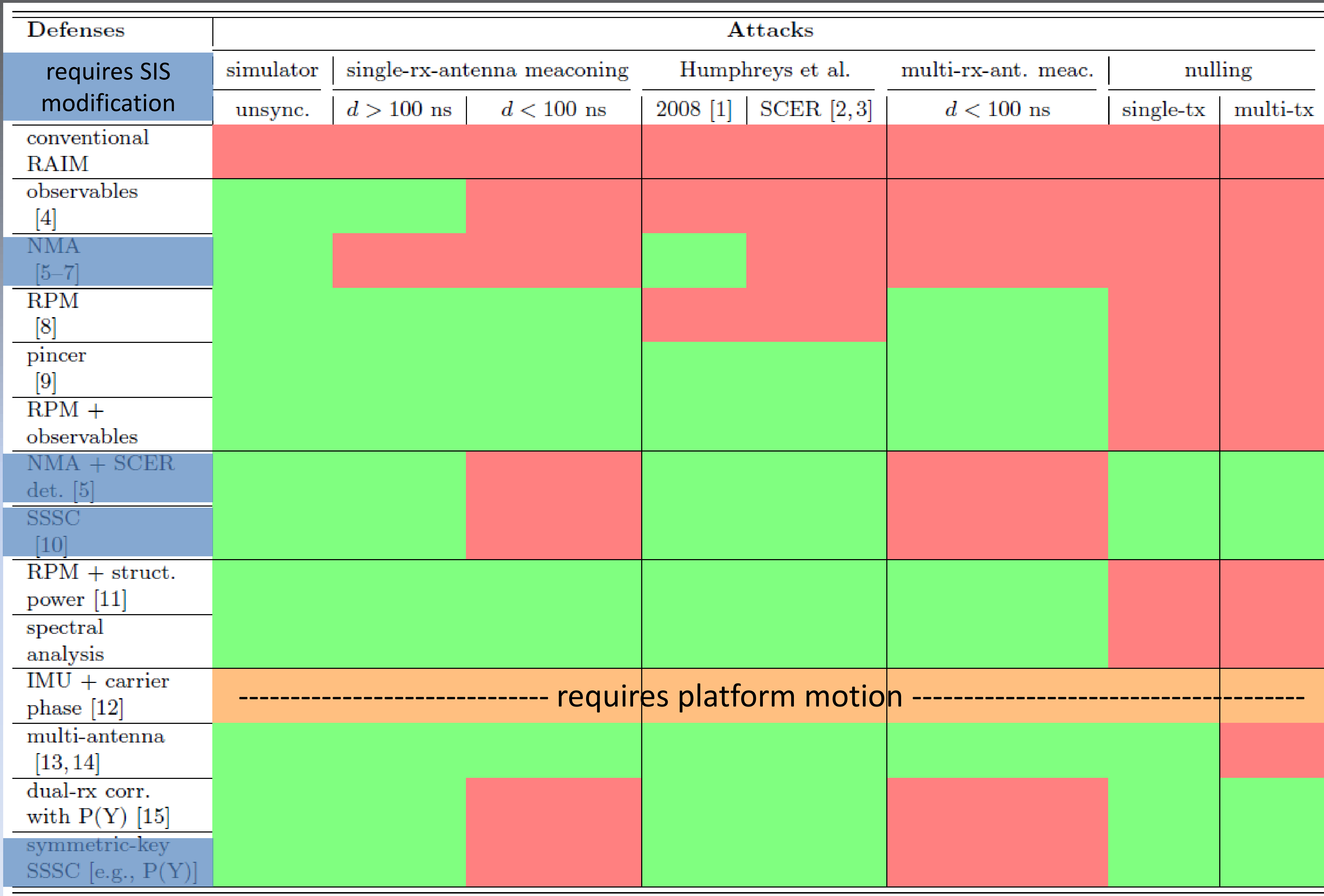
Increasing cost of attack
Increasing receiver-side cost of defense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Inexpensive (< $5k) COTS signal simulator/record-and-replay devices enable low-cost unsynchronized spoofing and meaconing

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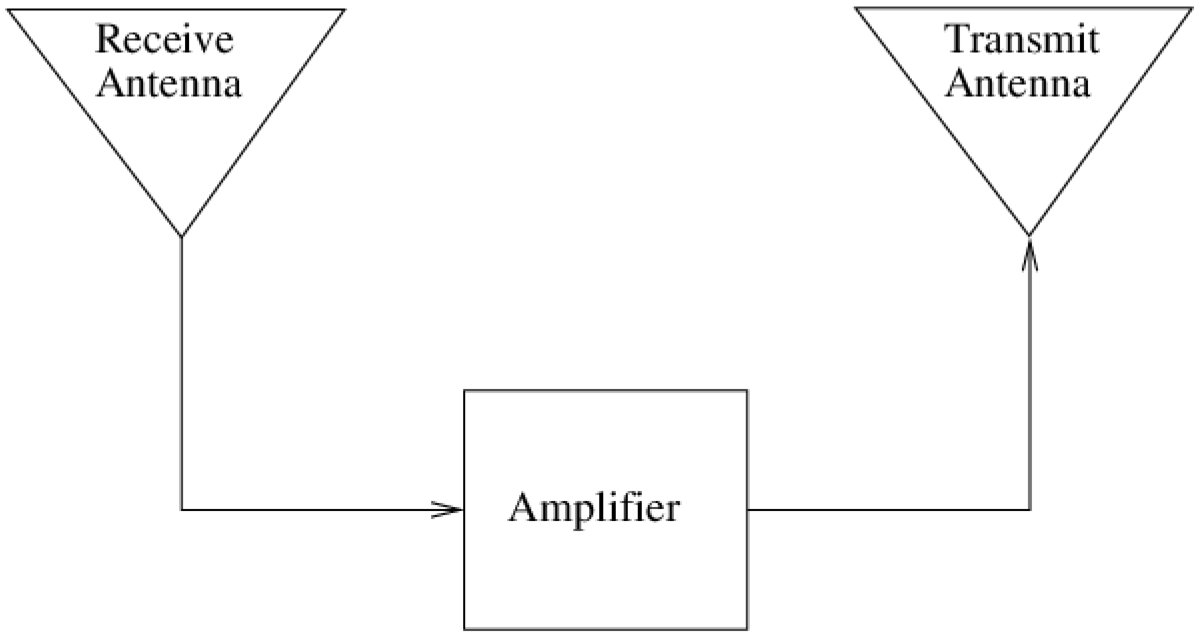

Synchronized (d < 100 ns) meaconing possible with a simple setup:
rx antenna → amplifier → tx antenna

Variable delay requires:
downconversion → A2D → FPGA → D2A → upconversion

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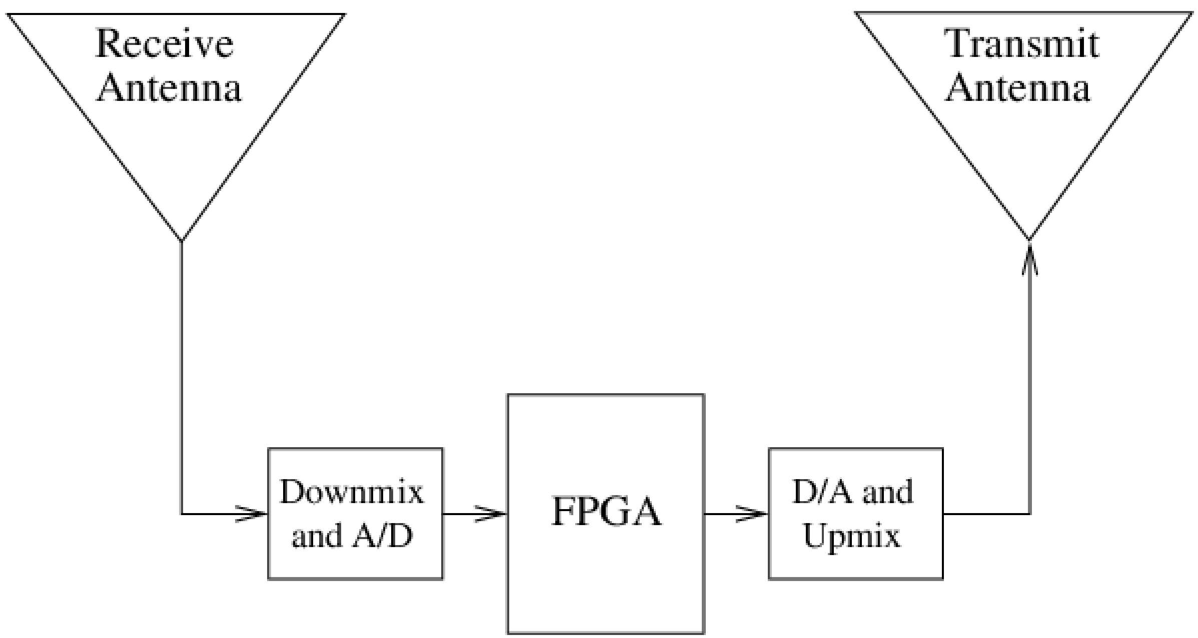

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requires SIS modification

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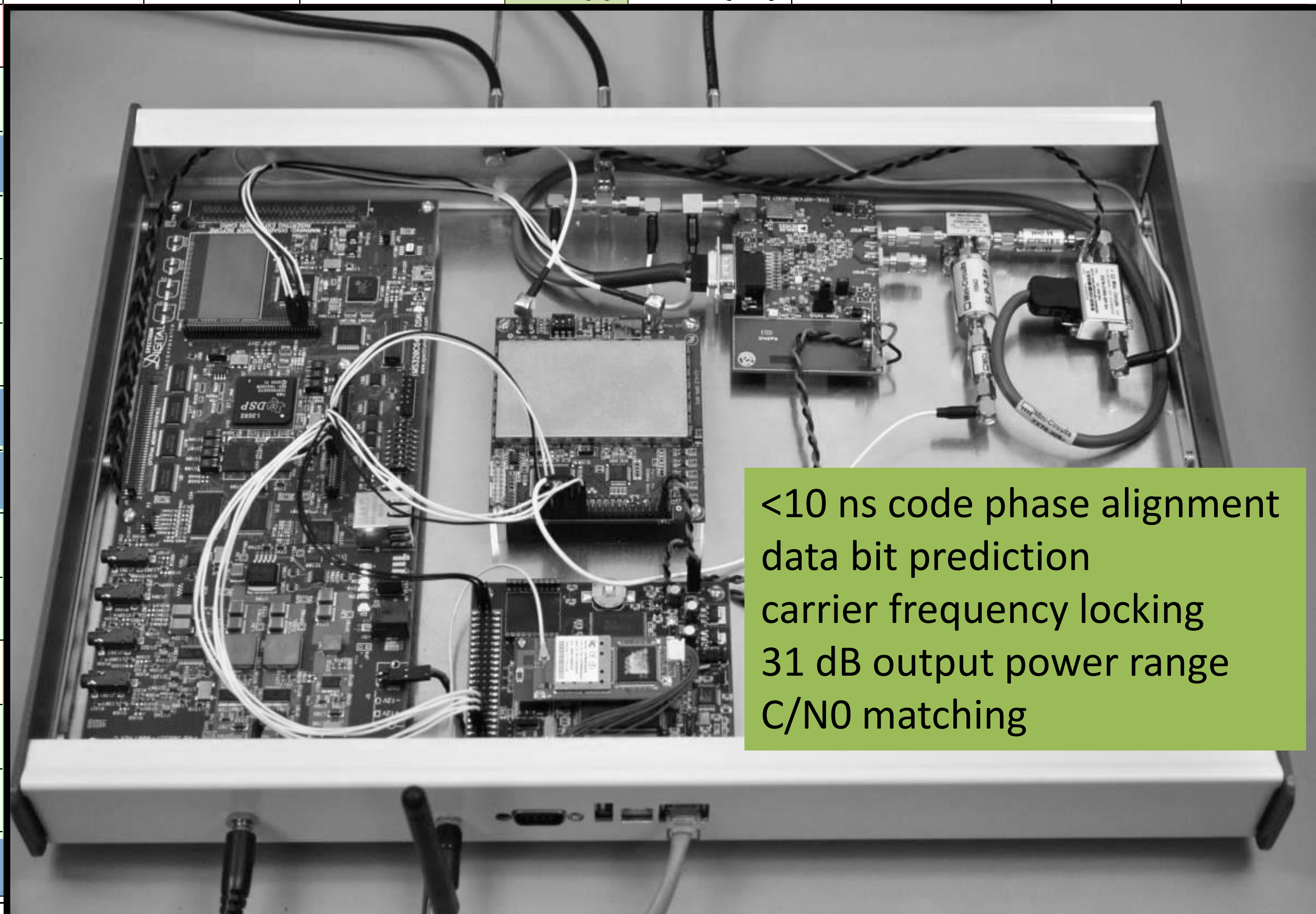

<10 ns code phase alignment
data bit prediction
carrier frequency locking
31 dB output power range
C/N0 matching

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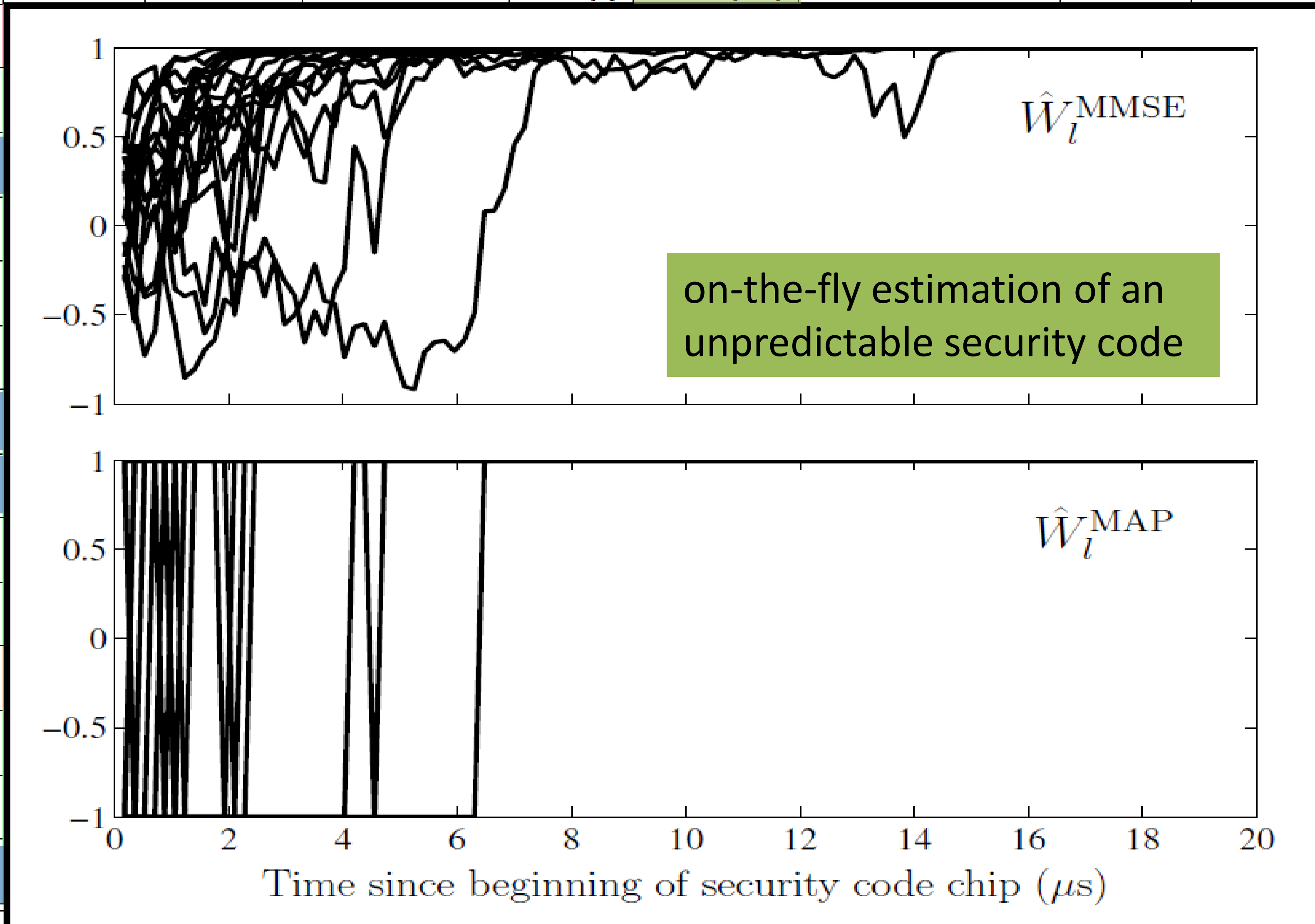

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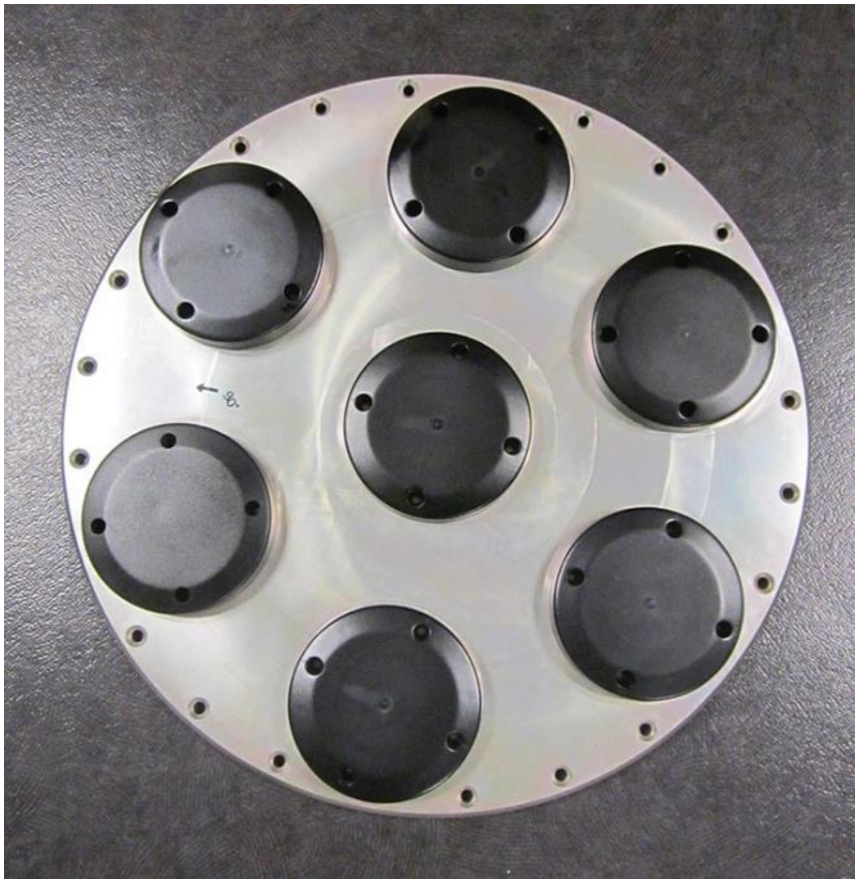

Each antenna's RF signal is independently digitized. The resulting complex digital streams are weighted and summed to achieve simultaneous beam steering toward any number of SVs. The SV-specific signals are time-shifted and summed to create the false signal ensemble.

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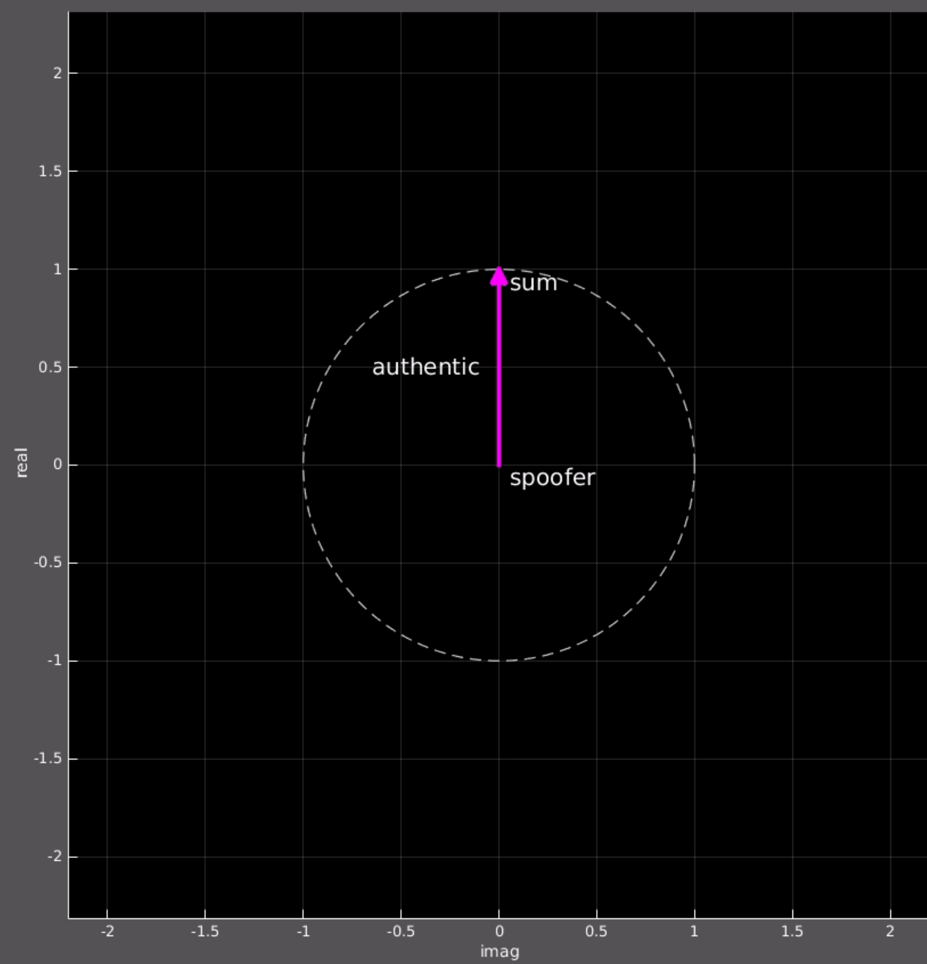

A nulling attack annihilates the authentic signal with an antipodal spoofing signal. Thereafter, no vestige of the authentic signal remains to interact with further spoofing. The attack can begin instantaneously at a data bit boundary or emerge gradually as shown by the phasor interaction in the video.

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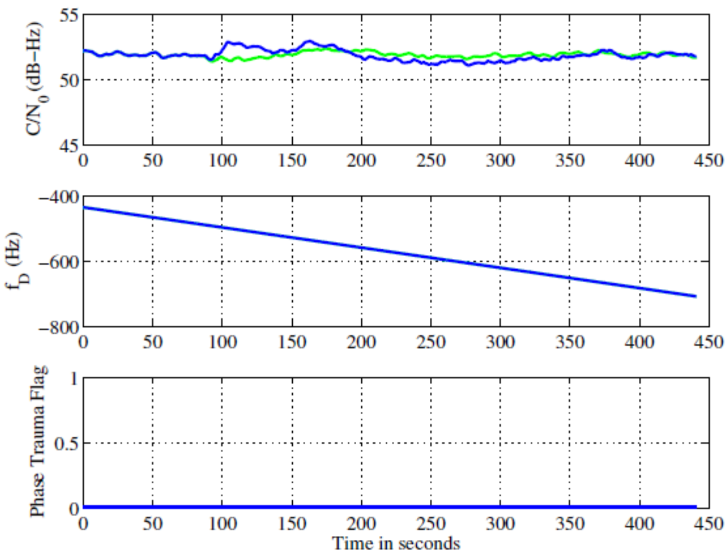

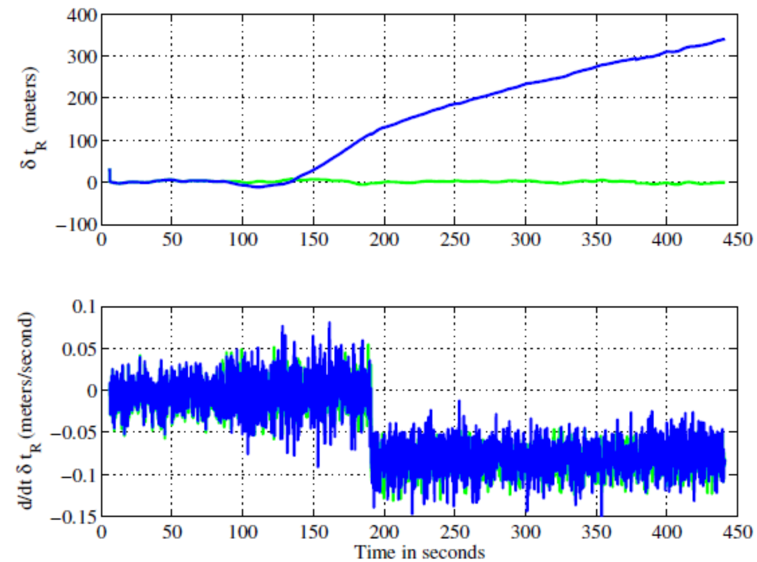

Standard GNSS pseudorange, Doppler, carrier phase, and signal strength observables can be analyzed to detect a spoofing attack. Detection is more powerful for static receivers.

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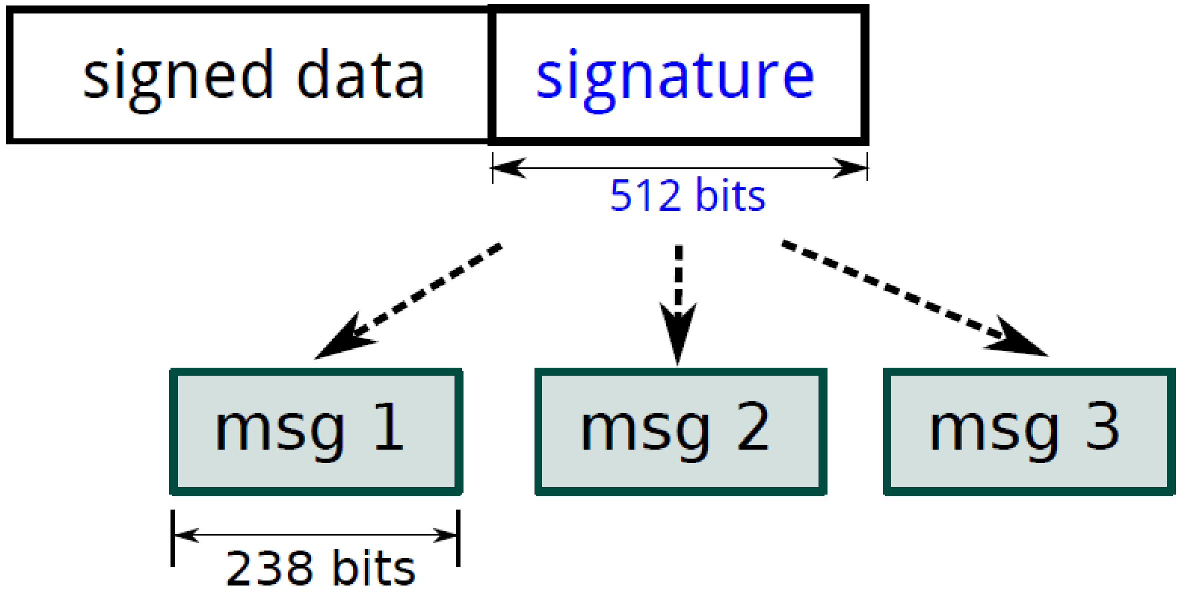

Signatures interleaved within navigation data stream. Authenticates origin of data. No need for secret keys to be stored in the receiver.

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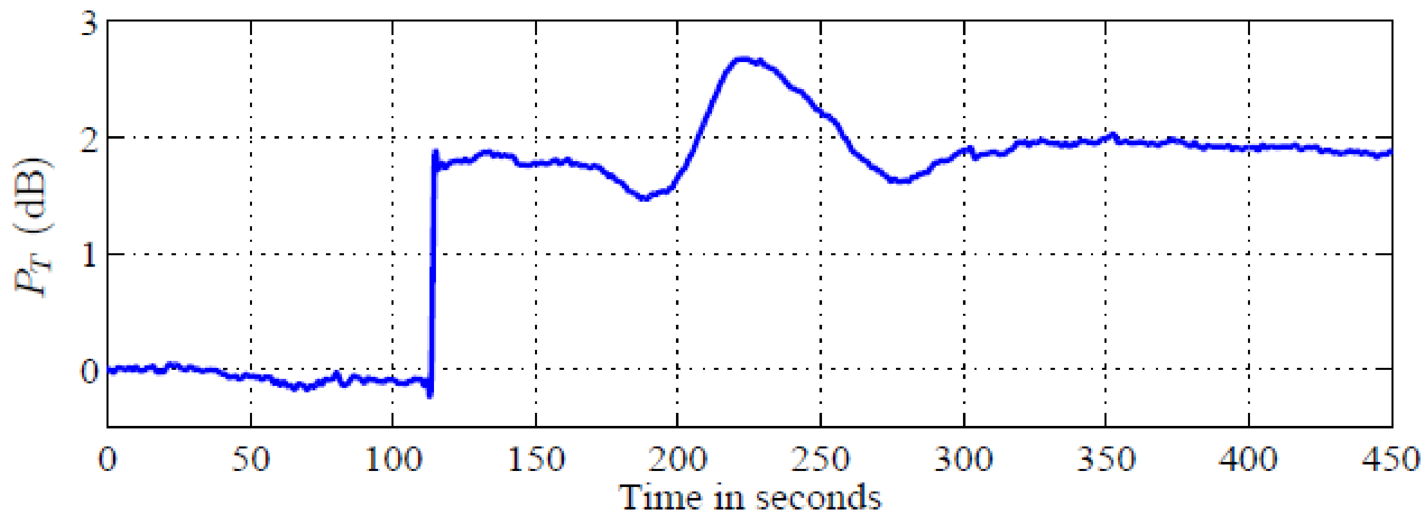

Received power monitoring: continuous measurement of the total in-band received power. Requires access to automatic gain control instantaneous setpoint.

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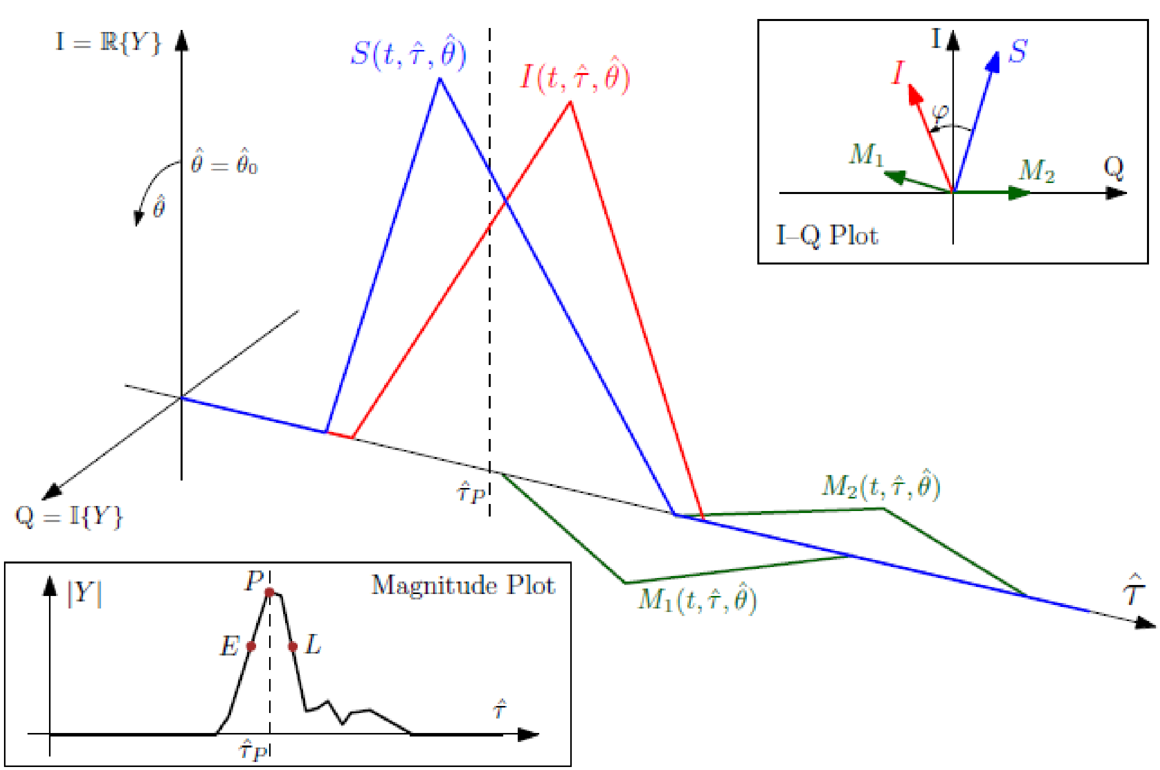

The Pincer defense: Exploit the attacker's difficulty in preventing distortion when spoofing signals are approximately power-matched to authentic signals; amounts to trapping the spoofer between (1) a received power monitor, and (2) a distortion monitor.

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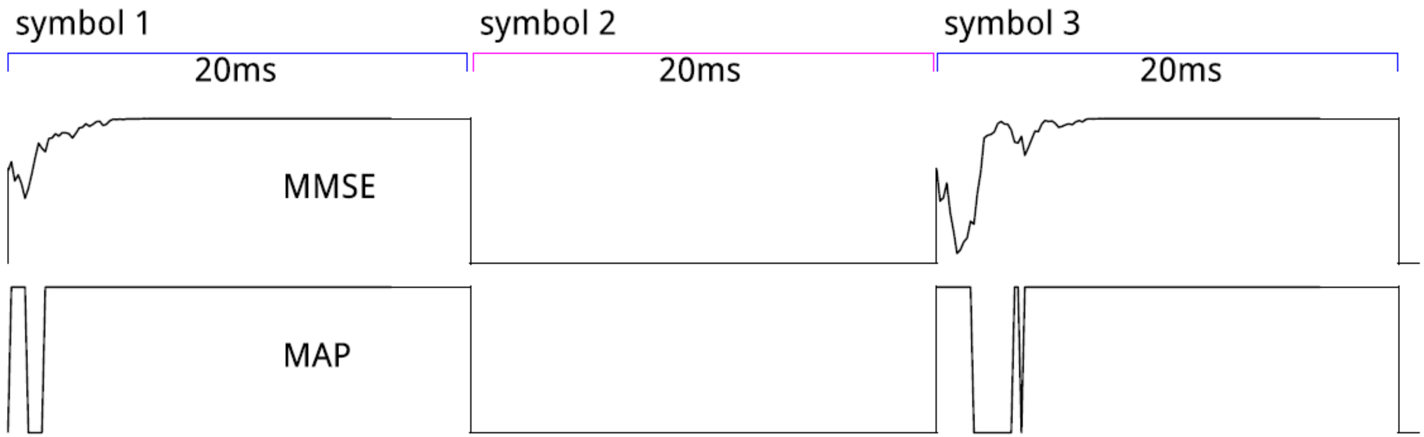

NMA + SCER detection exploits the attacker's inability to accurately estimate the security code chip values during the first few microseconds after an unpredictable transition.

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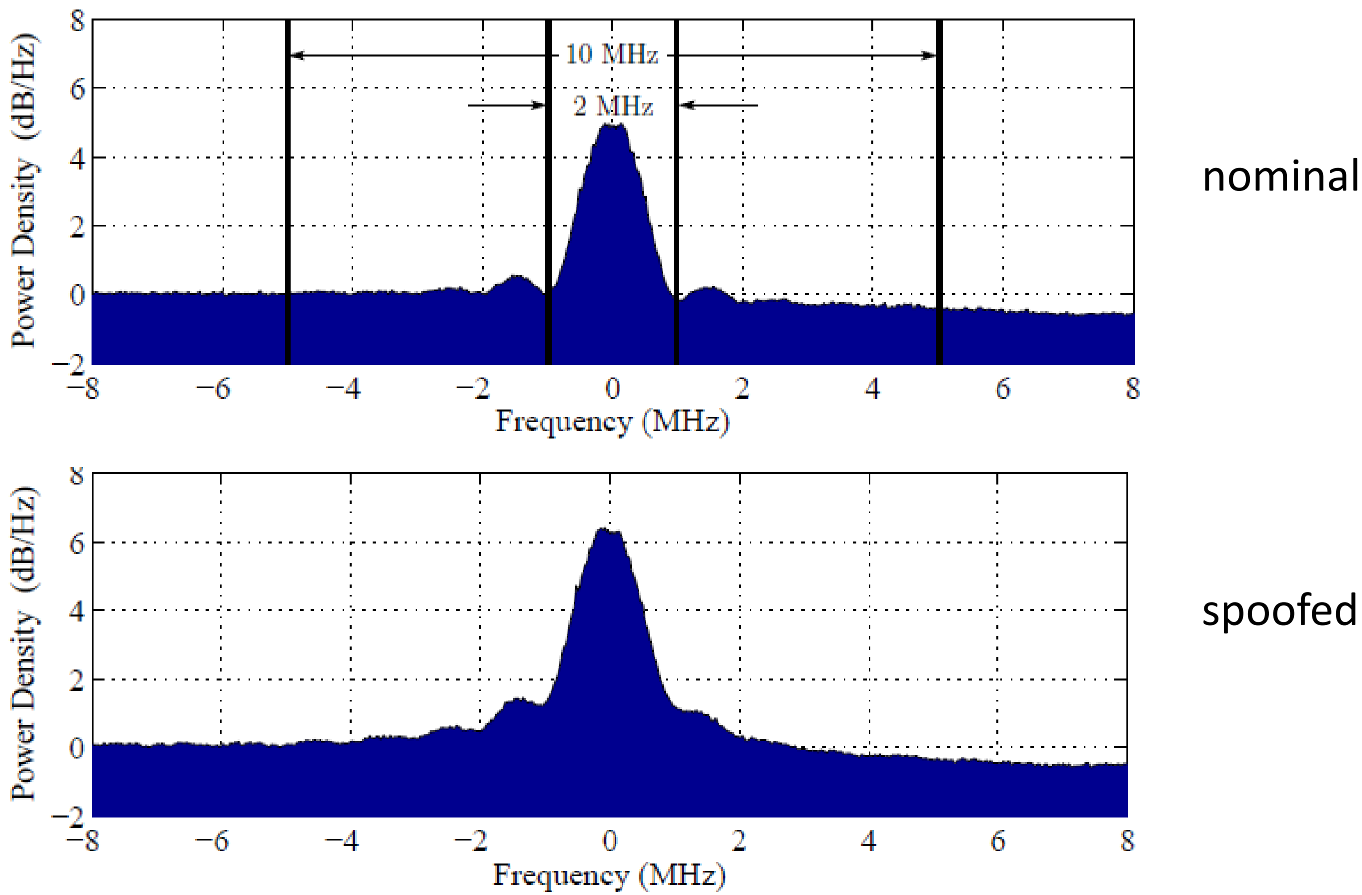

Power spectrum analysis is valuable diagnostic for all types of RFI

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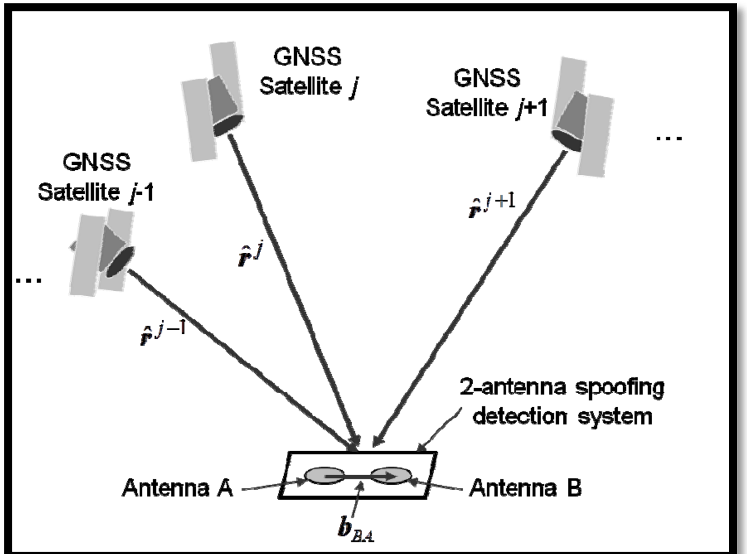

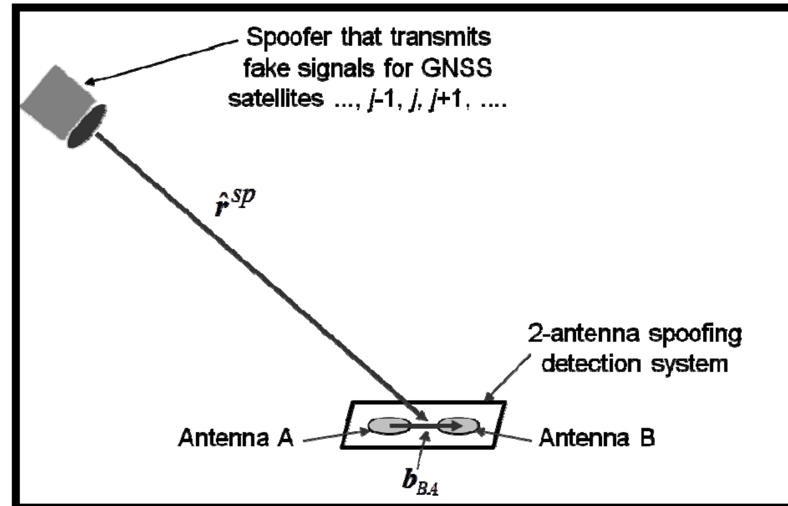

Psiaki et al., 2014

Spoofing signal arriving from a single spatial direction are easily distinguished from spatially diverse authentic GNSS signals.

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NMA + SCER detection offers substantial PNT security at low cost

NMA has been advocated for over a decade:
Scott (2003) [10]
Internal MITRE memoranda
Wesson (2012) [5]
Kerns (2014) [6]

No surprise that Europe is moving forward with NMA on Galileo [7]

NMA on Galileo

Basic Design

- To be included on E1B open service
- High rate: 20 security bits per second avg.
- Based on TESLA (keys successively revealed after use period)

Status

- Draft blueprint complete
- Over-the-air testing took place in summer 2014
- Journal paper forthcoming

NMA on GPS

May 2015: The University of Texas completed a 2-year contract with the GPSD to develop a blueprint for NMA on GPS.

Basic Design

- Targeted to CNAV on L2C and L5
- Low rate: <1 security bit per second avg.
- Hybrid of TESLA and digital signature scheme (e.g., ECDSA, BLS)

Status

- Draft blueprint complete
- Optimized scheduling across constellation
- Receiver demonstrates NMA + SCER det.
- Journal paper forthcoming

NMA on GPS L2C and L5

Case For

- Low cost to user (software update)
- Substantial improvement in PNT security for GPS users worldwide; patches a serious vulnerability in civil GPS

Case Against

- Narrow uplink pipe leads to long time between authentication (9 minutes; compare Galileo at 10-20 seconds)
- Response from industry: “If it’s not on L1, it’s not much use.”
- Bad time to be adding requirements to OCX

Recommendations

1. Implement NMA on WAAS quadrature channel; provide example for other SBAS. Much higher SBAS data rate (250 bps) will support short time between authentication.
2. Digitally sign GPS LNAV data, then broadcast signatures over WAAS quadrature channel: cross authentication.
3. Encourage GNSS mfrs. to adopt simple receiver-autonomous defenses such as Pincer.
4. Plan for NMA on L1C.

[1] T. E. Humphreys, B. M. Ledvina, M. L. Psiaki, B. W. O'Hanlon, and P. M. Kintner, Jr., "Assessing the spoofing threat: Development of a portable GPS civilian spoofer," in *Proceedings of the ION GNSS Meeting*, (Savannah, GA), Institute of Navigation, 2008.

[2] T. E. Humphreys, "Detection strategy for cryptographic GNSS anti-spoofing," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 49, no. 2, pp. 1073–1090, 2013.

[3] T. E. Humphreys, D. P. Shepard, J. A. Bhatti, and K. D. Wesson, "A testbed for developing and evaluating GNSS signal authentication techniques," in *Proceedings of the International Symposium on Certification of GNSS Systems and Services (CERGAL)*, (Dresden, Germany), July 2014. (available at `http://radionavlab.ae.utexas.edu/testbed`).

[4] V. Dehghanian, J. Nielsen, and G. Lachapelle, "GNSS spoofing detection based on receiver C/N_0 estimates," in *Proceedings of the ION GNSS Meeting*, (Nashville, Tennessee), Institute of Navigation, 2012.

[5] K. D. Wesson, M. P. Rothlisberger, and T. E. Humphreys, "Practical cryptographic civil GPS signal authentication," *Navigation, Journal of the Institute of Navigation*, vol. 59, no. 3, pp. 177–193, 2012.

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