Modeling Satellite Radio Interference

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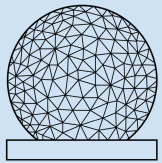

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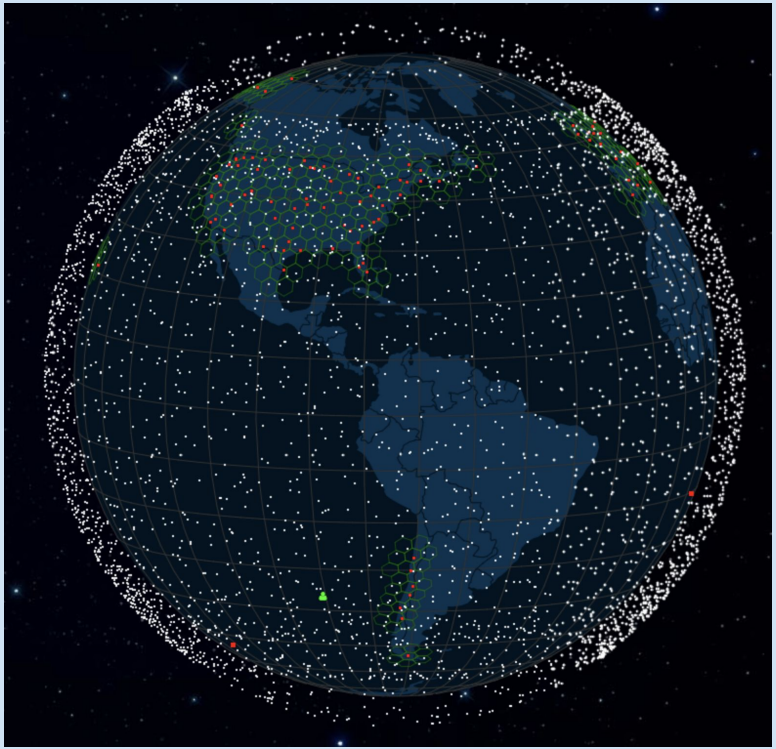
Starlink Constellation

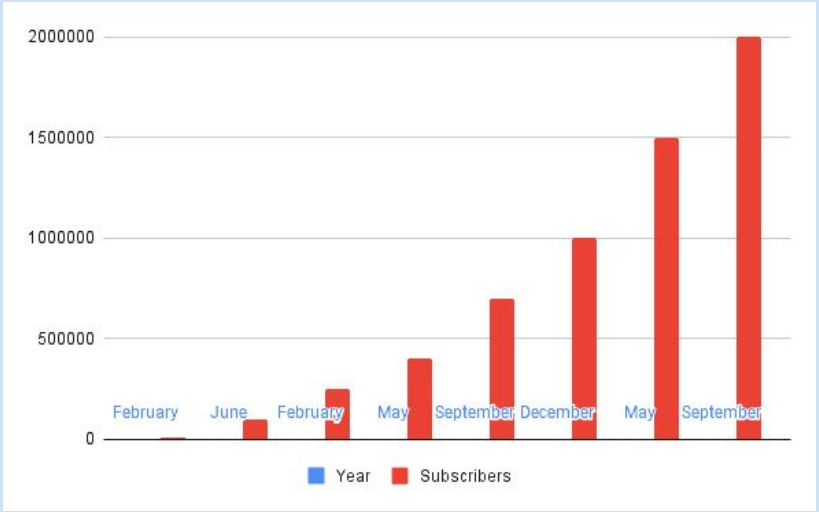
- Started with 60 satellites in 2019
- Grew to nearly 1000 satellites by 2021
- Over 6000 satellites currently (July 2024)
- Provides low-cost internet services to remote locations



(https://satellitemap.space/)

Plans of Expansion

- Number of satellites is exponentially growing
- SpaceX hopes to have over 42000 active satellites in this constellation within a few years
  - Explosive revenue growth from Starlink program
  - Projected revenue of $6.6 billion in 2024 (500% increase from two years ago)
  - Other countries and companies jumping into market
- DTC (Direct to Cell) Starlink to provide cell service direct to users' phones



Starlink Subscribers by month (2023)
(https://www.campingforge.com/starlinkstatistics/)

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Problems for Scientific Community?

Problems for geospace and radar technologies:

- Additional layer of orbiting objects
- Concerns with debris, launching more objects into space

Problems for astronomy:

- Starlink currently occupies specific radio frequency bands
- As technology improves, satellites might eat into available astronomy bands
  - Going to higher frequencies will improve amount of information that can be conveyed
  - These higher frequency bands might neighbor protected astronomy bands
- Unintended (and unregulated) out-of-band transmission[1]

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Purpose of the Project

- Model aggregate interference from satellite constellations to a radio telescope
  - Create a generalizable package
  - Focus specifically on Starlink constellation relative to Westford
- Evaluate in-band observations
  - Express interference as power
  - Compare with a common radio emission source
- Make predictions related to future constellation growth
- Try to answer: how will this impact astronomy?

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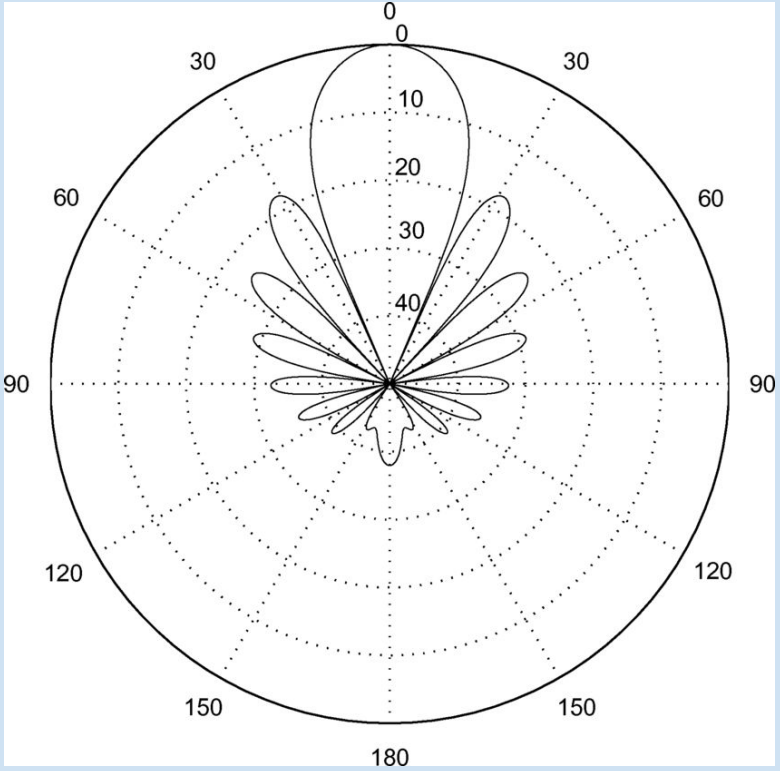
Overview of Antennas

- Directional
- Dish that “focuses”
  - Like whisper dishes

(https://ivscc.gsfc.nasa.gov/publications/ar1999/nswest.pdf)

Antenna Gain Patterns

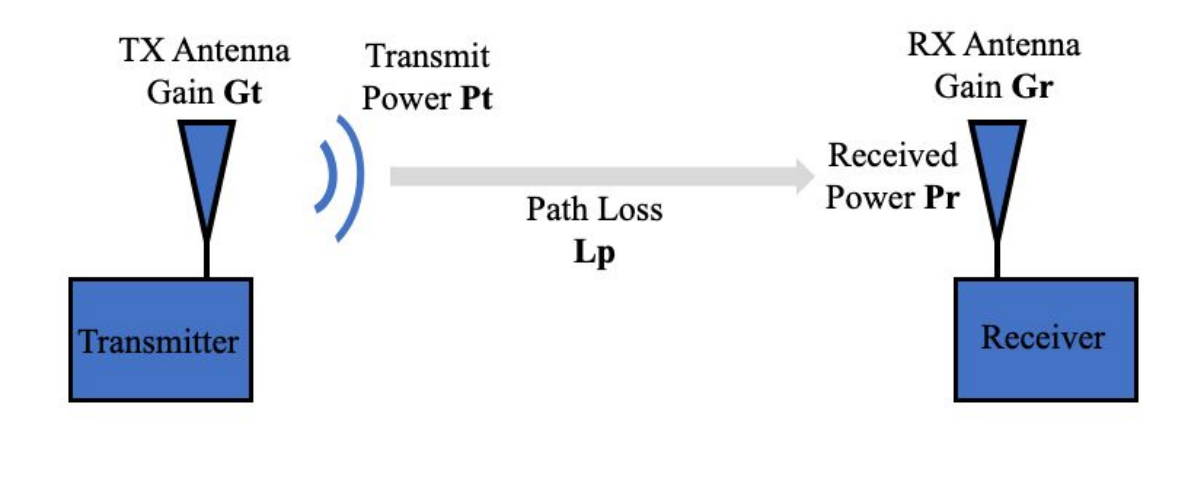
- Main lobe (pointing direction)
- Side lobes
  - Several dB below main gain



(https://www.researchgate.net/figure/Radiation-pattern-of-the-antenna-with-maximum-gain-with-2R-and-M-10_fig3_254019349)

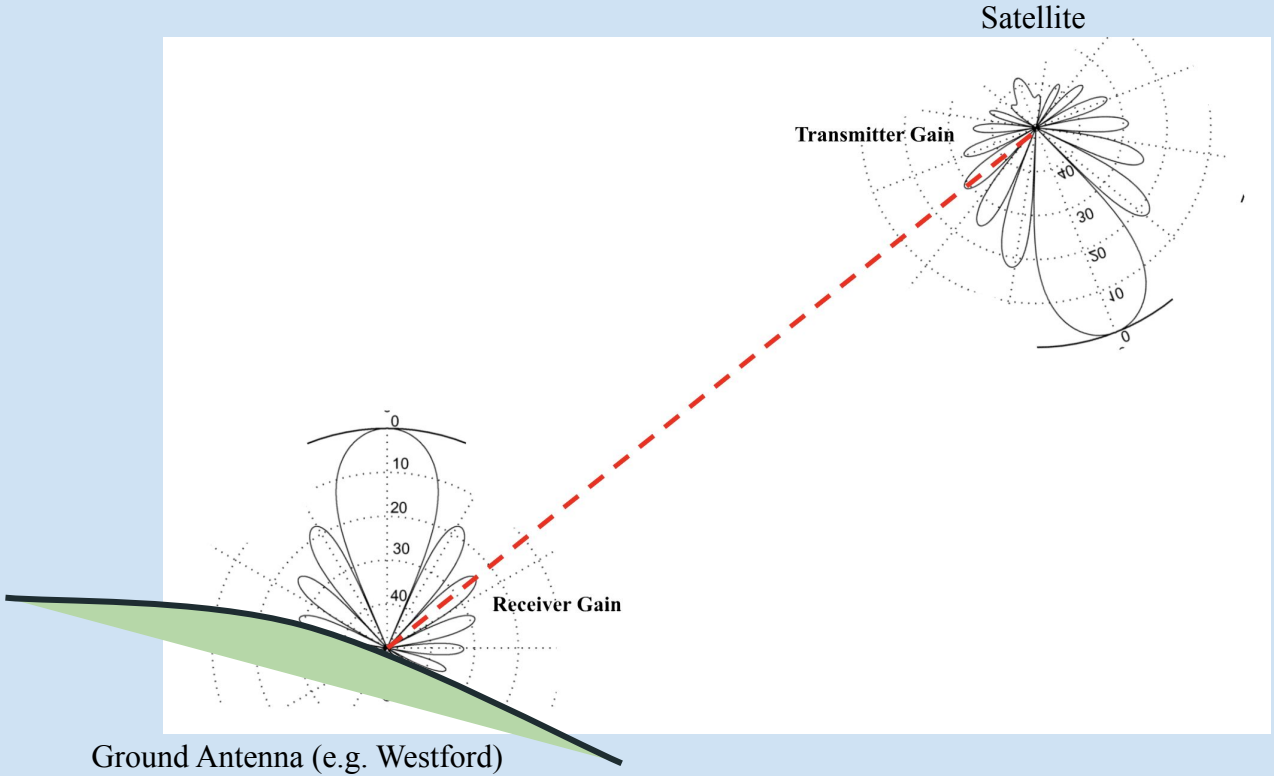
Link Budgets

- Accounts for gains and losses associated with signal transmission:
- Link budget equation: **(Pt * Gt * Gr) / (Lp) = Pr**



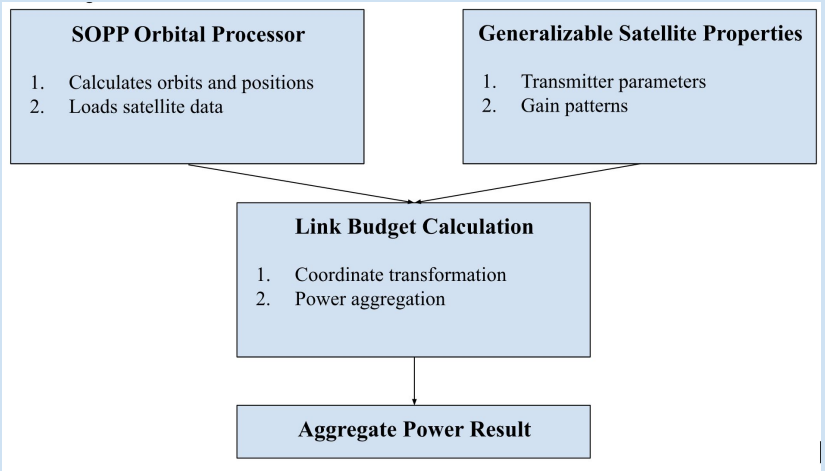
(https://pysdr.org/content/link_budgets.html)

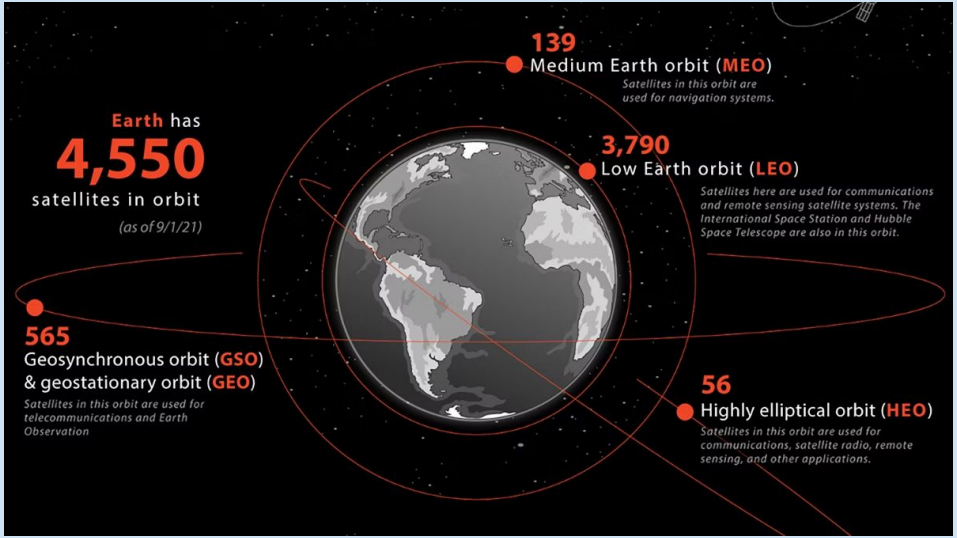
Link Budget + Gain Pattern Visualization



Modifying Orbital Processing Model

SOPP (Satellite Orbit Prediction Processor)





(https://nssa.gov.bh/satellites-and-leo/)

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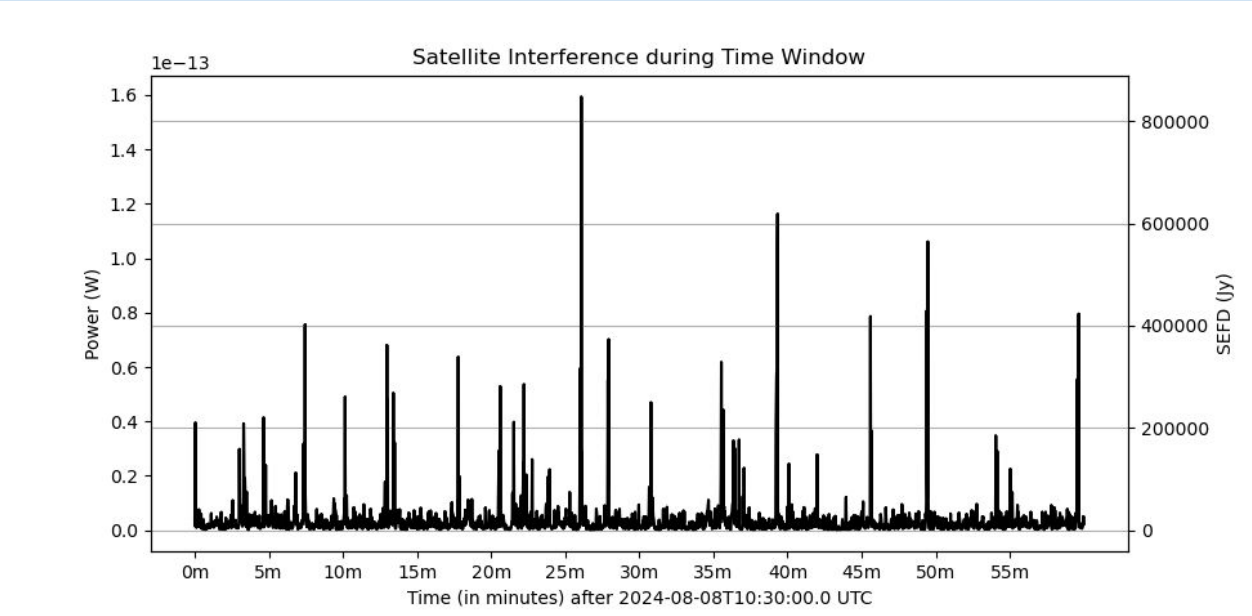
Worst-Case Scenario

If side lobes are at maximum of documented limit (30 dB down from main lobe):



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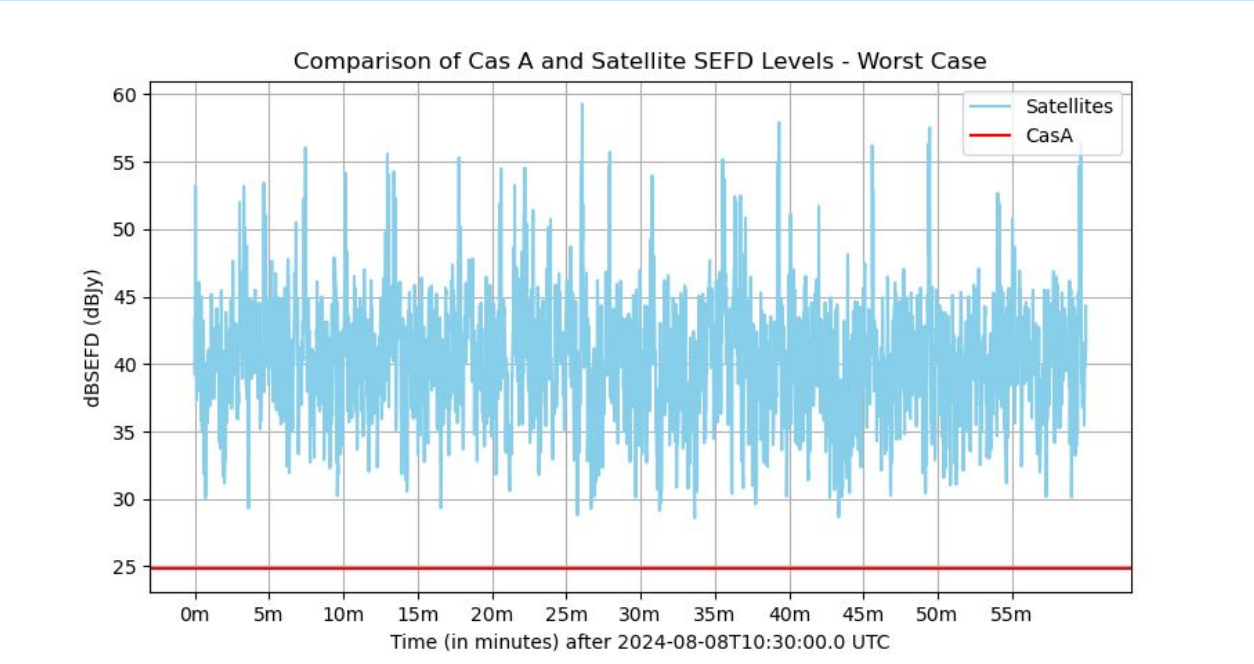
Worst-Case Scenario, cont.

When compared to Cas A (bright calibration source):

Note: SEFD is System Equivalent Flux Density



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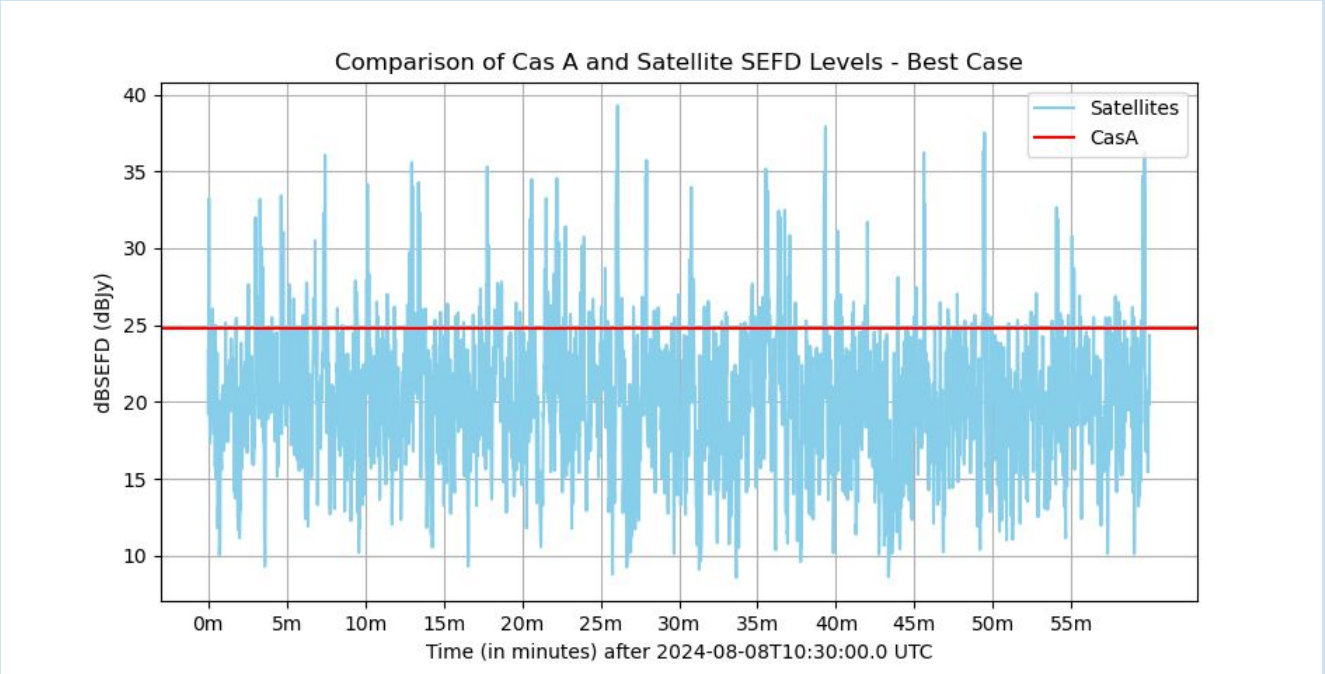
Best-Case Scenario

Assuming side lobes are on average 50 dB down from main lobe:



Implications and Takeaways

- At worst, almost complete inability to detect radio emission sources in-band
- At best, a much higher noise floor
  - Expensive to throw out unusable data (observation is costly)
  - More integration requires more data (also costly)
- And this is only due to the 6000 current satellites!
- DTC (Direct-to-Cell) Starlink emit higher power

In summary:

- In-band, satellite interference will overpower radio sources
- Out-of-band: our next step

Limits of Our Model

- Starlink satellite antenna gain pattern itself is unknown (proprietary info)
- Lack of steering angle data
  - Phased array antenna
  - Beamforming
- Difficult to balance parameters while maintaining real-time speed
  - Coordinate rotations
  - Steering randomization

Next Steps

- Compare with calibrated Westford data
- Assess accuracy of satellite model (gain pattern, transmitter, etc)
- Evaluate out of band interactions[1]
- Increase real-time capabilities

Acknowledgements + Questions?

Huge thank you to:

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My fellow Haystack interns,

MIT Haystack staff

Sources

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6. https://pysdr.org/content/link_budgets.html
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