

SECOND GENERATION RFI DETECTION OPTIONS FOR IMT SIGNALS AND NWP APPLICATIONS

Edward Kim, NASA Goddard Space Flight Center

NOAA/NASA Joint Polar Satellite System

February 16, 2022

RFI 2022

Outline

- Introduction
- “1st Gen” & “2nd Gen” RFI detection
- RFI hardware capabilities vs. NWP system constraints
- IMT (5G) RFI detection challenges and strategies
- RFI detection concept for future NWP satellites
- Future NWP sounder fleet configuration
- Summary

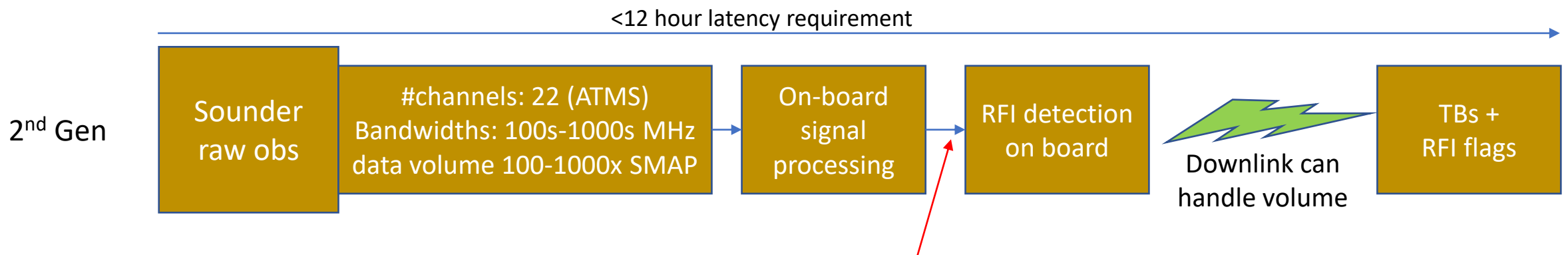
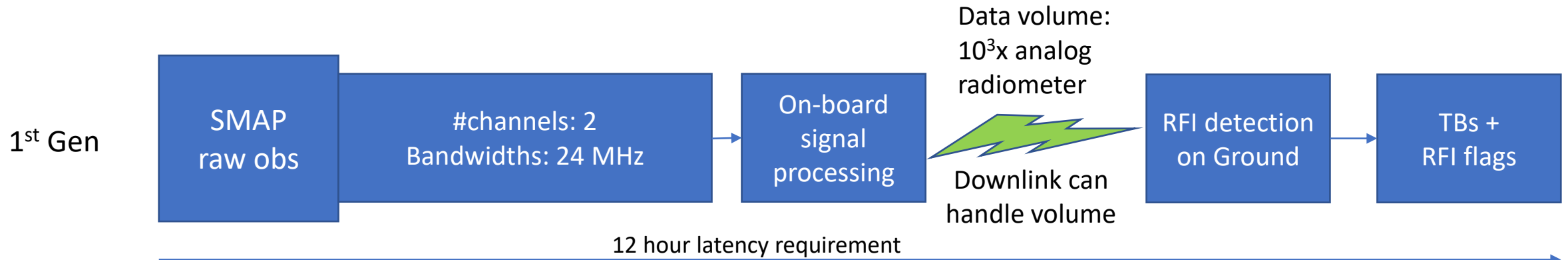
Introduction

- Focus: RFI detection options for future satellite MW sounders for NWP
- Motivations:
 - MW sounders provide highest-impact obs to NWP forecasts → essential backbone
 - Expanding deployment of IMT (5G) RFI sources over next decade
 - Existing satellite MW sounders have no RFI capabilities, but many are beyond end-of-design-life
 - Replacement sounders are being launched; ATMS on JPSS-2/3/4 to last until 2040
 - But due to long development times, those (e.g., ATMS) don't include RFI capabilities
 - NOAA's post-JPSS "LEO" architecture is being designed right now, for operational use starting around 2040, to last until maybe 2060
 - Identifying RFI options for this future LEO system needs to happen now, before the system design becomes fixed

“1st Generation” RFI detection

- Best (only) example = SMAP
 - 1.4 GHz passive, 24 MHz used
 - 6m real-aperture rotating imager
 - First dedicated RFI subsystem in space
 - Digital back end, 16 x 1.5 MHz subbands
 - Time & freq domain ‘spike’ detection; cross-frequency detection
 - 3rd & 4th Stokes detection, kurtosis detection
 - Designed to handle narrowband RFI
 - Relatively forgiving application: soil moisture 3K/percent; 4% requirement
- Digital back end technology:
- 96 Msps ADC x 2 IF signals
 - Space-qualified FPGA could handle
 - on-board time & frequency slicing, 4-Stokes, 1st-4th moments, kurtosis
 - 1000x traditional data volume downlinked
 - L1 data latency requirement: 12 hrs
 - Thresholding performed on ground
 - Detection, excision, and replacement of contaminated data

Data Volume, Latency Drivers on System Design



Data volume at this point: 10^5 - 10^6 x analog radiometer
→ too large to downlink → must do RFI detection on-board
→ impacts detection algorithms/strategy, conops

“2nd Generation” RFI detection

Key differences 2nd Gen vs. 1st Gen from previous slide

- Must digitize 10-100x wider signals in a channel; 10+ Gsps ADCs exist today
- Must perform all processing through RFI detection on-board
 - Including any FFT type operations
 - Fast FPGAs or ASICs exist today; some space-qualified or soon will be
- RFI detection algorithms choices likely more limited
- Downlink bandwidth limitations won't allow downlinking full intermediate variables, only final counts or TBs, RFI flags, and simple data
- NWP latency requirements are tighter → less time to generate results
- NWP worries about errors of ~0.1K vs. SMAP ~few kelvins

How IMT/5G RFI May Affect Satellite Radiometer Data

- Use ATMS as an example
- RFI is (almost) always additive
- RFI can be large, marginal, undetectable
 - Large RFI is easy to detect and already removed by ground processing
 - Marginal RFI is near or slightly above ATMS radiometric sensitivity
 - Difficult to detect, cannot be removed, and can adversely affect forecasts
 - Undetectable RFI is well below ATMS radiometric sensitivity with no effect
- 5G RFI amplitudes are expected to fall in the Marginal RFI regime
 - At or near ATMS sensitivity threshold (next chart for visual description)
- 5G RFI characteristics are similar to natural signals ATMS measures
 - It is harder to detect 5G RFI than other types of RFI

Likelihood of RFI in ATMS Channel 1 (23.8 GHz) is High

Marginal RFI (grey) regime will have greatest adverse affect on NWP forecasts = same power levels predicted for RFI from 5G; we are in or near this regime

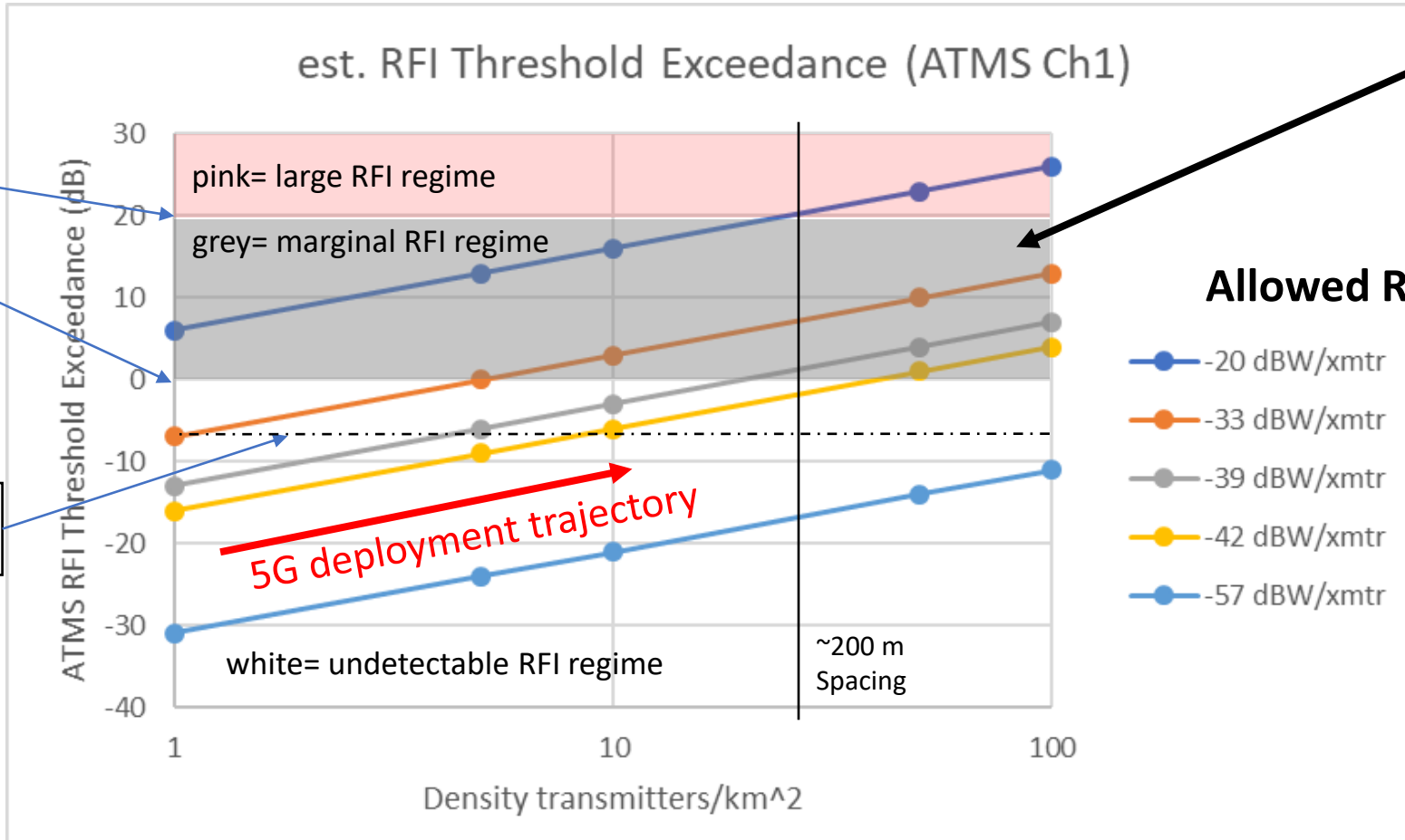
RFI detectability thresholds

10x NEDT

0.1x NEDT (notional threshold)

Grey zone moves downward as tech improves

-166 dBW/200MHz (ITU threshold)



Allowed RFI levels

- 20 dBW/xmtr FCC original proposed level
- 33 dBW/xmtr WRC-19 < 2027
- 39 dBW/xmtr WRC-19 > 2027
- 42 dBW/xmtr pre-WRC-19 proposed level
- 57 dBW/xmtr Interference-free

Orig. chart by D.Kunkee
Modified by E.Kim 7/24/20

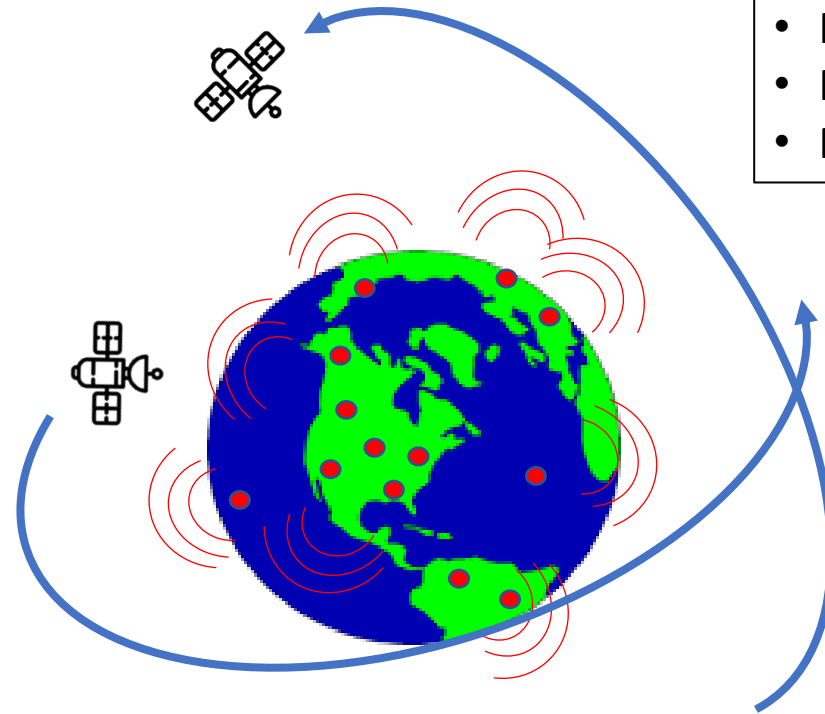
NOTE! Relative vertical positions of RFI regimes vs. allowed RFI levels not exactly known. Exact analysis requires RFI surveys + simulation.

IMT Signal Characteristics to Consider for 2nd Gen RFI Systems

- Noise-like modulation types
- Dynamic power levels
- Dynamic Antenna Patterns
- Dynamic channelization within 100-200 MHz blocks
- mmw systems in urban settings → random polarization
- Unknown density of base stations and mobile users

- Many of these characteristics are very different vs. 1st Gen case
- All make RFI detection more challenging
- Simulation of the IMT RFI situation is essential for quantitative guidance
 - Local to global scales
 - Combine RFI obs from multiple sources in space and across time (weeks/months/years) → intercalibration important to reduce error bars
- Simulation will need real-world RFI data to be accurate → real-world RFI surveys
- Radiometer intercalibration and RFI measurement standards become important

The Need for Accurate RFI Simulation



Required Ingredients (puzzle pieces)

- RFI source characteristics
- RFI victim characteristics
- Propagation from source to victim

Outputs

- RFI amplitude at victim
- Location/time statistics of exceedances
- Predict when RFI source deployment will exceed thresholds at victim

An accurate RFI simulation is the best way to integrate information on source & victim hardware characteristics, real world RFI measurements, plus regulatory limits in order to quantify current and future RFI risks, and to evaluate RFI detection algorithms and risk reduction options...all in a consistent way.

2 fundamental RFI detection scenarios

May see either independently or both

a) Adjacent-band RFI scenario

- RFI source is adjacent to the sounding channel
- RFI source is IMT transmitters in the red band
- This is the primary expected IMT RFI scenario

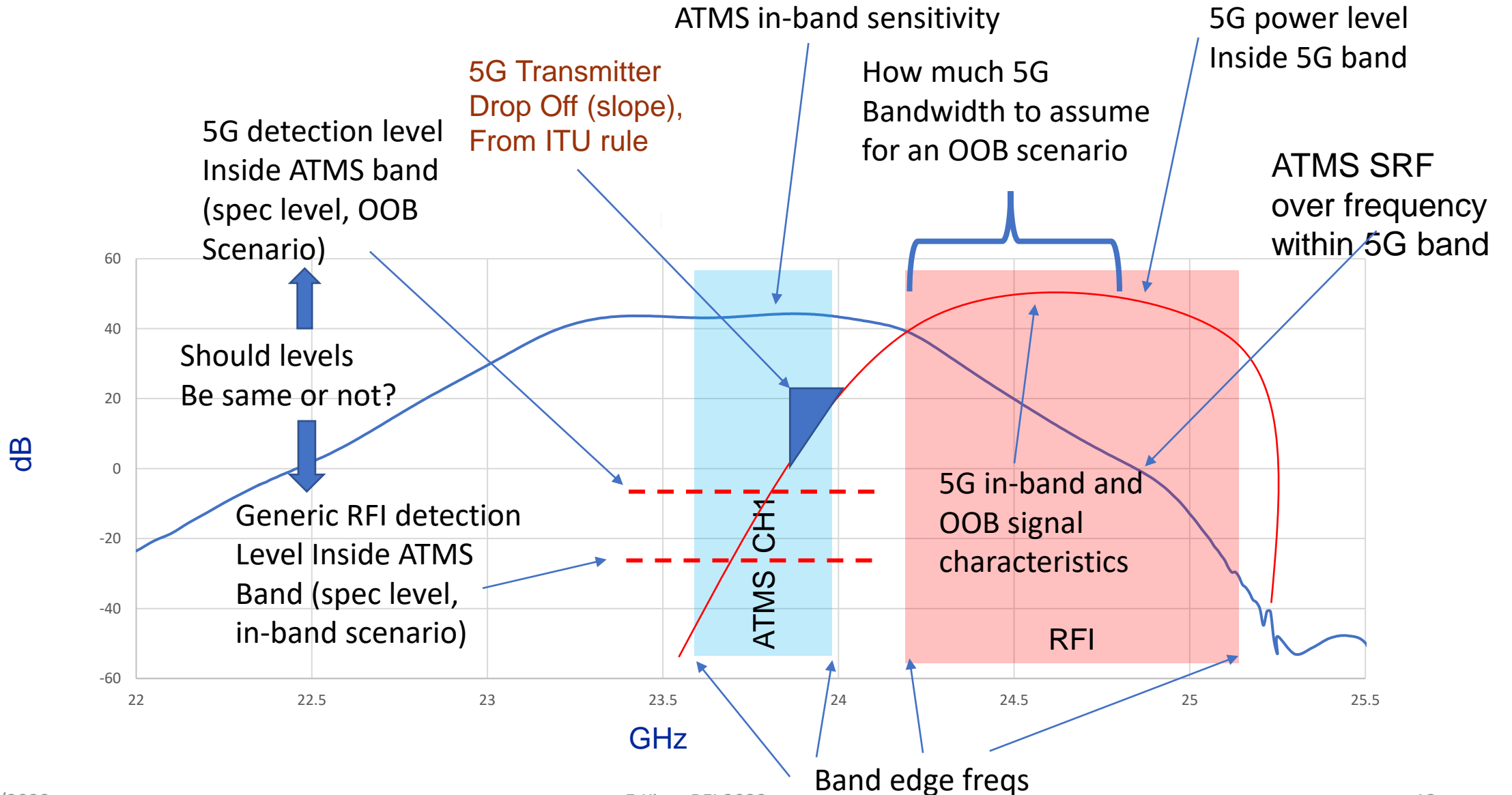
b) In-band RFI scenario

- RFI source is inside the sounding channel
- RFI source is any man-made energy in the blue band
- This covers the expected 'usual' or 'generic' non-IMT RFI scenario



SNR for RFI detection may be better in this scenario, assuming good rolloff of 5G signals
→ requires receiver to be able to “see” outside the sounding channel
→ design receivers to intentionally receive in IMT bands!

How to Characterize the Detection Scenario?



RFI detection expectations for future NWP satellites

This decade:

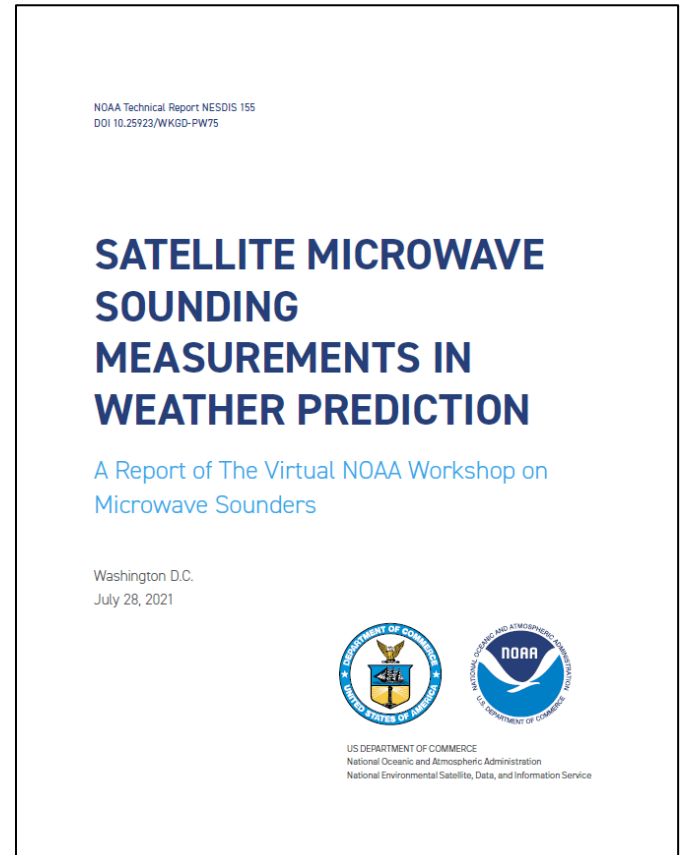
- NOAA plans to launch QuickSounder ~2025 to explore smallsat capability; currently no RFI detection capability planned
- Multiple cubesat sounders from academia/industry; expect some to include RFI detection capability
- Earliest chance for on-orbit RFI capability currently limited by programmatic constraints; hopefully this decade, but that will be well into deployment of 5G systems
- Latency requirements for future mw sounder obs may shrink to 3hrs or less. This can be met with multiple cubesats. Resulting high coverage duty cycles would reduce spectrum sharing availability.

Future NWP MW Sounder Fleet Configuration?

A just-released report from a NOAA workshop that asked major NWP organizations what they need from future MW sounders.

<https://doi.org/10.25923/wkgd-pw75>

- Backbone sounders w/ATMS-like channels (23-183 GHz); qty 3-6 depending on int'l partners & exact architecture details
- Augmentation by cubesat/smallsat sounders (50-183 or 118-183 GHz due to size limits); qty 2-dozens
- Interest in MW hyperspectral sounders (10s to 100s of channels)
- Recognition of RFI threat (see next slide)



Future NWP MW Sounder Fleet Configuration?

Executive Summary includes 2 items of interest with respect to future MW sounder observing architecture

11. Expanding commercial demand for Radio Frequency (RF) spectrum can degrade the ability to maintain and to improve NWP forecast capability. Both future backbone and supplemental MW sounder missions should incorporate technology to address radio frequency interference (RFI). Periodic real-world RFI surveys would provide highly valuable guidance.
12. A constellation architecture that combines diverse backbone and supplemental missions with differing launch dates and mission lifetimes needs a robust calibration strategy that recognizes inter-calibration, absolute calibration, and traceable calibration as intertwined. This will also help achieve NWP advances from future coupled models.

Summary

- Noise-like nature of IMT signals + wide bandwidth sounder channels require “2nd Gen” approach to RFI detection for satellite MW sounders
- Adjacent-channel detection scenario may present best chance of RFI detection → requires signal reception outside nominal sounding channel edges
- Future mw sounder fleet architecture under development now: ATMS-like backbone augmented by cubesats
- RFI threat is real and recognized; programmatic factors currently limiting earliest chance of on-orbit RFI capability in JPSS sounders
- Future satellite sounder designs (post-JPSS for backbone sounders, today for cubesats) will incorporate digital back ends (DBEs)
 - DBEs are well-suited for implementing RFI detection
 - More robust calibration: important for short-lived radiometers like cubesats
 - Flexibility: some designs would allow reprogramming after launch
 - “post-ATMS” could begin late-2030s to 2040; earlier opportunities for infusion of 2nd Gen desirable
 - Space-qualified capabilities already exist (GHz bandwidths) and keep improving rapidly
- 2nd Gen RFI designs also generate challenges
 - Larger data volume & rates → system design & algorithm choices
 - Some DBE designs require significant power & thermal accommodation (extra 10s to 100s of watts of power and waste heat)
 - Can scale back to fit available power, etc. but performance must also scale back (# channels, bandwidths, NEDT, etc)

A note on Spectrum Sharing

From NASA's Spectrum Office:

NASA is always open to discuss and consider technical solutions that enable equitable spectrum access and recognizes that novel techniques may be needed to facilitate NRDZs. NASA is investigating the use of NRDZs as a potential solution to sharing on a case-by-case basis. NASA Spectrum does not currently support or oppose spectrum sharing in passive bands. There are issues related to the practicality of implementing, monitoring, and enforcing the complex regulations that would need to be addressed prior to adopting such an approach.

My own thoughts:

Spectrum sharing sounds nice on paper, and the technology exists to an extent (although it might require connectivity that isn't available everywhere/all the time). But I believe there are major practical and regulatory challenges, and it sets a scary 'slippery slope' paradigm for the future.