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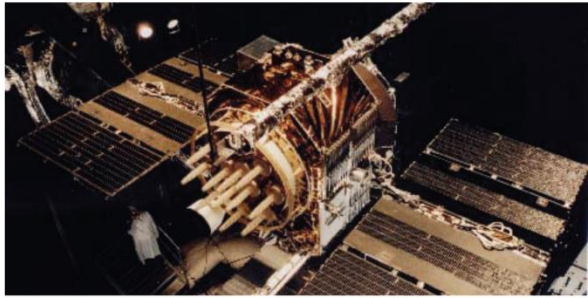
inside unmanned systems

APPLYING
GNSS Interference Detection
INSIDE AND OUT

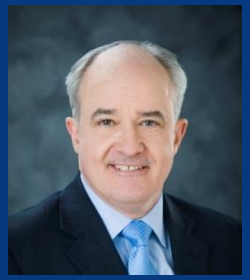


Thursday, January 25, 2018

10 a.m. PST • 11 a.m. MST • Noon CST • 1 EST

WELCOME TO

Applying GNSS Interference Detection Inside and Out



James Poss, Maj Gen (ret)
USAF
CEO
ISR Ideas

Sandy Kennedy
Chief Engineer
Receiver Cards
NovAtel

John Schleppe
Engineering Fellow and
Manager of Research
NovAtel

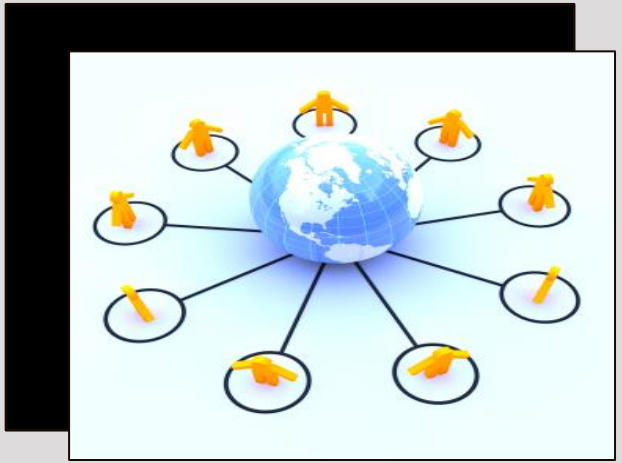
Paul Alves
Principal Research
Engineer
NovAtel

Co-Moderator: Lori Dearman, Executive Webinar Producer

Who's In the Audience?

A diverse audience of over 400 professionals registered from 52 countries, representing the following industries:

- 20 % GNSS equipment manufacturer
- 18% System Integrator
- 16% Product/Application Designer
- 15% Professional User
- 11% Government
- 20% Other



Welcome from *Inside GNSS*

Richard Fischer
Publisher
Inside GNSS / Inside Unmanned Systems

James Poss, Maj Gen (ret), USAF
CEO
ISR Ideas

Poll #1

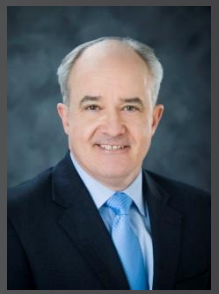
Have you experienced interference before?

a. Yes

b. No

c. Not sure

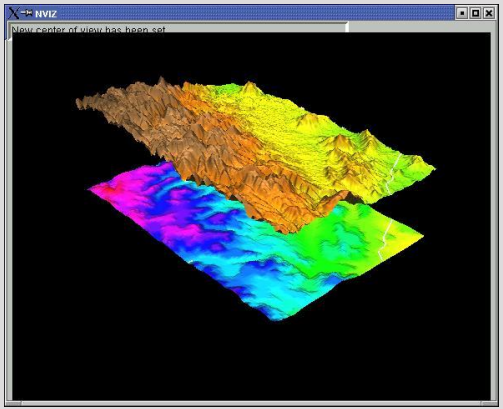
GPS: Who KNEW it was so vulnerable?



James Poss, Maj Gen (ret), USAF
CEO
ISR Ideas

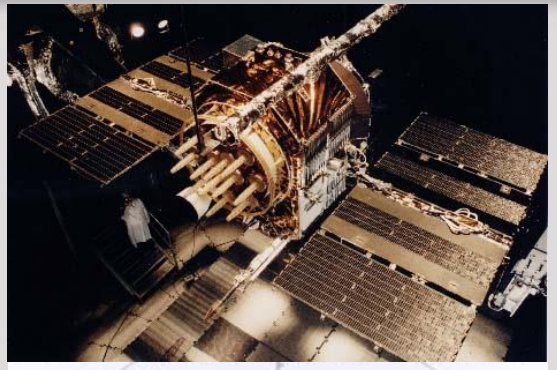
Invention of GPS

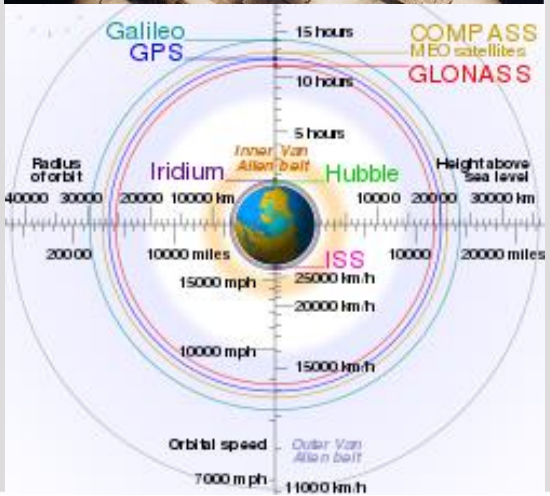
- The Objective: Strike anywhere, anytime with tremendous accuracy.
  - Plan A: Cruise Missiles and TERCOM.
    - Pros: Worldwide coverage, great accuracy.
    - Cons: You have to image the EARTH.



Invention of GPS

- Plan B: Put 24-ish satellites in mid-earth orbit, give everyone a GPS receiver and hope no one jams the signal.
  - Pros: Worldwide coverage, AMAZING accuracy.
  - Cons: Low power, orbiting at 12,000 miles, going 8,700 mph – you do the math . . .
    - Easy to jam/interfere with signal.





Training Without GPS

- The Objective: Learn how to Strike anywhere, anytime with tremendous accuracy WITHOUT GPS.
  - Plan A: Jamming GPS can't be THAT hard. Safety measures:
    - Massive Nellis Range Complex site for first exercise.
    - 98th Range Wing (the Gomers) read riot act.
    - FAA, Highway patrol warned.
  - The result:
    - Everyone trusted their GPS and "died" horribly.
    - No ATMs, gas pumps, weather reports for MILES around range.

FEDERAL LANDS IN SOUTHERN NEVADA

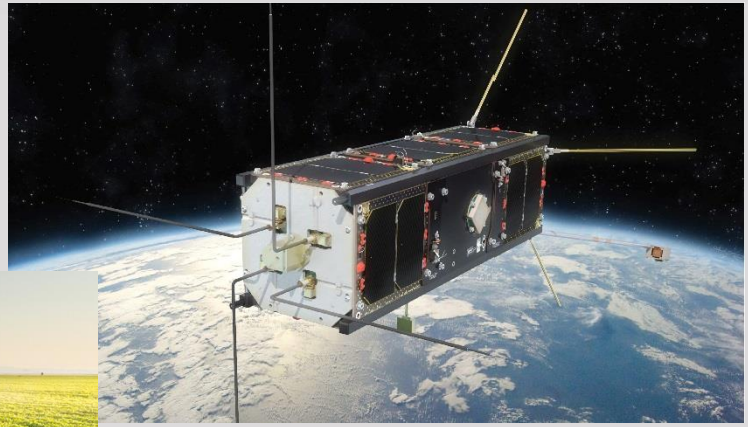
The Result

- No one trusted GPS; everyone checked for jamming, meaconing.
  - GPS interference reports skyrocketed.
  - Expected nefarious actors with powerful jammers.
    - Turns out, cigarette charger GPS jammers are a thing . . .
    - Bozos with RF devices always manage to take out GPS.
  - Intentional and unintentional GPS interference a huge issue worldwide.

GNSS Interference Detection: Inside and Out

Sandy Kennedy
Chief Engineer, Receiver Cards
NovAtel

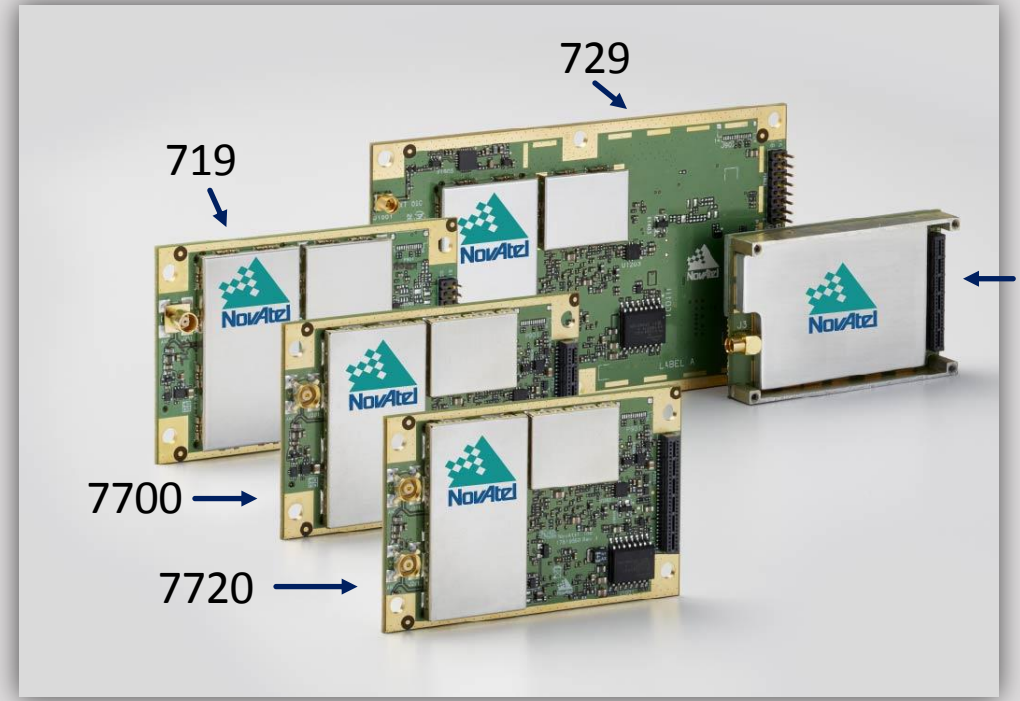
NovAtel GNSS – Everywhere!



Sportvision

Image Courtesy of Sportvision

OEM7 Generation



Interference Toolkit (ITK)

Built In Detection Routines

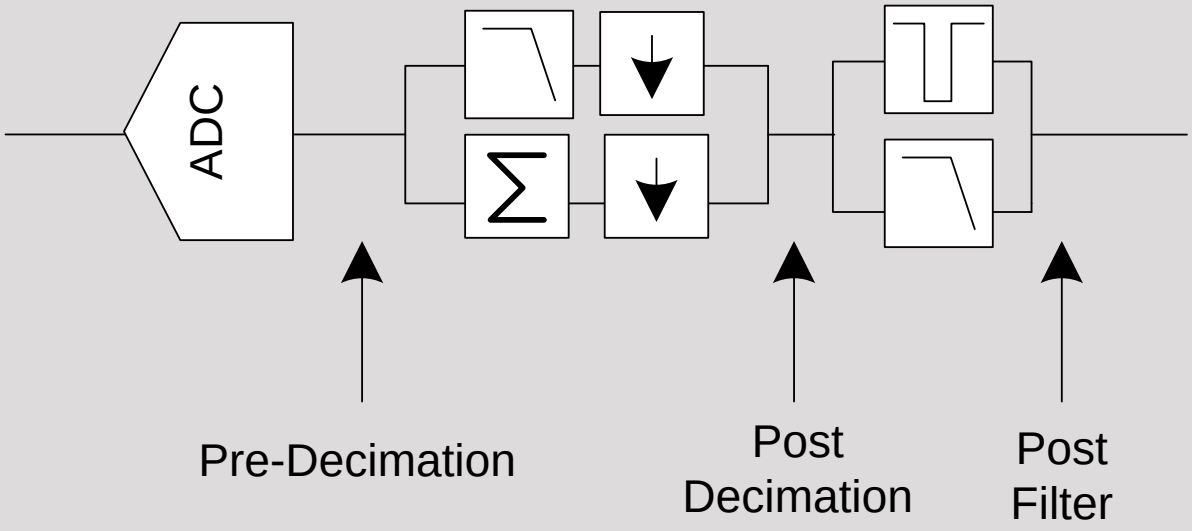
Healthy RXSTATUS Word

```
#BESTPOSA,UNKNOWN,0,45.0,FINESTEERING,1980,420733.000,00000000,b1f6,32
768;SOL_COMPUTED,PPP,51.11668316483,-114.03880704536,1064.4727,-
16.9000,WGS84,0.0323,0.0196,0.0512,"TSTR",23.000,0.000,28,28,28,28,00,
00,3f,37*35e5a931
```

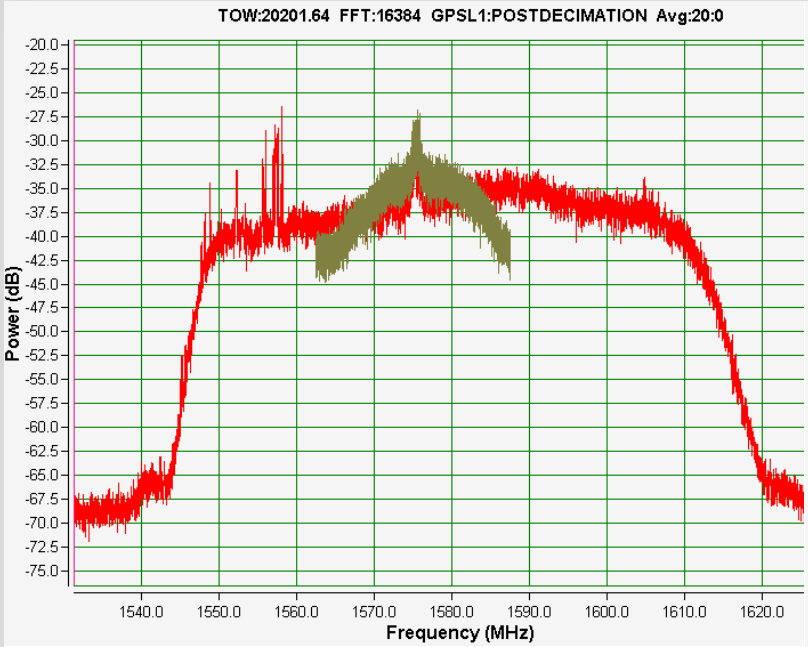
Jammer Detected – bit 15 of RXSTATUS word set

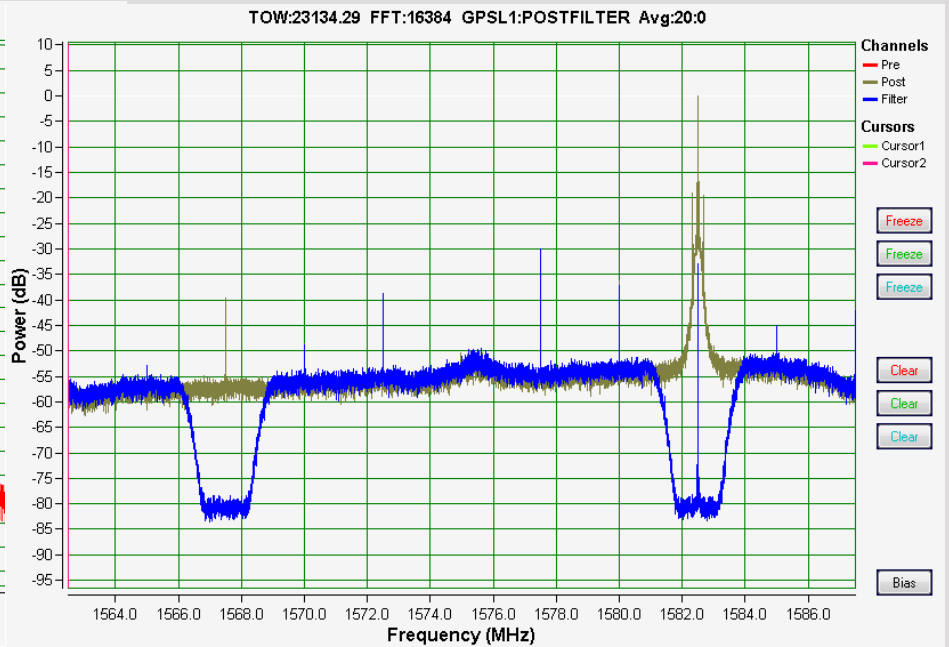
```
#BESTPOSA,UNKNOWN,0,27.0,FINESTEERING,1980,420135.000,0200c020,b1f6,32
768;SOL_COMPUTED,PPP,51.11668315170,-114.03880713426,1064.4389,-
16.9000,WGS84,0.0349,0.0213,0.0551,"TSTR",15.000,0.000,24,24,24,23,00,
00,2f,37*302e5f9c
```

Spectral Analysis



Power Spectrum Examples





Behind the Scenes

- Previous publications on mitigation capability:
  - Demonstrated Interference Detection and Mitigation Capability with a Multi-frequency High Precision GNSS Receiver, Gao and Kennedy, ION GNSS+ 2016, Portland, Oregon
  - Signal Selection and Protection in a Quad Constellation World, Gerein and Kennedy, RIN INC 2016, Glasgow
  - GNSS for UAV Navigation, Kennedy, ITSNT 2016, Toulouse
- Today we'll focus on detection capabilities

Know Before You Have a Problem

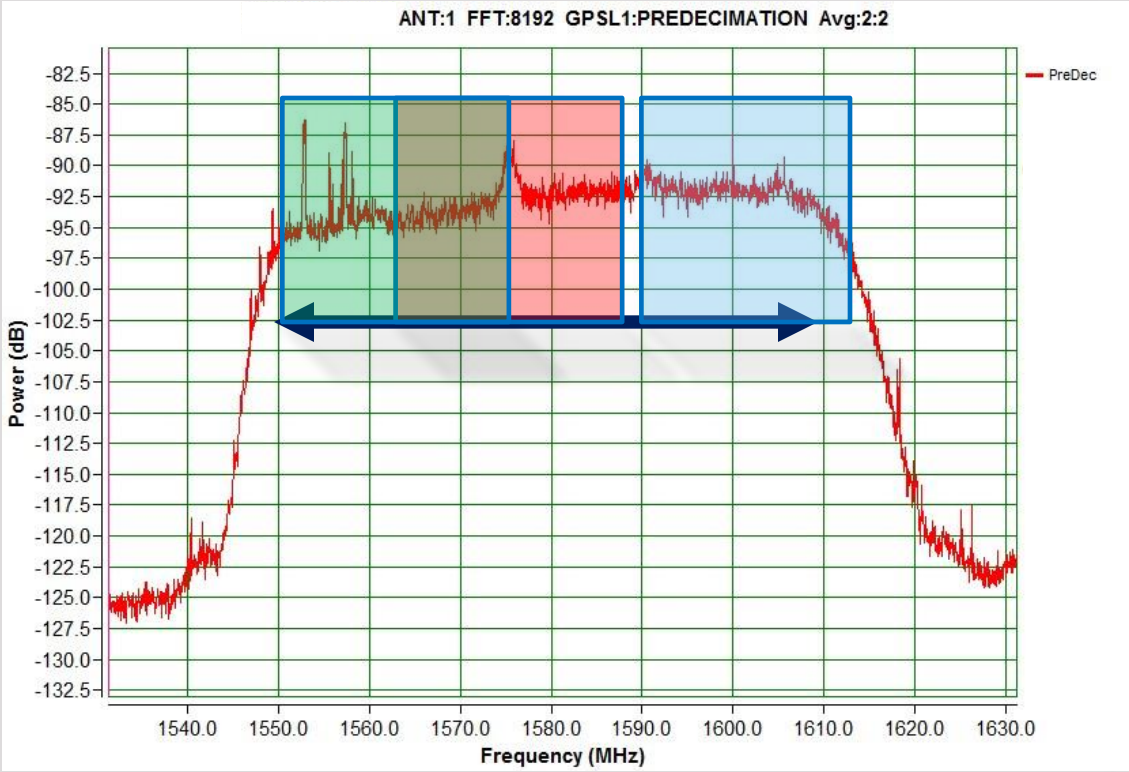
- Prevention is better than any “medicine”
- Interference threats are increasing, never decreasing
- Detection capabilities of the Interference Toolkit reveal the threats to your high performing system – inside or out

Solving self-interference using the Interference Toolkit

John Schleppe
Engineering Fellow and Manager of Research
NovAtel

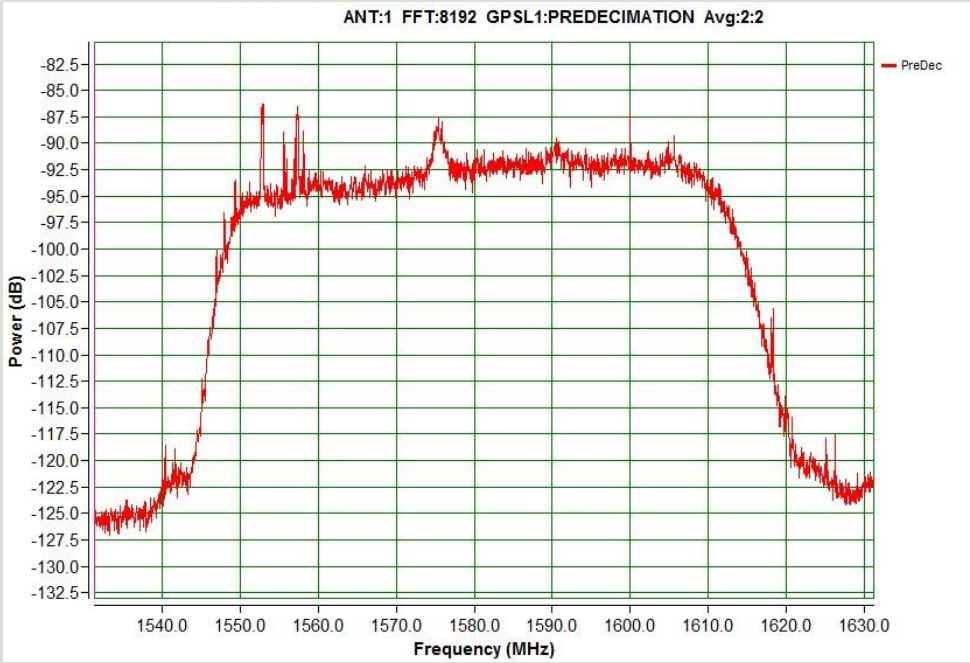
Power Spectral Density Graph

- X Axis – Frequency
  - GPSL1 is 1575.42 MHz
- Y Axis – Power in dB
  - Log10 based
- Size of the FFT
  - # of bins containing the power
  - FFT Size here is 8192 (8K)
- L1 Spectrum
  - GPS L1, QZSS L1, GALILEO E1
  - BeiDou B1
  - GLONASS L1



ITK Tools Available – Power Spectral Density

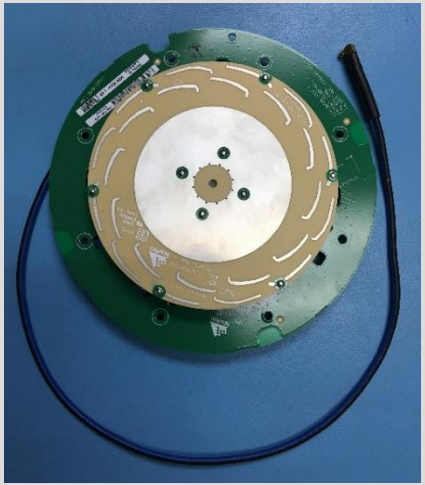
- Command:
  - ITSPECTRALANALYSIS
    - Size from 1K to 64K
    - Interval from 50 ms
    - RF Path and Location
- Log:
  - ITPSDFINAL
    - Status Word
    - Power Spectral Density



ITSPECTRALANALYSIS predecimation gpsl1 100 8K 2 2

http://docs.novatel.com/OEM7/Content/Commands/ITSPECTRALANALYSIS.htm
http://docs.novatel.com/OEM7/Content/Logs/ITPSDFINAL.htm

Smart Antenna Components



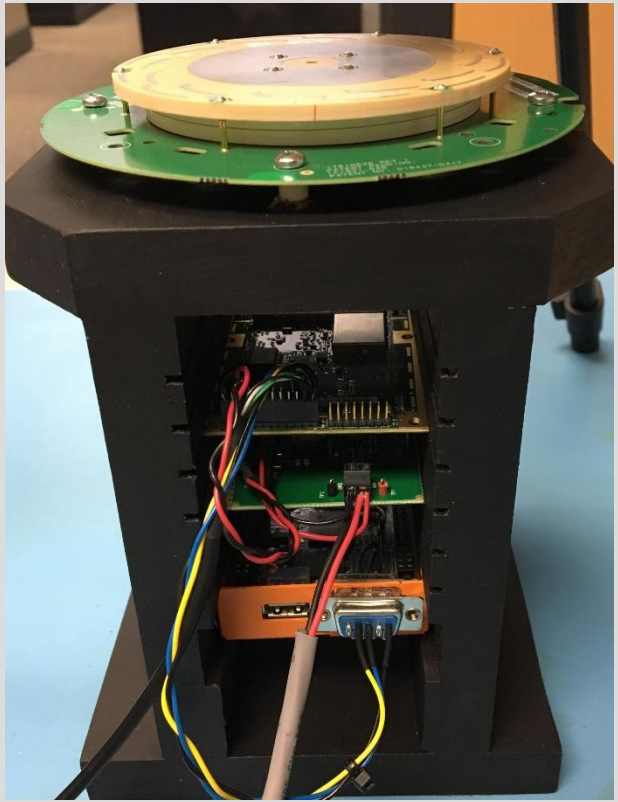
GPS 850 Antenna Element
L1/L2/L5/Lband
+Antenna Cable

OEM729 – GPS, GLONASS, Galileo, BeiDou, QZSS
+ Power, USB, Serial Cables

BeagleBone Black
Low Cost
Linux Platform
USB, Ethernet, Serial, HDMI

Power Supply – 12 VDC In, 3.3 and 5.0 VDC Out
+ OEM729 Power cable And BBB Power Cable

Prototype Smart Antenna



GPS 850 Antenna Element

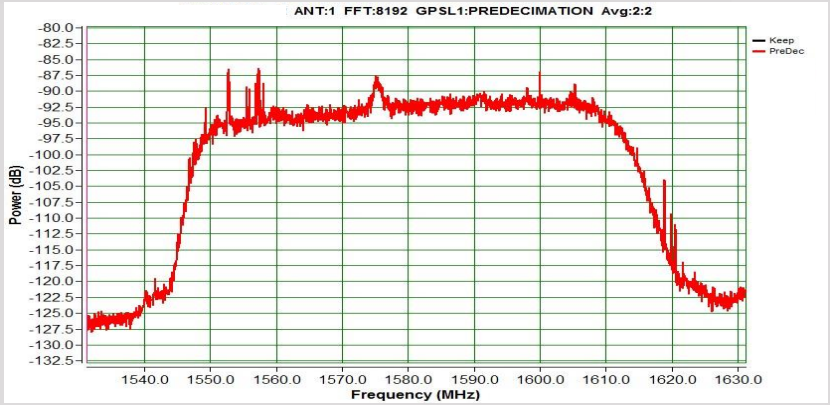
NovAtel OEM729 GNSS Receiver

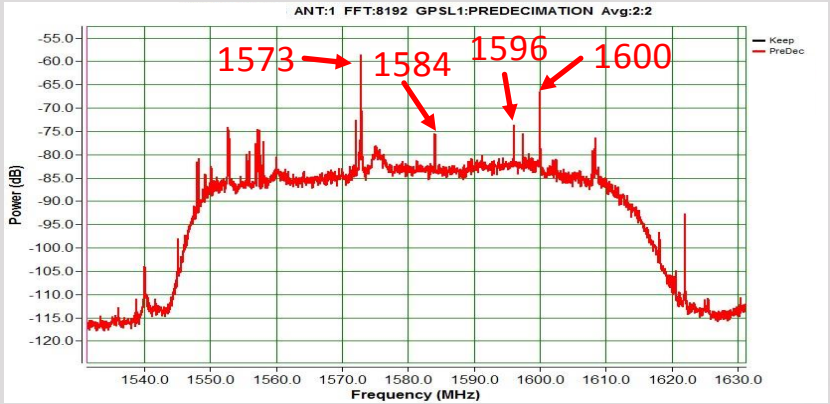
Power Supply

BeagleBone Black

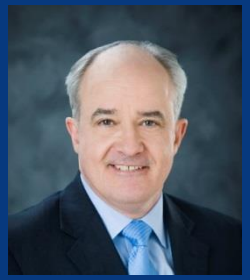
Clean Spectrum vs Self-Interference

- Important to know what a clean spectrum in the test area looks like.
- When eliminating self-interference we will work towards eliminating the additional spikes
- The top plot is the result of using the 850 antenna element and OEM729 outside.
- The bottom plot is our initial design with an unshielded BBB using re-radiated GNSS signals.





Ask the Experts – Part 1



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Moderator: James Poss, Maj Gen (ret), USAF

Poll #2

Which of the following are you concerned about:

a. Intentional/malicious jamming
b. General wireless communication interference
c. Self-induced system interference
d. Another type of interference not mentioned above
e. None

Solving self-interference using the Interference Toolkit Part II

John Schleppe
Engineering Fellow and Manager of Research
NovAtel

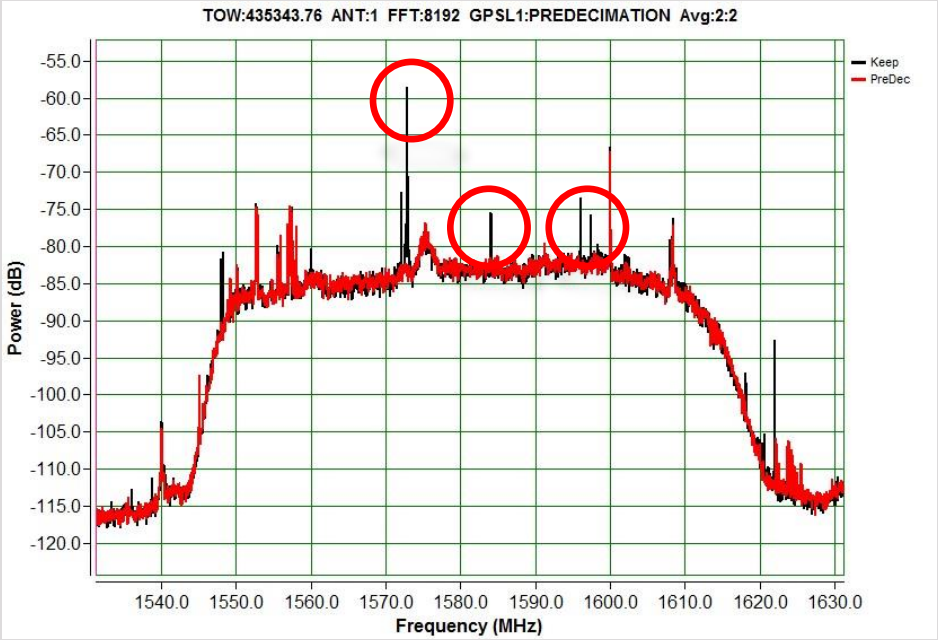
First Design

- Unshielded BBB
- Long antenna cable (blue)
- Long power cable to BBB (red & black twisted)

- Antenna
- OEM729
- Power – 3.3V and 5.0V
- BBB Datalogger

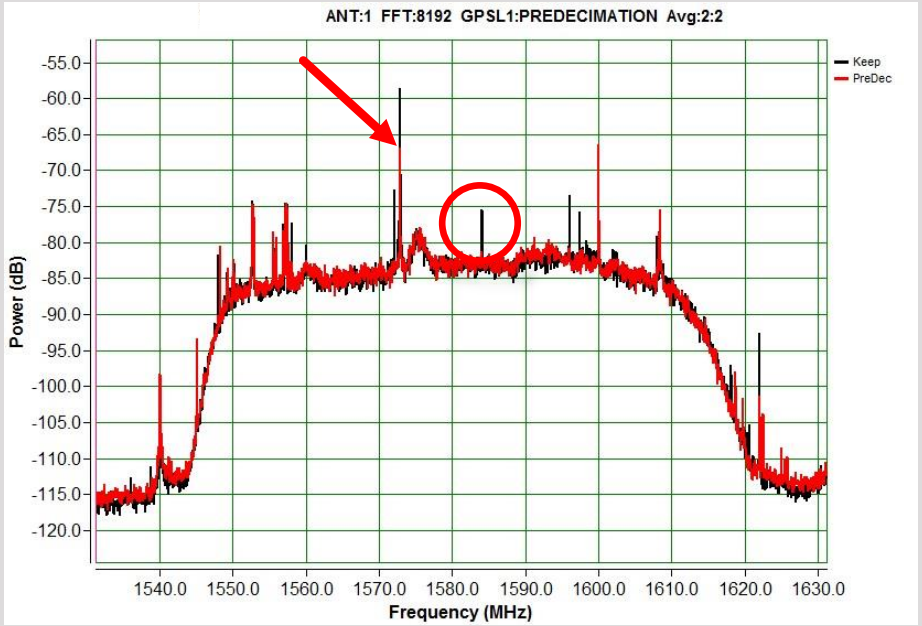
Isolating the Noise – turn off the BBB

- Removing the power from the BBB cleaned up the L1 spectrum – except for interference at 1.6 GHz.
- Black curve is from previous slide, red curve is with BBB powered down.
- Next Step – clean up the BBB since we need it for datalogging



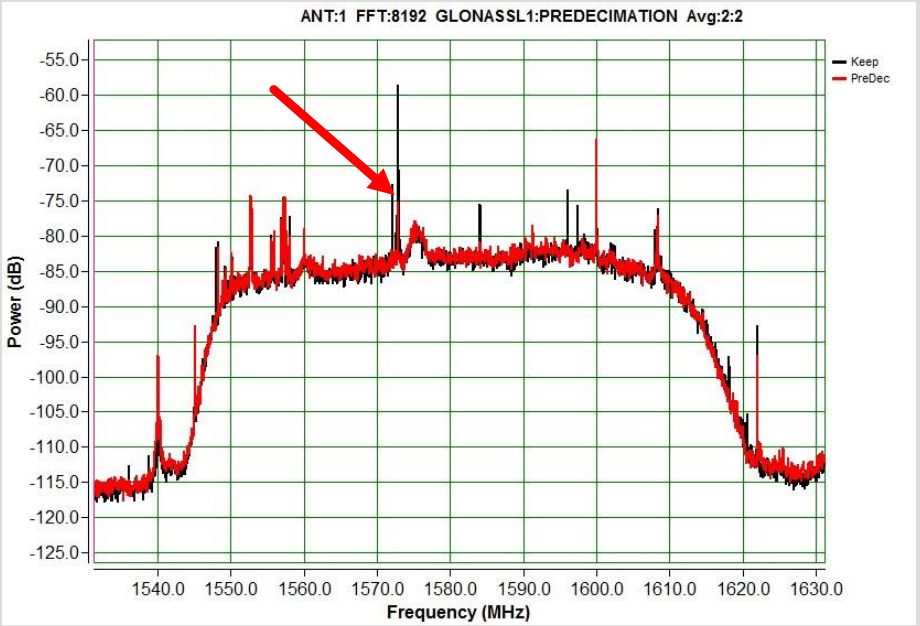
Shielding the BeagleBone Black

- Shielding the BBB improved the interference at 1572.9 MHz and 1584.1 MHz



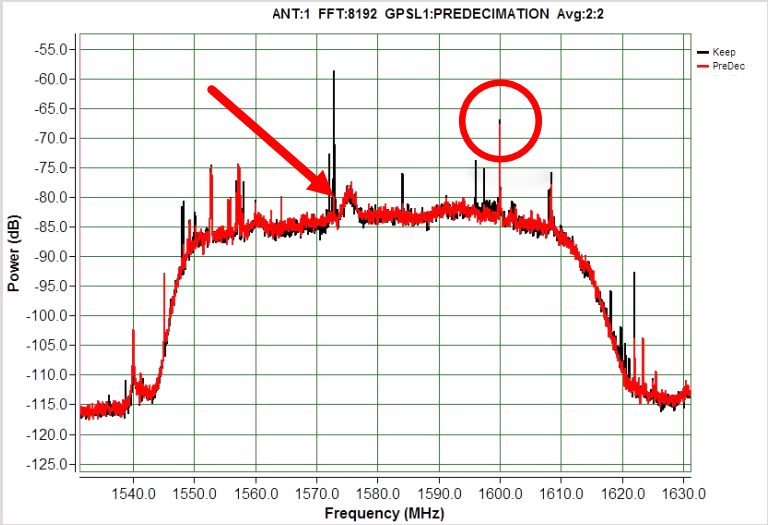
Turn the BeagleBone Black over

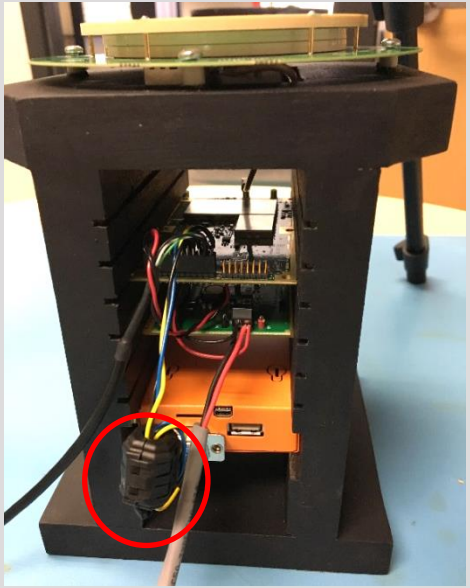
- Turning the shielded BBB over further reduced the interference at 1572.9 MHz

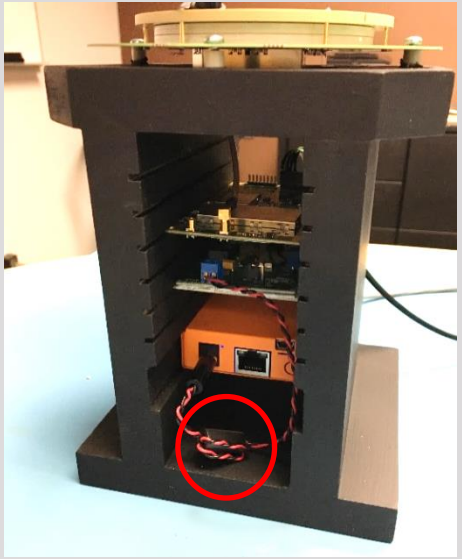


The Cables are Emitting!

- Put a choke on the BBB's power and serial cables



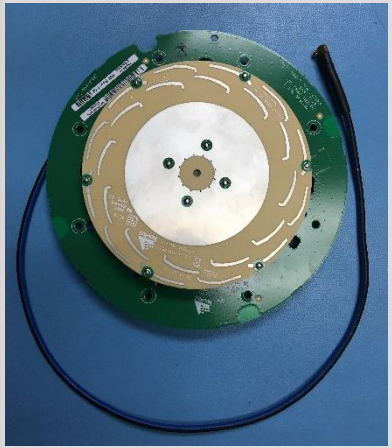


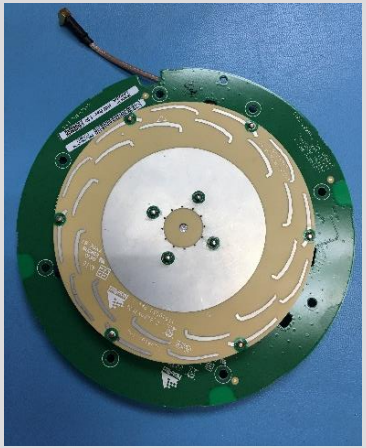


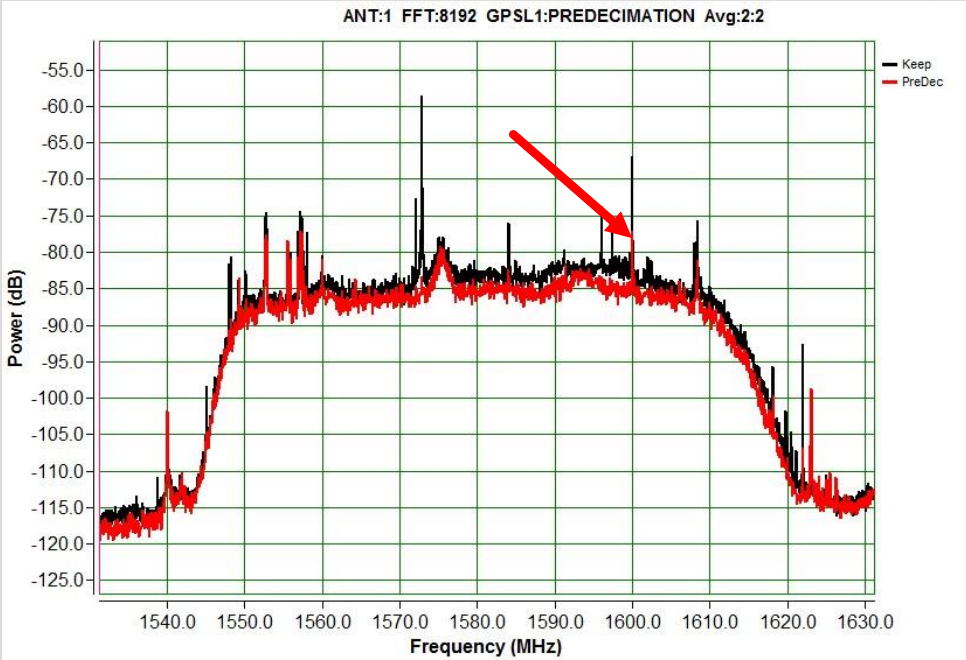
Ferrite chokes put on serial and power cables

Reduce the interference at 1.6 GHz

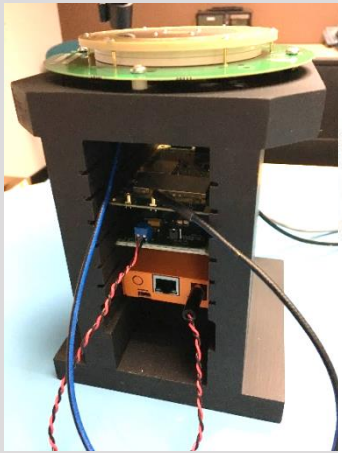
- Changed to a shorter antenna cable

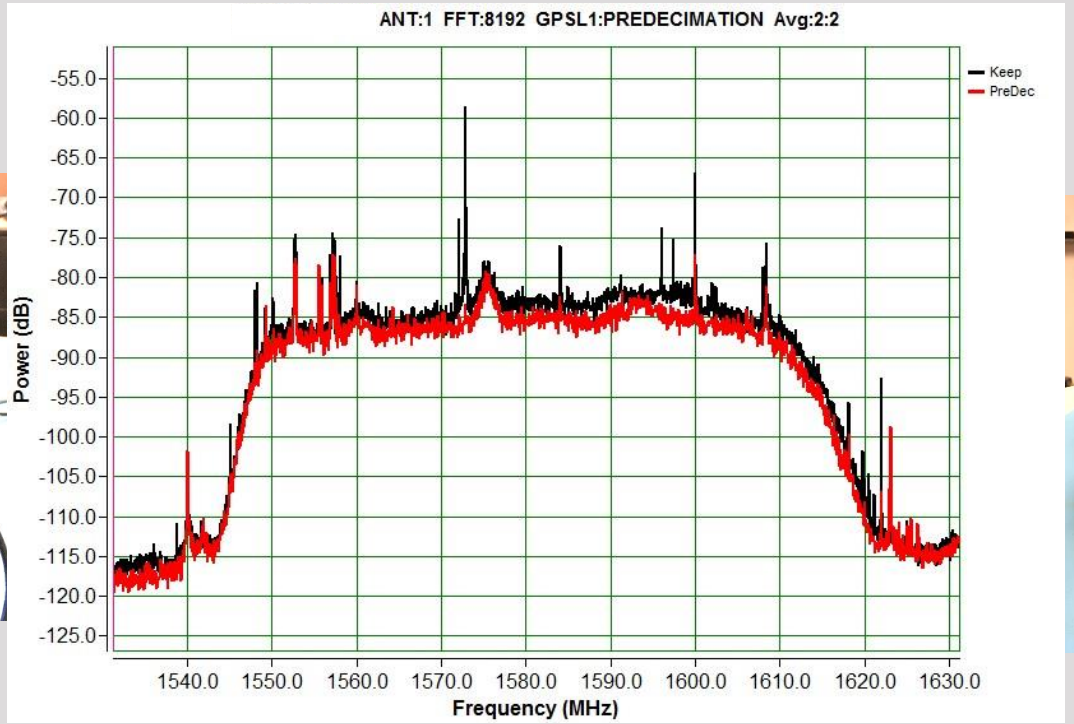




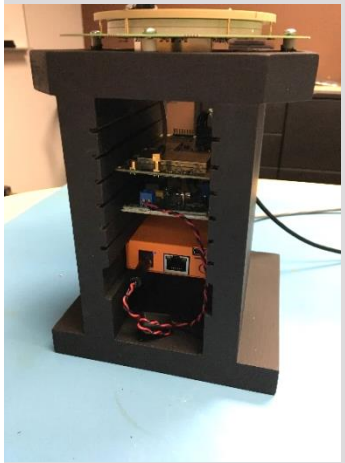


Final Results – Before and After

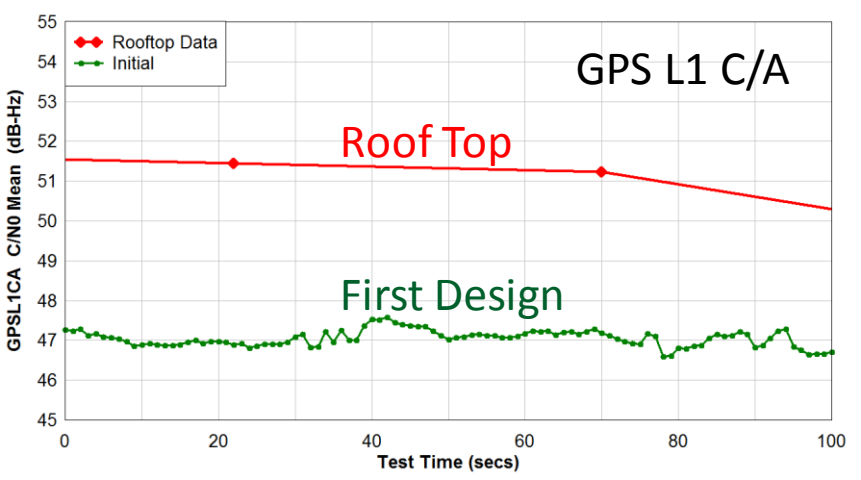


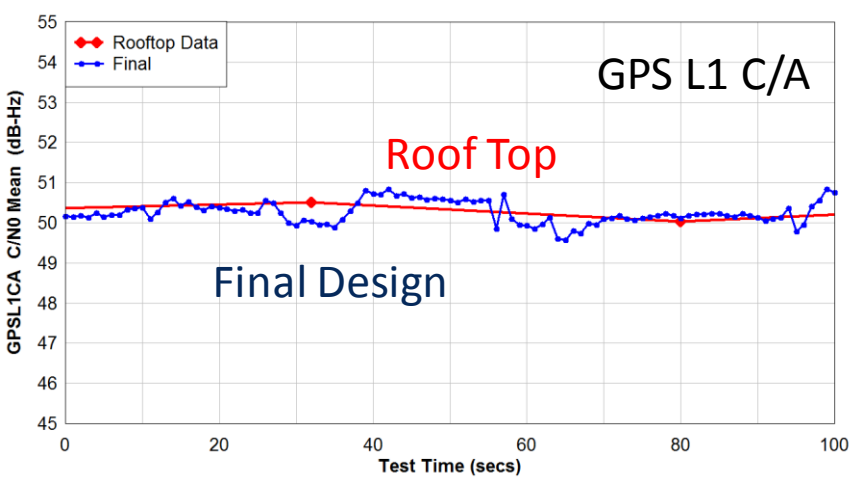


Improved GPSL1 C/N0 by 4 dB



Final Results – Before and After





Finding External Interference using the Interference Toolkit

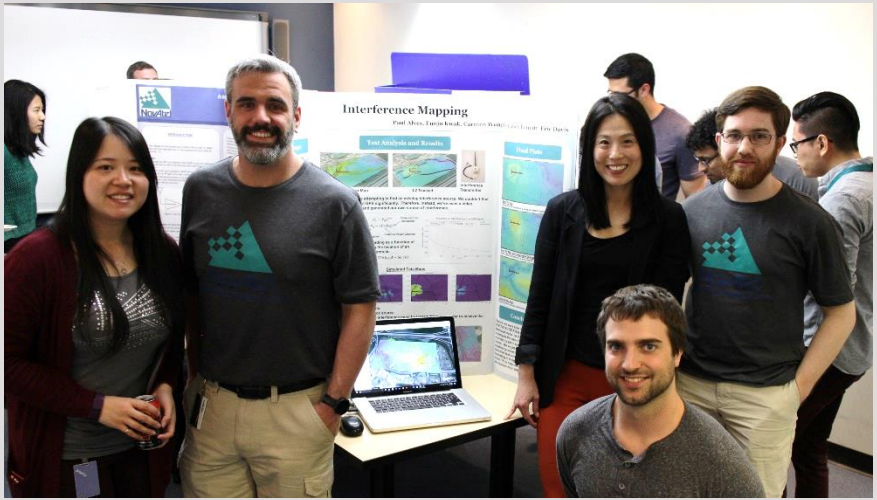
Paul Alves
Principal Research Engineer
NovAtel

Special Thanks

- Thanks to my Innovation Week 2017 team:
  - Carmen Wong
  - Matthew Clampitt
  - Eric Davis
  - Eunju Kwak

- NovAtel Customer Service

  For support and helping me find data
  - Bryan Leedham
  - Saravanan Karuppasamy

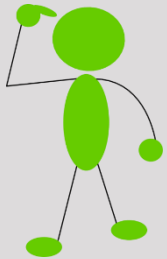


Motivation

- Customer service case in Assam, India
- Periodic GNSS performance issues were reported
- Data collected using ITK to investigate the problem

Searching for Interference

- Playing hot and cold to find the interference source
- Numbers are the received interference power



(Map data: Google, DigitalGlobe)

Interference Found

- Interference source was identified
- Weather antenna transmitting at 1580MHz
- Recommended to customer to move the antenna to another building
- Applying an Interference Tool Kit notch filter also mitigates the problem

Goals and Assumptions

- Goal:
  - Visualize the interference so that it is easier to understand where the interference is coming from and find the source of the interference
- Plan:
  - Use the received power levels to estimate the location of the interference
- Assumptions:
  - The interference source is static
  - The interference source is continuous
  - The gain is the same on all measurements

Power Loss Function

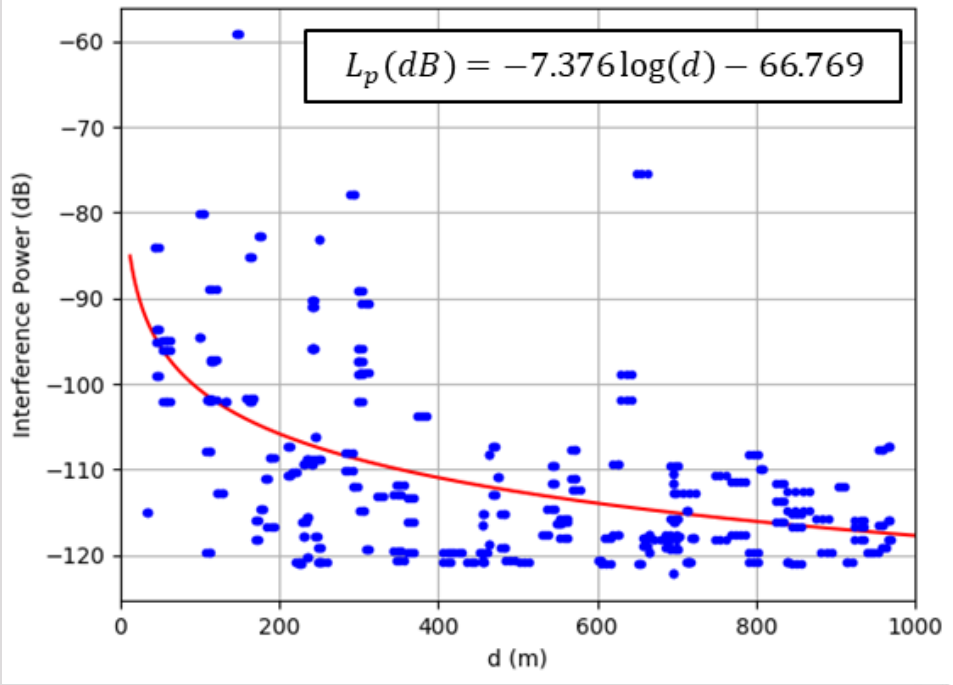
Free space loss

$$L_p(dB) = 10\log\left[\left(\frac{4\pi d}{\lambda}\right)^2\right]$$

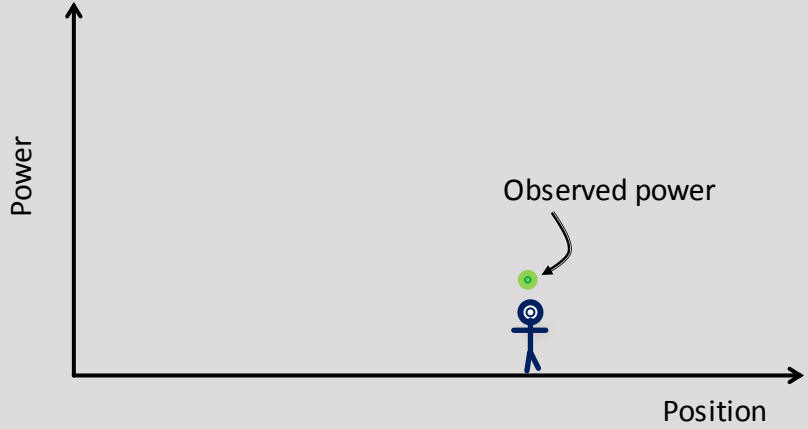
$$L_p(dB) = 20\log(d) + 20\log(f) - 147.55$$

d - distance in m
f - frequency in Hz

Actual power loss



Mapping a Single Observation



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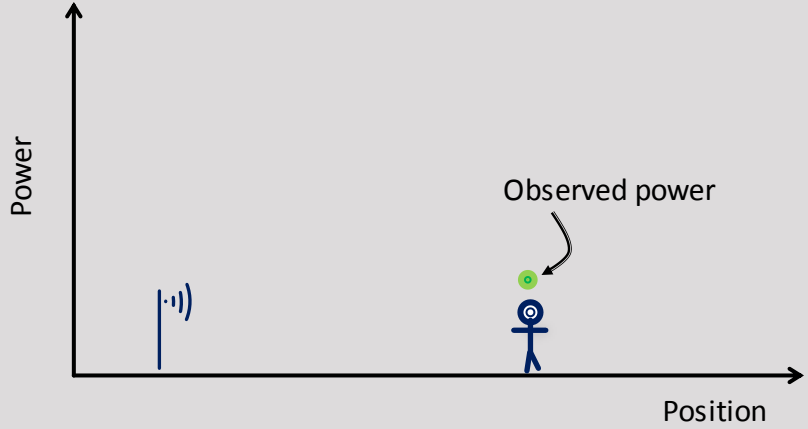

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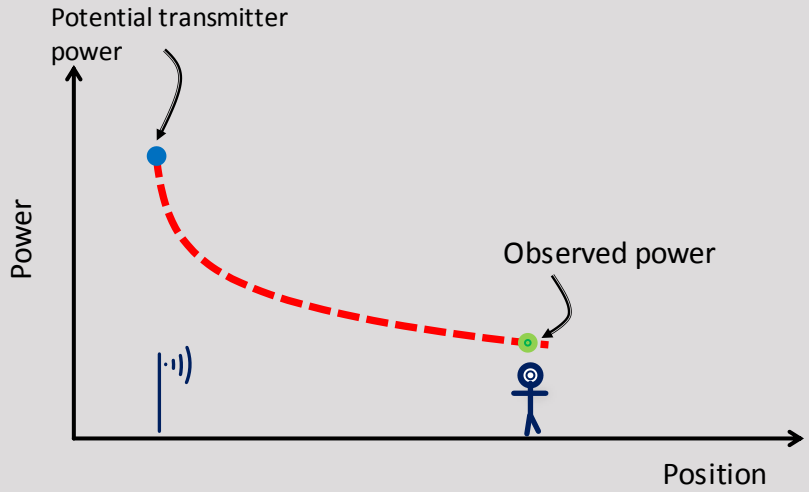

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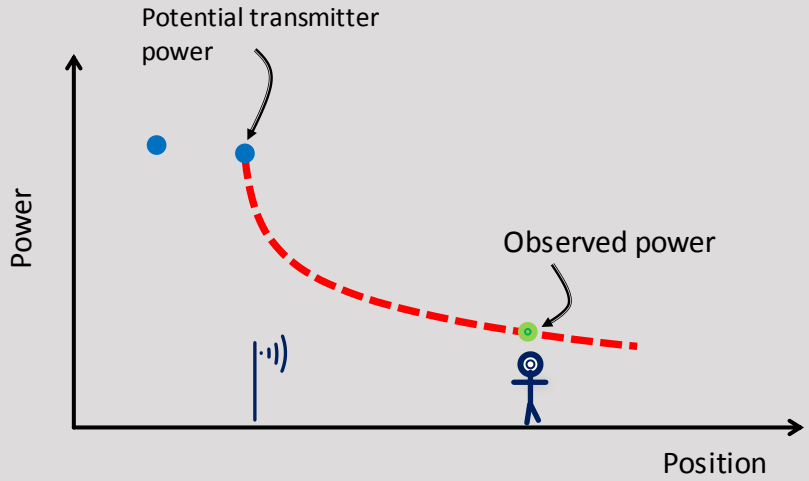

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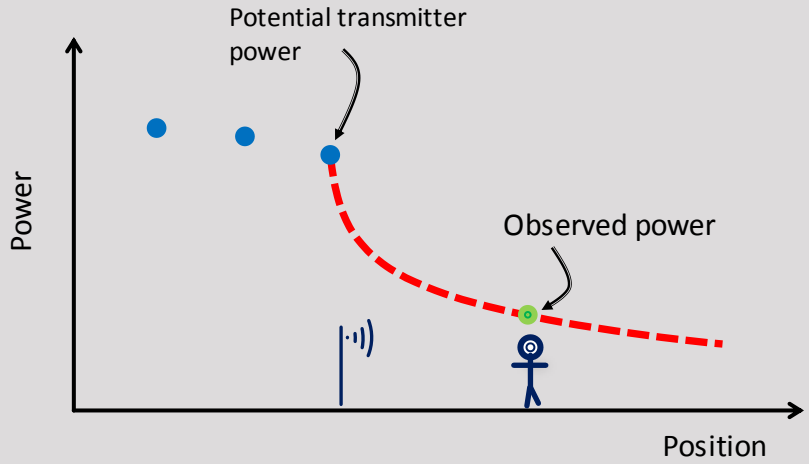
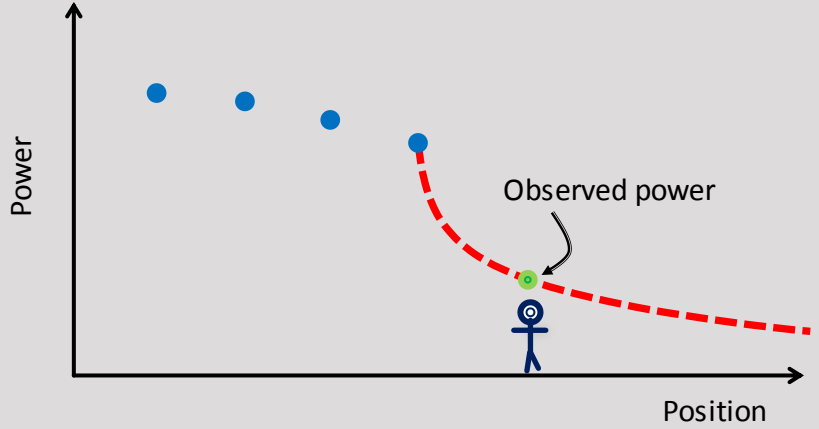
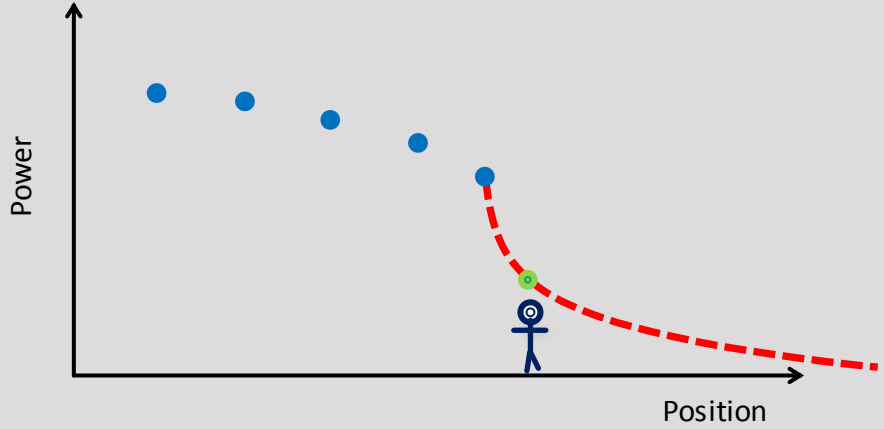


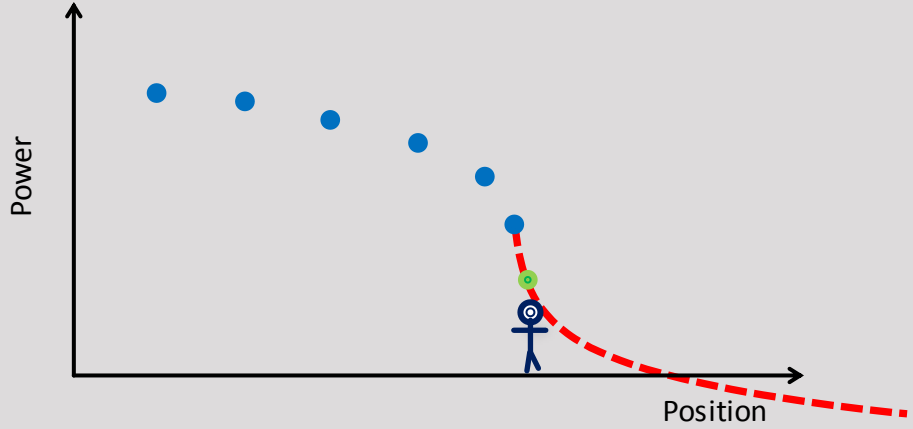
Mapping a Single Observation



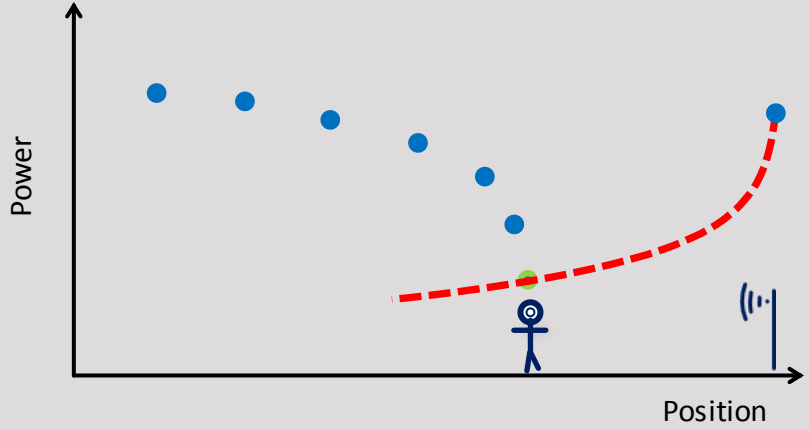
Mapping a Single Observation



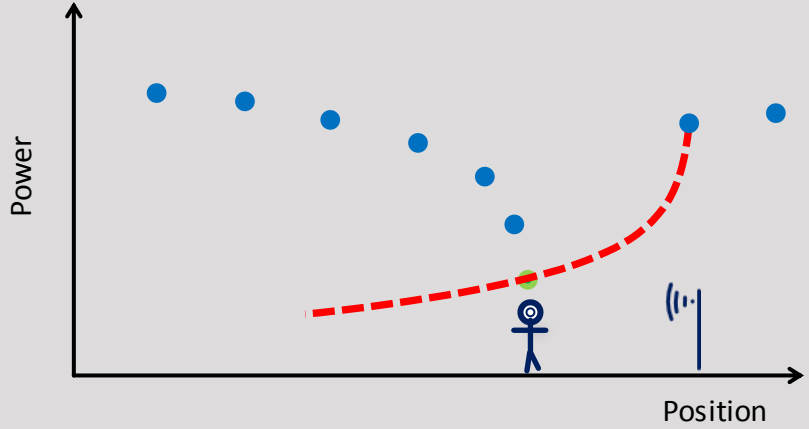
Mapping a Single Observation



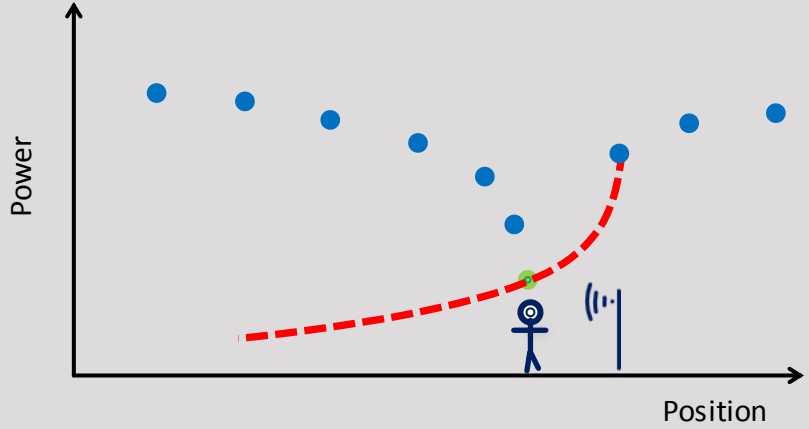
Mapping a Single Observation



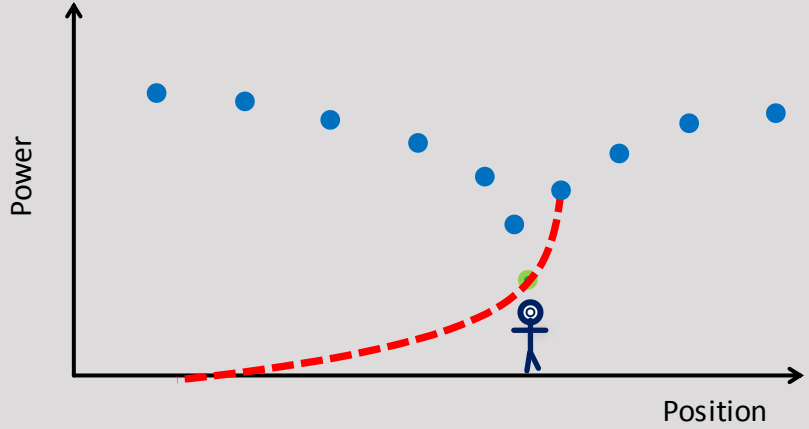
Mapping a Single Observation



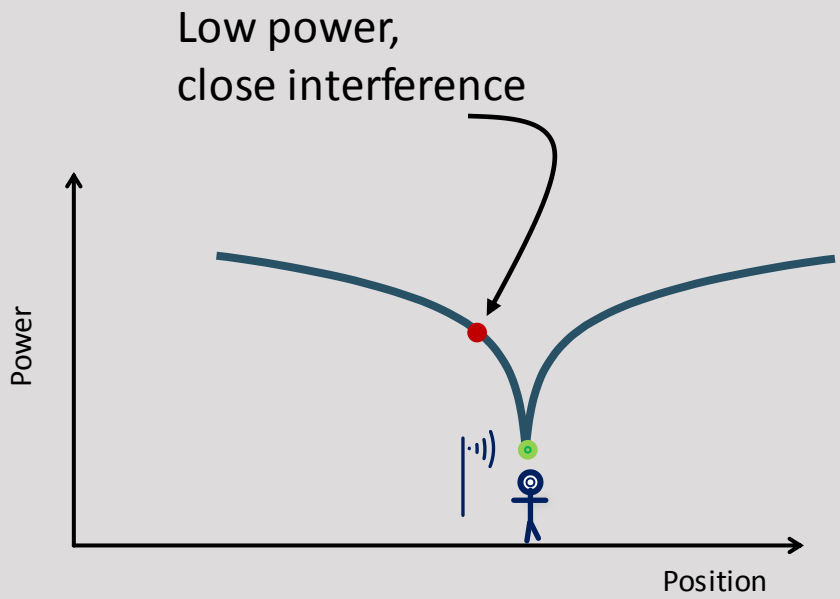
Mapping a Single Observation



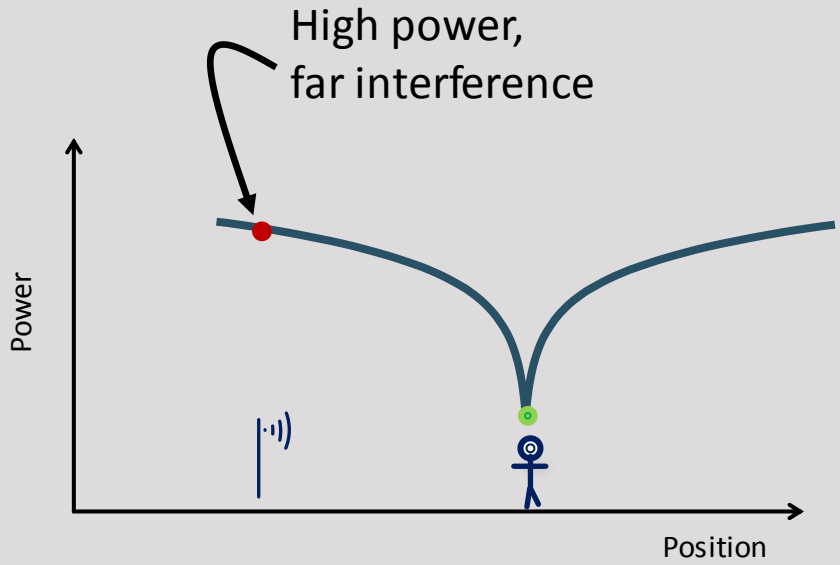
Mapping a Single Observation



Mapping a Single Observation

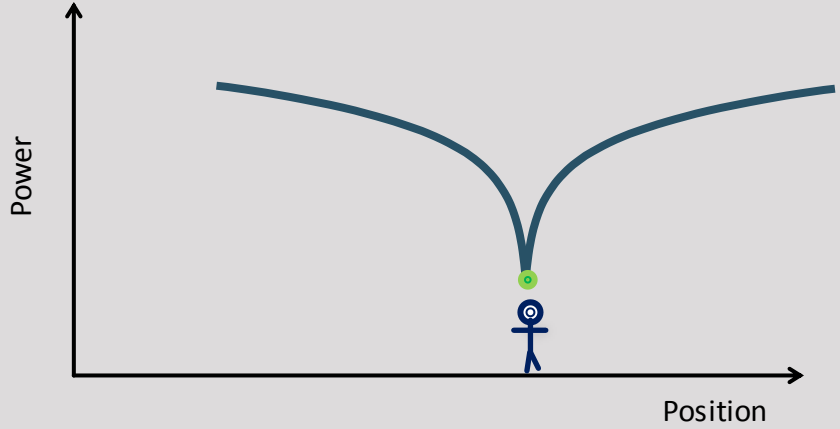


Mapping a Single Observation



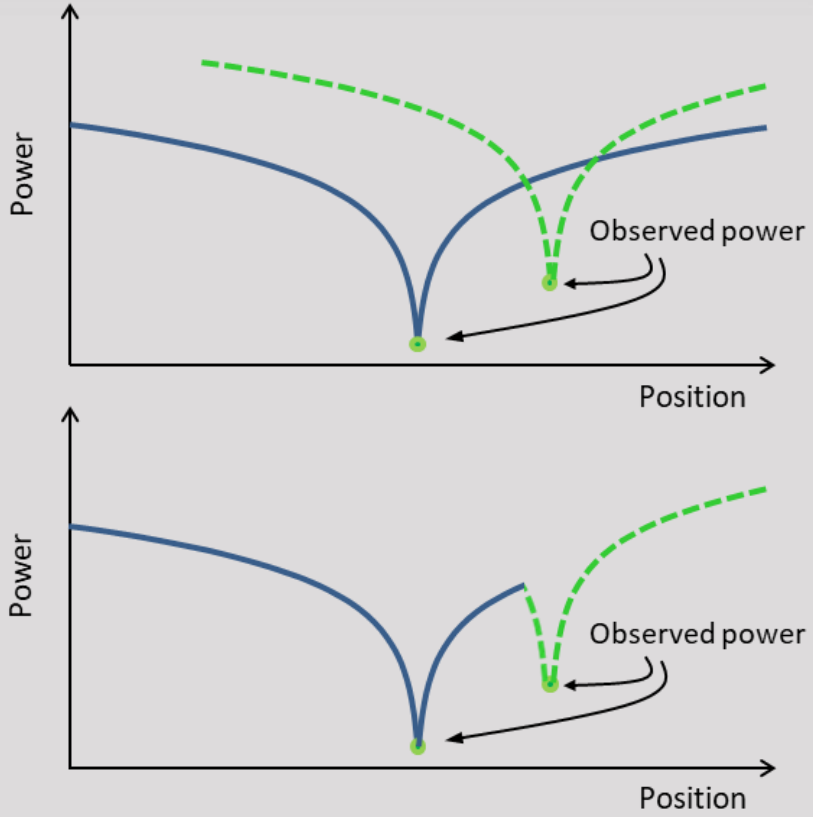
Mapping a Single Observation

Transmitter can be anywhere!



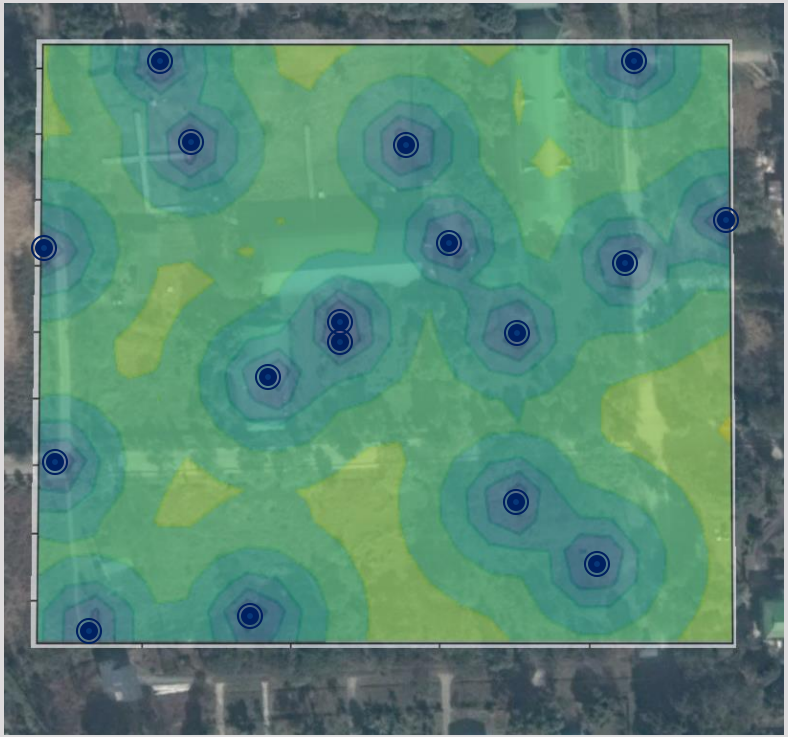
Adding More Observations

- Multiple observations are combined.
- Many options for mixing/combining measurements.
- Minimum value used in this research.



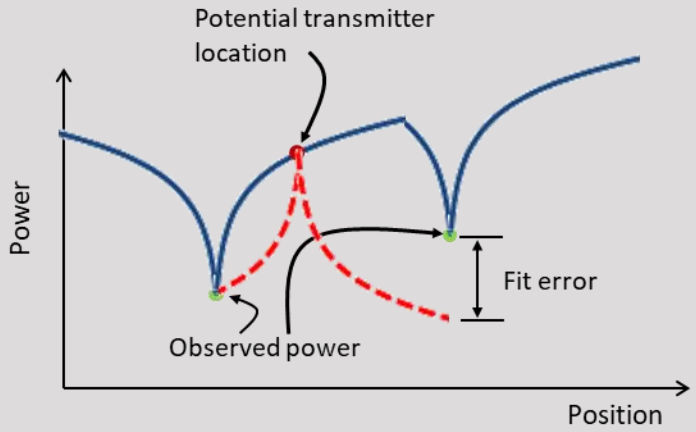
Minimum Detectable Interference

- The visualization of this step give the minimum detectable interference.
- Shows the power of hidden interference sources in the region.
- Light colors/yellow are high power. Dark colors/blue are low power.



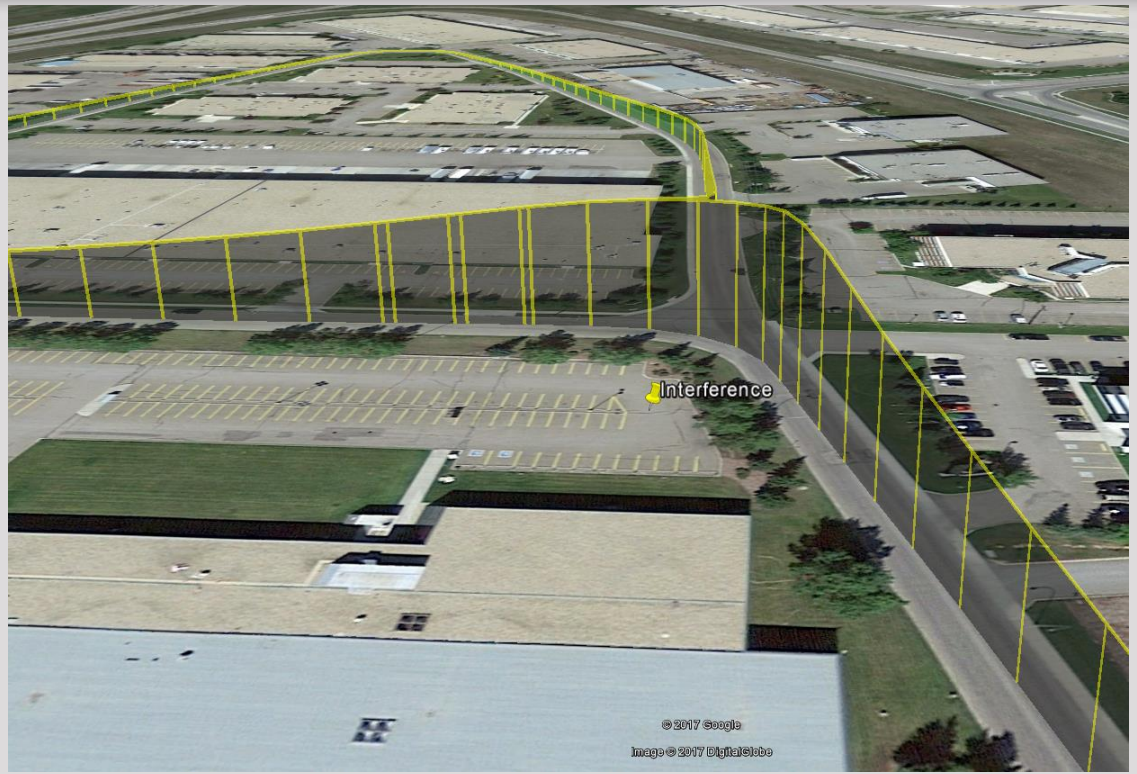
(Map data: Google, DigitalGlobe)

Goodness of Fit



- To find the interference source, reverse the calculation.
- Create a grid of locations.
- For each location, calculate the expected received power for each measurement
- Difference between expected receiver power and measurement is the fit error
- Calculate the RMS fit error for all measurements.

Rollercoaster plots



(Map data: Google)

Simulated Results (1)

- Roller-coaster plots show the interference power
- Interference simulation is “perfect” with no noise or errors. Matches power loss model perfectly.
- Goodness-of-fit map agrees with the interference location

Light color = higher likelihood of interference location

(Map data: Google)

Simulated Results (2)

Light color = higher likelihood of interference location

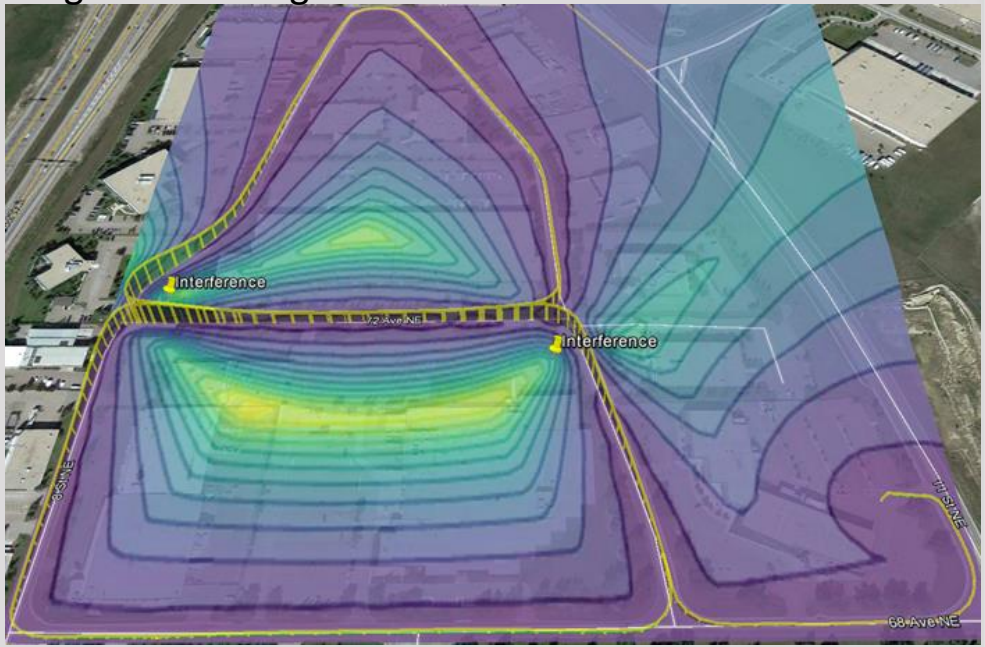
(Map data: Google)

(Map data: Google)

Simulated Results (3)

- Multiple interference sources do not work well with this model.
- Roller-coaster plots are still very useful for visualizing the data.

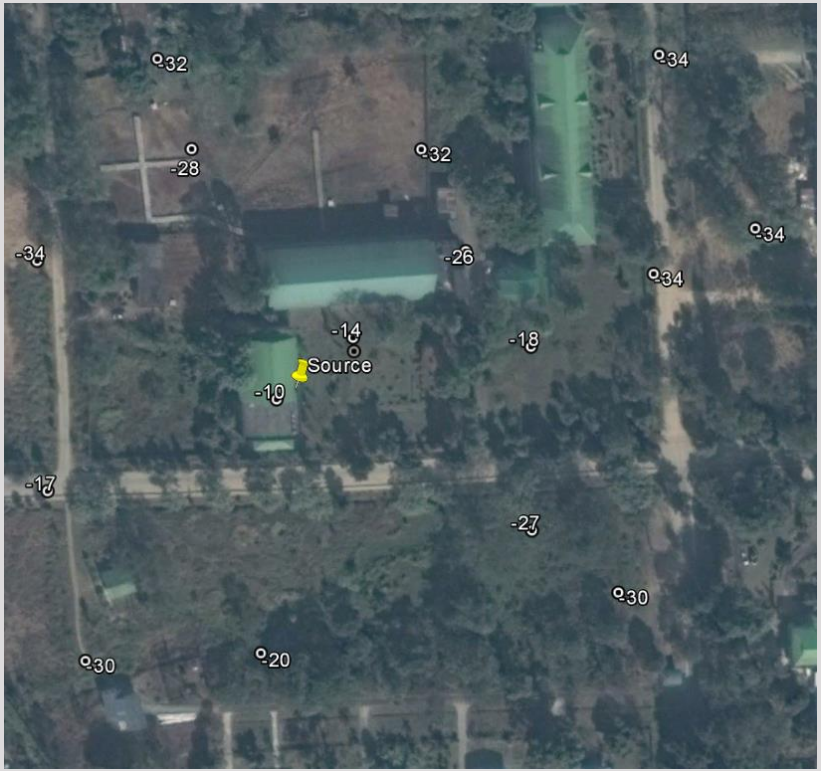
Light color = higher likelihood of interference location



(Map data: Google)

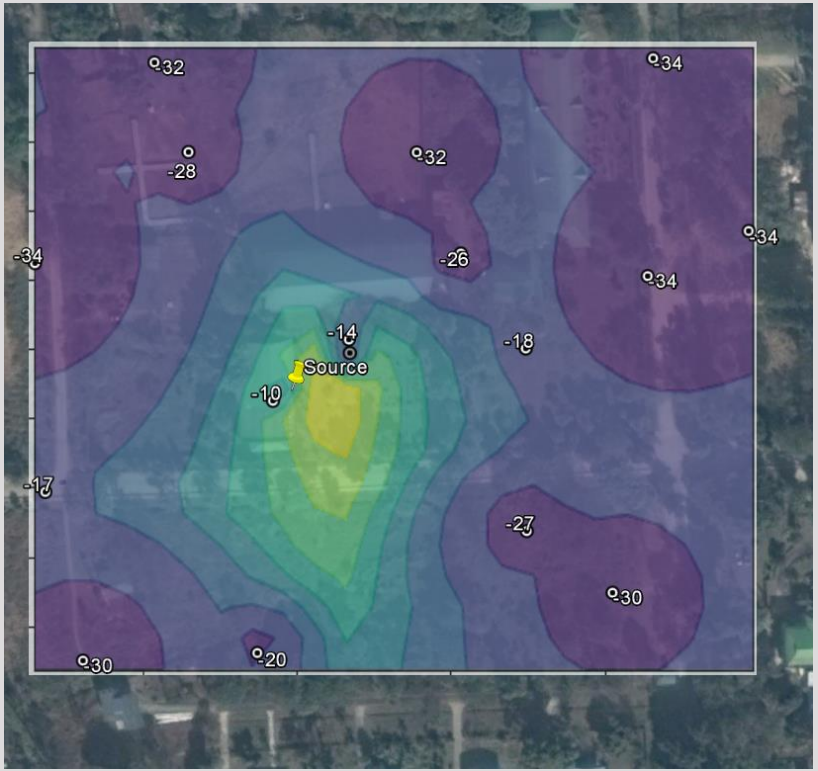
India Case Study

India Case Study



(Map data: Google, DigitalGlobe)

India Case Study - Map



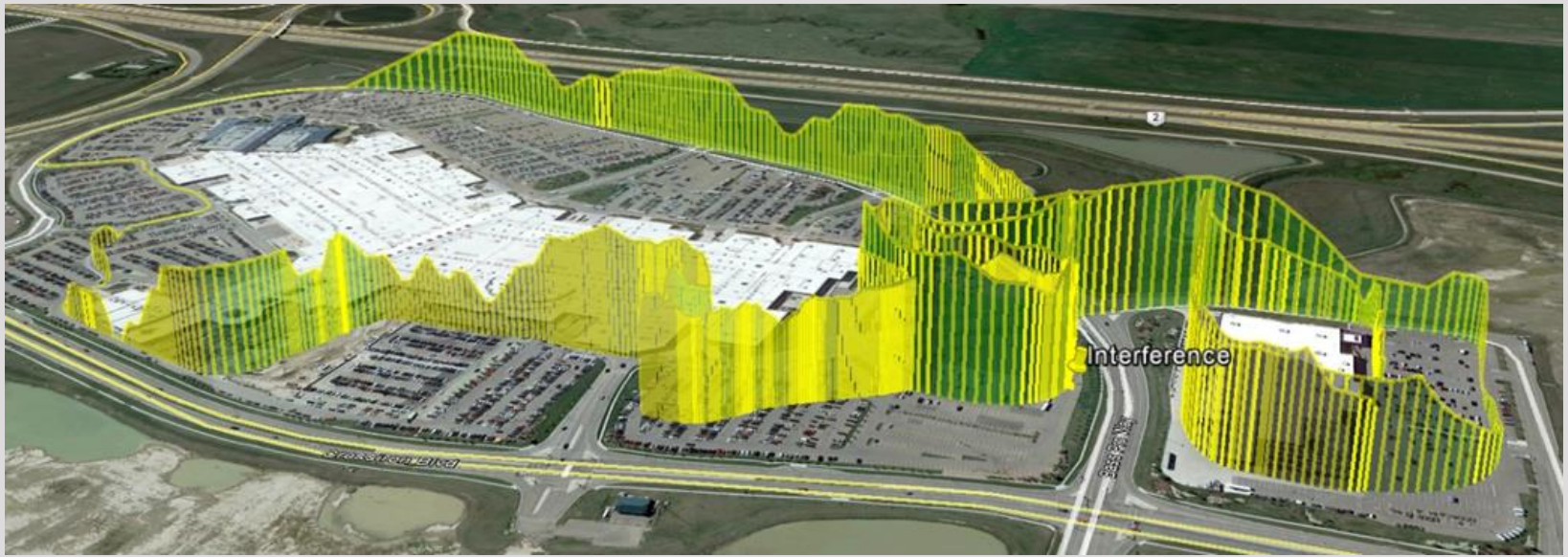
(Map data: Google, DigitalGlobe)

Calgary Case Study

Calgary Case Study

- Potential interference device was identified
- Interference source is a video transmitter intended for UAVs
- Broadcasts at 1.2GHz at 800mW
- Data was collected with
  NovAtel OEM729 with ITK

Calgary Case Study - Interference



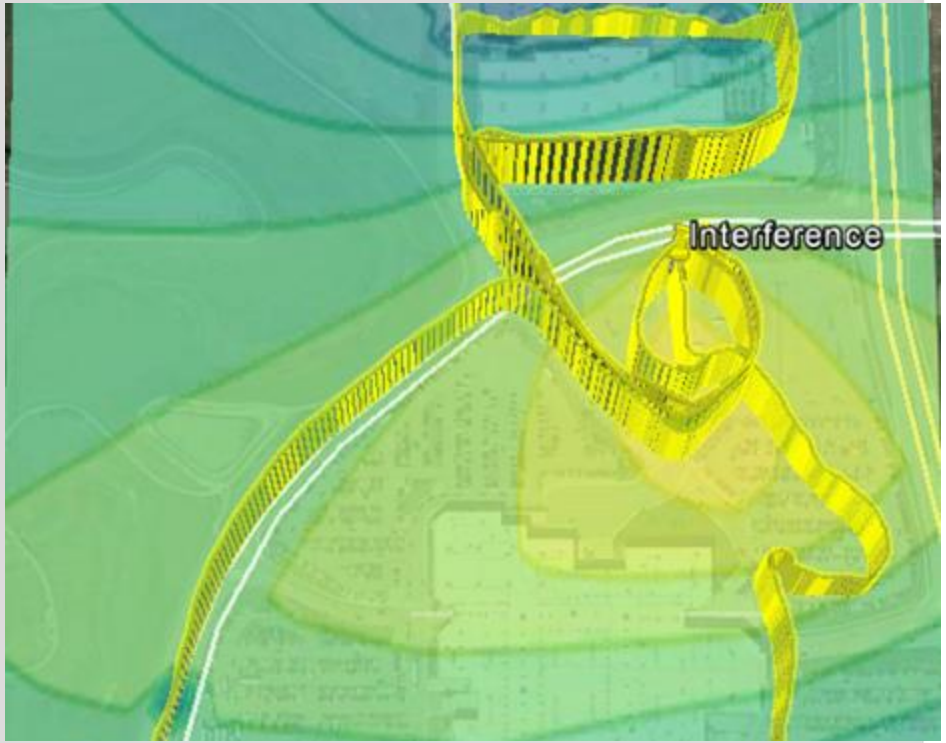
(Map data: Google, Landsat / Copernicus, DigitalGlobe)

Calgary Case Study – Number of L2 Sats Tracked

(Map data: Google, Landsat / Copernicus, DigitalGlobe)

Goodness-of-Fit Map – All data

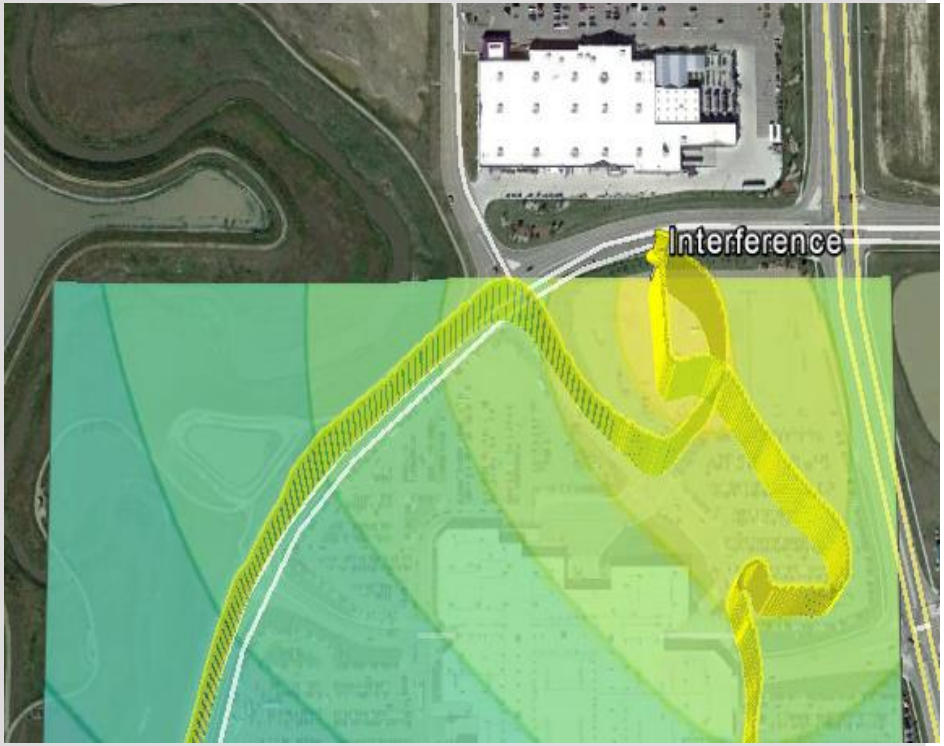
- Interference map pretty good
- Shifted south due to building at the north
- Much easier to identify the interference source than the “hot and cold” method



(Map data: Google)

Goodness-of-Fit Map – South data

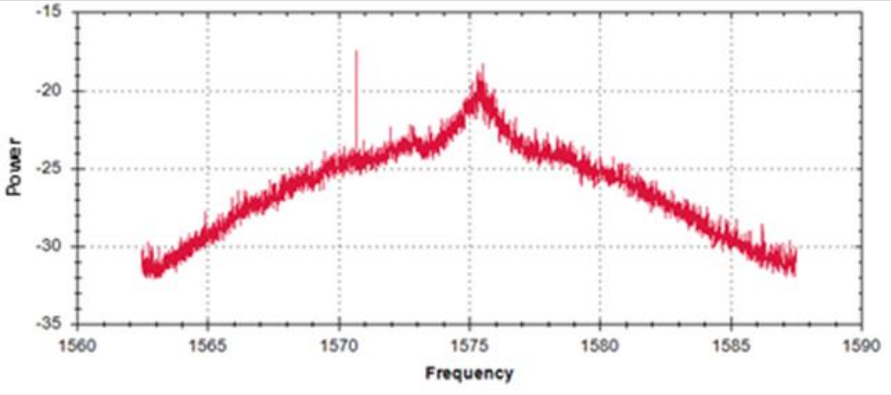
- Map with north data removed
- Goodness-of-fit improves without the data behind the building at the north



(Map data: Google)

Tokyo Case Study

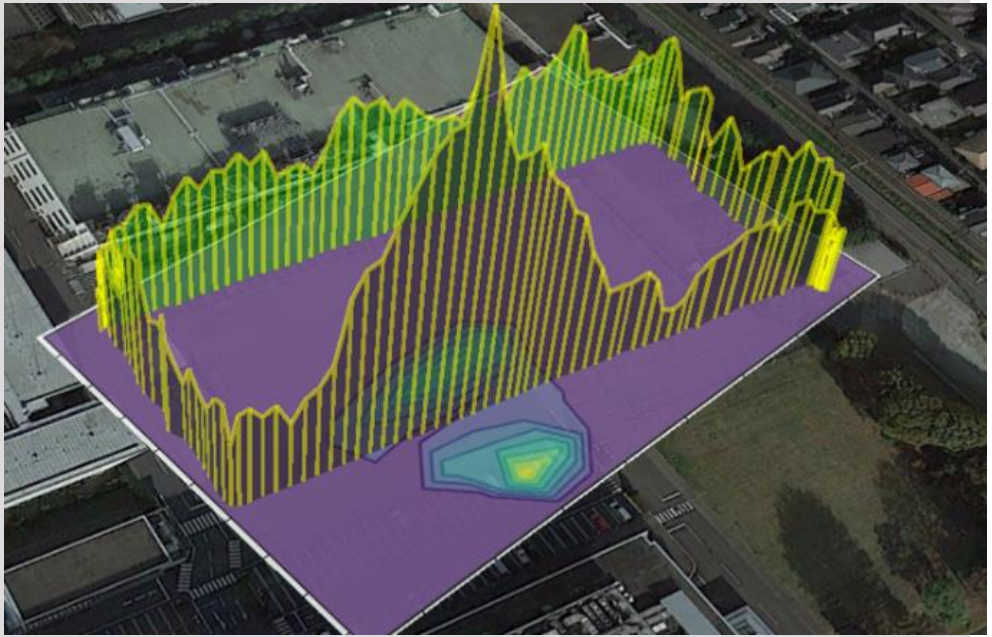
Tokyo Case Study



- Customer in Japan asked for a pre-scan of a few areas to decide the best location for a product demonstration
- Minor interference was discovered at one of the locations.

Tokyo Case Study - Interference

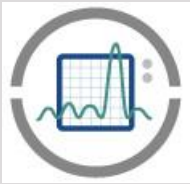
- Potential interference was identified.
- OEM729 receiver was used to investigate
- Believe that interference was originating from a vehicle in the parking lot
- No noticeable impact on GNSS performance in this case



(Map data: Google, Zenrin)

Key Take Away Today

- Often it is unintentional interference that creates problems.
  - No matter what the intention, the effect on performance is the same
- Make sure that your own integration isn't hurting your GNSS performance
  - Time to acquisition/re-acquisition
  - Time to first RTK fix/PPP convergence time
- The Interference Toolkit is on every OEM7 receiver.



Poll #3

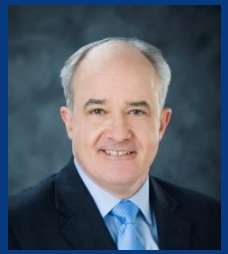
Would having these options on your receiver influence your receiver purchasing decision?

a. *Interference detection*
b. *Interference mitigation*
c. *Both*
d. *Neither*

Next Steps

- Contact support@novatel.com
  - If further assistance is required to locate previous publications on mitigation
- Visit www.novatel.com/solutions/interference-mitigation
  - To watch Interference Mitigation videos and find related product information
- Visit www.novatel.com/ITKWebinar2018
  - To sign-up for feature and PC software updates on NovAtel's Interference Toolkit

Ask the Experts – Part 2



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Manager of Research
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