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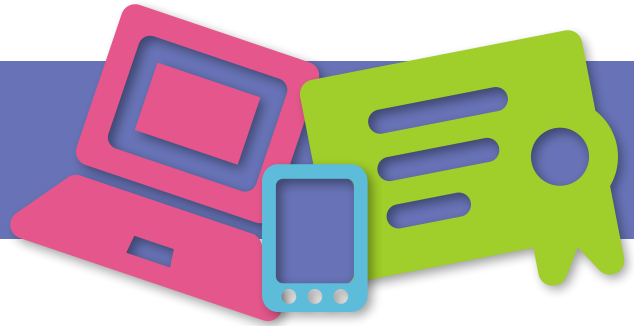


Software-Defined Radios Expose NFC and GPS Vulnerabilities

Tomáš Rosa
RaiffeisenBANK

Software-Defined Radio

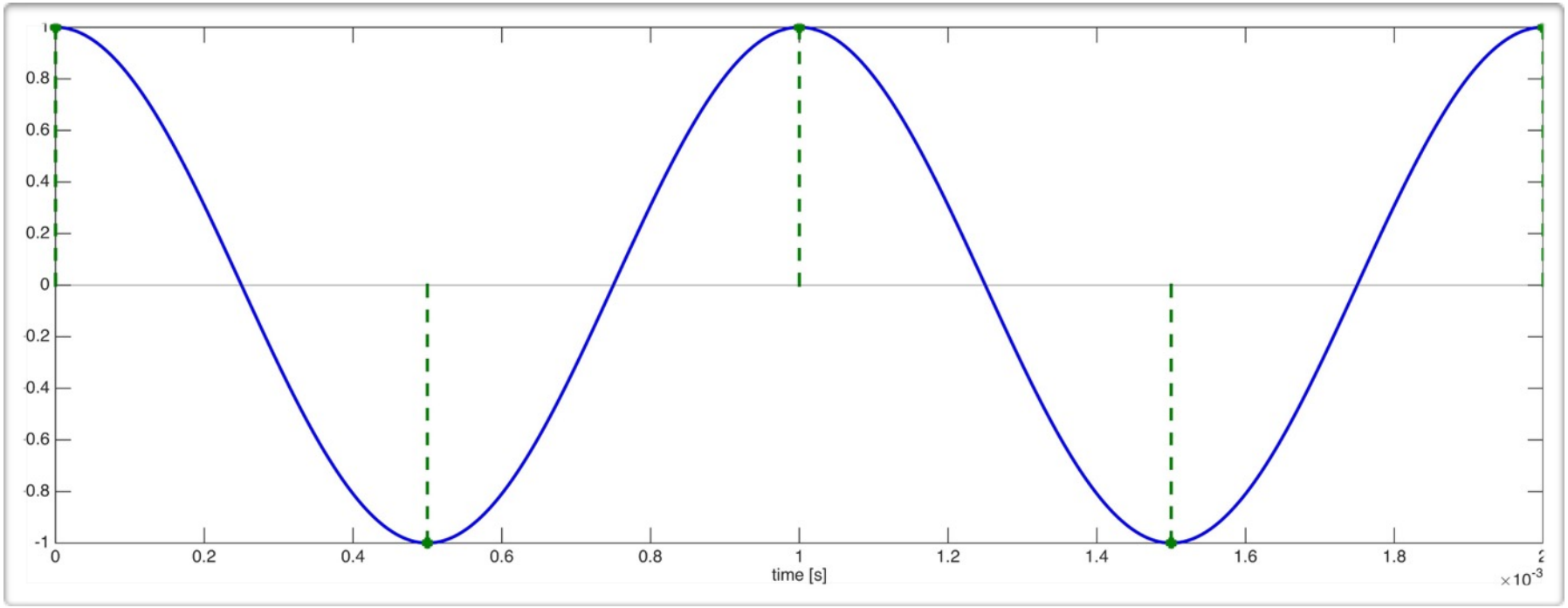
Baseband Sampling Theorem

- *Let s(t) be a Fourier-integrable signal having its highest non–negligible frequency $|f_{max}| < f_s/2 = 1/2T_s$.*
- *Such s(t) can be then fully reconstructed from its discrete-time samples as:*

$$s(t) = \sum_{k=-\infty}^{\infty} s(kT_s) \frac{\sin \pi(\frac{t - kT_s}{T_s})}{\pi(\frac{t - kT_s}{T_s})} = \sum_{k=-\infty}^{\infty} s(kT_s) \operatorname{sinc}(\frac{t - kT_s}{T_s})$$

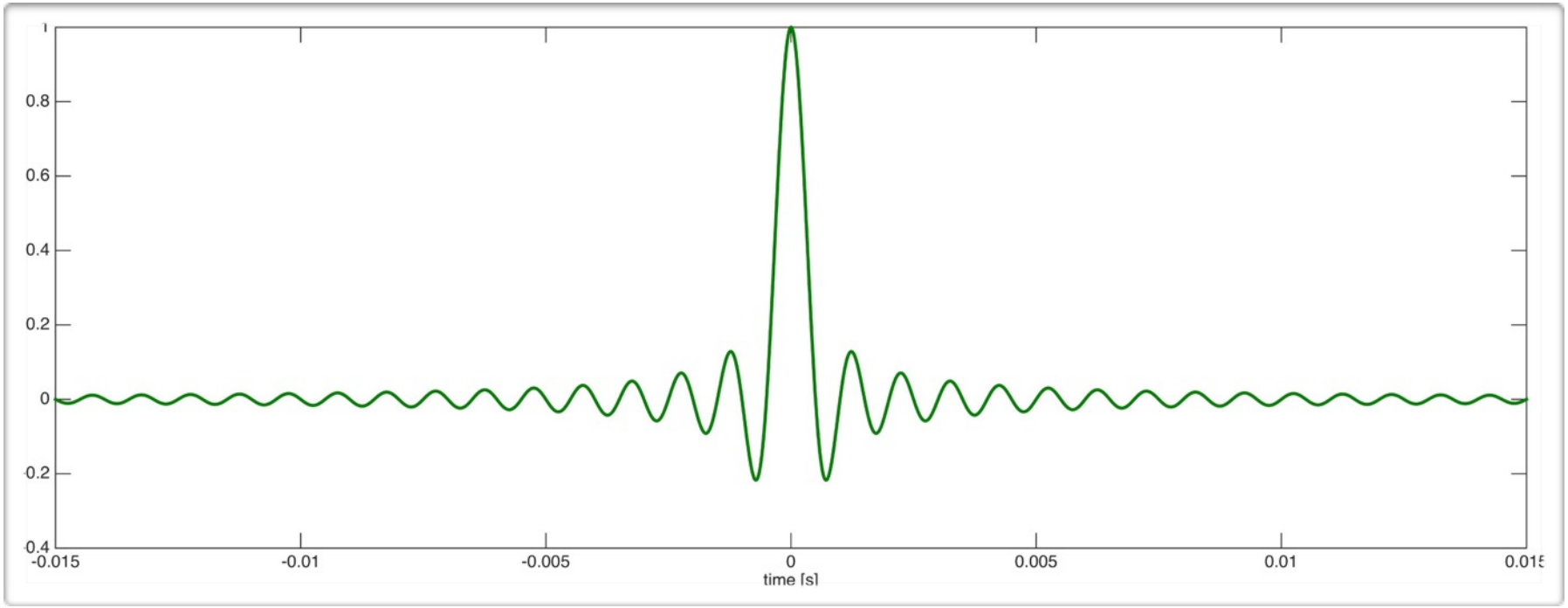
— Kotelnikov, Nyquist, Shannon, Whittaker

Limit Example - Nyquist Rate Sampling of Even Harmonics



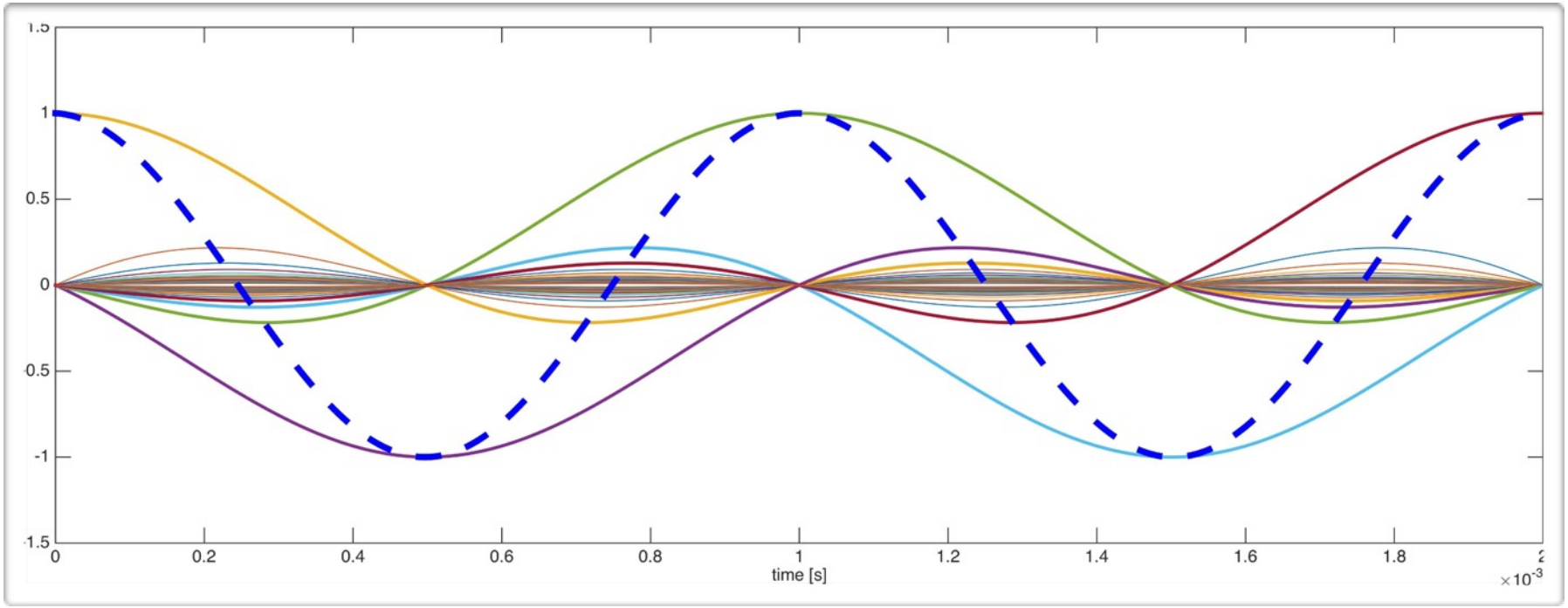
1 kHz @ Nyquist sample rate f_s = 2 kHz

Sinus Cardinalis



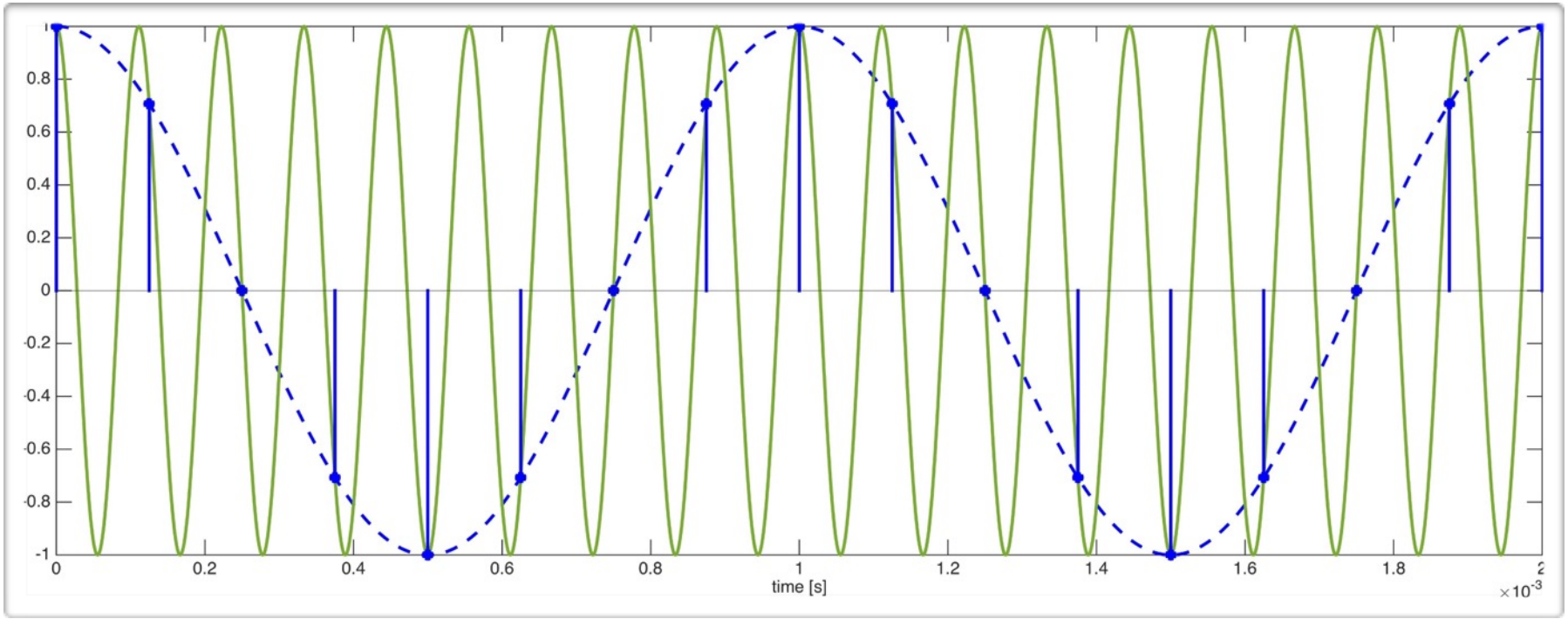
in lowpass filter impulse response scale @ 1 kHz

Interpolation



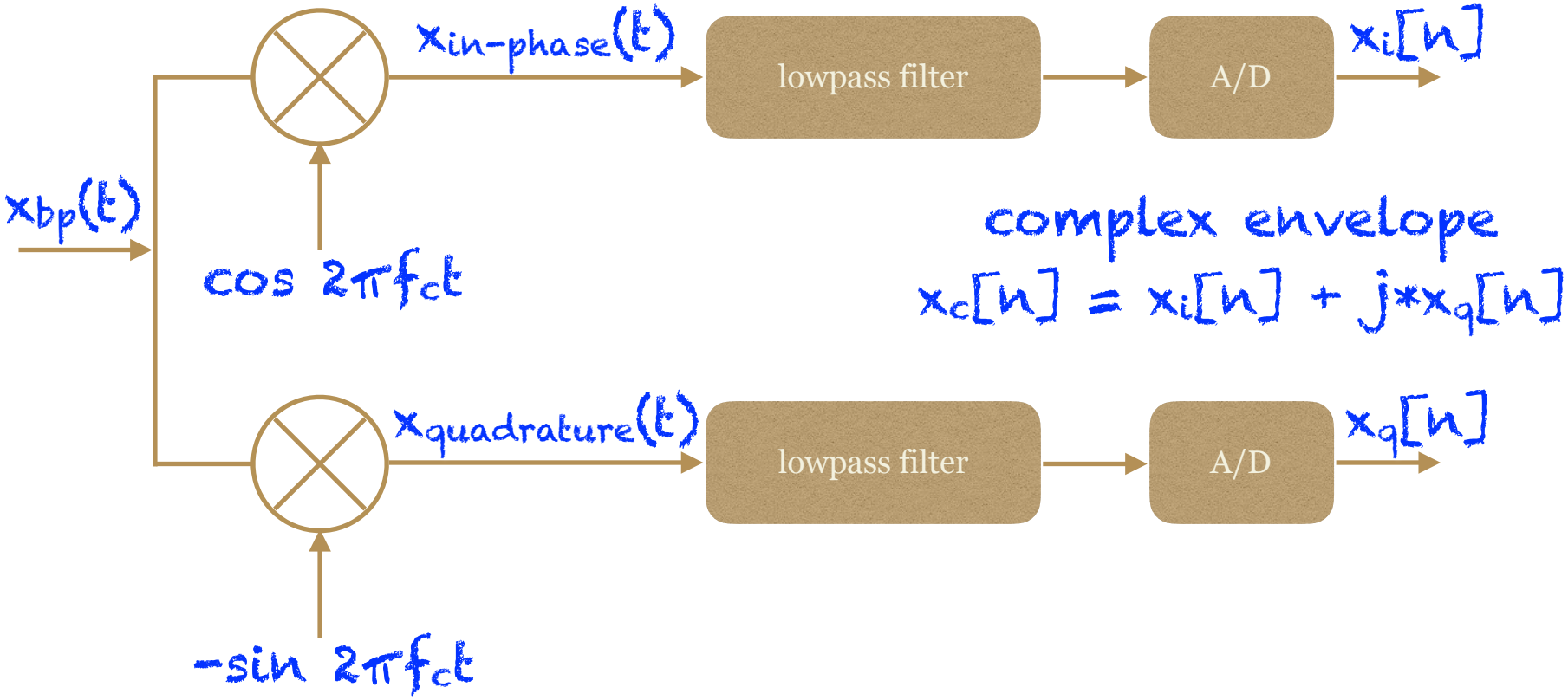
1 kHz recovered @ f_s = 2 kHz with 30-sample delay

Aliasing Example



9 kHz -> 1 kHz @ sample rate f_s = 8 kHz

Bandpass Signal Quadrature Sampling



complex envelope

$x_c[n] = x_i[n] + j*x_q[n]$

bandpass complex signal sampling at $f_s = B$

cf. [Lyons, 2011] for an excellent explanation

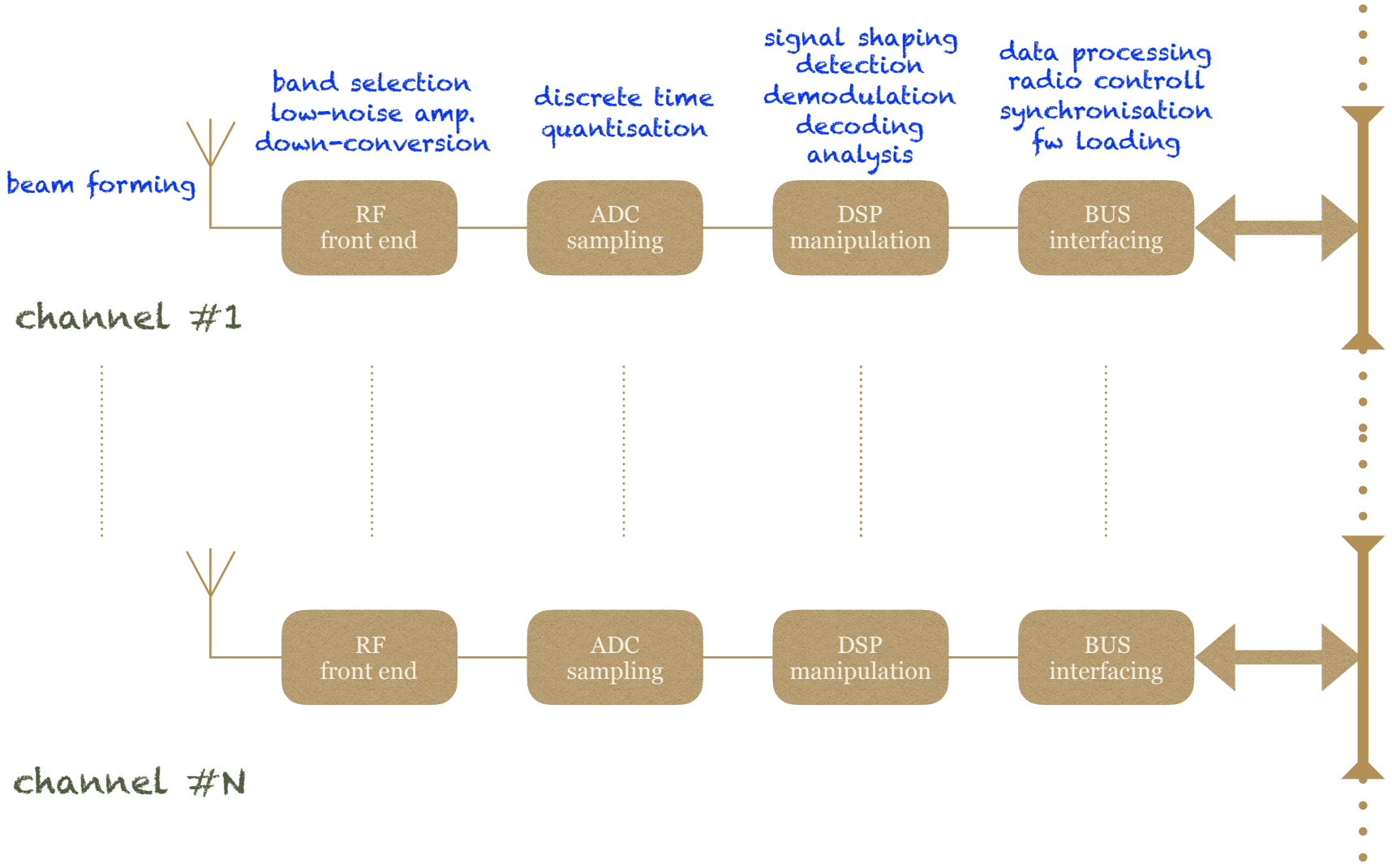
Digital Signal Processing (DSP)

… uses the correspondence of continuous-time functions and discrete-time sequences to process the input signals by digital operations instead of analog circuits

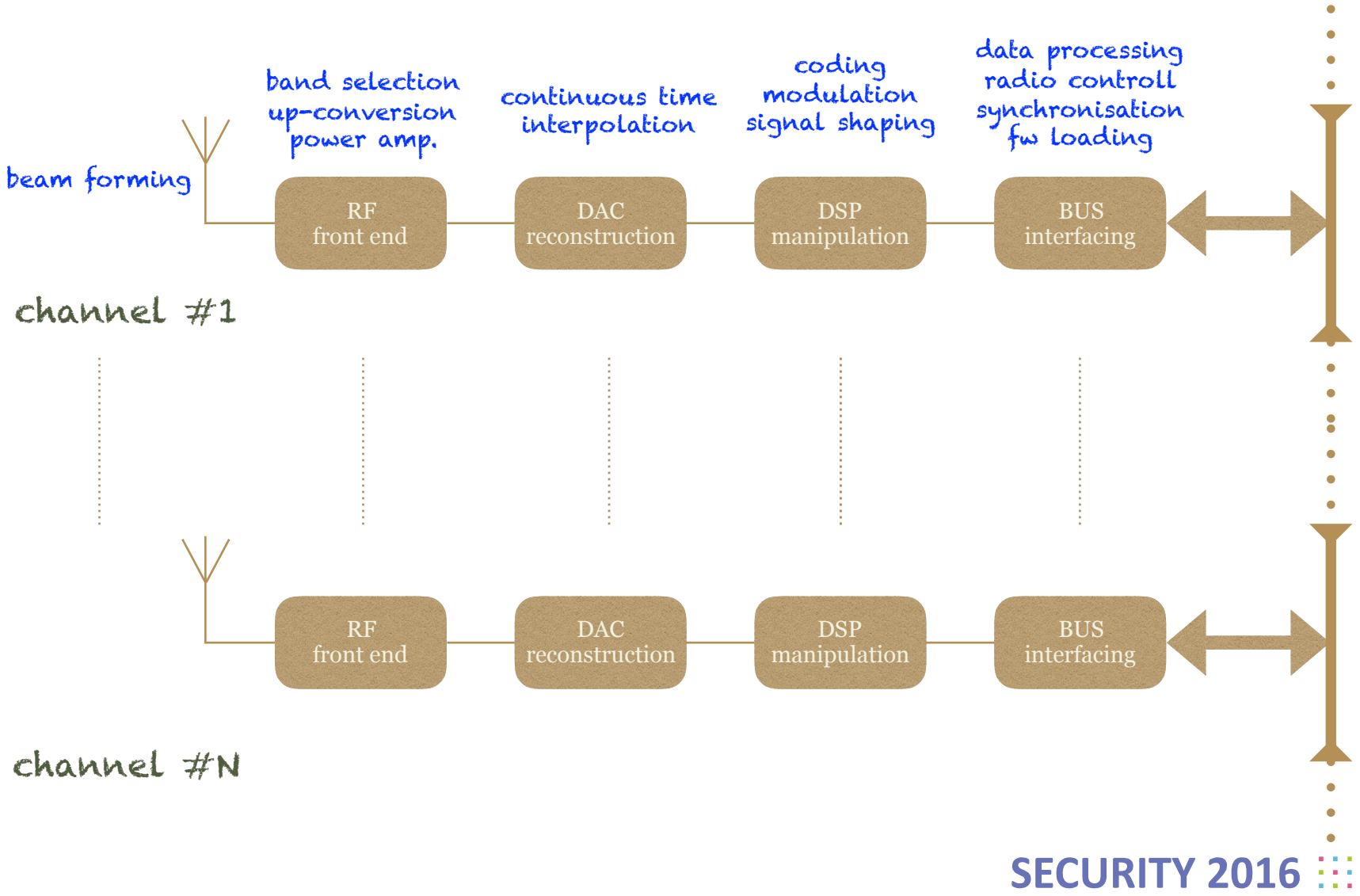
Software-Defined Radio (SDR)

… components that have been typically implemented in (analog) hardware are instead implemented by means of software on a personal computer or an embedded system

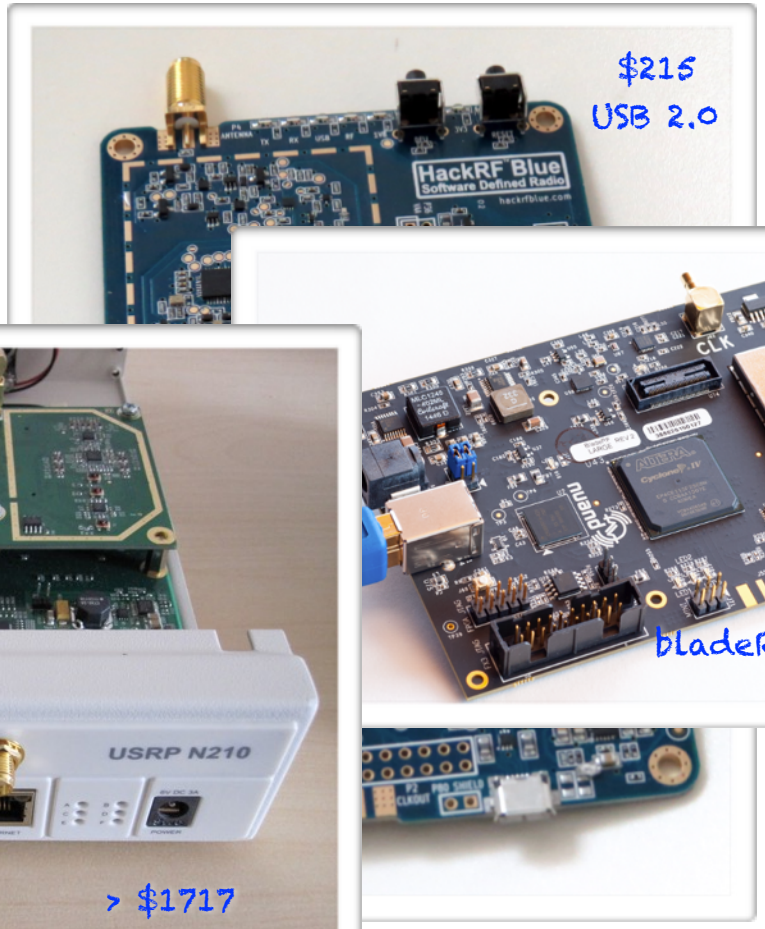
SDR Concept - RX Path



SDR Concept - TX Path



Popular Hacking SDRs



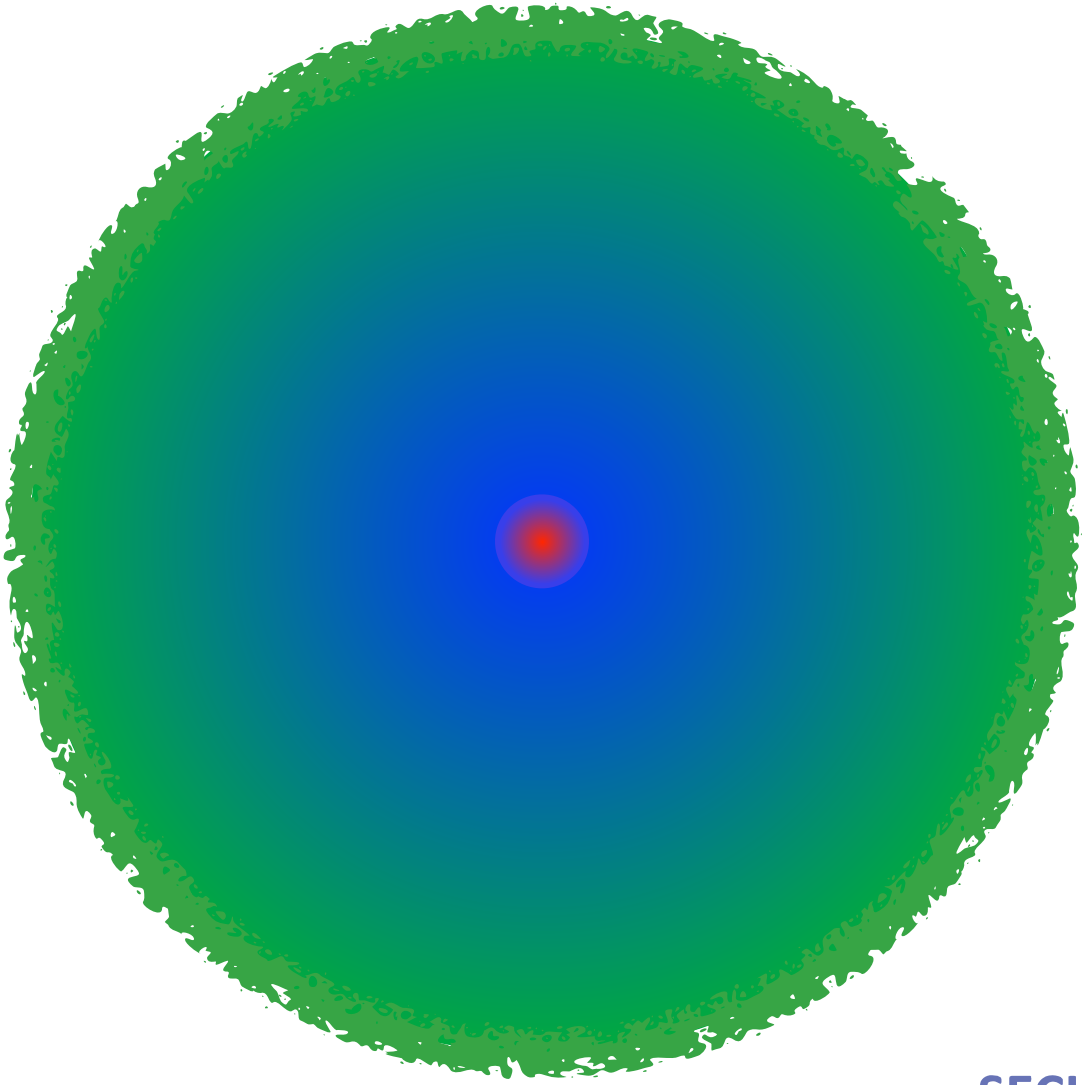
SDR As a Threat

DSP routines are SW. This can be shared, installed, and executed all around the world instantly with a very modest background.

Just like any other exploit code.

Near Field Communication

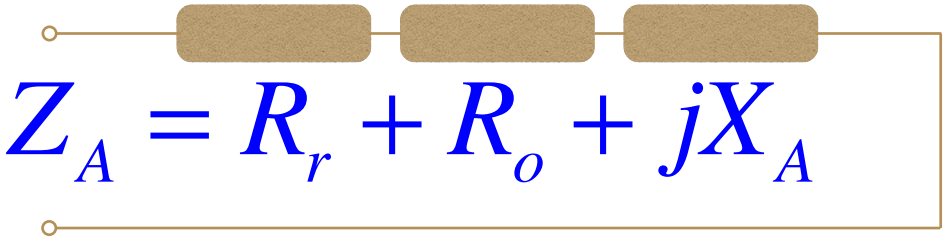
EM Radiation Regions



Near, Far, Wherever You Are…

- Basing on the different dominating EM field components implying different dominating field behaviour, it is useful to distinguish:
  - *Reactive near field* (XNF). Energy is mainly stored and exchanged between *E* and *H*. It is closest to the radiator and evades as $1/r^3$.
  - *Radiating near field* (Fresnel region). Energy is mainly radiated with unstable patterns, however. It starts roughly with $r > \lambda/2\pi$ and evades continuously with $1/r^2$.
  - *Far field* (Fraunhofer region). Energy is radiated with a distance-independent field pattern. Several conditions shall be met: $r > 2D^2/\lambda$, $r > 5D$, $r > 1.6\lambda$, where *D* is the largest antenna dimension. It evades continuously with $1/r$.

Antenna Impedance



- The input impedance Z_A describes the antenna from the lumped circuit parameters viewpoint. *It also encapsulates the observable antenna field behaviour.*
  - R_r is the equivalent radiation resistance representing the energy emanated through the radio waves
  - R_o describes the dissipative energy loss
  - X_A reflects the energy exchanged back-and-forth with the reactive near field

Yes, It Can!

- NFC antenna is generally capable of transmitting its signal into the far field region
- Due to its construction, the radiation resistance is very small leading to a very poor energy transfer
- Nevertheless, it does not mean there is no transmission at all

Parasitic Antennas

- From the security viewpoint, we shall recognise it may not be the *primary* antenna only that can radiate sensitive data
- In general, any spatial distribution of a time-varying current modulated (or sensed!) by the internal processing unit is a potential backdoor
  - we are getting to the well-known phenomenon of the electromagnetic side-channels
  - in principle, applying anti-RFI techniques for all those patch cables and power lines is a good idea to start with

Initiator Range Extension

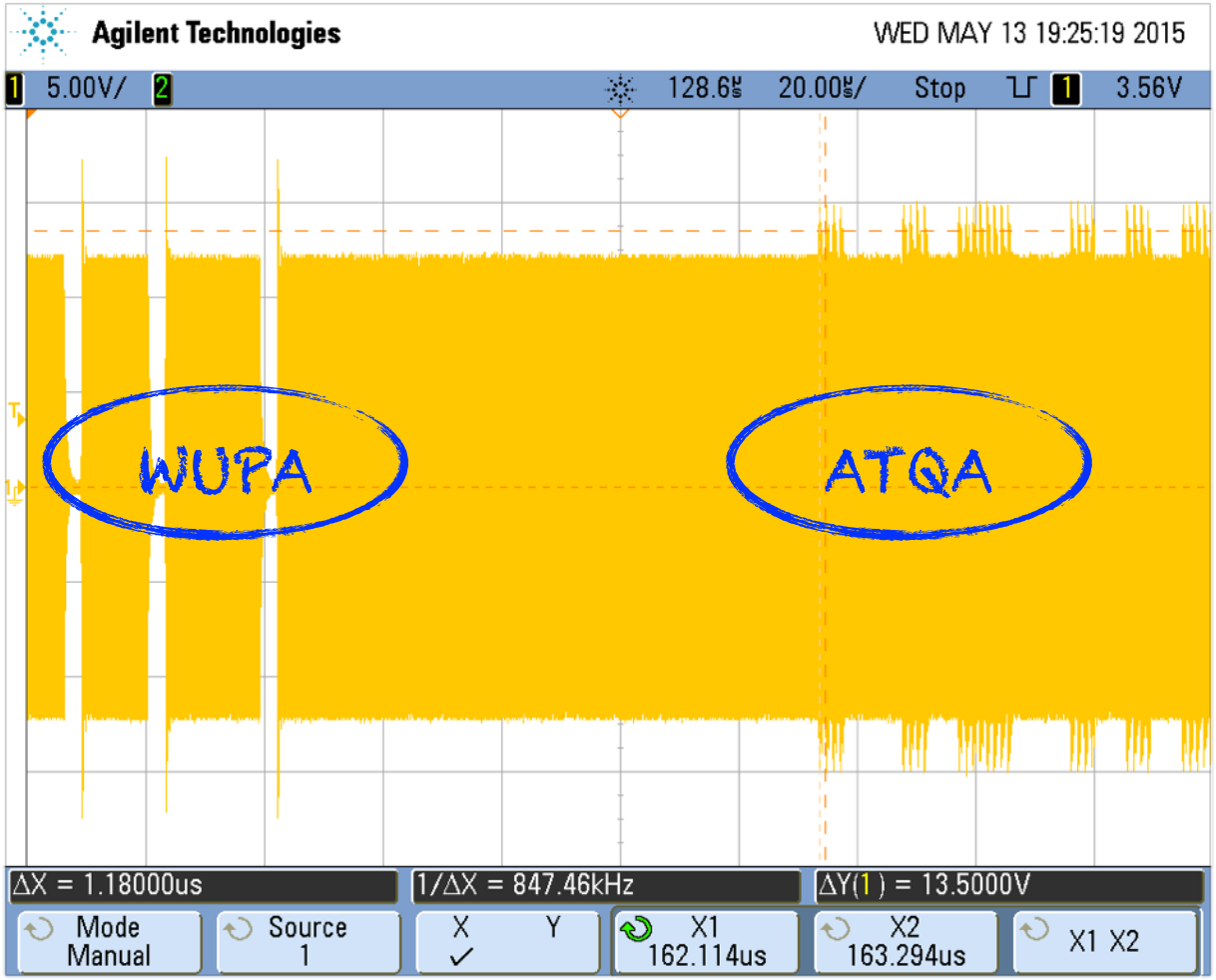
- Allows RF skimming or wormhole (relay) attacks
- Due to a very low efficiency and very high power consumption, it is practically limited to the reactive near field region (XNF)
- Antenna diversity separating downlink and uplink channels may help significantly
- Distance: Decimetres (confirmed), reliably working at around 20 cm. Principal upper limit ≈ $\lambda/2\pi$, i.e. circa 3.5 m, is infeasible to achieve practically. So, we are limited to a kind of *bumping attack*.

Sniffing

- Sensitive data capture, identity theft
- **Often, this scenario induces the most serious risks**
- Works over all zones, from XNF to Fraunhofer region
- For regions outside XNF, the important idea is to look for higher harmonics of the 13.56 MHz carrier
- Distance: Metres to dekametres. Confirmed for both downlink and uplink channels.

All You Need is *Loop*

Intercepted Signal Example (NFC-A)



Spying in the Lane (Still in XNF)

[https://www.youtube.com/watch?v=9QjxwejBPHs]

Going Far → Small Loop (HAM Illustration)

[AlexLoop by Gary, KE2YK]

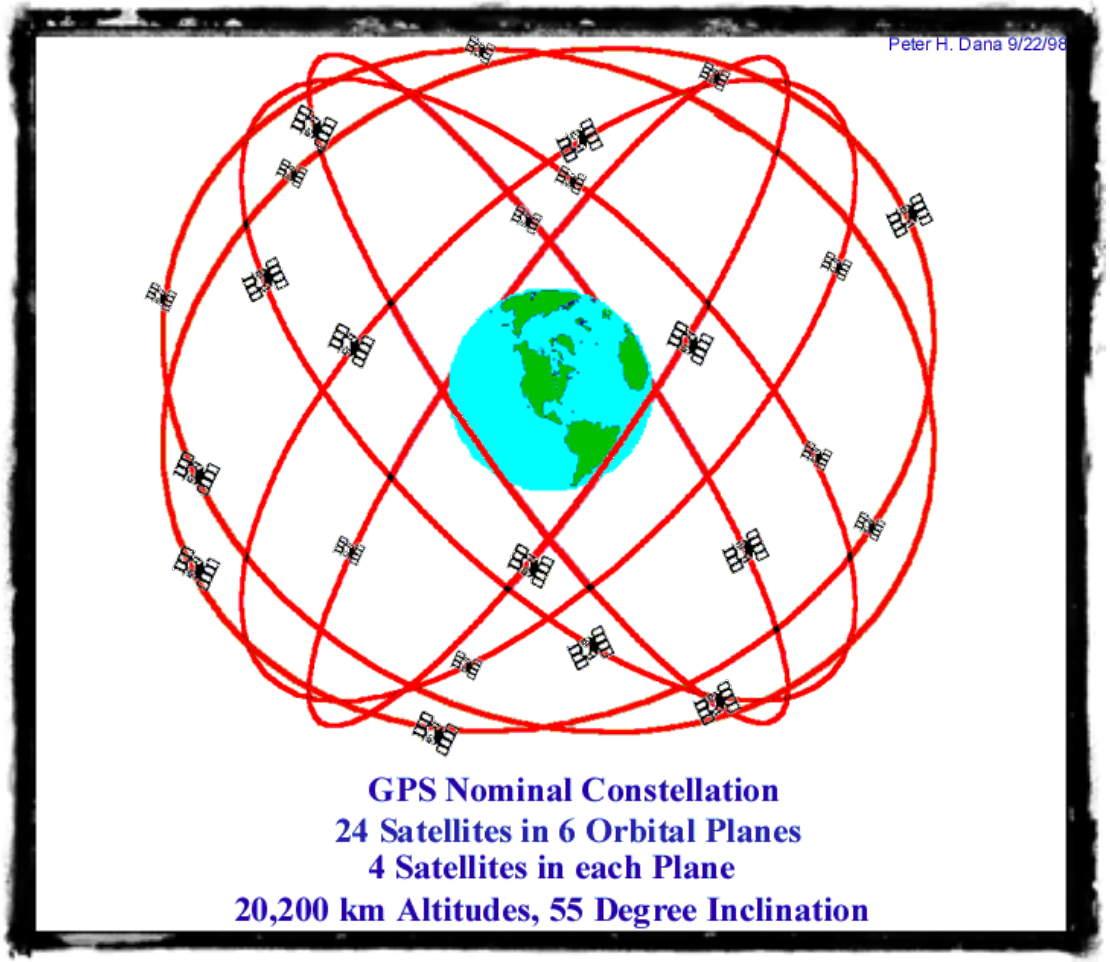
The Show Still Goes On…

- ✓ Target range extension (metres, confirmed)
- ✓ Traffic injection - MITM (decimetres to metres for uplink TX only, confirmed)
- ✓ Initiator location (dekametres, confirmed)
- ✓ Target location (decimetres confirmed to metres estimated)
- ✓ Jamming (metres confirmed to dekametres estimated)
- ✓ Device destruction (decimetres)

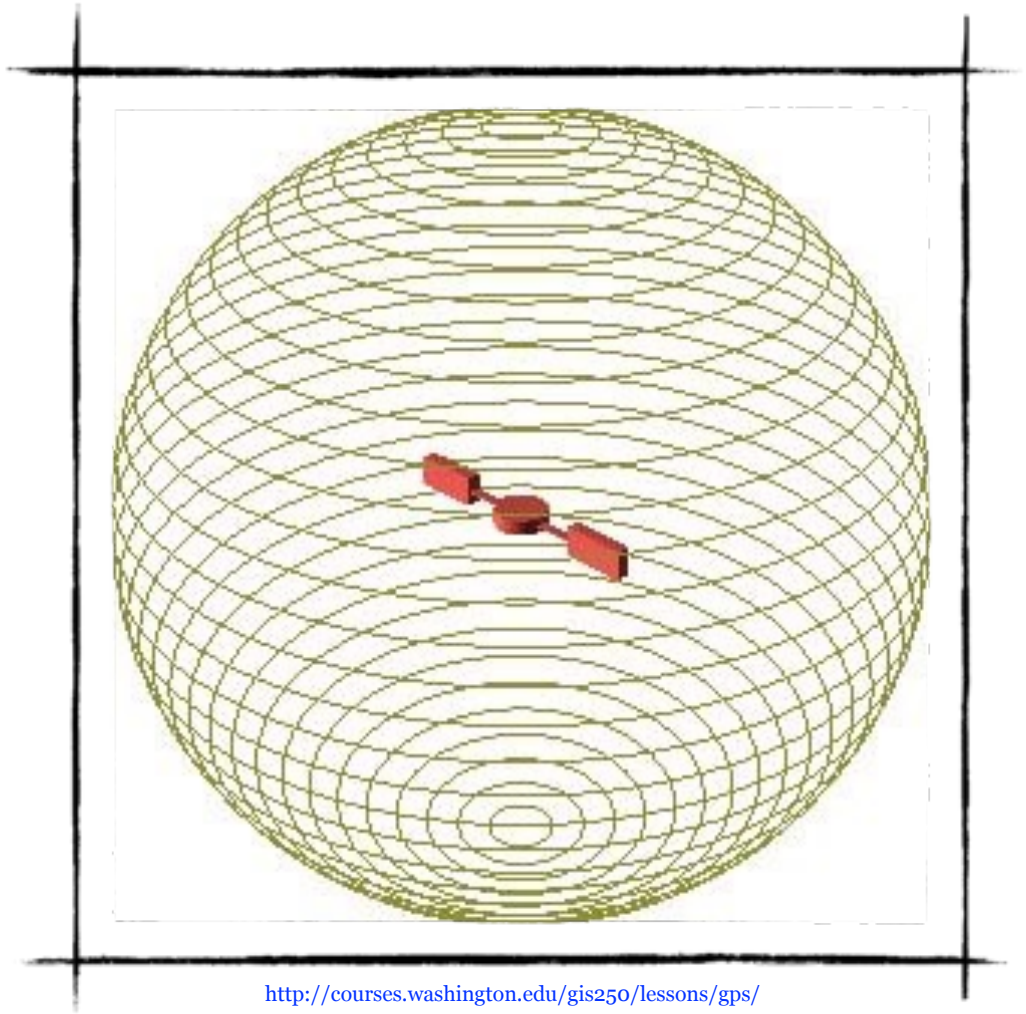
NAVSTAR
Global Positioning System

Space Segment Vehicle (Block IIF)

GPS Space Segment

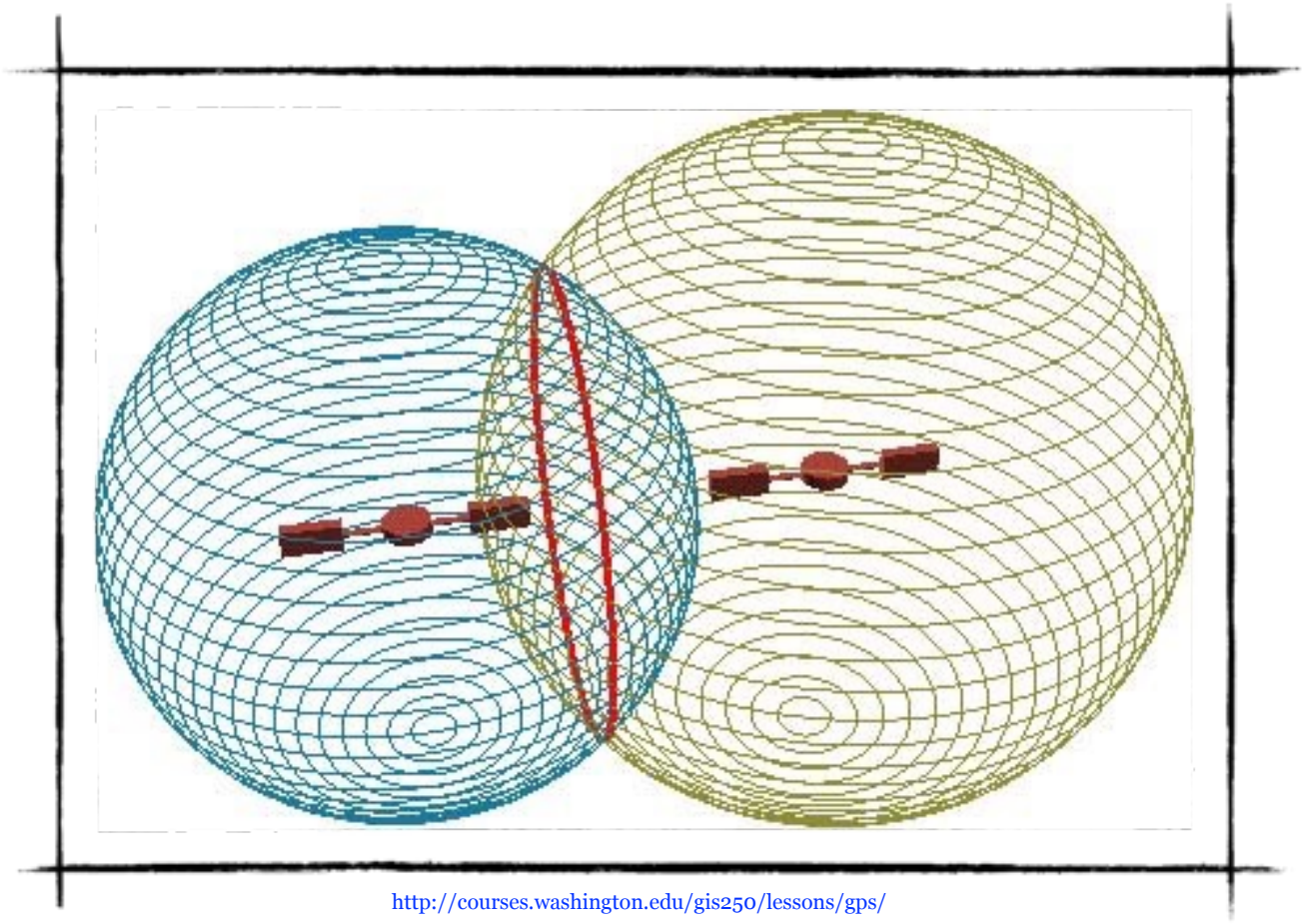


Trilateration I



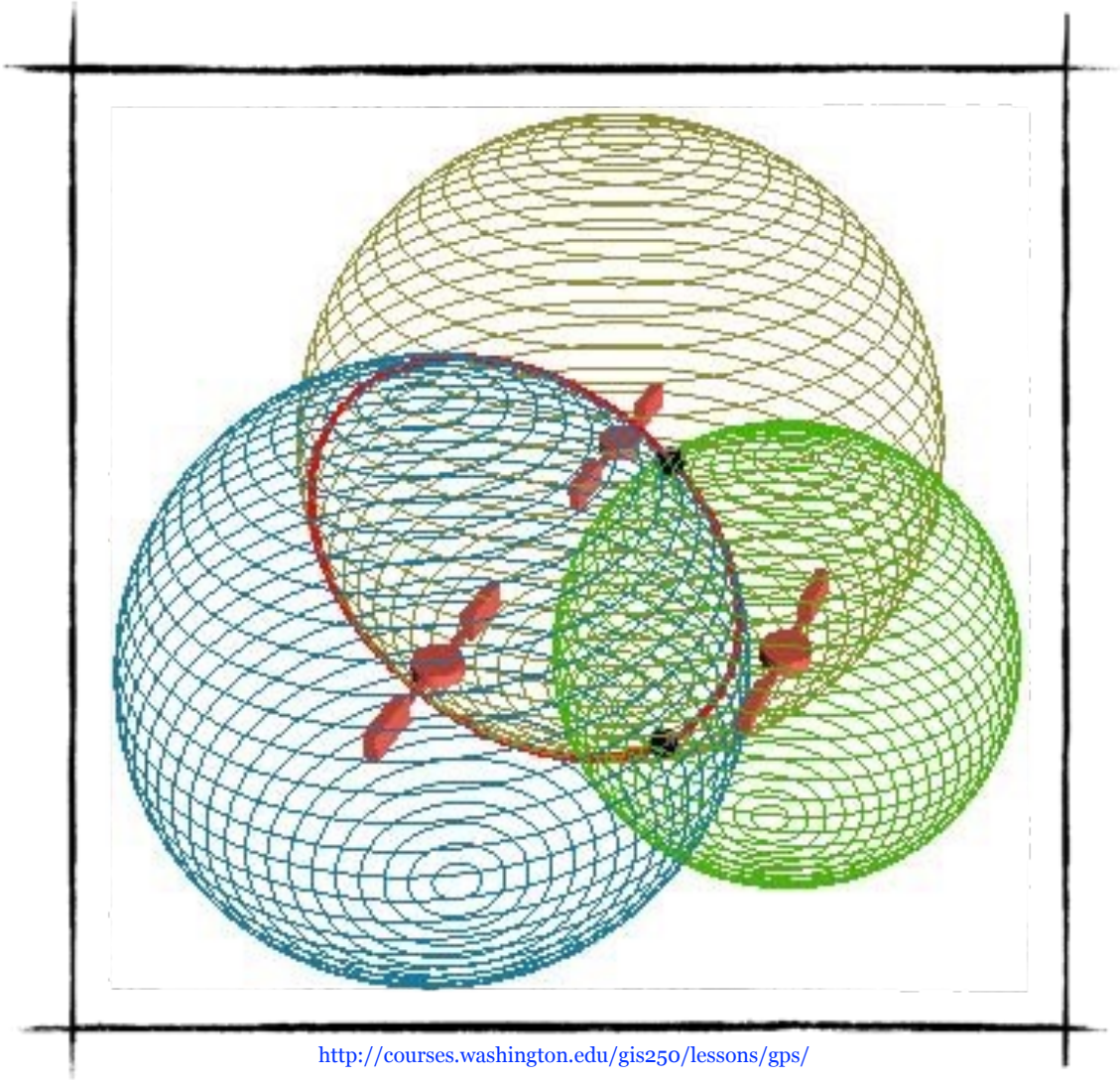
http://courses.washington.edu/gis250/lessons/gps/

Trilateration II



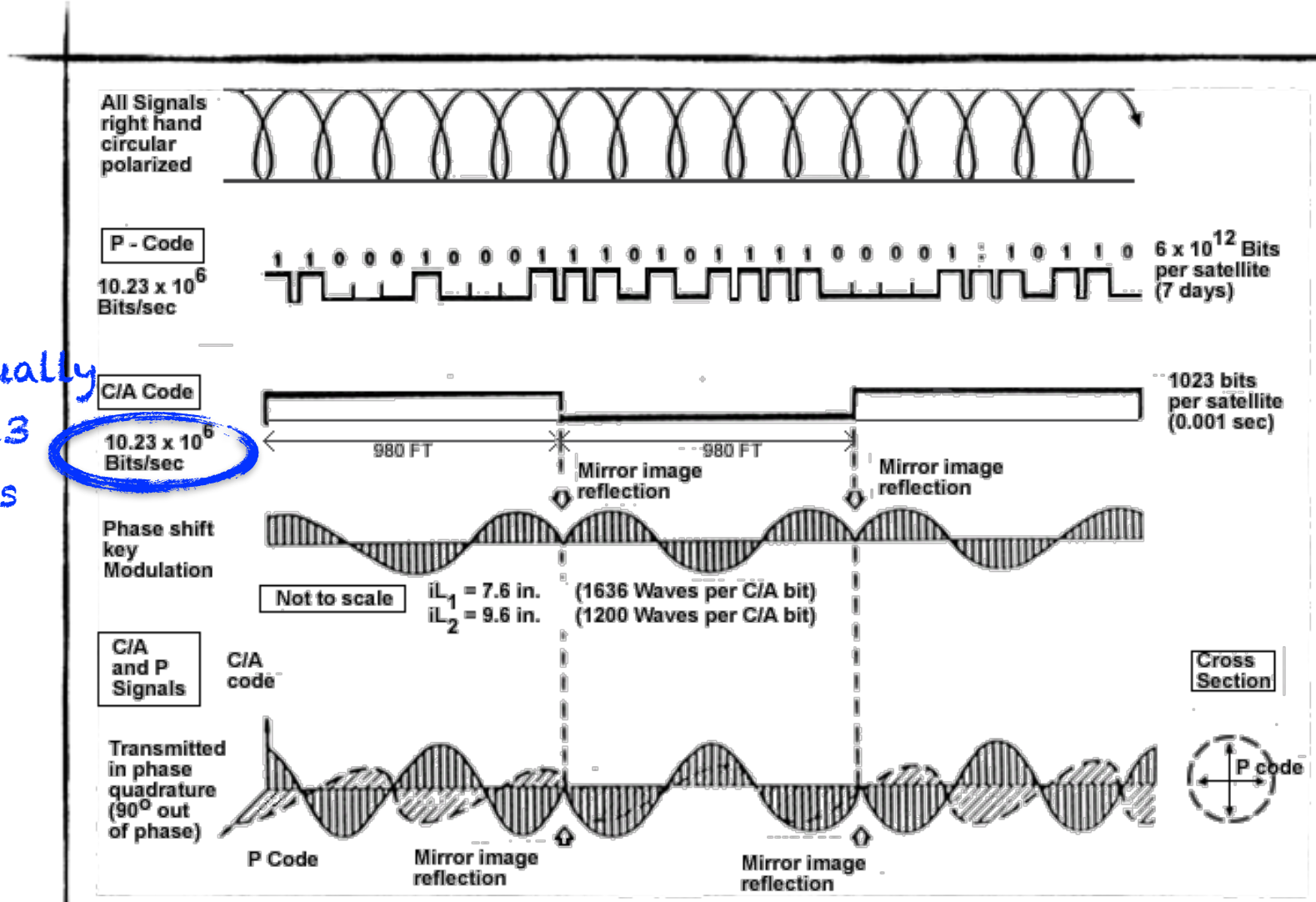
http://courses.washington.edu/gis250/lessons/gps/

Trilateration III



http://courses.washington.edu/gis250/lessons/gps/

GPS L1 C/A ⊗ P(Y) (Illustration ONLY)



actually 1.023 Mbps

Kulshreshta, 1997

Satellite Clock Replicas Expose Time Delays

t_{sent_sv1}

t_{sent_sv2}

t_{sent_sv3}

four SVs to get
X, Y, Z, and t_{bias}

t_{sent_sv4}

$t_{rec}+t_{bias}$

Civil GPS in Serious Applications

NTP server

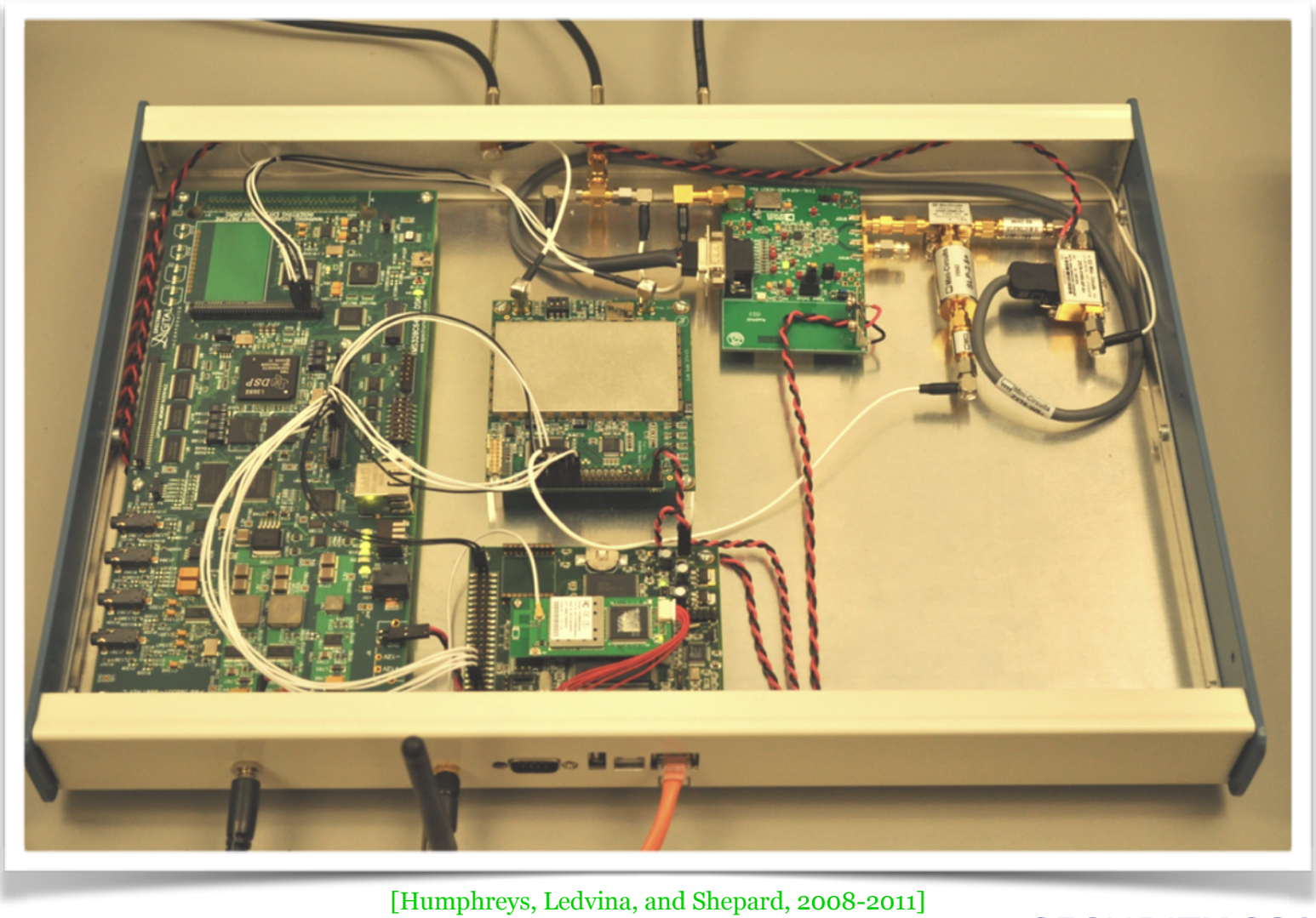
L1 C/A Signal in Brief

- CDMA at the common carrier frequency of 1575.42 MHz
  - BPSK-R(1) Direct Sequence Spread Spectrum (DSSS) according to the notation of [Betz, 2016]
- Satellites distinguished by their unique chipping sequence (Gold codes)
- Allows creation of a delayed replica clock of the particular satellite (implicit time synchronisation)
- Carries 37 500 bits of navigation data for the particular satellite (explicit time synchronisation and position computation)
- Includes corrections according to the General Theory of Relativity
- … does not include any cryptographic protection

L1 C/A Security

- Position/Velocity/Time (PVT) spoofing is accessible to a moderate-level attacker
  - real-life scenario may (allegedly) be that **“Iran-U.S. RQ-170 incident”**
  - actually, a GPS “replay attack” is a standard advanced tutorial for the LabView platform using the USRP Software Defined Radio (SDR)
- OK, this signal was never meant as a military-grade service and the lack of protection here can hardly be called a “discovery”
- On the other hand, a lot of L1 C/A applications have grown up to be vital parts of our critical infrastructure today…

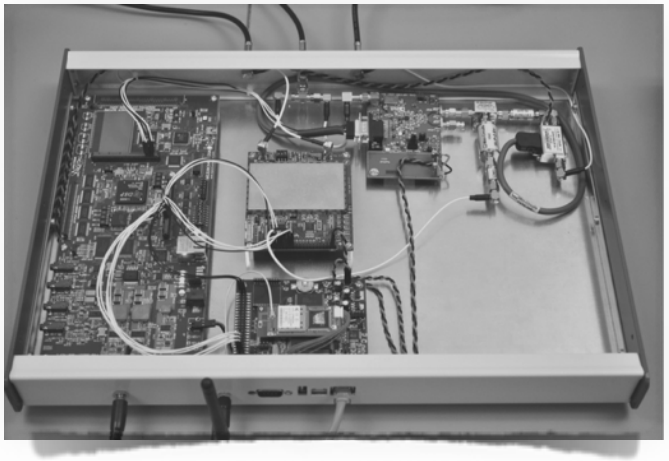
Civil GPS Under Serious Attack



[Humphreys, Ledvina, and Shepard, 2008-2011]

Precise SDR Spoofer

- receiver-spoofer (MITM) architecture
- tracks original L1 C/A and L2C
- manipulates individual SV signal channels of L1 C/A (up to 12)
- re-mixes and re-transmits the spoofed signal
- precise phase sync for a smooth take over
- SDR architecture; someday it could be just downloaded and run
- HW parts were off-the-shelf components of approx. $1500 (2008)



[Humphreys, Ledvina, and Shepard, 2008-2011]

Achievements Announced in Public

[Bhatti, Humphreys, Ledvina, Pesyna, Shepard, Huang, Yang, et al. - cf. references]

SBAS to the Rescue?

- Satellite-Based Augmentation System in general
  - European Geostationary Navigation Overlay Service (EGNOS), for example, in particular
- Provides integrity report and differential corrections for the original L1 C/A signal
  - However, it rather applies to the *transmitted signal*, instead of the signal received by the individual user station

In Other Words

"…Degradations of the received signal that occur after transmission, such as … reception of invalid signals transmitted by others, *are not addressed* by SBAS integrity indications."

– [Betz, 2016]

The Next Target?

- Recall those 37 500 bits of navigation data transmitted on each and every L1 C/A channel
- It has been observed the baseband processors in GPS user modules seldom care about the integrity of this data as well as of the plausibility of PVT results obtained
  - [Sheppard and Humphreys, 2011], [Nighswander et al., 2012]
- Interestingly, this suggests a new infection vector allowing malware installation right into the GPS receiver…

Conclusion

- RF signals are ubiquitous, we probably cannot live without all that electromagnetic tweeting anymore
- Often, the relative inaccessibility of the RF interface is the only protection
- SDR phenomenon offers an unprecedentedly easy access to the whole RF spectrum, while also allowing the rapid and massive exploit sharing
- The era of intensive RF hacking is coming and it will go far beyond the usual scope of Wi-Fi and Bluetooth!


REALLY, DO THE PENTEST!

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Děkujeme za pozornost.

Tomáš Rosa, Ph.D., OK1SFU
RaiffeisenBANK
tomas.”my_last_name”@rb.cz