NTIA Interference Analyses: Overview and Future Directions

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Outline

- Overview of NTIA/ITS
- Interference analysis
  - Definitions / scenario
  - Transmission loss
  - Propagation models
  - Antenna modeling
- Example problems
- Future directions in interference analysis

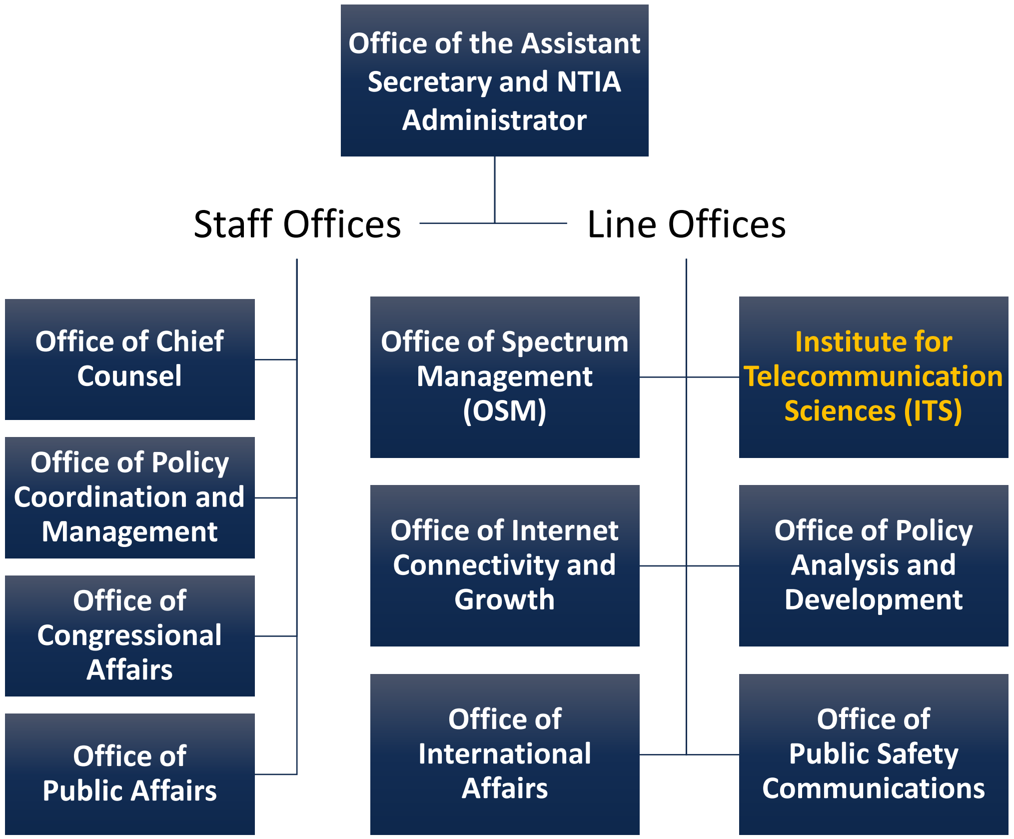
Overview of NTIA/ITS

ITS Mission

To ADVANCE innovation in communications technologies, INFORM spectrum and communications policy for the benefit of all stakeholders, and INVESTIGATE our Nation's most pressing telecommunications challenges through research that employees are proud to deliver

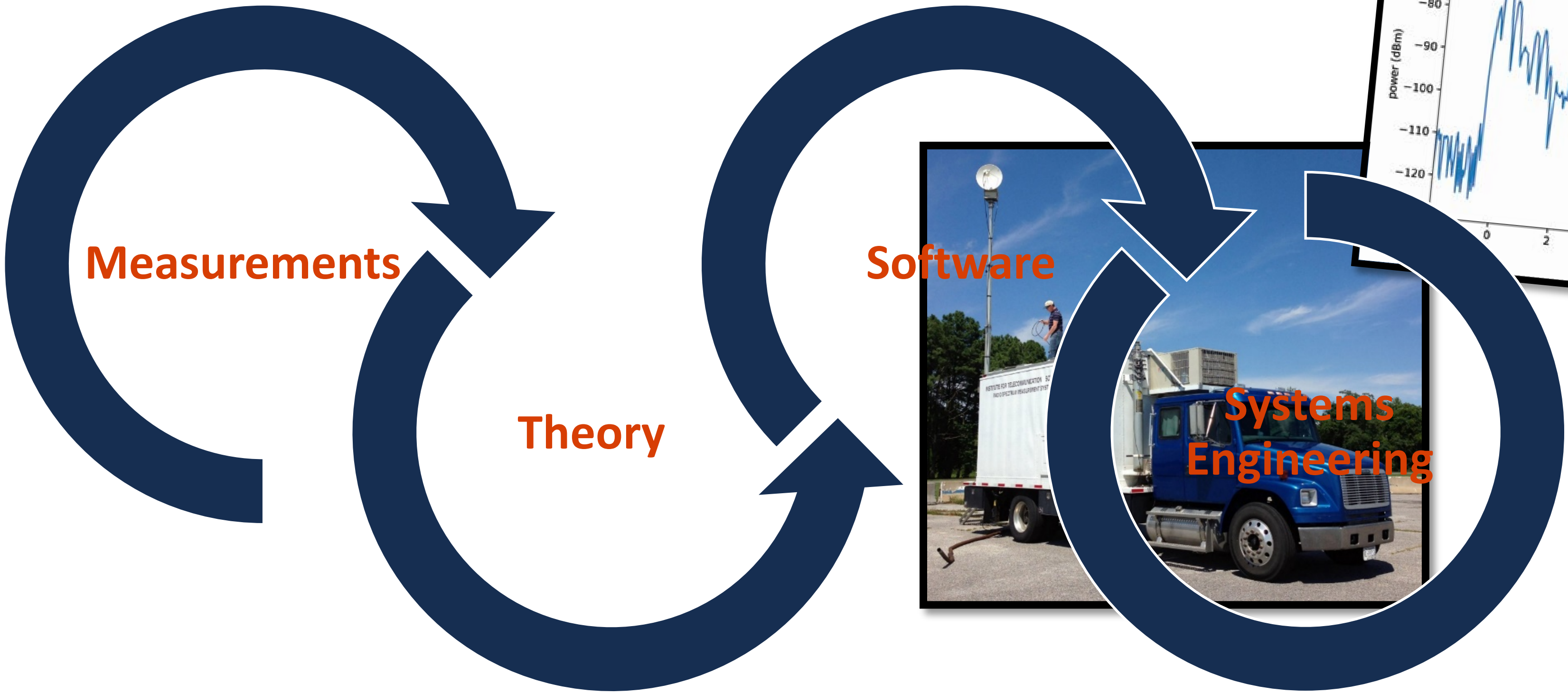
NTIA Mission and Changing Scope

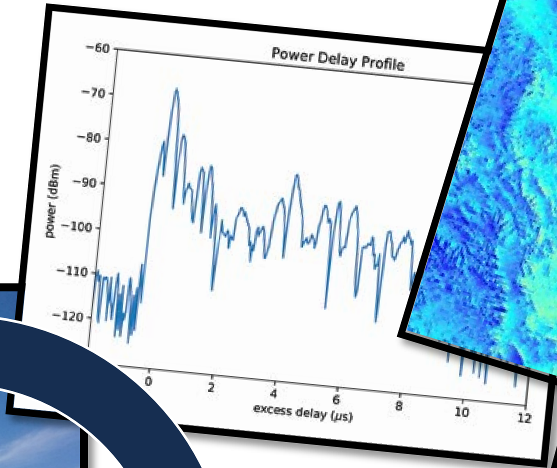
- NTIA scope has increased from Government-only spectrum management (IRAC) to Government-industry spectrum sharing
- ITS manages the telecommunications technology research programs of NTIA
- ITS works closely with other NTIA line offices to support Administration and Agency needs
- ITS engages with other stakeholders via OSTP, CSMAC, NITRD/WSRD, PPSG, DoC 5G Working Group, National Spectrum Consortium, etc.
- ITS manages the Department of Commerce owned Table Mountain Radio Quiet Zone

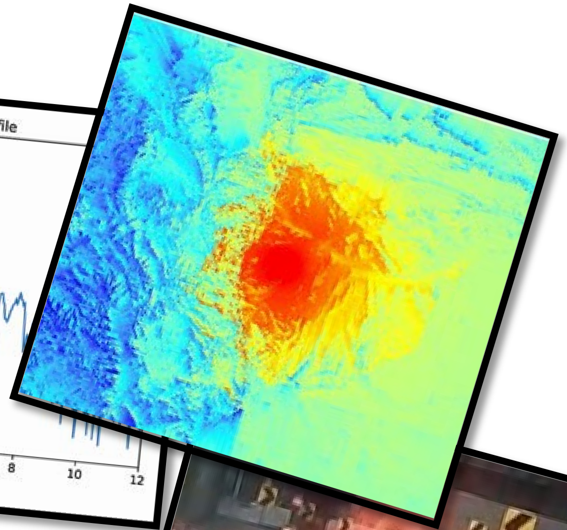


*Interdepartment Radio Advisory Committee

Our Teams


Measurements
Theory
Software
Systems Engineering


Power Delay Profile
power (dBm)
excess delay (μs)



NTIA Visiting Researcher Program (In Progress)

Designed to provide participants with opportunities to exchange views and align research with NTIA spectrum management R&D objectives

Research areas

- Enhancing spectrum utilization
- Propagation modeling and software
- Electrical engineering
- Spectrum monitoring
- Telecommunications policy
- Improving telecom networks

Subject Matter Expert

Serve as a resource on topic(s) of expertise
Apply knowledge and experience to project

Intern

Be mentored by subject matter experts
Work on exciting projects in a team setting

Liaison

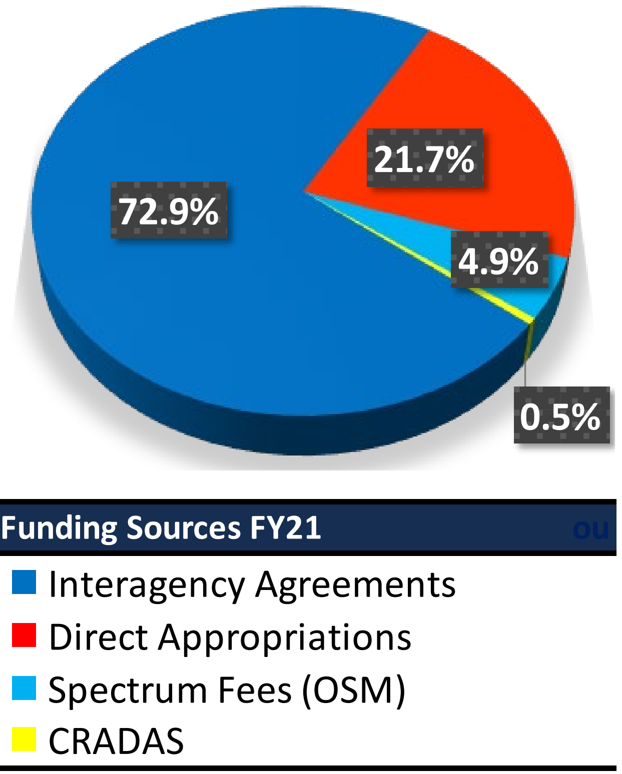
Enjoy a "day in the life" of subject matter experts
Participate in spectrum management training

Work Environment

- ITS is NTIA's R&D lab with ~70 technical staff
- ITS serves other federal agencies via the IRAC and Interagency Agreements (IAAs)
- ITS engages directly with industry and academia via Cooperative Research and Development Agreements (CRADAs)
- Growth of OSM Spectrum Management R&D Program demonstrates increased importance of spectrum R&D that produces science and tools to help modernize spectrum management and policy decision processes
- Growth of other agency (OA) projects demonstrates importance of applied spectrum R&D that helps government adapt to changing spectrum rules and assignments

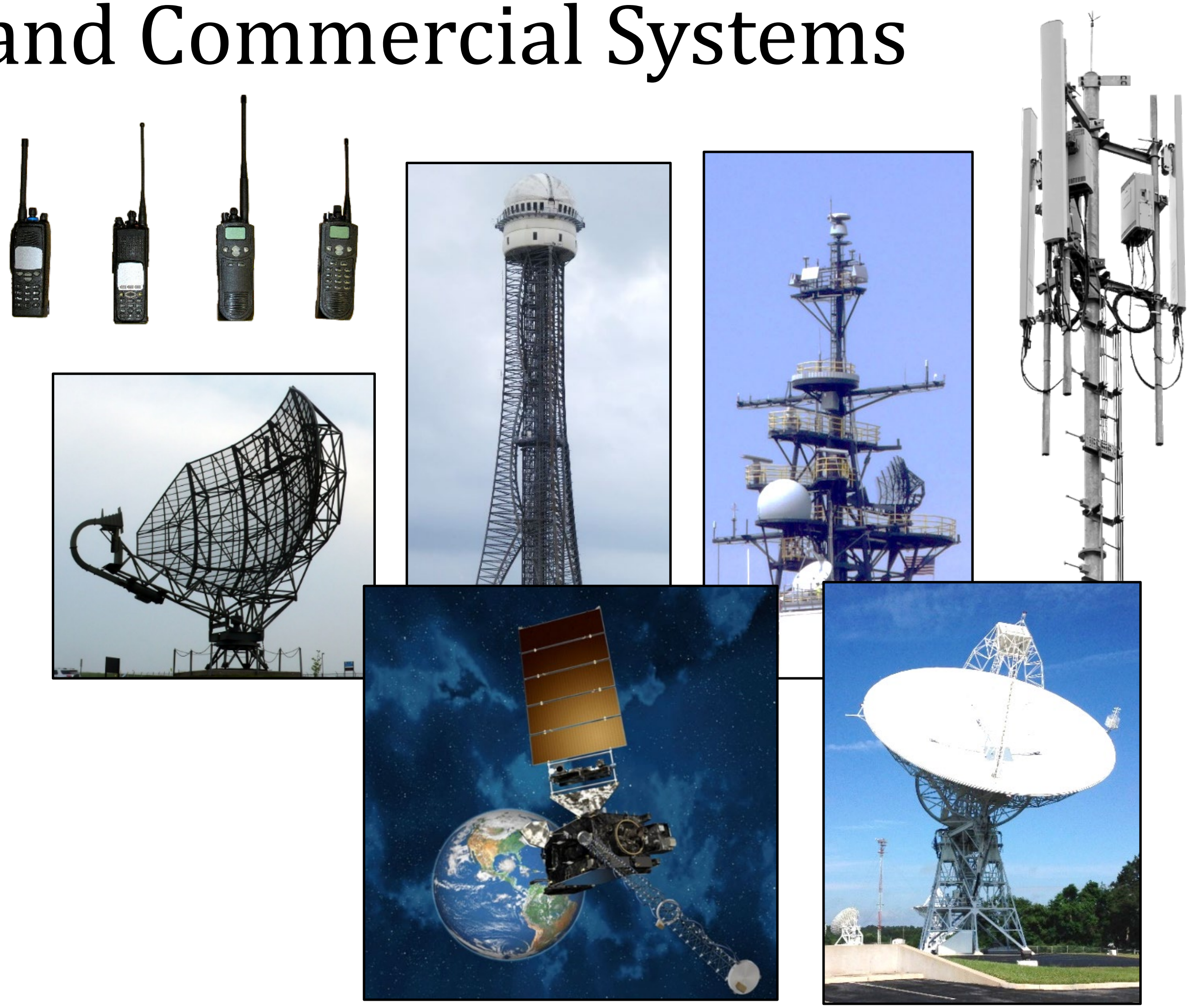
49 IAAs & CRADAs in FY21

ITS Funding Sources FY21

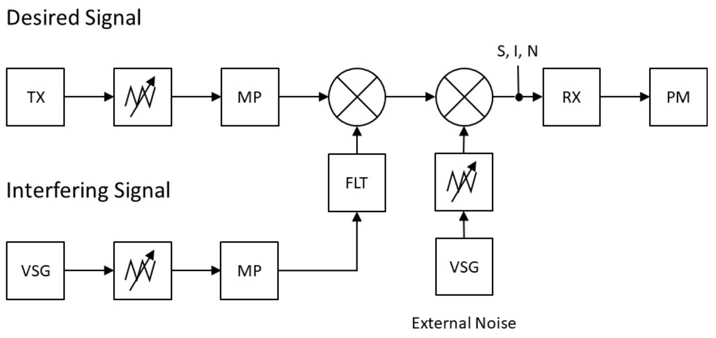


Expertise in Government and Commercial Systems

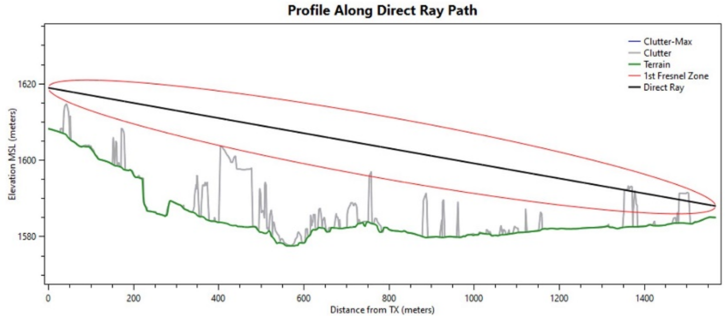
- Radar
- Meteorological and GPS satellites
- Military tactical, telemetry, training
- Public Safety LMR and LTE (FirstNet)
- Intelligent Transportation, CV2X
- HF communications
- Cell phones, Wi-Fi devices, FCC Part 15 devices
- Broadcast
- UAVs
- DoD AWS-3 assets, threat sims
- IoT devices

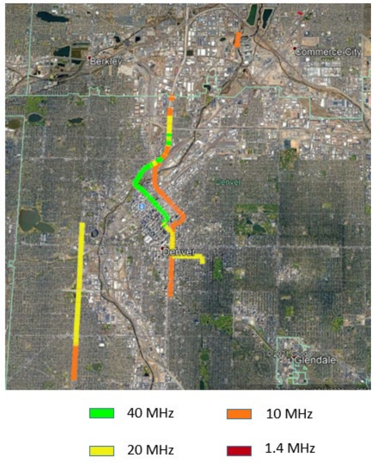


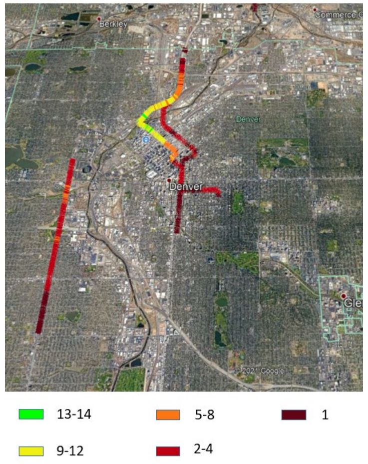
OSM Spectrum Management R&D

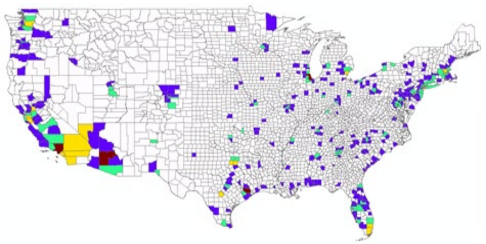


- **Goal:** To provide planned R&D (*i.e.*, science, models, data, analyses, and software) and quick-reaction subject matter expertise to advance NTIA spectrum management processes and decisions
- **Approach:** Planned R&D projects
  - Clutter propagation modeling
  - Propagation code library (proplib)
  - ITU-R Study group 3 (SG 3)
  - mmWave propagation measurements and modeling
  - RSEC modernization
  - Spectrum quantification, verification, and characterization (SQVC)
  - Interference analyses









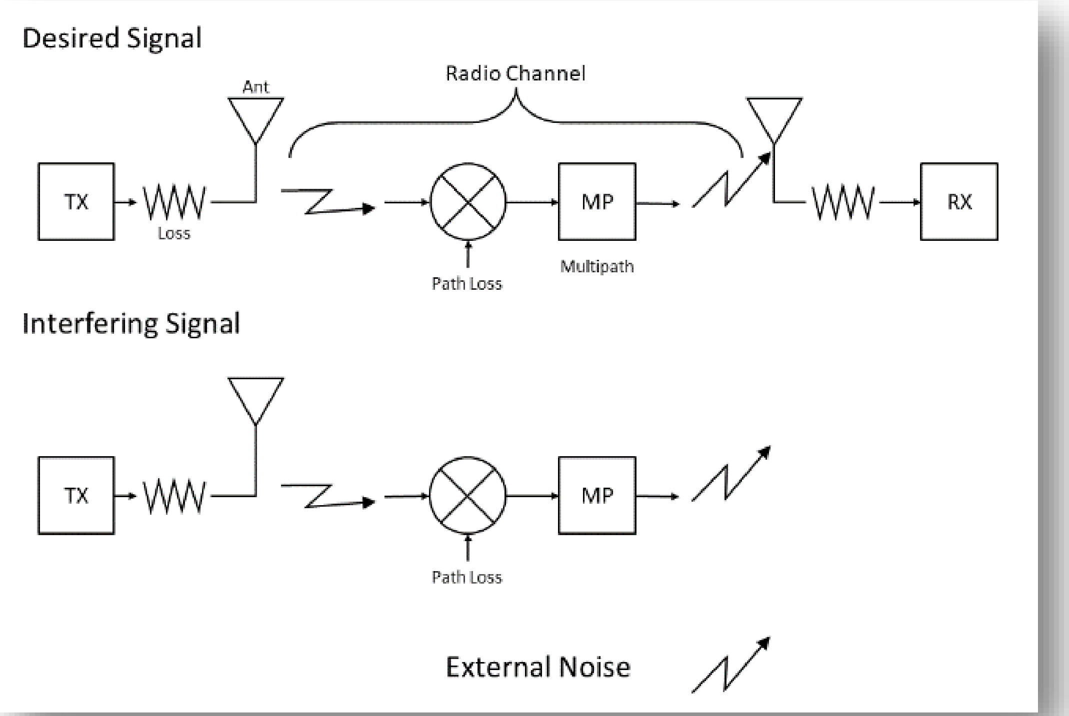
Interference Analyses

What is Interference Analysis?

- Methodology to quantify interference (non-harmful and harmful) to interferees
  - Interferers (source systems) can be in-band or out-of-band
  - Interferees (affected systems) can be active transceivers or passive receivers
- Necessary components
  - Scenario and assumptions
  - Interference protection criteria (IPC) and metrics
  - Interferer power and waveform model
  - Transmission loss models
  - Propagation models
  - Antenna models
  - Interferee characteristics (hardware) and signal processing (software)

Scenario – What Is Happening?

- Consider the variables and assumptions
  - Radars sharing a band (scanning? waveforms? distance?)
  - A narrowband protected passive scientific receiver
  - A wideband passive scientific receiver
  - A safety-of-life RF system, adjacent to comms
  - HF comms (anthropomorphic noise, radar, etc.)
- Interference can seem likely, but is it harmful?
  - Interferee defines a scenario
    - "*X* causes my radar to see *L* false targets"
    - "*Y* produces a *M* degree error in my radiometer"
    - "*Z* reduces my throughput by *N* %"

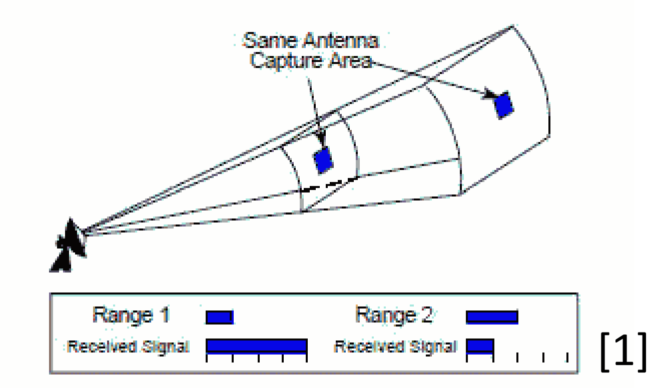


Generalized IA Model*

*"All models are wrong; some are useful." – G. Box

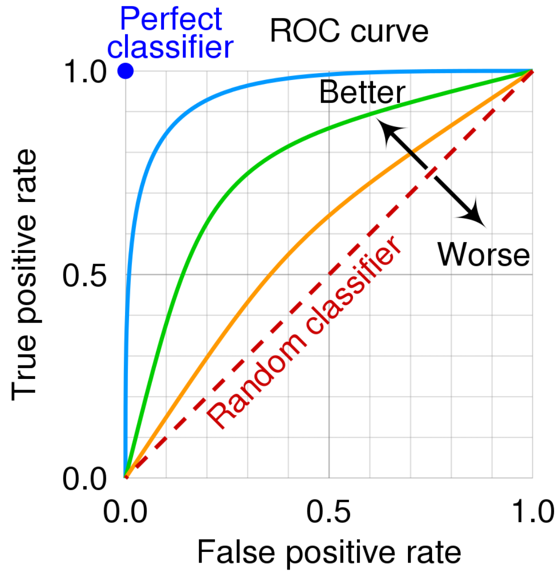
Interference Protection Criteria

- Basic
  - Power levels and ratios (C, I, S, N) w/BW, *e.g.*, “INR = -6 dB”
  - Power density at a particular location [W/m^2]



[1]

- Better
  - Metric w/statistical quantification of time (CDF)
  - Consider interfering signal type (pulsed vs. noise-like)
- Even better
  - Specific system performance baselines/requirements
    - P_d decrease or P_{fa} increase by X % for specific target
    - Reduction in throughput from theoretical capacity by Y %
  - Specific system models (incl. receiver settings / processing)
  - Channel conditions (*e.g.*, multipath, specular)
  - Ultimately: interferer-SNR-based threshold



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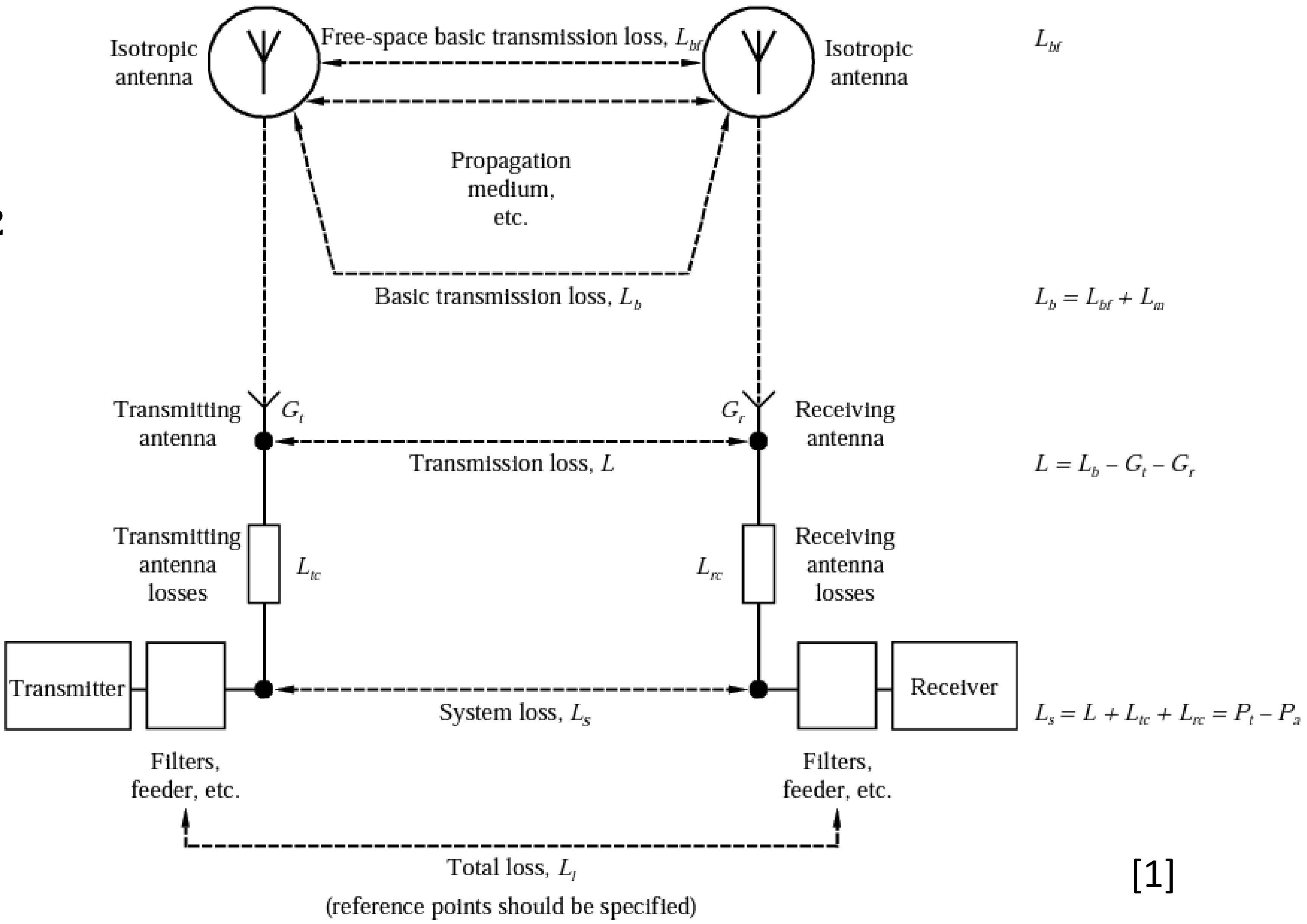
Transmission Loss

- Defined in ITU-R P.341-5 [1]
- Not just "path loss": $L_{bf} = \left(\frac{4\pi d}{\lambda}\right)^2$
- Includes channel, antennas, system loss, etc.
- Must consider TL model for each source of signal, interferer, and noise in scenario



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Propagation Models

- Predict basic transmission loss (BTL), L_b, the loss between isotropic antennas at specific locations or distance
  - Can include diffraction, troposcatter, ducting, statistical atmospheric conditions, interference
- Ground-to-ground: Longley-Rice, a.k.a. Irregular Terrain Model (ITM)
  - Statistical model based on extensive measurement campaign
  - Point-to-point mode w/terrain profile, or area mode with Δh
  - Calculates BTL for *time*, *situation*, and *location* variability quantiles
- Ground-to-air: P.528, IF-77
- Ground-to-space: P.618

ITS Propagation Library (PropLib)

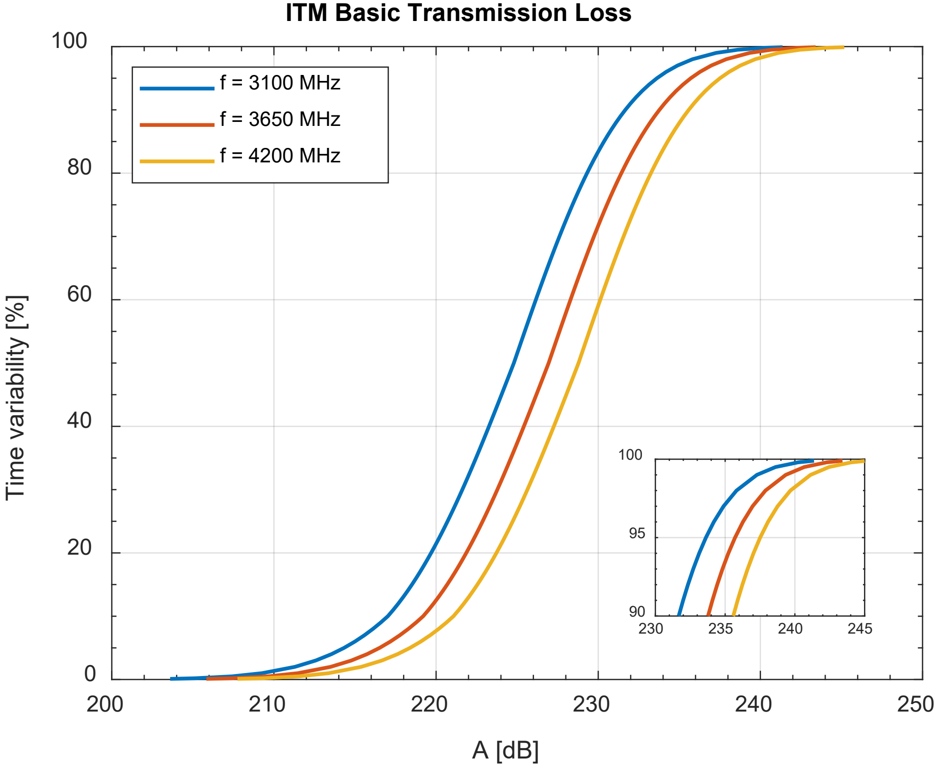
https://github.com/NTIA

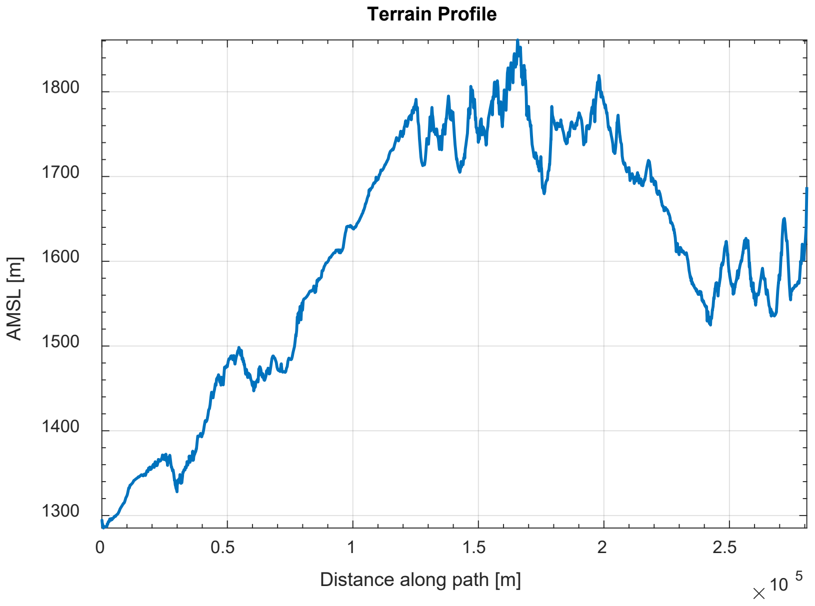
- **Goal:** To establish authoritative and widely-used propagation model software
- **Approach:** ITS establishes modern software development process to ensure reliability and integrity of software research products. Once proplib codes are released, improvements originate through (1) ITS scientific process and (2) open-source collaboration.
- **Process:**
  - In development
  - Internal production
  - Publicly released

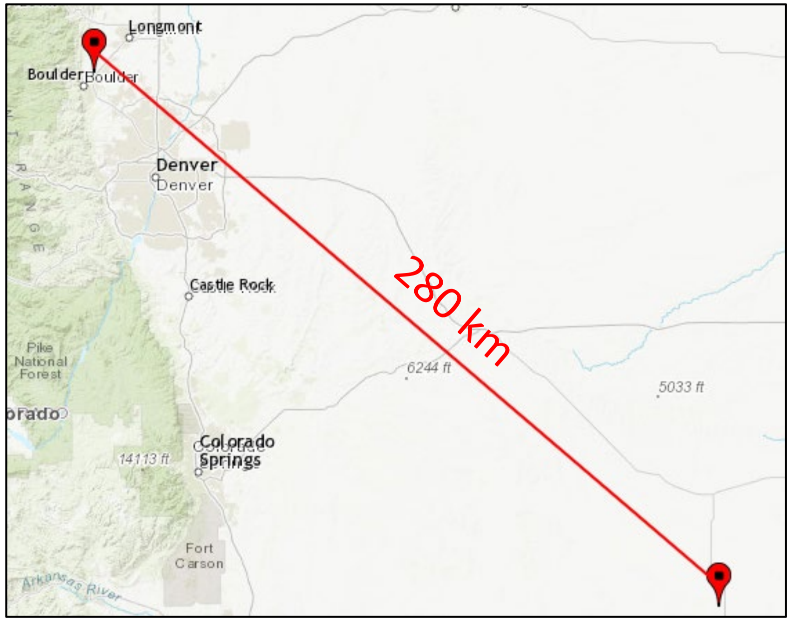
In Development	Internal Production	Publicly Released
• MPM • P.1812 • P.526	• Ohiopyle • **IF-77** • PropCore • P.676 • P.835 • P.2108	• **ITM** • eHata • P.528 • LFMF-SmoothEarth
• Actively developed • Locally published (restricted users)	• Suitable for stable dev • Published NTIA-wide • Okay for external shipping	• Fully open-source • Publicly supported • Code signed and formally citable

Irregular Terrain Model (1/3)

- ITM calculates both tropospheric scatter and diffraction loss, selects lowest loss

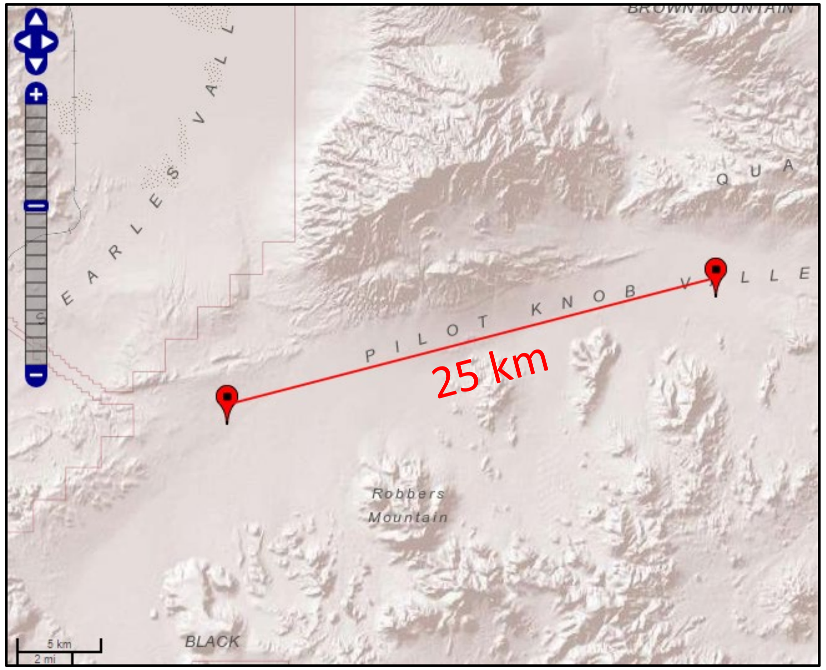


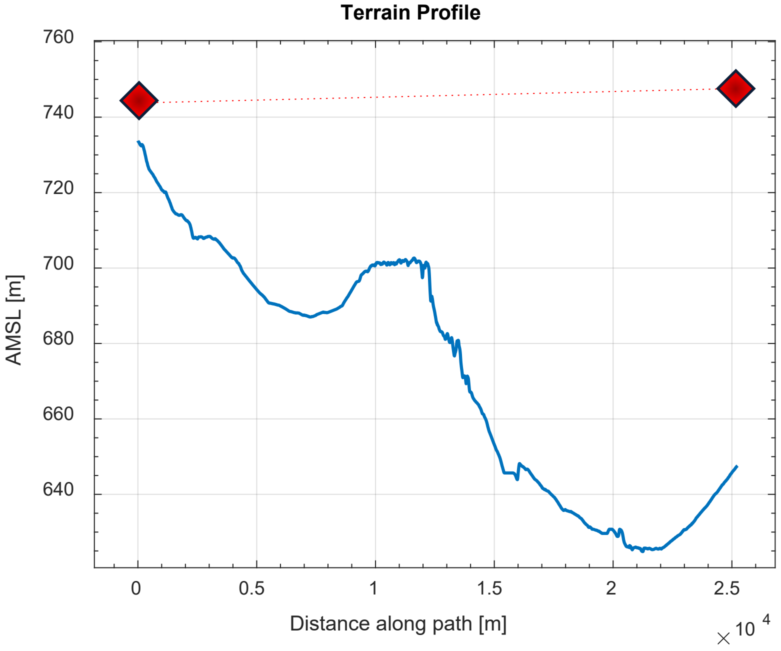


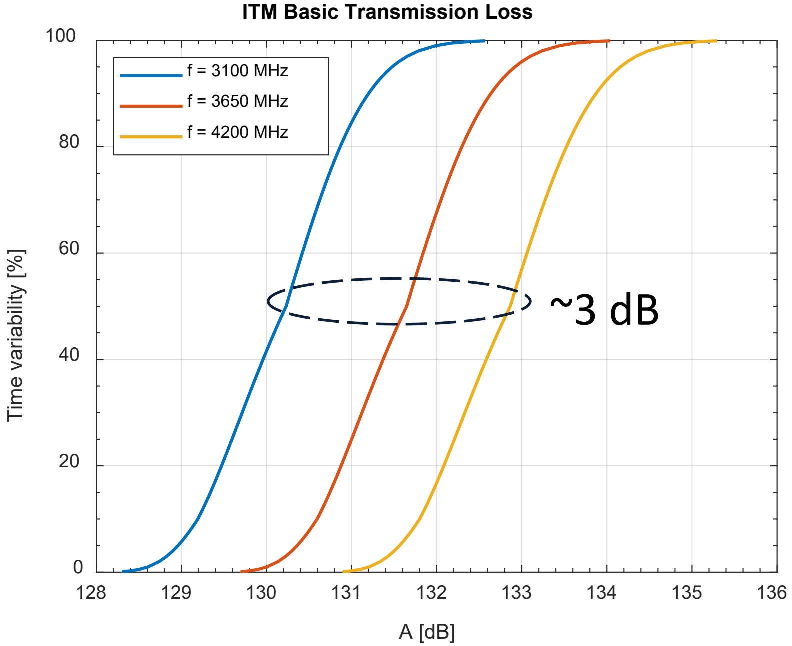


Irregular Terrain Model (2/3)

- Demonstrate magnitude of diffraction loss at 3 mid-band frequencies
- Tx 10 m above ground level (AGL), Rx 100 m AGL (low-flier)
- Case #1: No diffraction; ITM returns FSPL as 50 % time variability



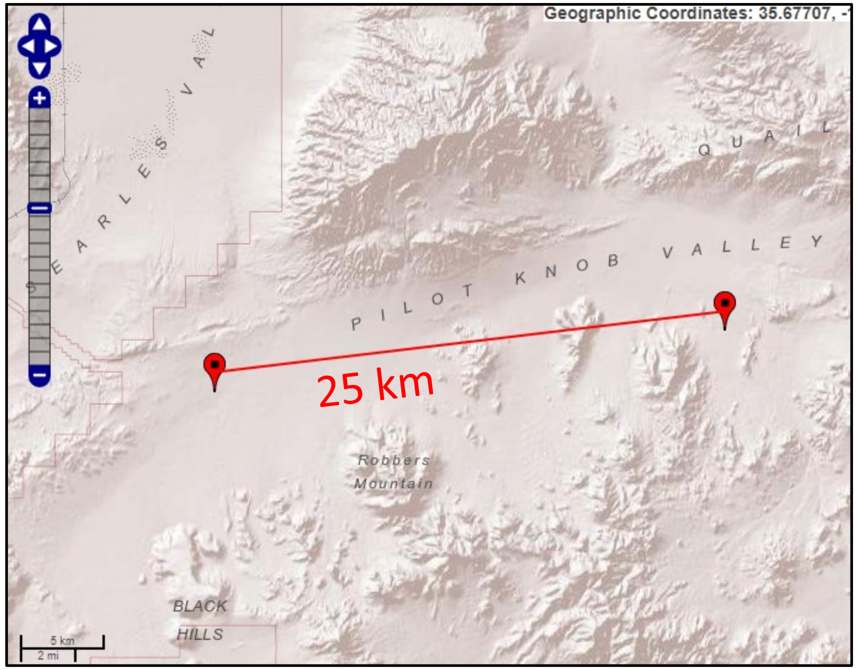


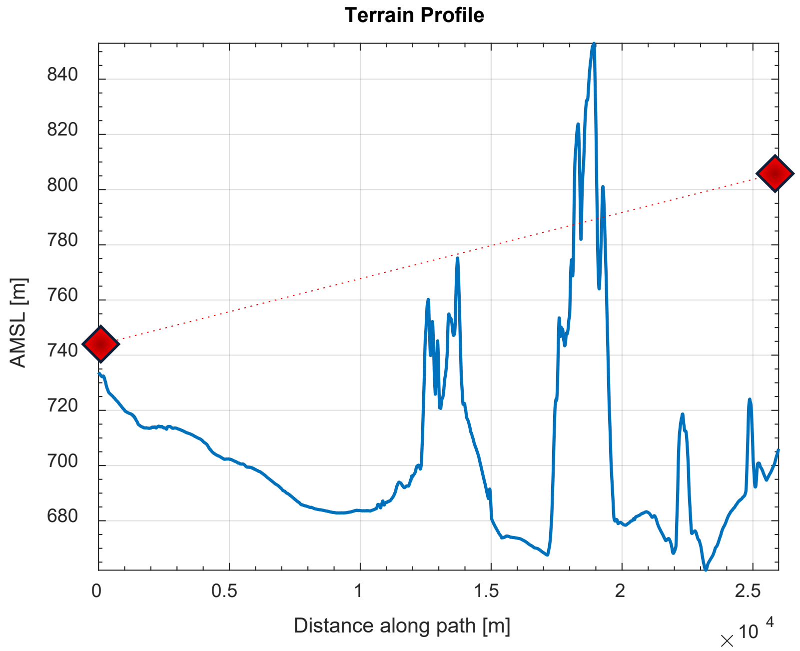


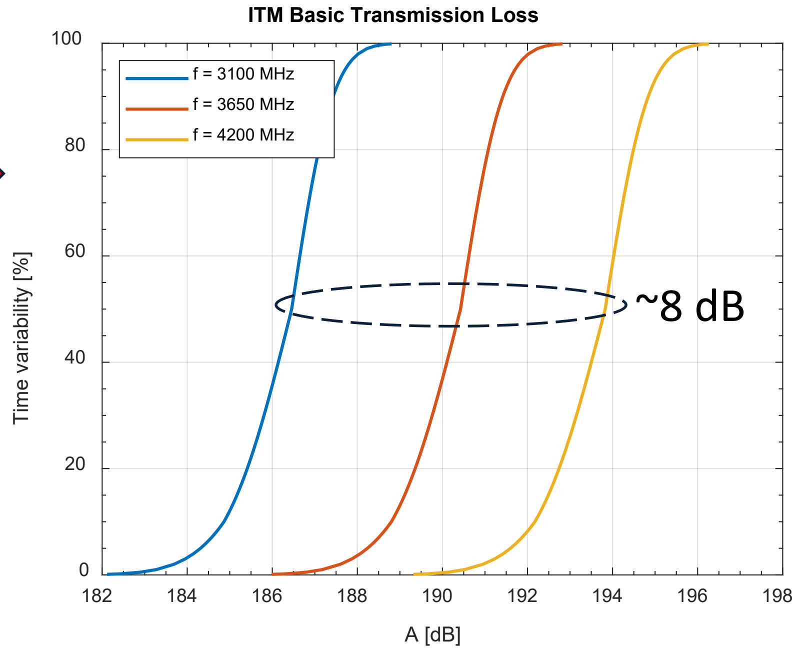
FSPL = 130.3, 131.7, 132.9 dB

Irregular Terrain Model (3/3)

- Low-flier now behind geographic features (same AGL)
- BTL approximately 55-60 dB greater than FSPL due to diffraction



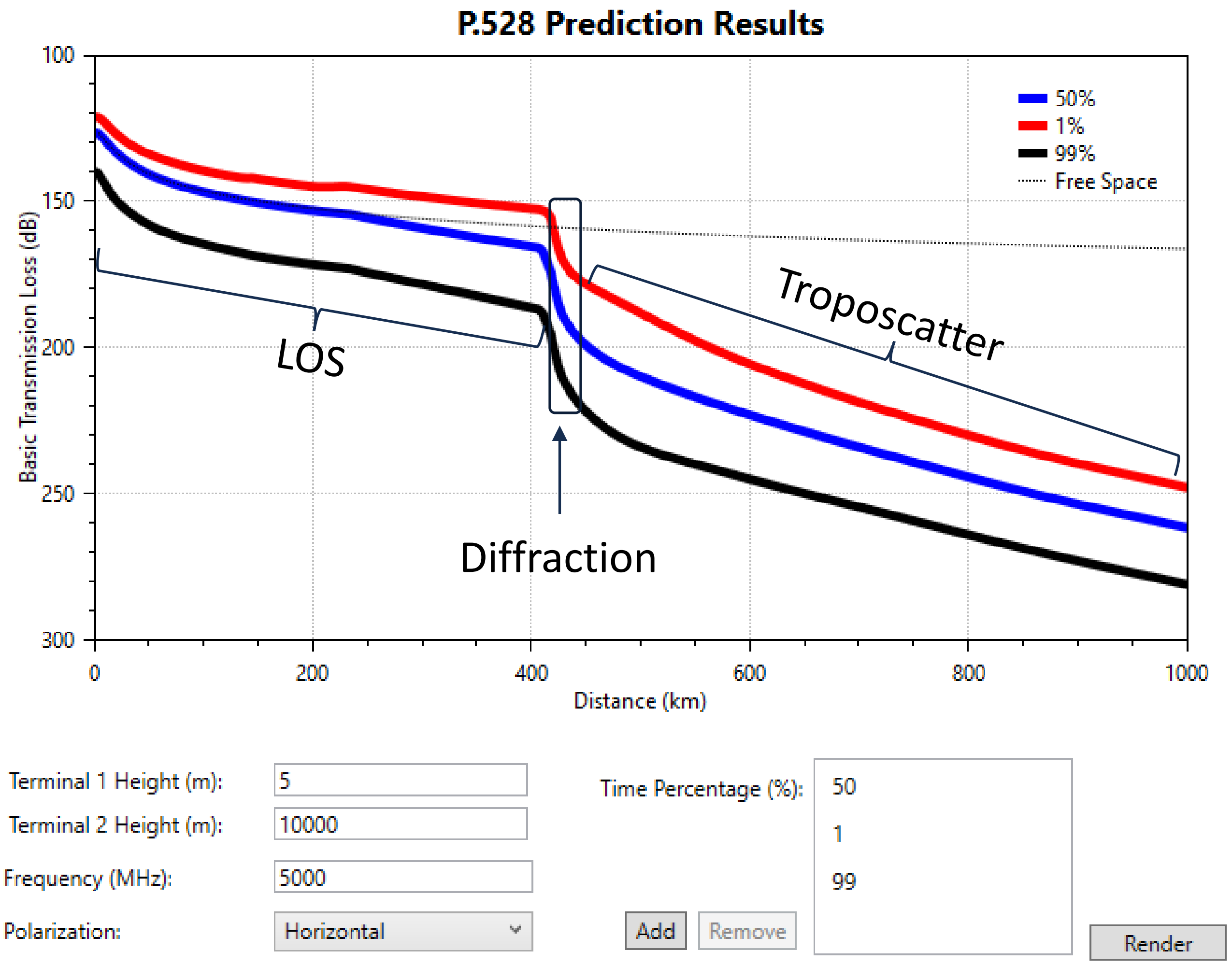




FSPL = 130.3, 131.7, 132.9 dB

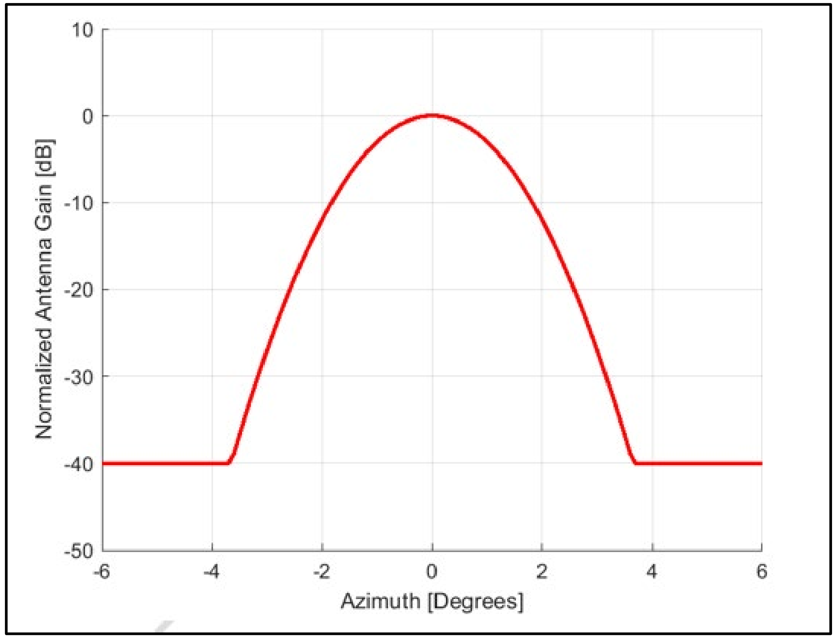
P.528 – Air/Ground

- P.528 is an international recommendation predicting BTL for air/ground & air/air
- ITS code is U.S. reference implementation of annex 2, the "step-by-step" method of computing loss
- https://github.com/NTIA/p528
- https://github.com/NTIA/p528-gui

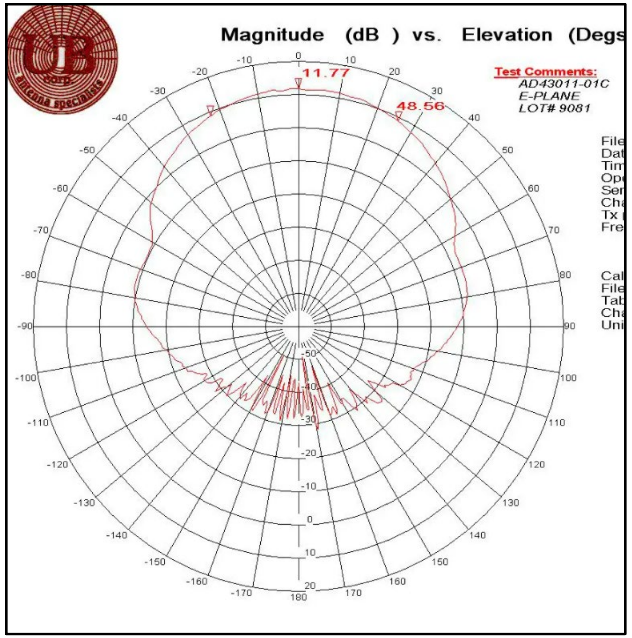


Antenna Models

- From simple to complex, analytic to measured
- Does the scenario require a complex model? What does the model include, or miss?



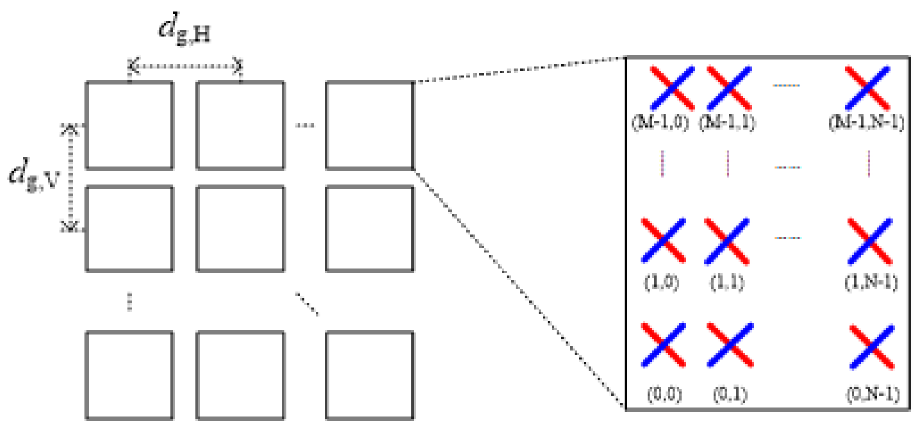
ITU long-range radar pattern
No side or backlobes!



Measured radar altimeter pattern
No null at ±90°! $\cos^2(\theta)$ model invalid

Antenna Models: 5G gNodeB

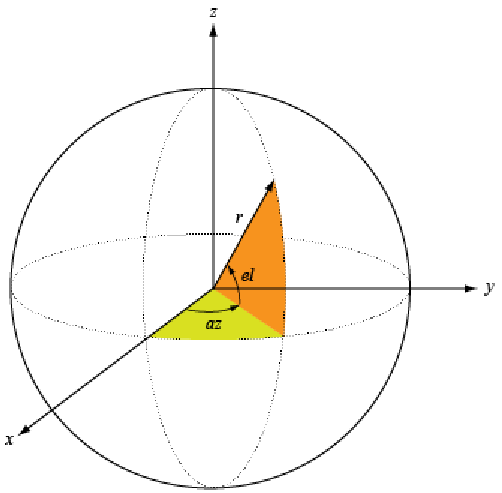
- 3GPP describes basestation (BS), array, and elements
- BS contains multiple uniform rectangular array (URA) panels
- Each panel is an array of crossed elements, partitioned into subarrays
- 3GPP addresses nominal behavior

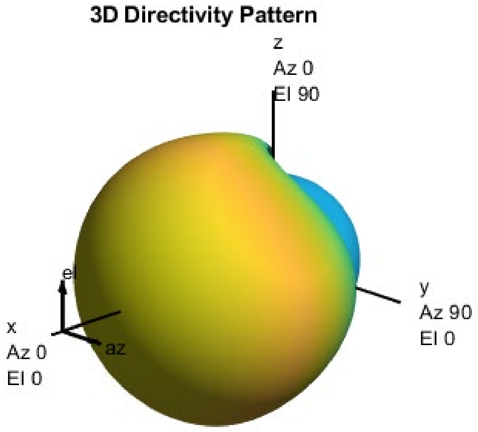


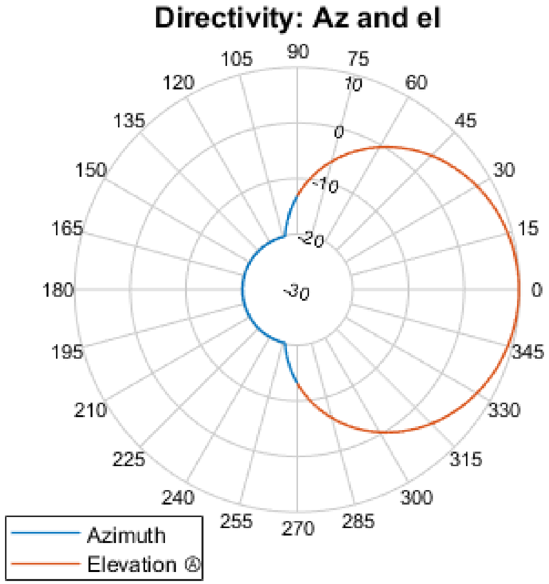
Parameter	Values
Vertical cut of the radiation power pattern (dB)	$A''_{dB}(\theta'', \phi''=0°) = -\min\left\{12\left(\frac{\theta''-90°}{\theta_{3dB}}\right)^2, SLA_V\right\}$ with $\theta_{3dB}=65°, SLA_V=30$ dB and $\theta'' \in [0°, 180°]$
Horizontal cut of the radiation power pattern (dB)	$A''_{dB}(\theta''=90°, \phi'') = -\min\left\{12\left(\frac{\phi''}{\phi_{3dB}}\right)^2, A_{max}\right\}$ with $\phi_{3dB}=65°, A_{max}=30$ dB and $\phi'' \in [-180°, 180°]$
3D radiation power pattern (dB)	$A''_{dB}(\theta'', \phi'') = -\min\{-(A''_{dB}(\theta'', \phi''=0°) + A''_{dB}(\theta''=90°, \phi'')), A_{max}\}$
Maximum directional gain of an antenna element $G_{E,max}$	8 dBi

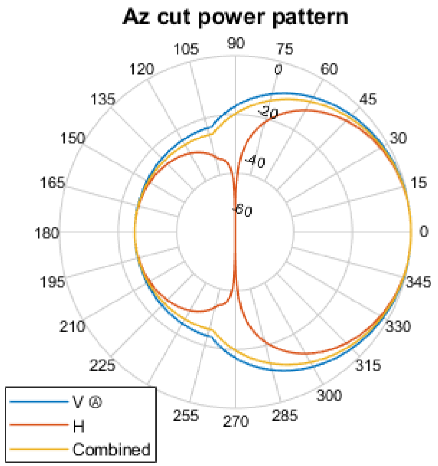
gNodeB Antenna Element

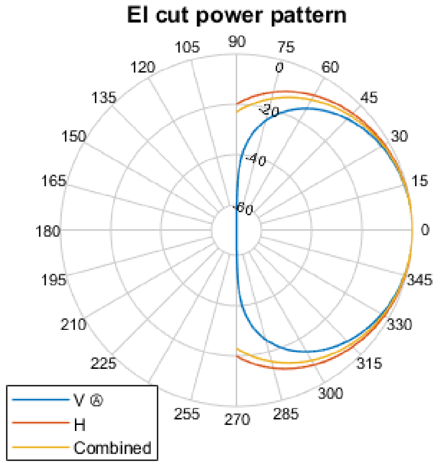
- As per 3GPP
  - 65° FWHM beamwidth
  - 8 dBi maximum gain (MATLAB® model: 9.2 dBi directivity)
- MATLAB® coord. system: -180° < Az < 180°; -90° < El < 90°
- This example: `PolarizationAngle` = +45°





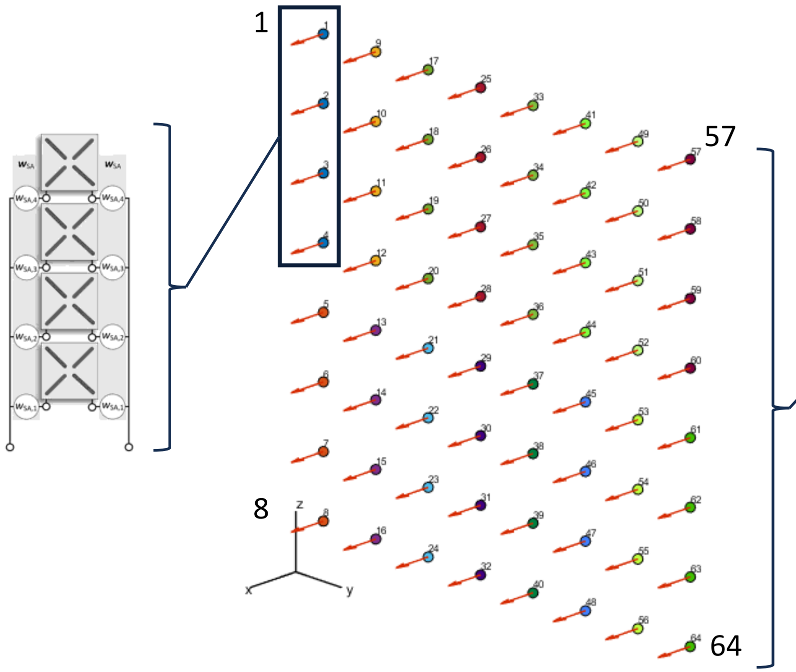


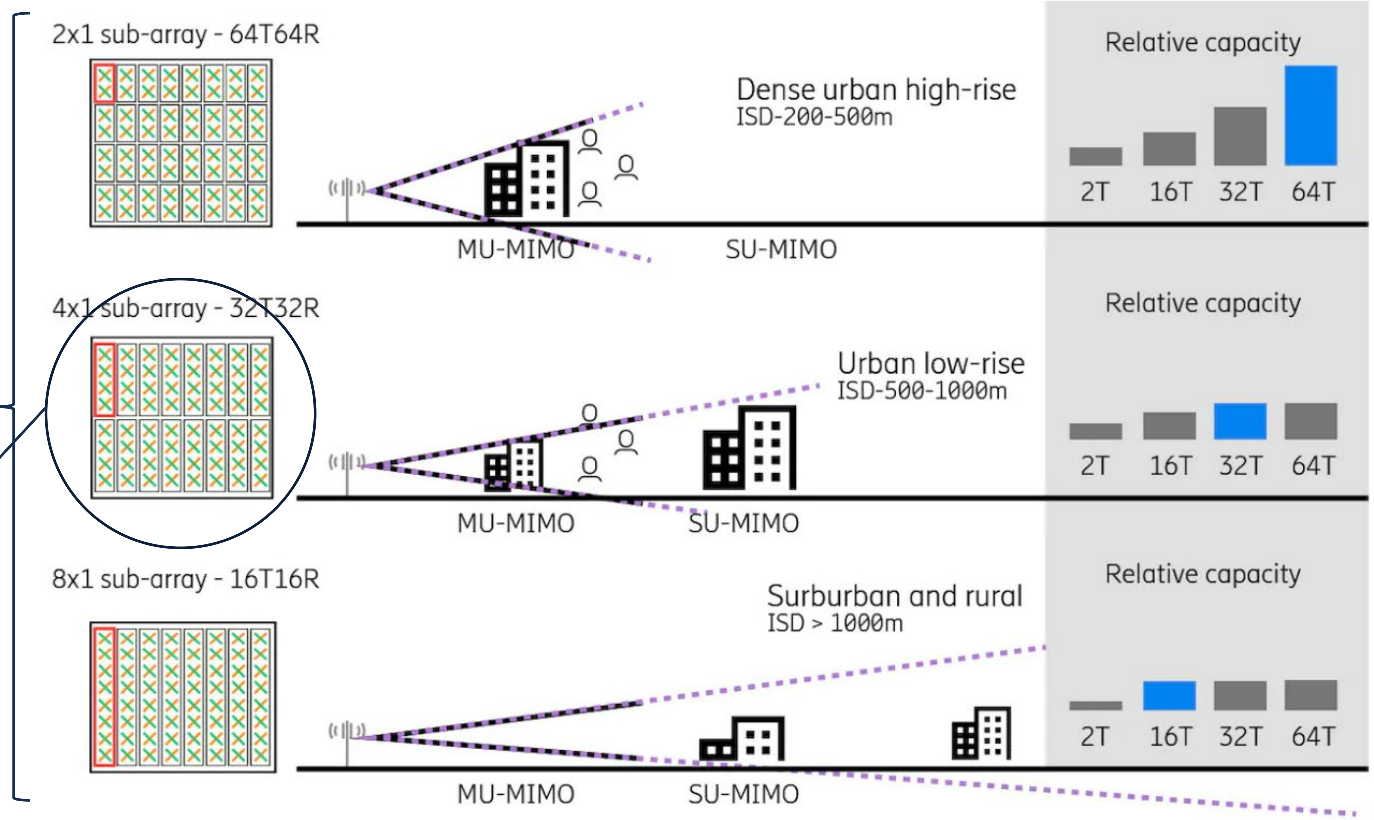




gNodeB Subarrays & Scenarios

- Ericsson describes 8x8 arrays w/fixed subarray configs
- MATLAB® support
  - URA, subarrays



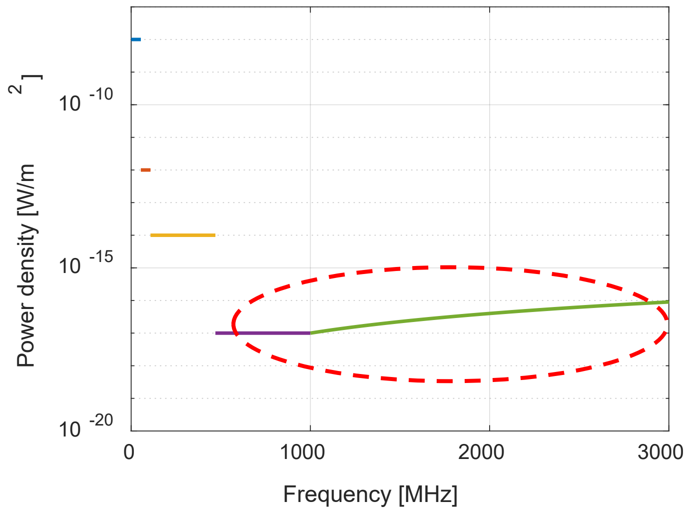


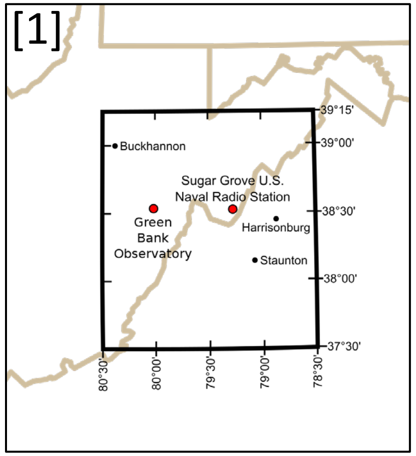
[1]

Practical IA Examples

Green Bank Telescope, National Radio Quiet Zone (1/3)

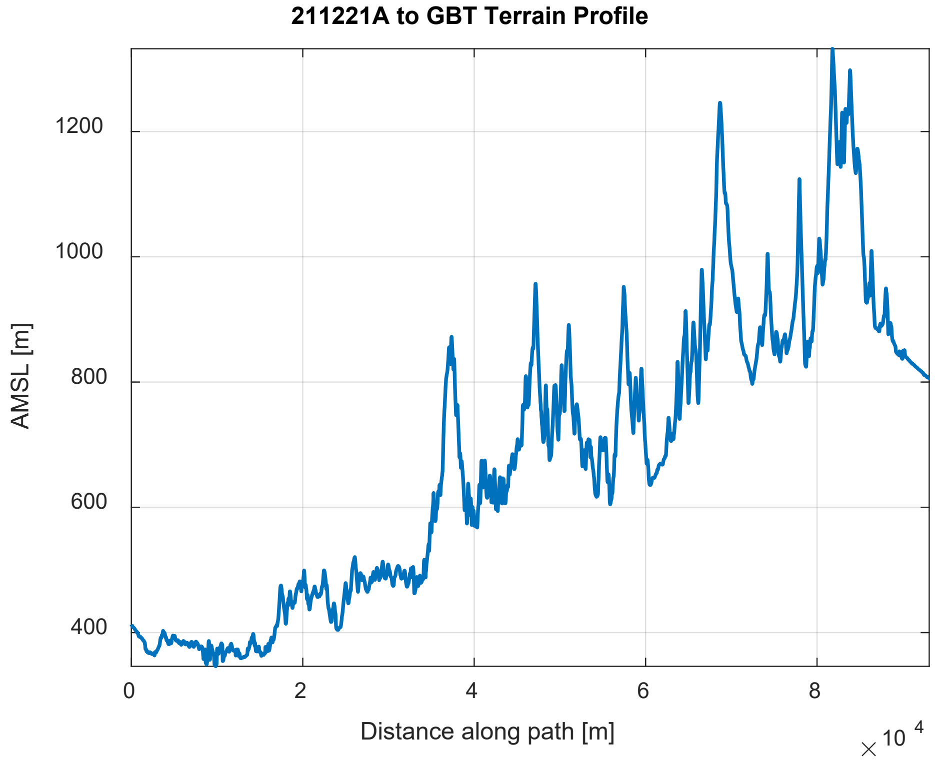
- What happens when a cellular service operator wants to change a base station parameter?
- GBT employs cryogenic receivers
  - Power density threshold (W/m^2) to protect GBT is function of freq. in 20 kHz measurement bandwidth
  - Rx noise temperature ~ 20 K: kTB = 5×10^{-18} W

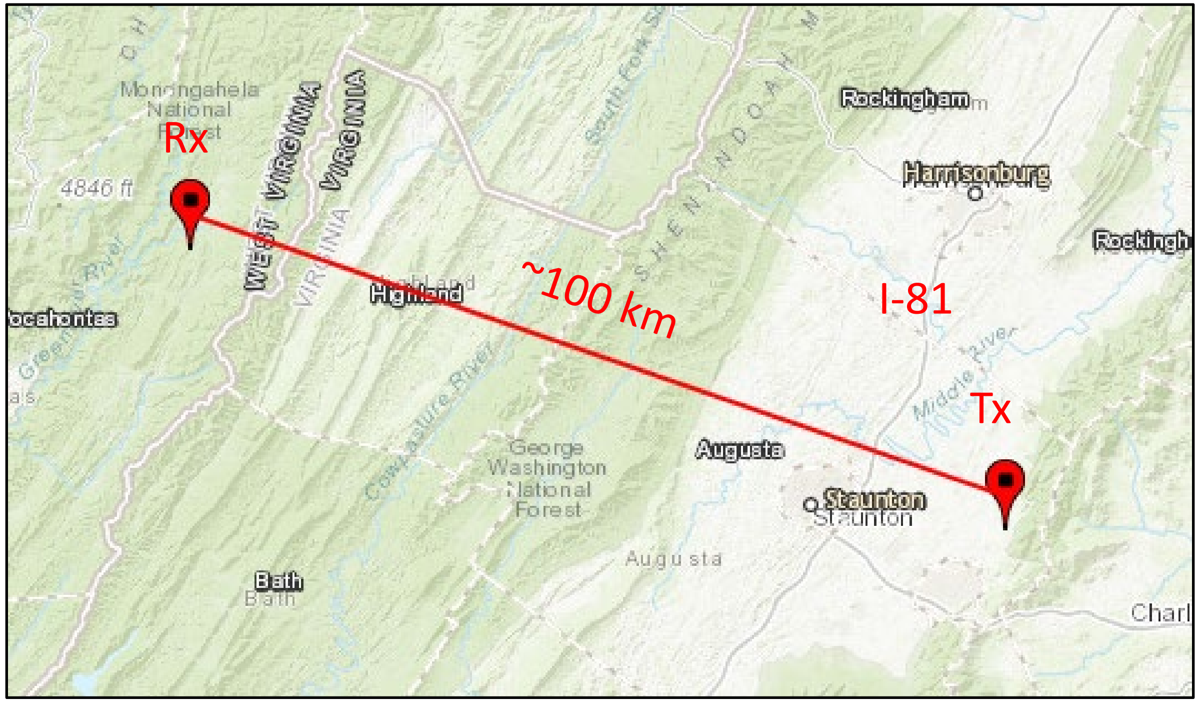




GBT NRQZ Approach: Irregular Terrain Model (2/3)

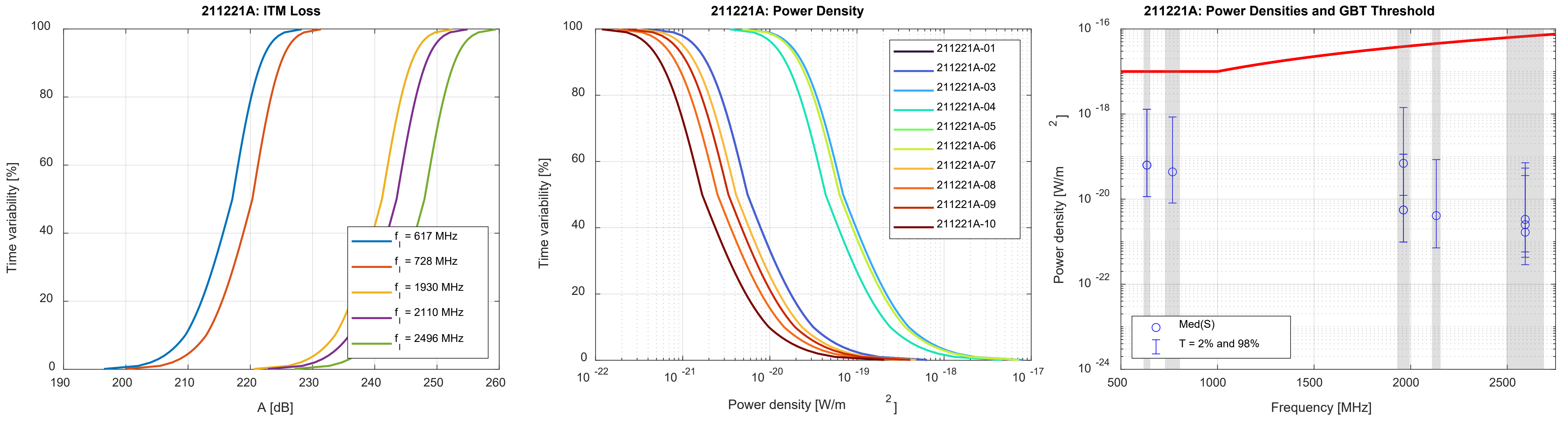
- Use ITM in point-to-point mode
- Import USGS elevation tiles with ITS's data access framework





GBT NRQZ Results (3/3)

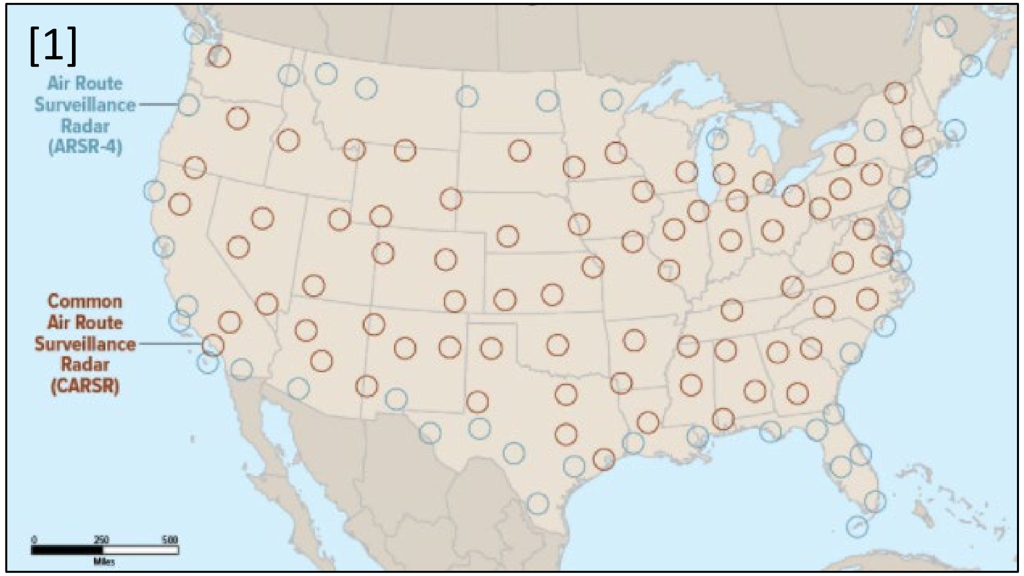
- Example results for one tower, with 5 frequencies and multiple antenna heads

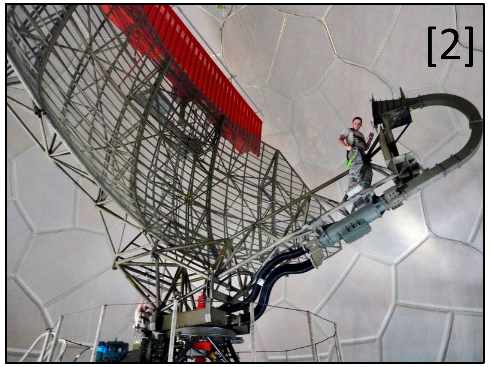


Aircraft Surveillance Long Range Radar (LRR)

- LRRs can “see” each other – necessary to eliminate spatial coverage gaps
- Multiple propagation aspects
  - Diffraction, troposcatter
  - Clutter?
- Freq. separation is inefficient use of spectrum
- If we overlap them in frequency, what happens?
  - Mutual antenna gain (MAG) time-domain aliasing
  - Undesired pulses

[1]





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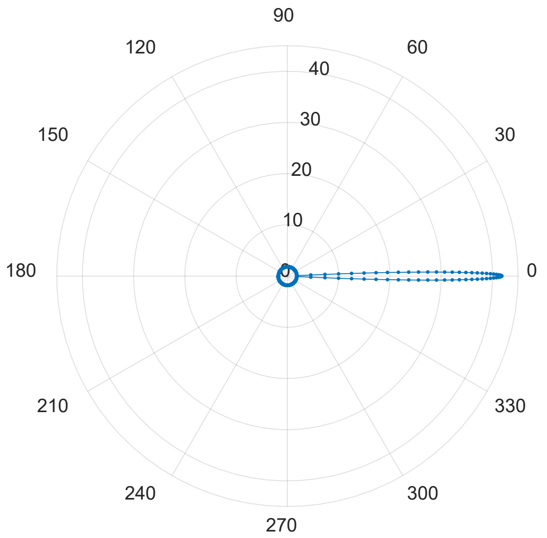
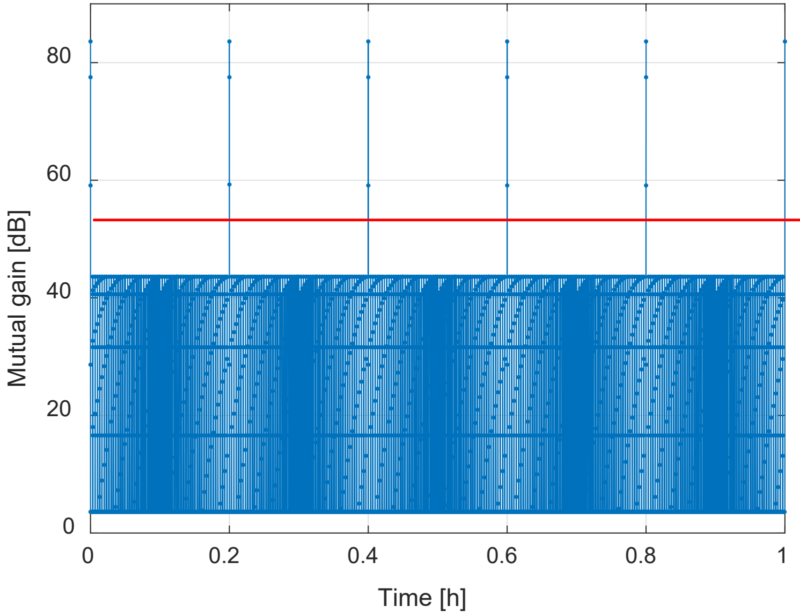
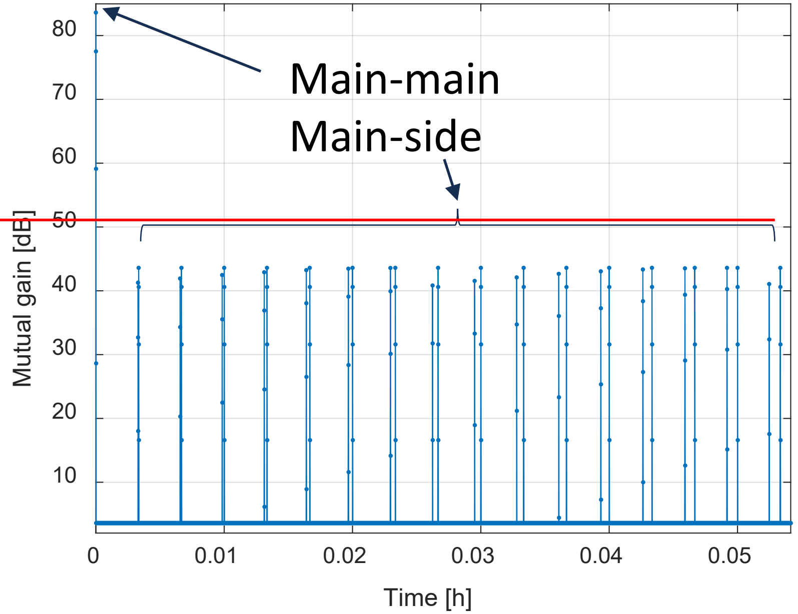
[3]

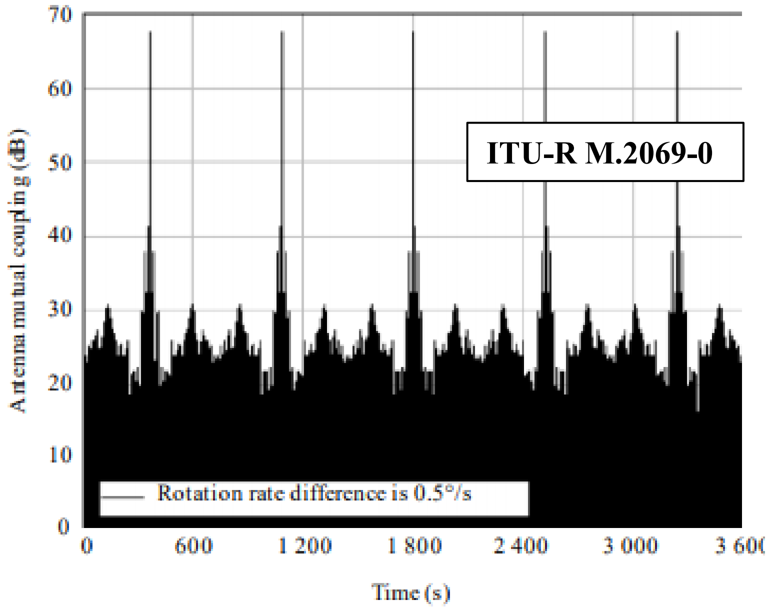
Time Between Main Beam Interactions



- <u>Constant</u> 0.5 °/s rotation rate difference; ideal antenna pattern →
- Interaction every 12 min (as expected: $\frac{360\,°}{0.5\,°/s}$)
- Percentage of main-main interaction very low: 0.03 %

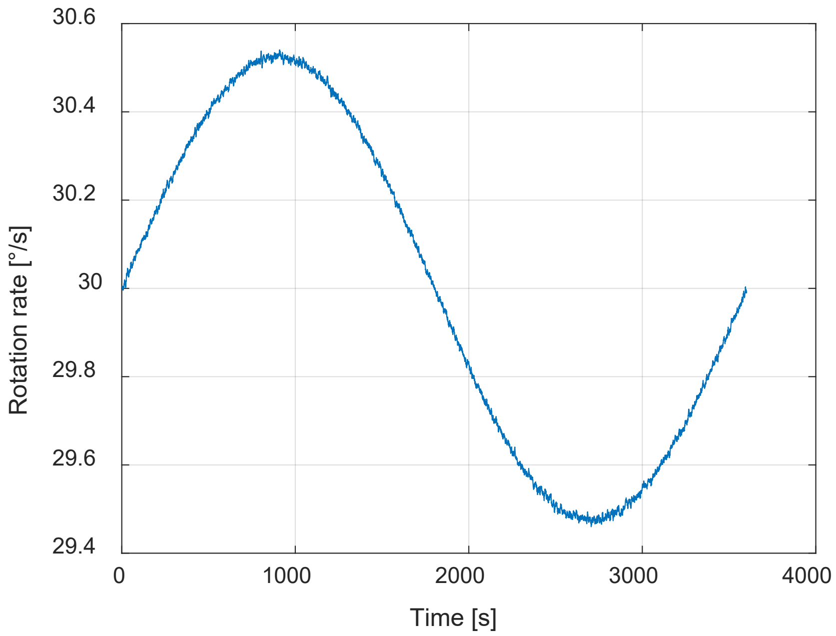


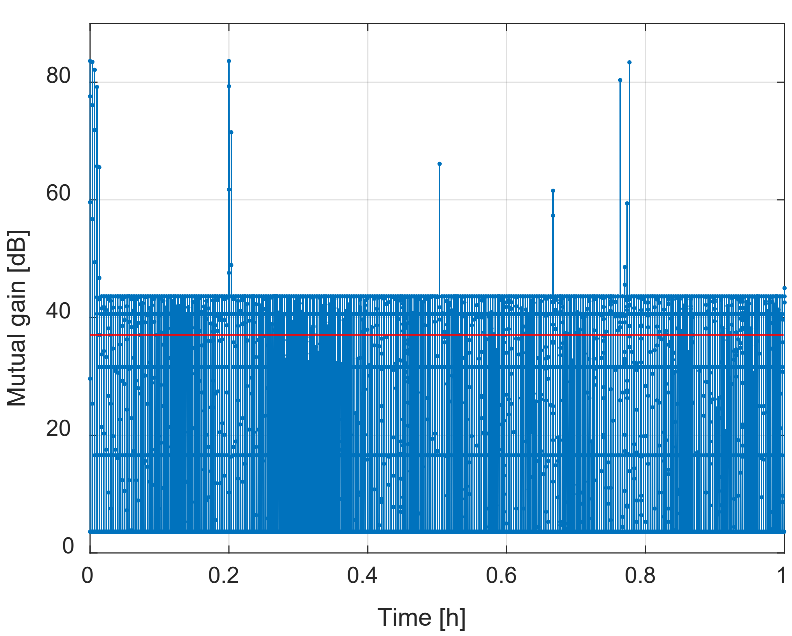




Effect of Non-Constant Rotation Rate

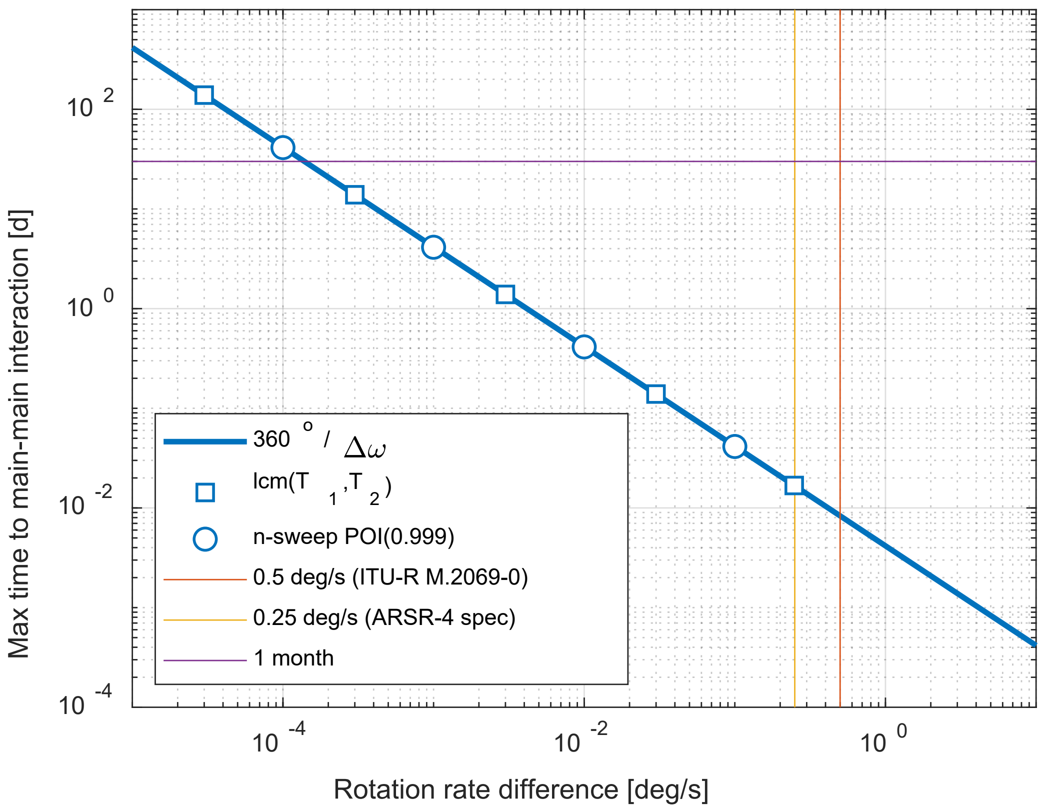
- Add slow (wind load) and fast (jitter/noise) rotation rate variation to radar 2
- Main beam interaction periodicity less predictable
- Percentage of main-main interaction similar: 0.011 %





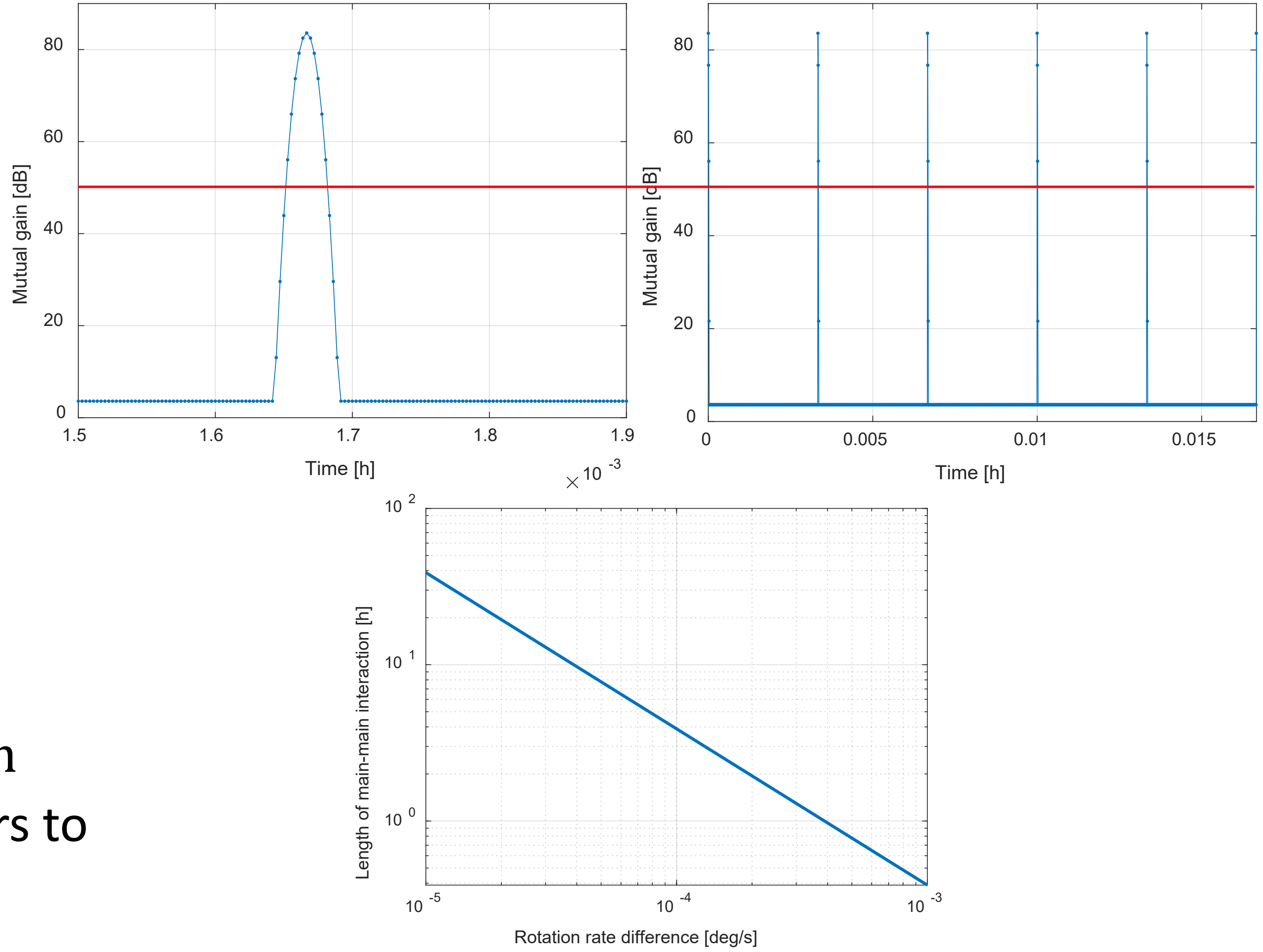
Periodicity of Interference Eras

- Aliasing is a function of rotation rate difference
  - $T_E = \frac{360\,°}{\Delta\omega\ °/s}$
- When rotation rates nearly synchronized (10^{-4} °/s), eras can occur only monthly
- $\mathrm{lcm}(T_1, T_2)$ ✓
- Analytic *n*-sweep POI ✓

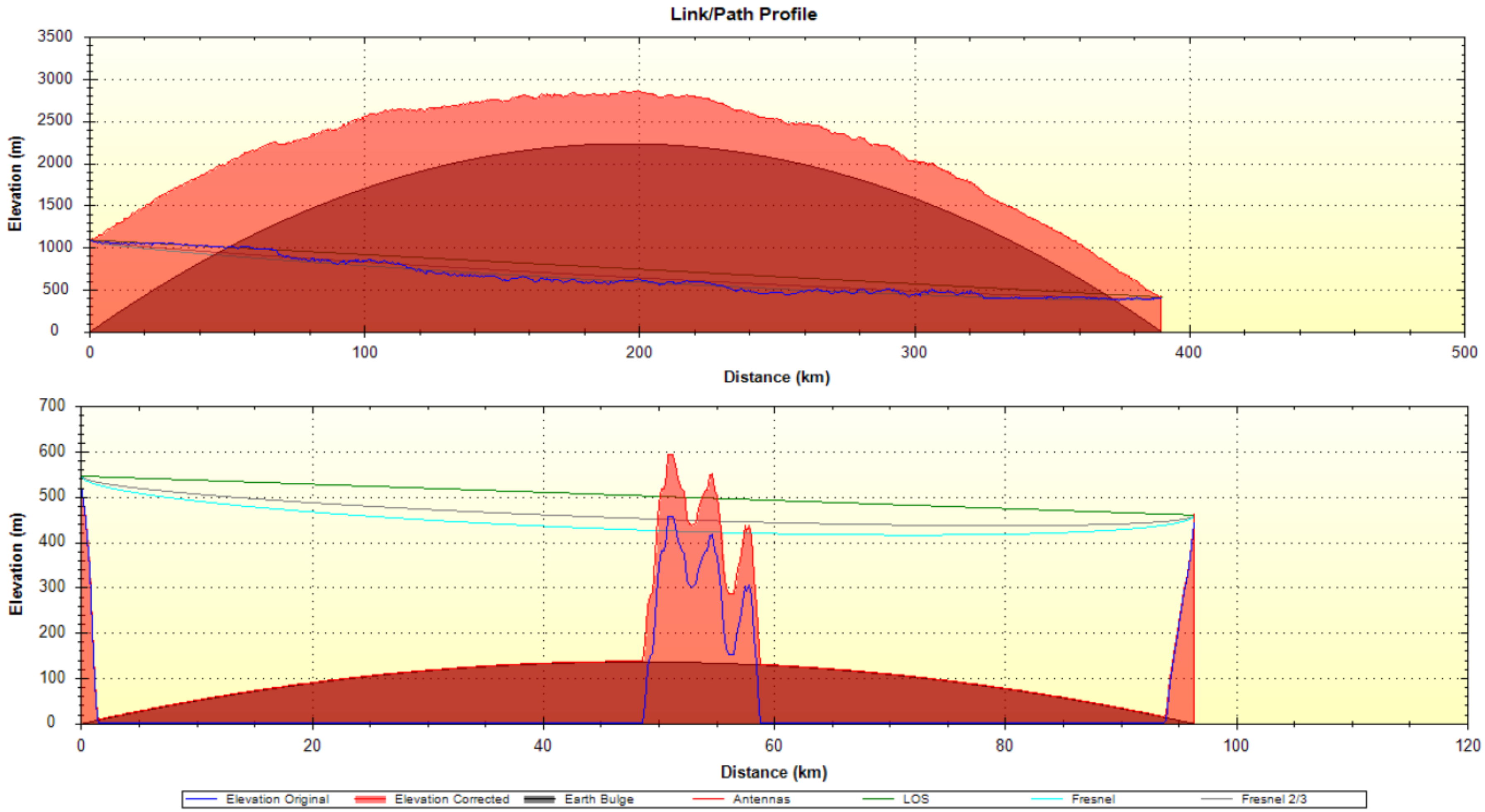


Duration of Interference Eras

- When synchronized, main beams will interact upon every rotation
  - Interference duration: $\frac{1.4\ °}{30\ °/\mathrm{s}} = 47\ \mathrm{ms}$
  - Main-main interaction: 0.92 %
    - (time G_{mut} > 50) / (total time)
    - Could also define as 47 ms / 12 s = 0.39 %
- Duration of these eras is a function of rotation rate variation
  - Example era duration: $\frac{1.4°}{\Delta\omega=10^{-4}} = 3.89\ \mathrm{h}$
  - In the nearly-synchronized regime, hours to days is possible



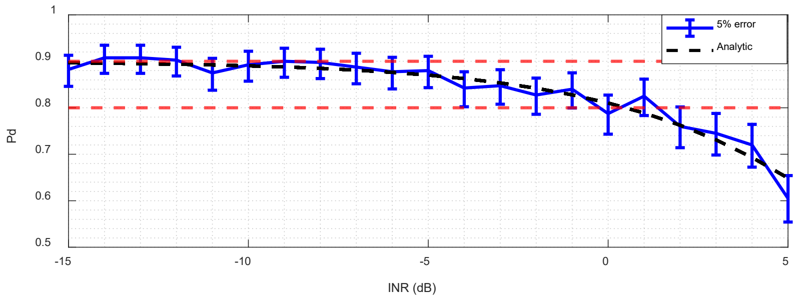
LRR – Multiple BTL Mechanisms



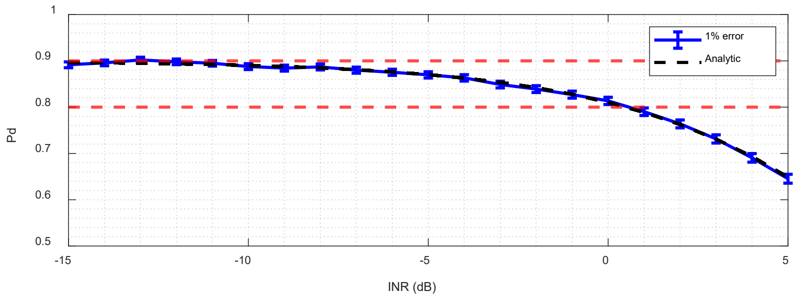
Radar Signal Modeling

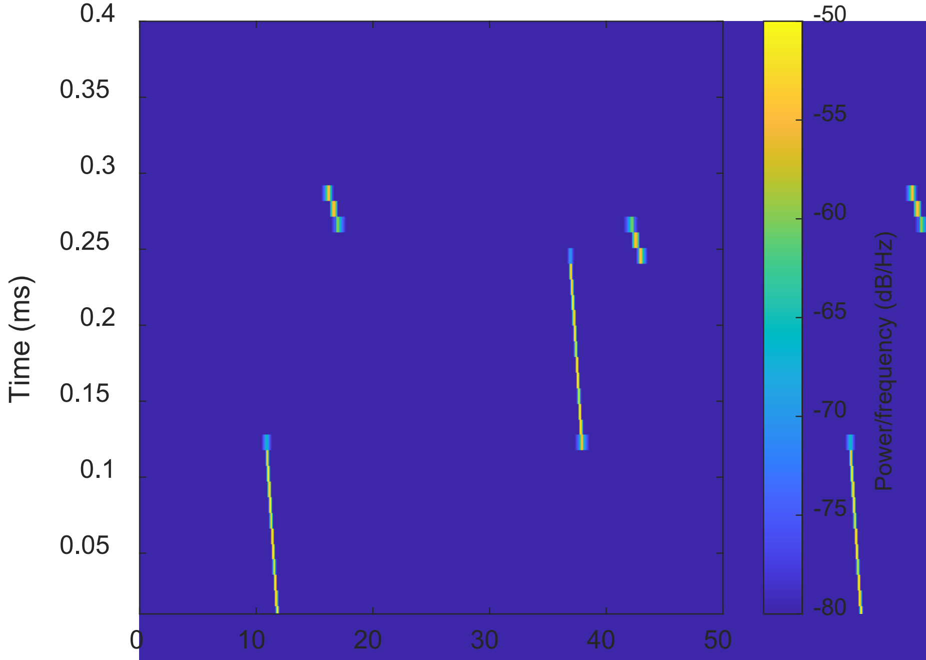
- What happens with different interferer signals? There are a lot of L-band radars (~40)
- When do they synchronize (time-domain again)?
- What is the effect? What is the concern?

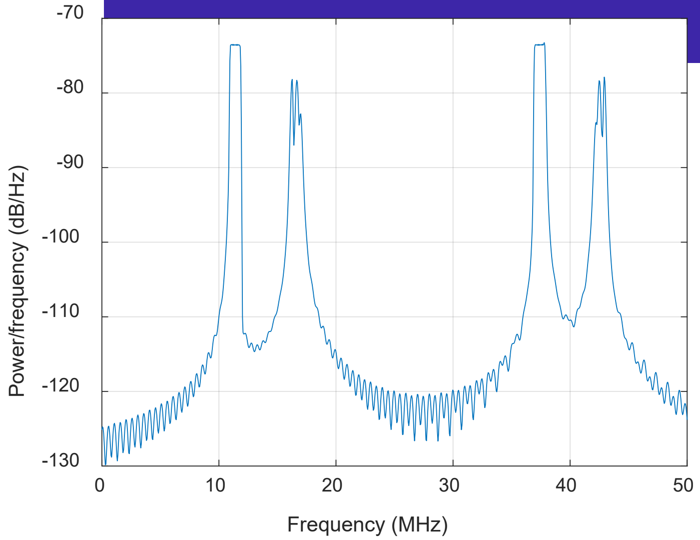
400 trials



10k trials

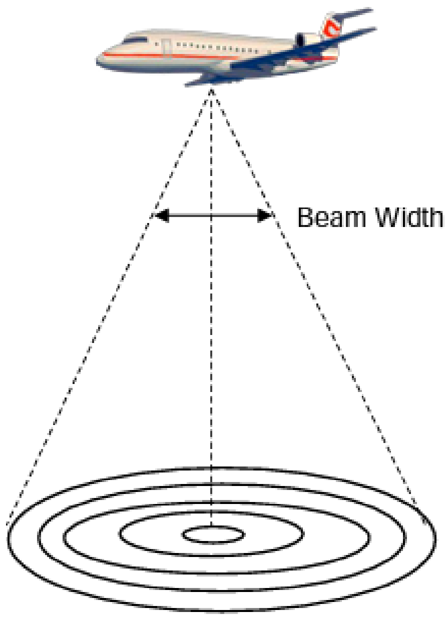


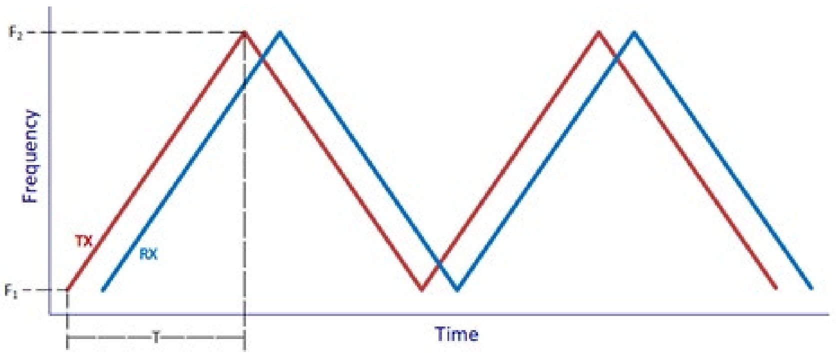


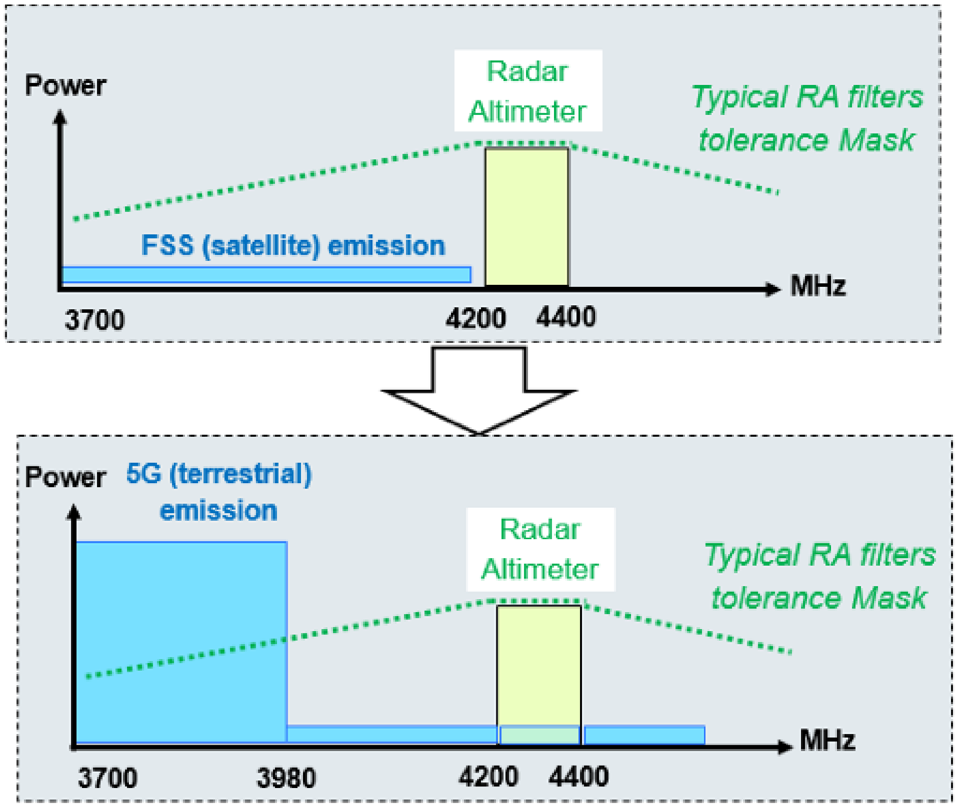


5G and Civilian Radar Altimeters (RADALT)

- Linear FMCW radar, 4.2-4.4 GHz, homodyne
  - Potential gNB OOB interference?
  - Potential RADALT Rx gNB in-band signals?

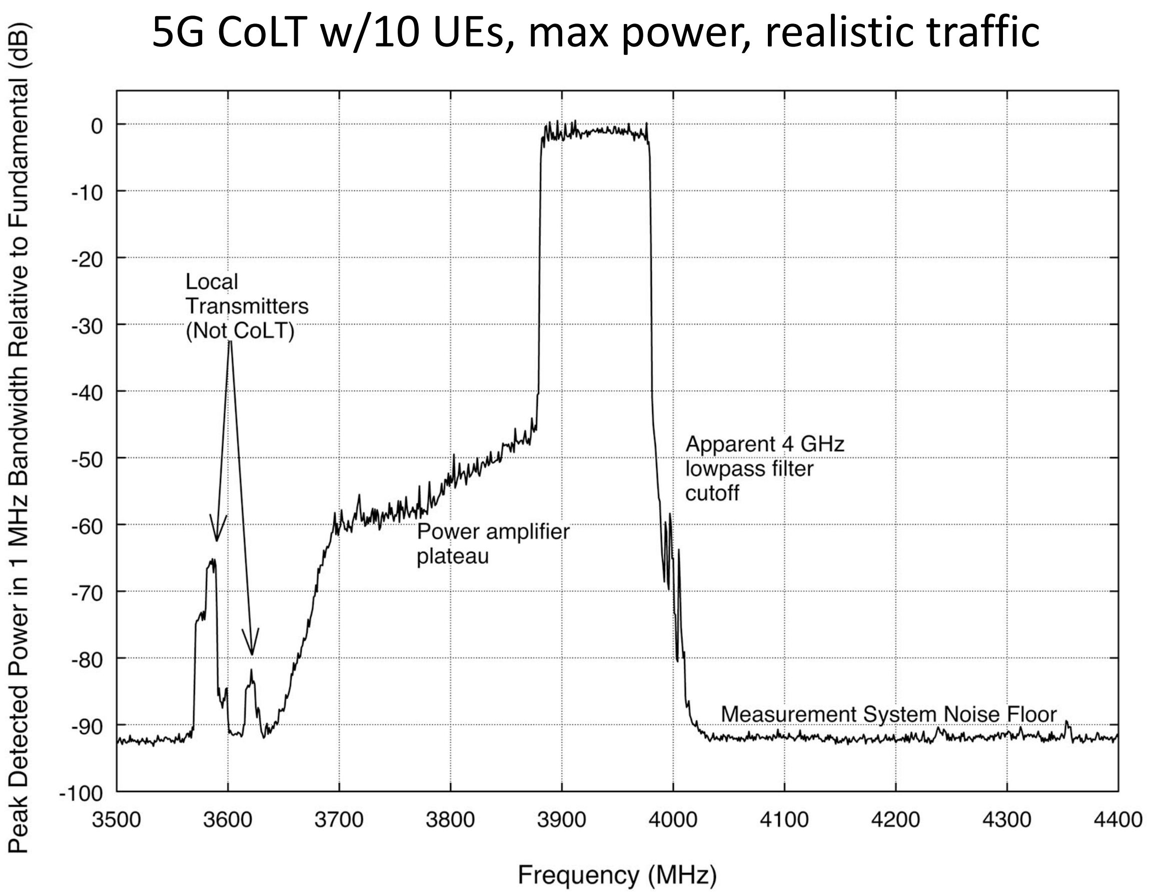






5G and Civilian Radar Altimeters (RADALT)

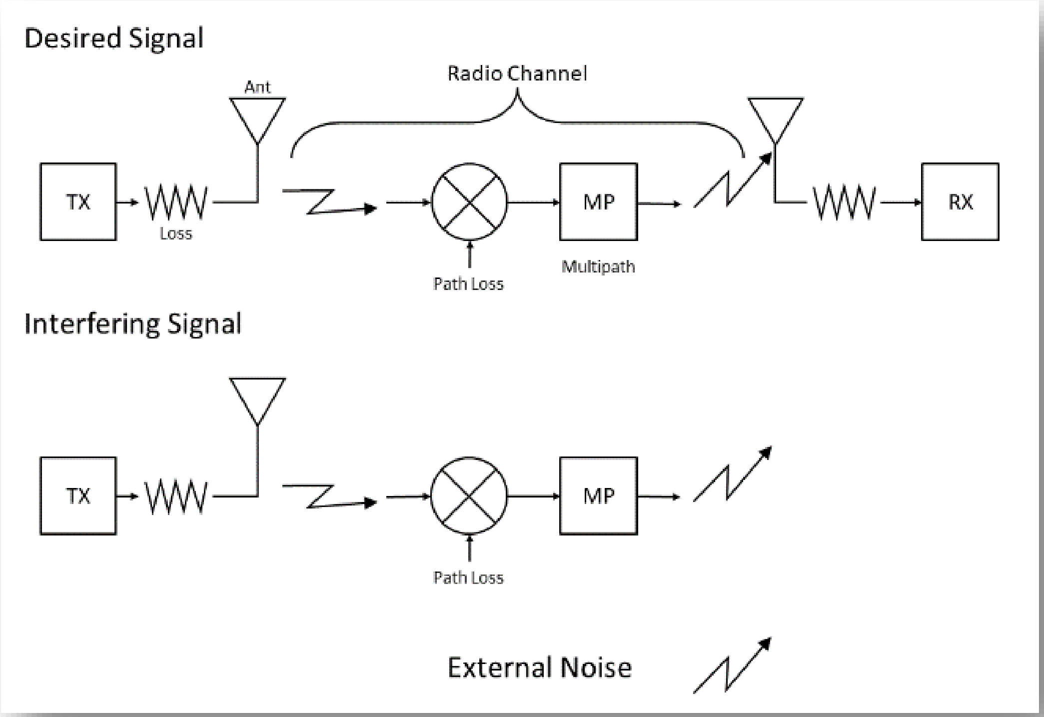
- The “when” becomes complex
- Antennas are critical – OOB, outside of beam
- Front-end RADALT measurements needed
- More gNB measurements needed
- But wait, there’s “more” (aggregate)
  - FMCW mostly unsynchronized



Modernizing Interference Analysis

Path Forward

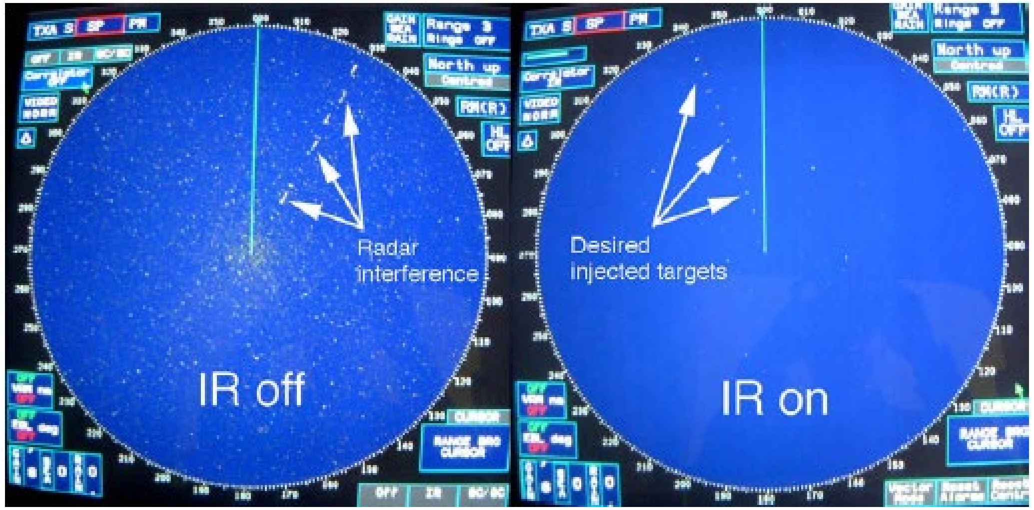
- Develop generalized IA model and framework
  - Define required functions and API
- Standardize core IA libraries and publish to GitHub, w/pedagogical examples
  - Amplitude probability distribution
  - Frequency-dependent rejection
- Develop "best practices" guidance for IA modeling and measurements
  - Which one of these is right?
  - Proactive vs. reactive
- Recommend adding additional criteria to IPC



Baseline SNR (dB)	Required SNR (dB)	Pd	Trials	IPC INR (dB)
13.8	13.8	0.9	400	-1
13.8	13.8	0.9	1e6	< -15
10.5	10.5	0.8	400	-7
10.5	10.5	0.8	1e6	<-20
14.2	10.5	0.8	400	4
14.2	10.5	0.8	1e6	1

Measurements are Critical

- Validate IA framework with previous and new measurements
  - Models can generate measurement requirements
  - Measurements can validate and drive development of models
- Measurements are challenging to scale to statistically-significant results
  - 500 trials may be possible – but 1M?



Questions?