Current PNT System/Sensor Challenges

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Before GNSS(GPS)

- **Positioning and Timing were huge problems**
  - We had many different systems working on different principles, different equipment

    LORAN, TACAN, VOR, DME, TERCOM, …
  - Had OK performance locally – short distances

    (200 m was excellent result for most applications)
  - In long distances we had to rely on Inertial Navigation which is very expensive, big, power hungry and under strict control (MTCR)
  - Even if you paid all that cost for INS the errors increased by t^2 and t^3

Then GPS (GNSS) came

- You can get position less than 5 m (< 1m if you have WAAS)
- You can get timing < 1 µsec (< 15 ns if you have military signal)
- Can be a few dollars (Your phone has more than one system)
- If you have some basic maps you can use them for navigation
- Available in almost all of earth (Except caves, indoor, valleys)
- Basicly unbelieveable performance to almost no cost to user

- Ended up being used everywhere – **intended or not**

Some Use Areas

- Military and civilian Navigation (Positioning and Guidance to target)
- Time synchronization of military communication equipment

- Time synchronization of Banking system (Transfers, ATM's etc)
- Precision Farming (Knew exactly where each crop is and …)
- Air Traffic Control (ADS-B)
- Autonomous Driving
- UAV Flying (Autonomous or not)
- Rail System optimization
- Freeway average speed calculation / speed tickets

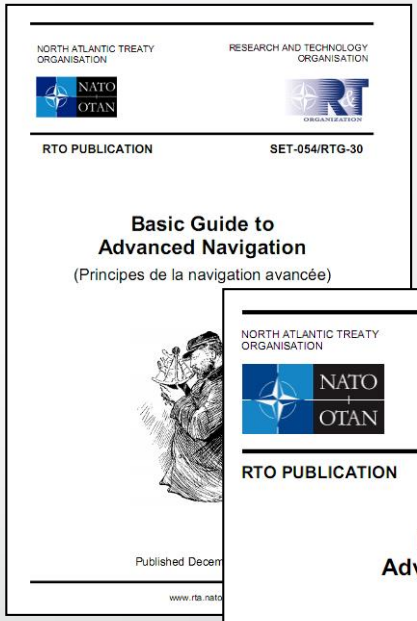
- **WE RELY ON GPS ON EVERY ASPECT OF OUR EVERY DAY LIVES.**

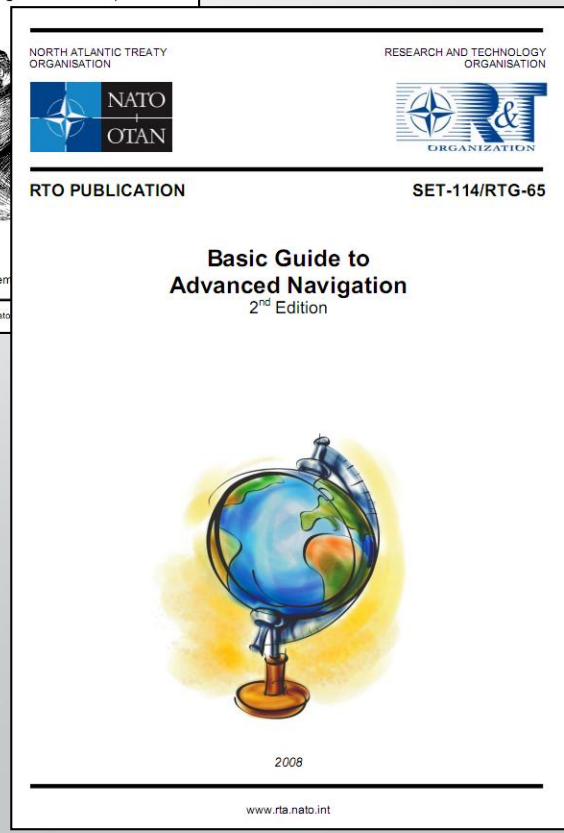
GNSS is the trend Now!

	First Launch	Operational	Status (Now)
GPS	1978	1993	31 of 24+3
GLONASS	1982	1993 – 1995 - 2010	27 of 24
BEIDEU	30/10/2000	2020	3+3+24
GALILEO	28/12/2005	2016	22 of 30 satel.
IRNSS	1/7/2013	Regional	3+5
QZSS	11/9/2010	Augmentation	1+3

NATO Navigation Booklets

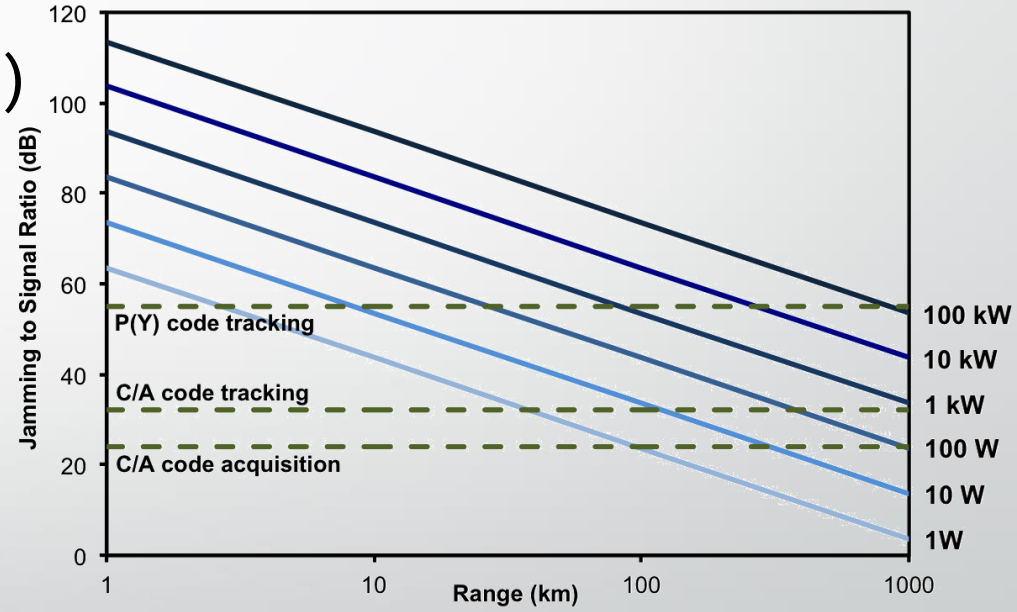
- We prepared 3 NATO Booklets over the years
  - Basic Guide to Advanced Navigation
    - INS, GPS, INS/GPS and Technology Trends
  - Basic Guide to Advanced Navigation 2nd Ed.
    - Dead Reckoning Navigation Systems
    - Map Matching Navigation Systems
    - Externally Dependent Navigation Systems
  - Navigation Sensors and Systems in GNSS Degraded and Denied Environments
    - GNSS Vulnerabilities
    - Scenarios and effect of GNSS jamming, spoofing
    - Possible technological solutions

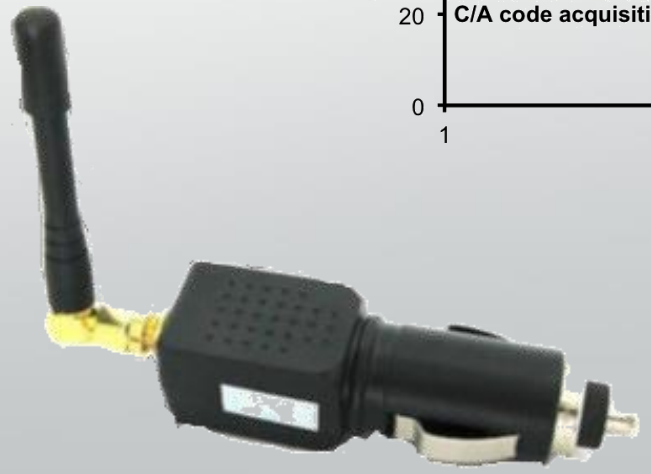




What's the problem?

- **But GNSS (GPS) can be stopped – Way too easily**
  - Interference (unintended jamming)
  - Jamming
  - Spoofing
  - Space weather
  - Space attack
  - Cyber Attack





CHALLENGES

PROTECT GNSS (GPS)

- Antijam antennas
- Improvements (M-code)

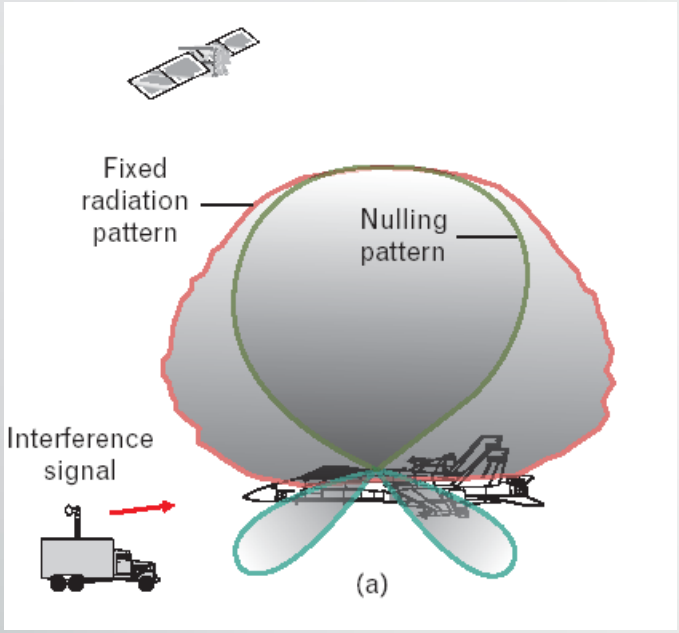
INDEPENDENT TIMING

- Chip Scale Automic Clock

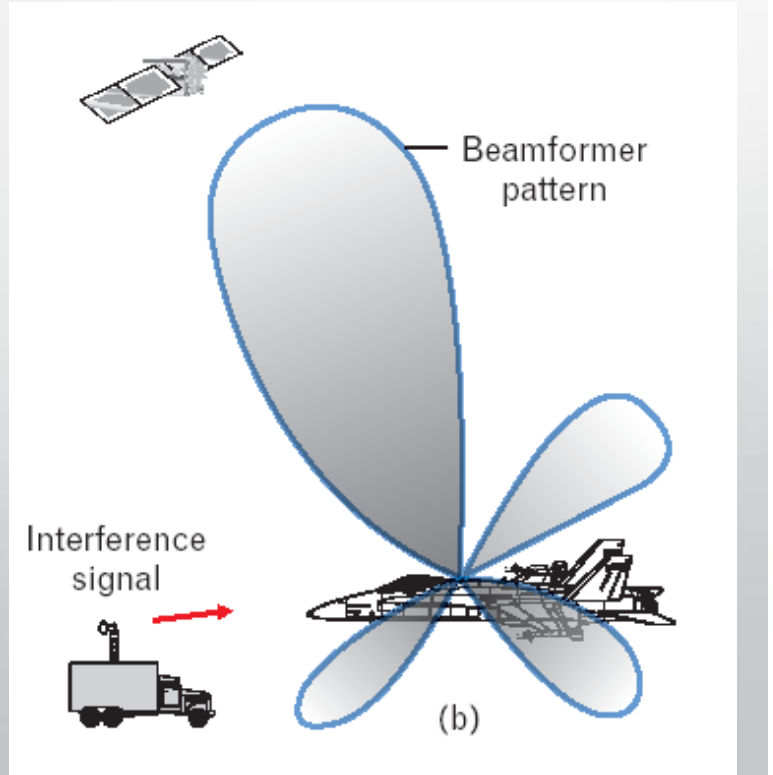
Alternate Nav Systems

INS
e-Loran
UWB
TACAN / VOR+DME
Map Matching
Visual Navigation
Pulsar Navigation
Doppler Based Navigation
STARLINK
...
Integrated Navigation Systems

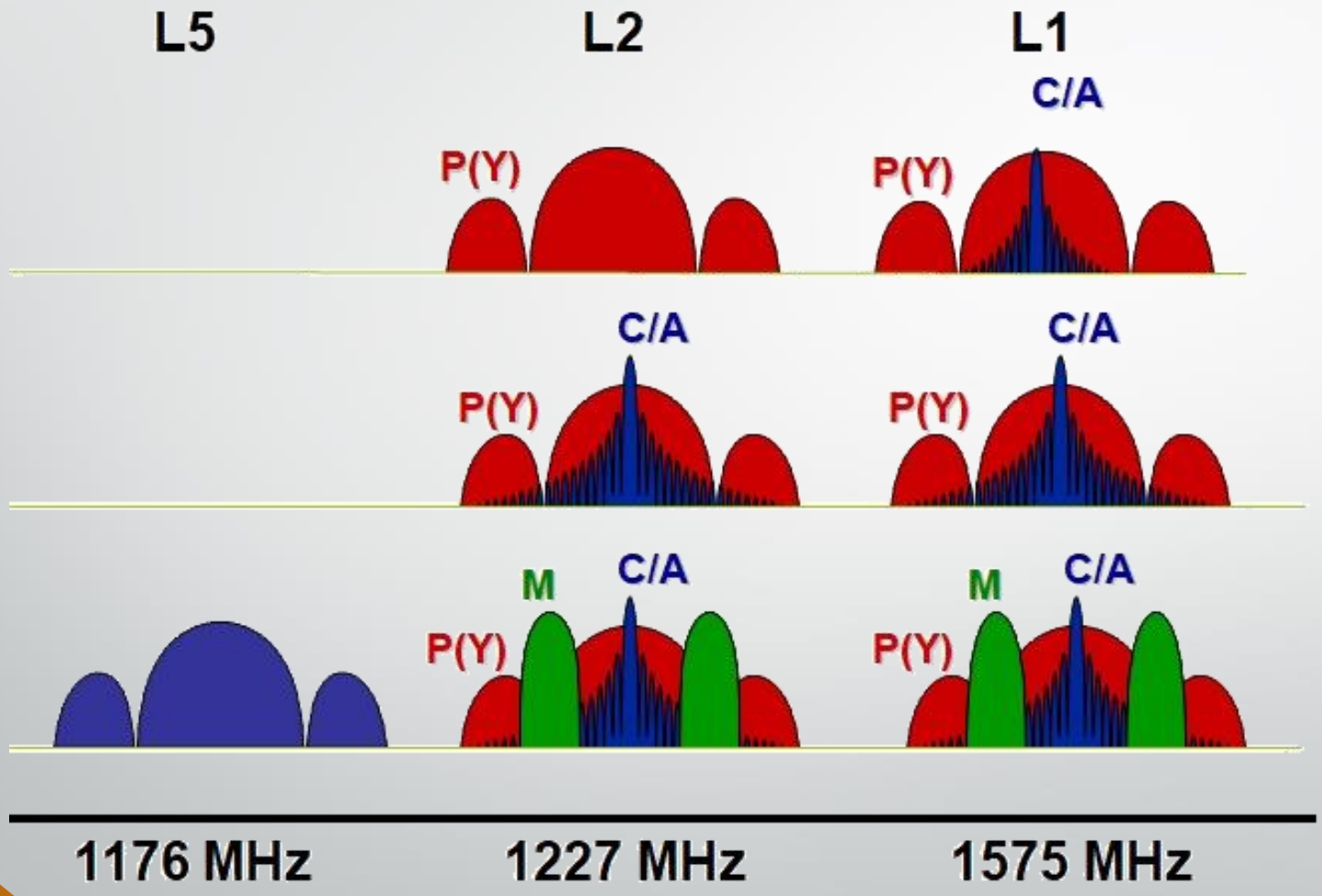
Anti Jam - CRPA Antenna

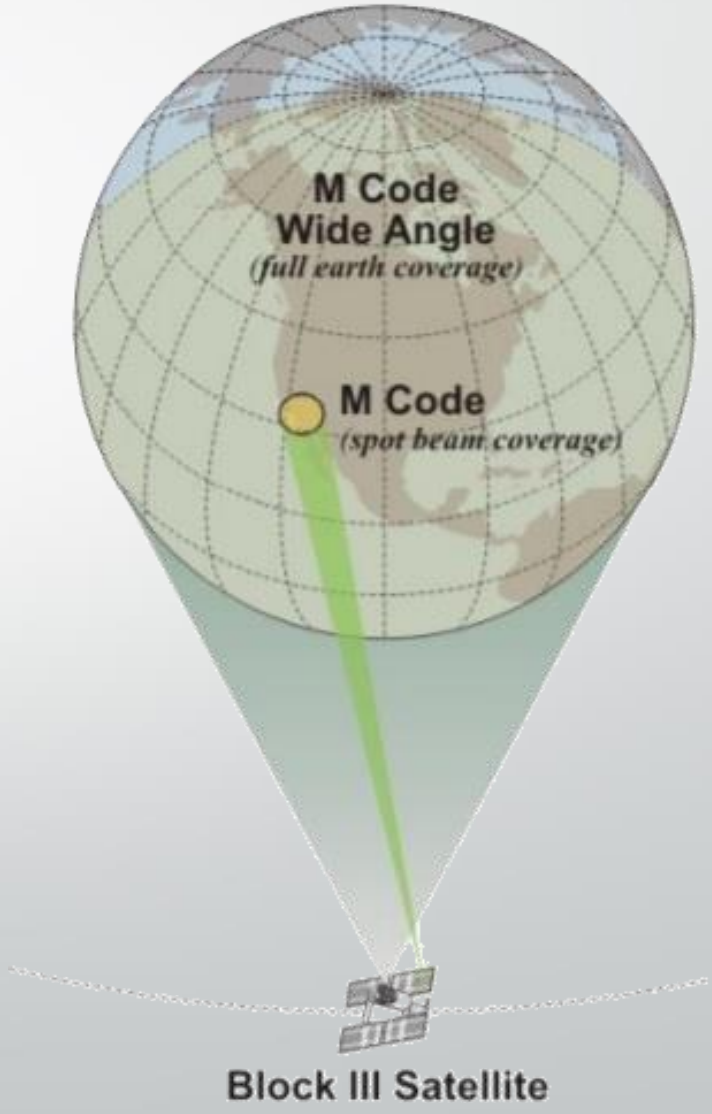


- Use Multi antenna systems to get
  - Directional capability
  - Nulling



GPS/GNSS Modernization

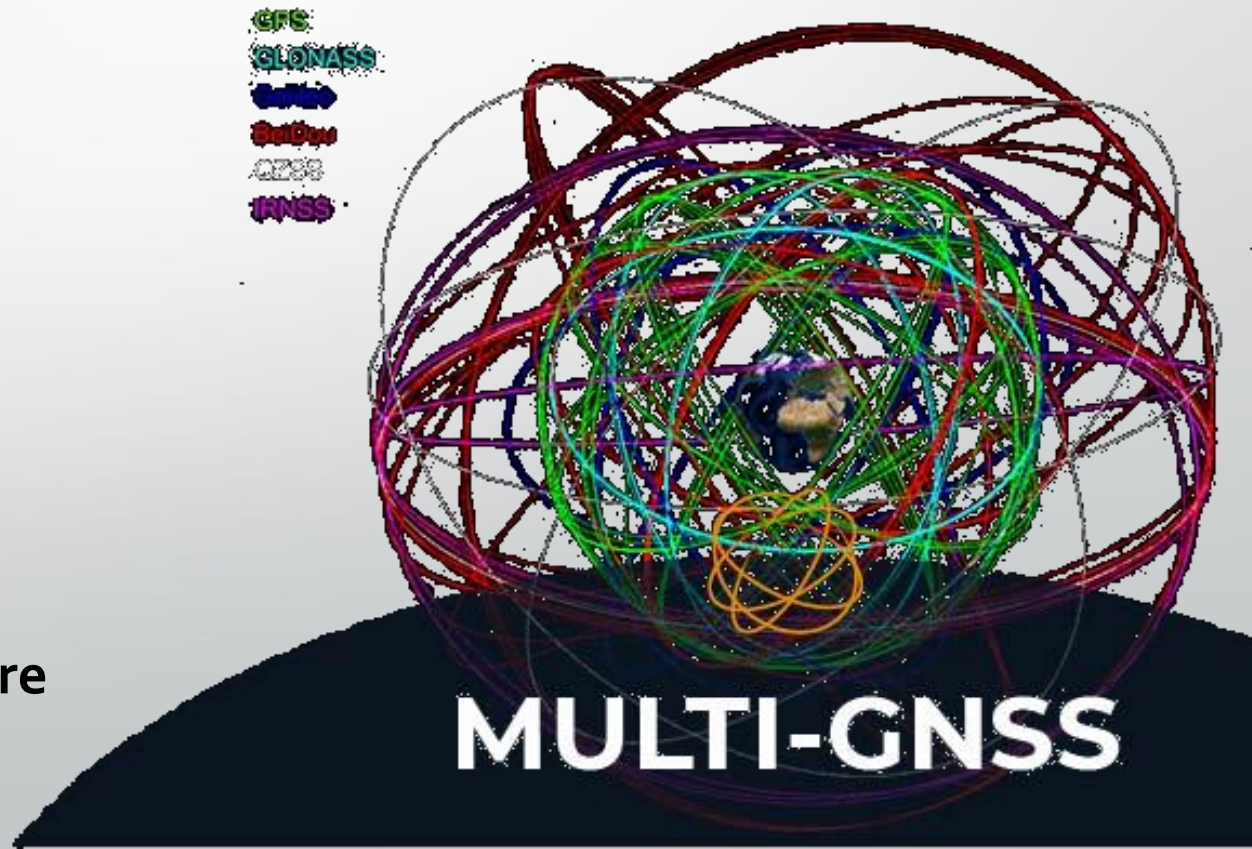




Multi Constellation

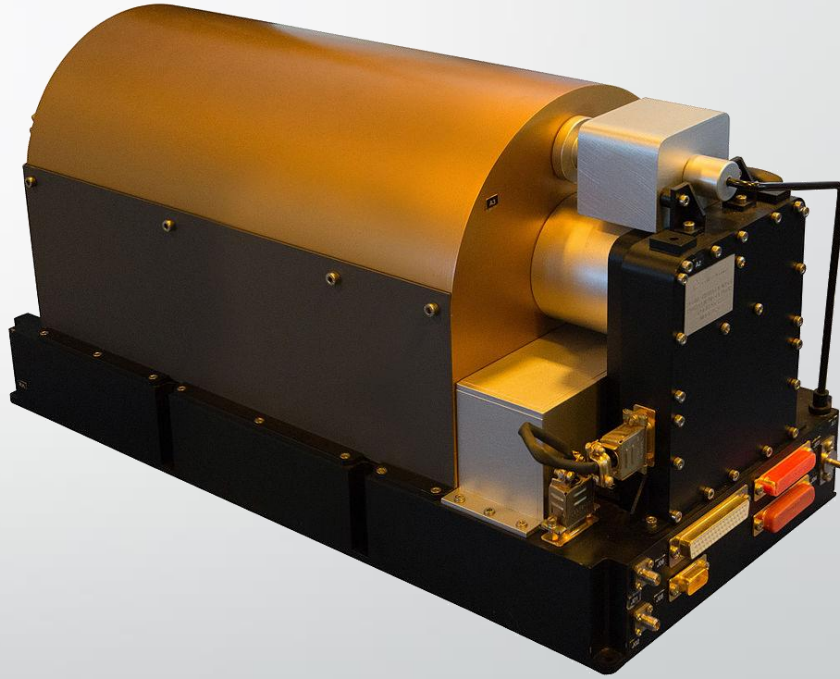
- Once there were only GPS and we were worried about seeing at least 4 satellites
- Now There Are
  - GPS - 31
  - GALILEO – 22
  - BEIDEU – 30
  - GLONASS – 27
  - + Others

- Why not use all available
- Such commercial system are now available

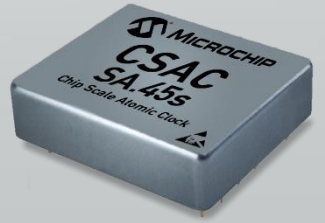


Independent Time Source

- If GPS is jammed timing will also be lost
  - Cyrpto technology
  - Bank Systems
  - Average Speed calc.



- Need independent time
  - Automic Clocks are big and expensive
  - Chip scale automic clock



Military Code vs. Multi Constellation

- If you don't own your own GNSS System then :
  - Should you use Country X's military receivers
    - Better performance under jamming
    - Very hard to spoof
    - Reliance on country X
  - Or Should you use all GNSS systems but civil signals
    - More than enough free signals
    - Easier to jam and Spoof
    - Commercial / Cheap Solutions readily available
  - Or Should you start your own GNSS

Anti UAV vs. Anti Jam

- UAV
  - Many different sizes, shapes etc.
  - Now they can also be armed
  - Are they friendly or are they a threat
  - Most of them rely on GNSS for navigation
  - Jamming GNSS is one of the ways to stop UAV attacks

  - It will also effect your own systems
  - Will effect civilian systems, air traffic
  - Not easy to find, eliminate jammers in real World.

Integrated Navigation Systems

- Which ones to Integrate
  - Legacy but still operational systems
  - Inertial Navigation Systems (Still expensive and Heavy)
  - For which user – Air, Land, Sea or Space
  - How many different versions is enough

- How to integrate
  - INS/GPS – you know how use Kalman Filter, error covariances
  - Legacy systems – No error covariances, not aware that there are other systems out there
  - Newly developped – Still most thinks he is the king

Is there a better way of doing things?

- How many times I (We) have to do the same job
  - INS / GPS
  - INS / GNSS
  - INS / Dopler Radar
  - INS / Speed Sensor (Tachometer, Log speed etc.)
  - IMU / UWB
  - IMU / Vision Based
  - IMU / Radar

  - Then restart using 3 at a time then 4 at a time etc.

SET 309 - PNT Open System Architecture

- Can we create a standart architecture where each navigation system provides data ready to be integrated by other systems
  - Position, Attitude
  - Timing
  - Error covariances
  - Others
- So that any navigation system can automatically be integrated by an integration algorithm
  - Several separate navigation systems
  - An hardware to integrate
  - An algorithm to integrate

PLUG AND PLAG INTEGRATED NAVIGATION SYSTEM