# Opportunistic Multiple Spacecraft Per Antenna (OMSPA)

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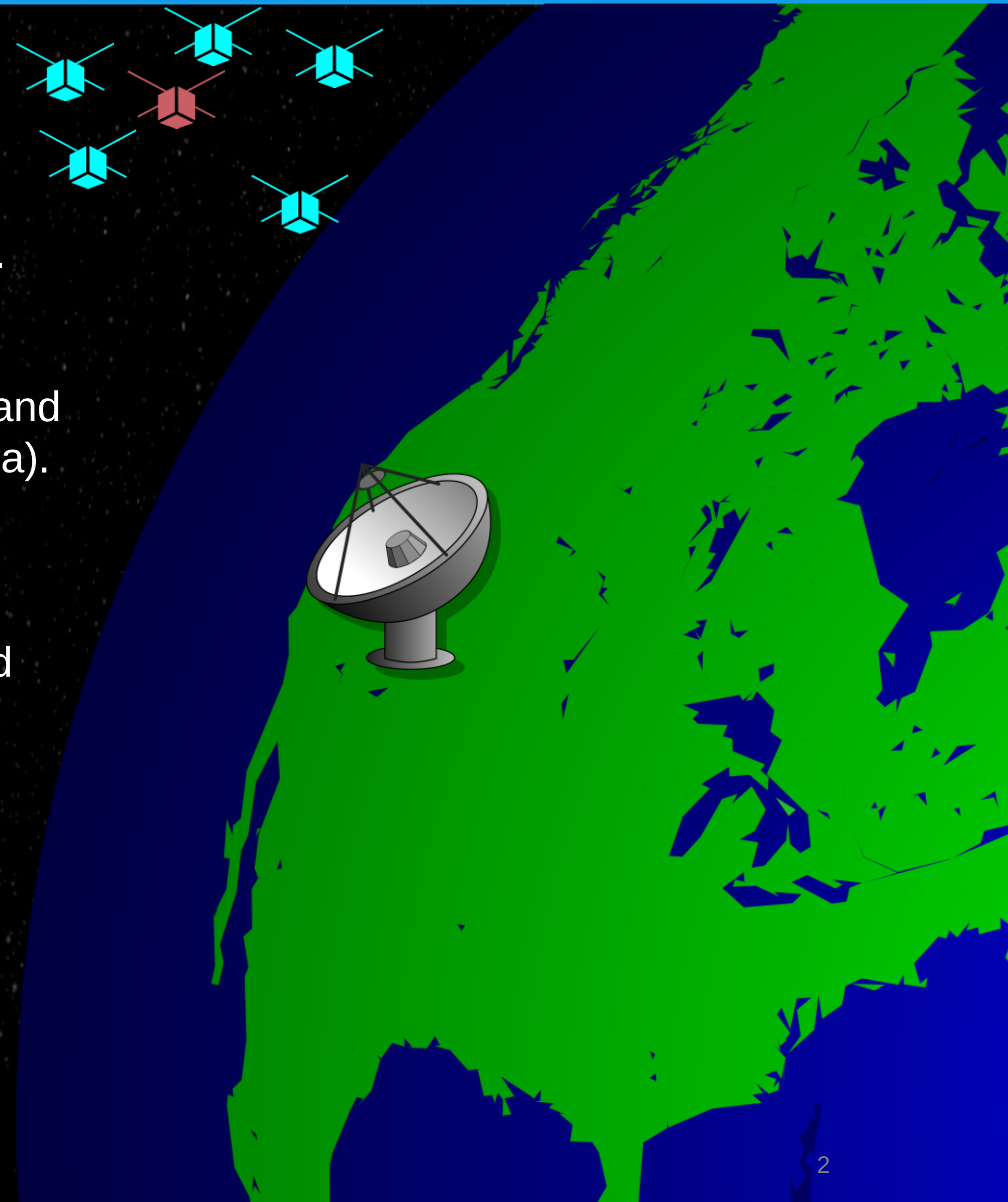
# Opportunistic MSPA Setup

- A single cubesat is ‘tracked’ and is always ‘in-beam’ (in center of main beam).
- Other cubesats may enter the main beam by following their own trajectory.
- We simulate the *EM-1* scenario[+] with 10 cubesats over a span of 96 hours (4 days) and 3 ground sites (Goldstone, Madrid, Canberra).
- EM-1 scenario does not include any TCMs.
- Receive antenna modeled as a 34m X-band antenna with 65dBi gain.
- Each cubesat EIRP assumed to be 5 dBW.
- Ground stations assumed to have 10dB noise figure.



[+] Cubesat trajectory created by Dave P. Heckman (332H) <david.p.heckman@jpl.nasa.gov>

# ICPS & Cubesat Motion Modeling


- Four-body trajectory calculations for each cubesat & ICPS: Gravity from the Earth, Moon, and Sun.
- ICPS on reference trajectory for 2018 OCT 07 launch (it flies by the Moon in about 5 days, 17 hours).
- ICPS is in a stable “BBQ” roll at 1 RPM, moving tail-first while rolling, and cubesats leave from the open “rear”.
- Cubesats launched at the first 2 documented “bus stops” only, with 6 at the first and 4 at the second. The 6$^{th}$ cubesat launched is treated as the tracked host for aligning antenna line-of-sight.
- Cubesats’ deployment interval at bus stops will be between 5 and 60 seconds; was modeled as 20 seconds.
- 4 days’ worth of time was analyzed, avoiding fly-apart at lunar flyby.

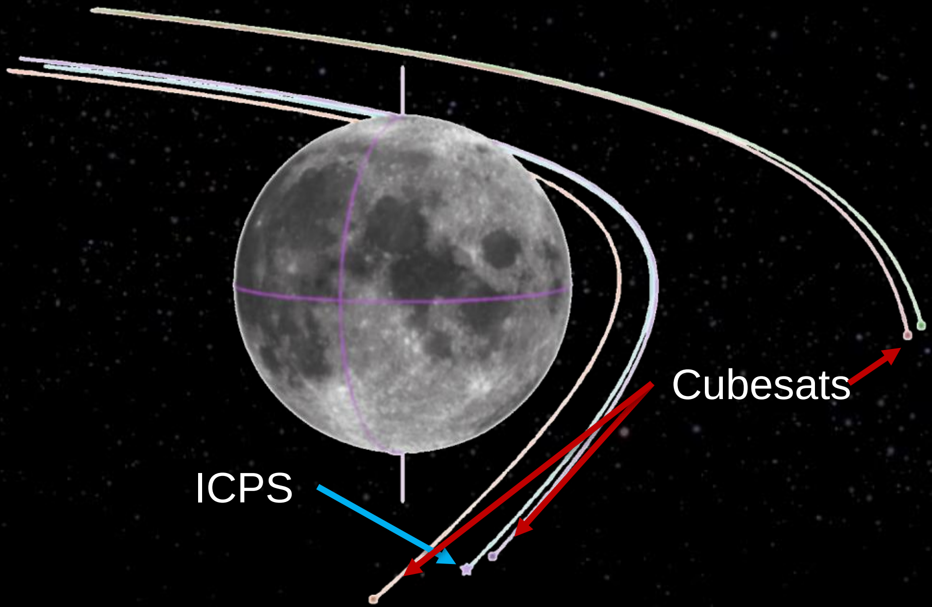
Note: Real cubesats generally maneuver! The model used here does not include that effect.

# Deployment Data & Assumptions

Documents from Marshall SFC provide:

- Cubesats' fairing position angles and deployment sequence are determined
- Cubesats' deployer angle in the ICPS fairing is known
- Cubesats' launch speeds occur in a known range (modeled here at 1.5 m/s)
- ICPS basic fairing dimensions are known
- ICPS roll is 1 RPM and the longitudinal axis remains stable to the Moon

The lunar flyby tends to spread cubesats apart:

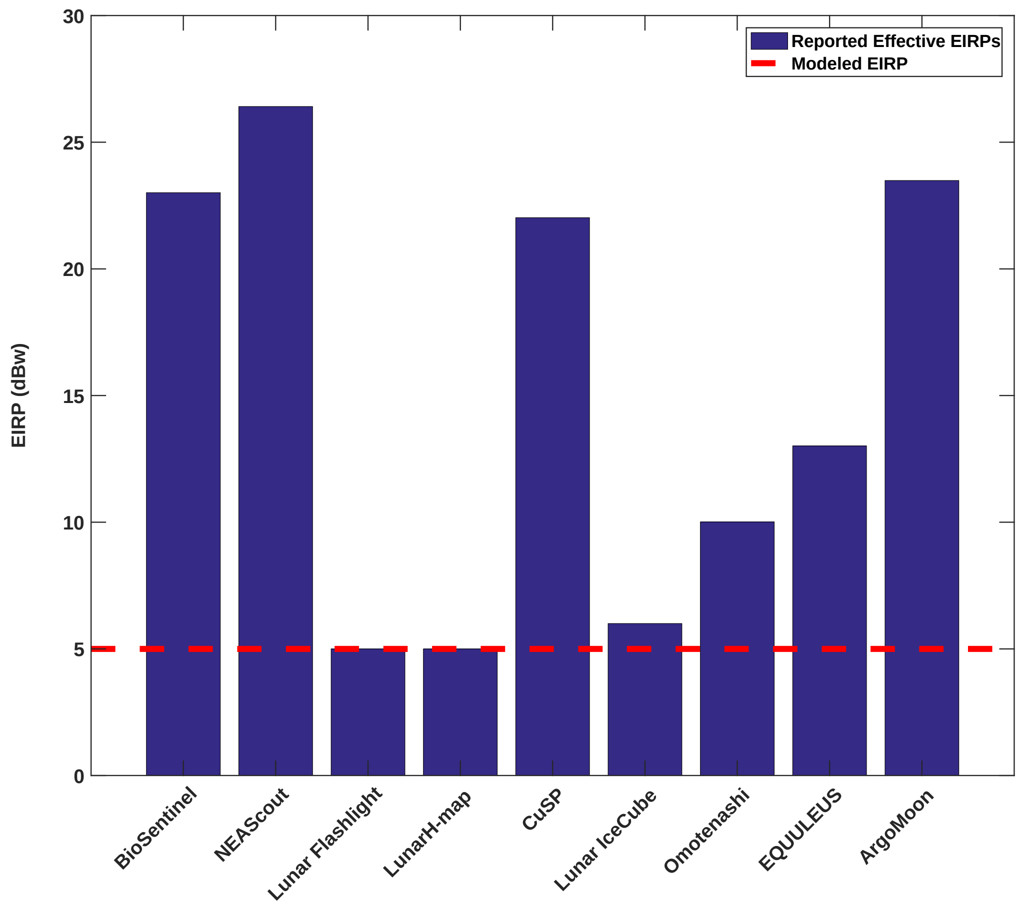



Real cubesats will execute their own maneuvers, and this study does not model those. Results in this study are for non-maneuvering objects launched from the ICPS with a single spring impulse.

# Simulated Waveforms

- An IRIS MarCO-B waveform was recorded in lab:
  - 48 KSPS (8 kbps data throughput)
  - BPSK
  - Manchester/Biphase Coding
  - Turbo 1/6 Code [includes cyclic-redundancy-check (CRC) block]
- This waveform was synthesized to generate 10 signals from different sections of the recording.
- The cubesats are assigned non-overlapping frequencies:
  - 8402.78, 8405, 8407, 8408, 8409.57, 8416.36, 8443.52, 8453, 8454, 8487 MHz.
  - Synthesized signal covers 85 MHz.
- Received power at ground antenna a function of:
  - Free-space Path-loss
  - Antenna gain due to antenna pattern (65 dBi main-beam gain)
  - Cubesat EIRP (5 dBW)
- Simulation results are sampled once every 2 hours during the 96 hour trajectory. The ground site with largest elevation angle > 10 degrees is chosen at each simulation time instant.

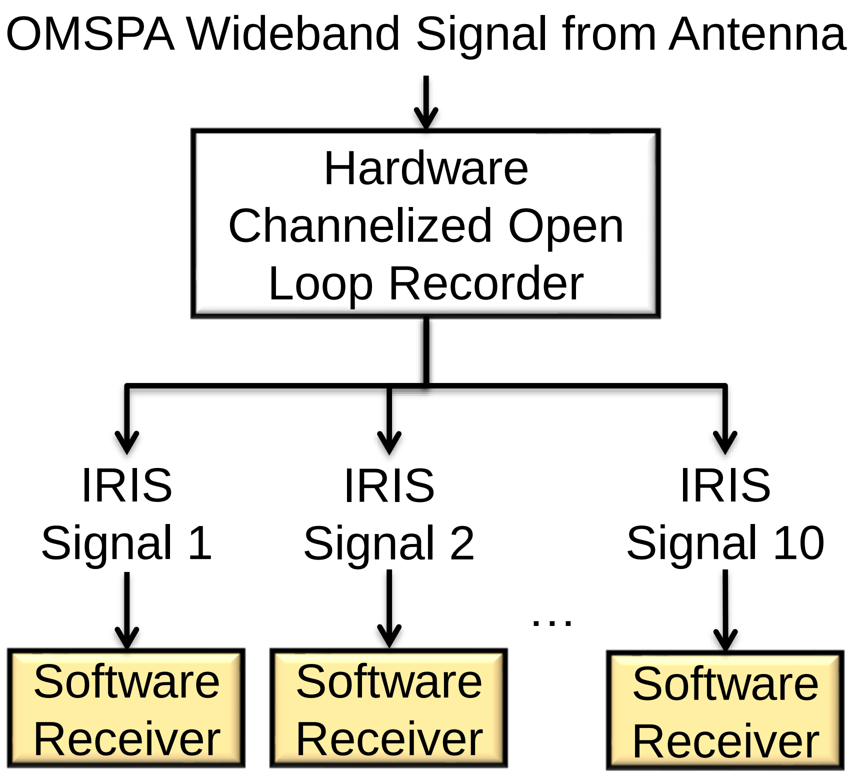
# Reported vs Modeled Cubesat EIRPs



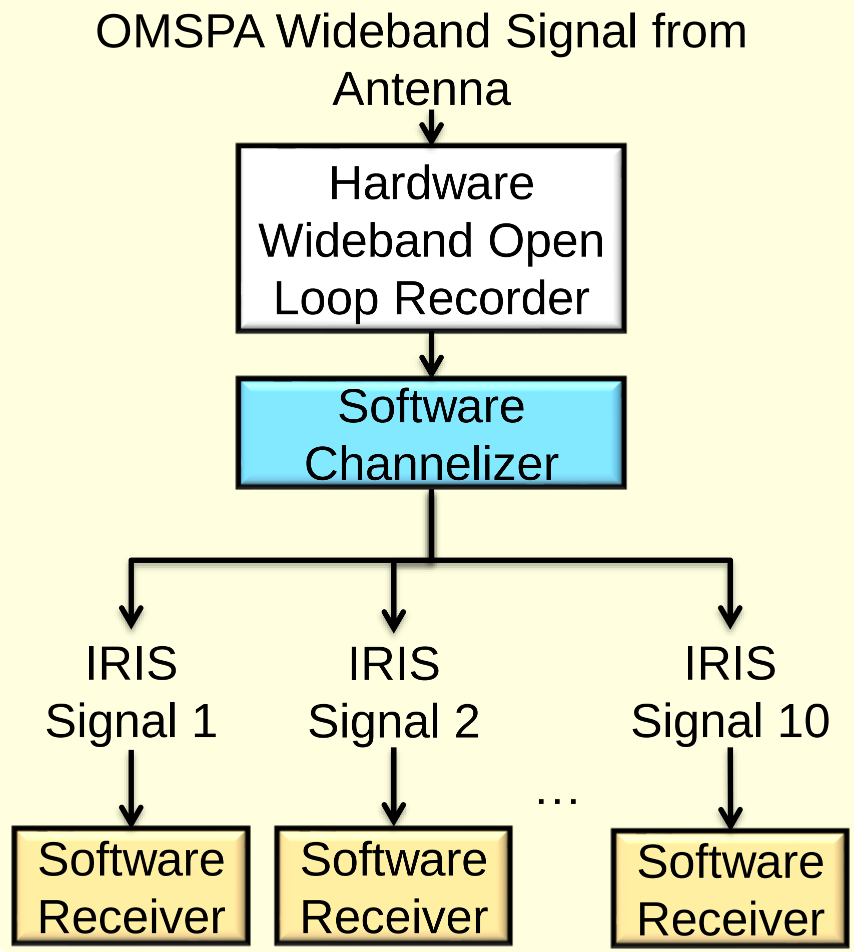

Modeled EIRP is conservative relative to actual values.

# Receiver Architectures Options

**Option 1**: Channelized Recorder

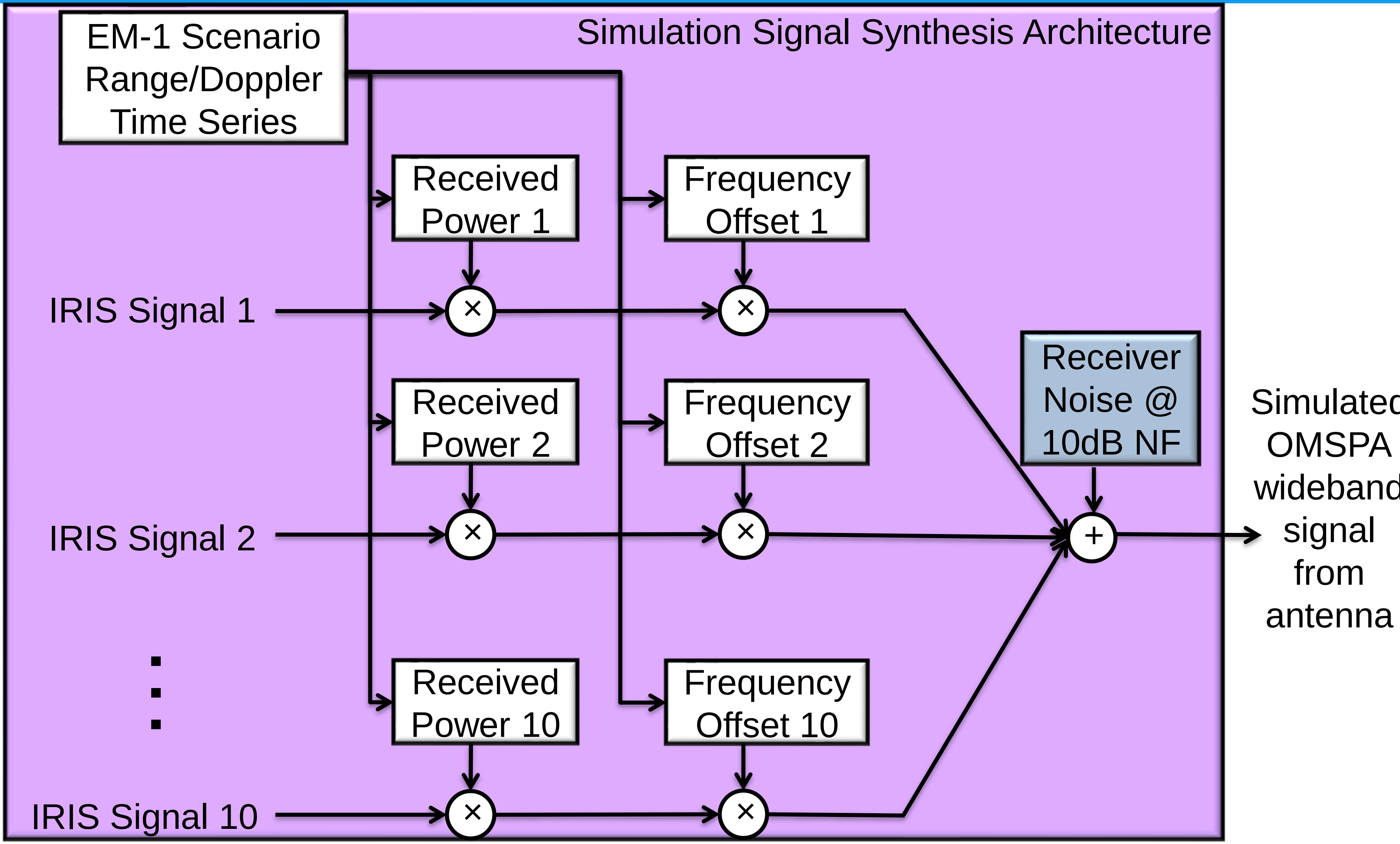



**Option 2**: Wideband Hardware Recorder

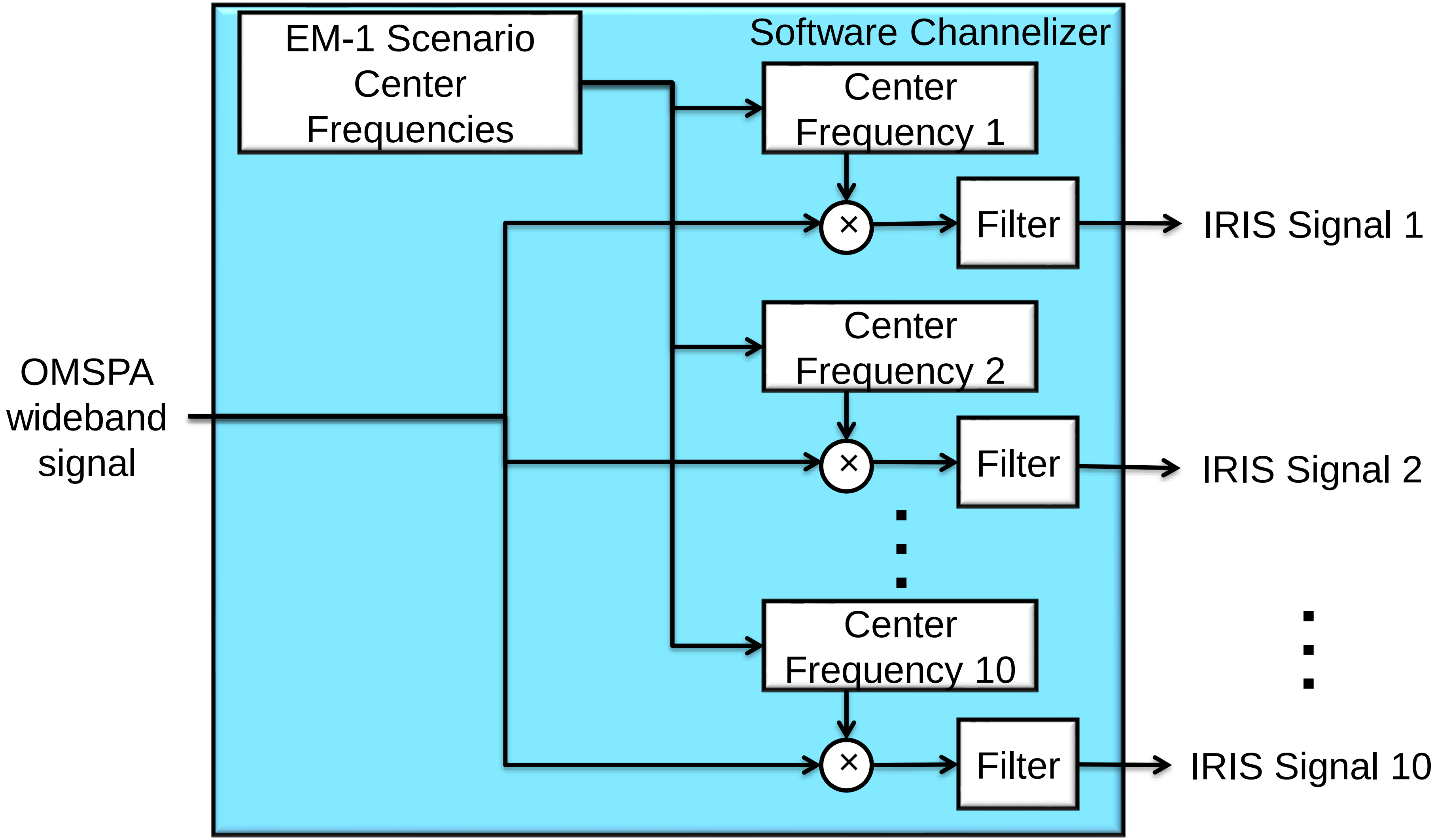



**Option 2 is chosen for this simulation effort**

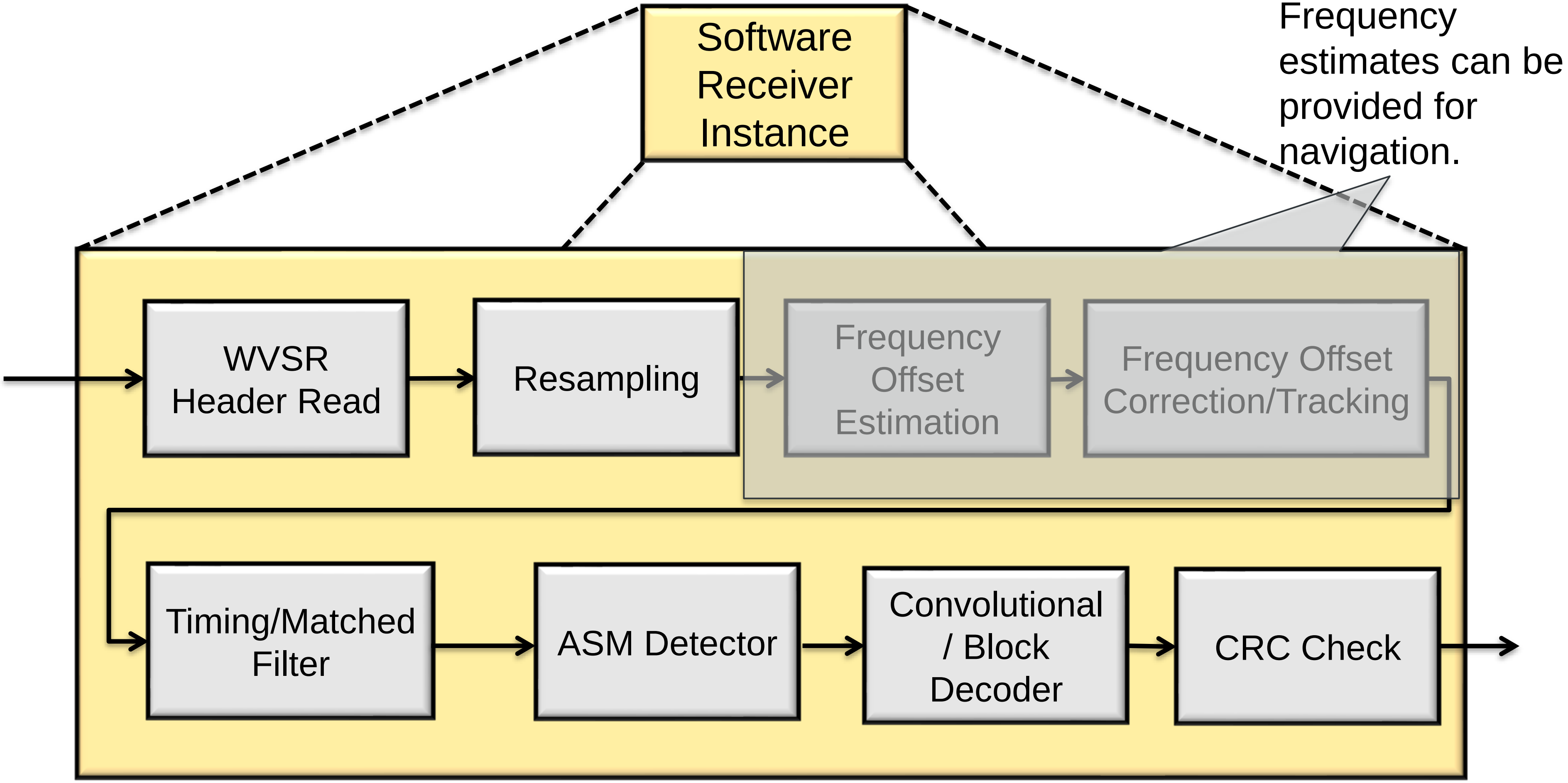
# Synthesis of Received Signal



# Software Channelization Architecture



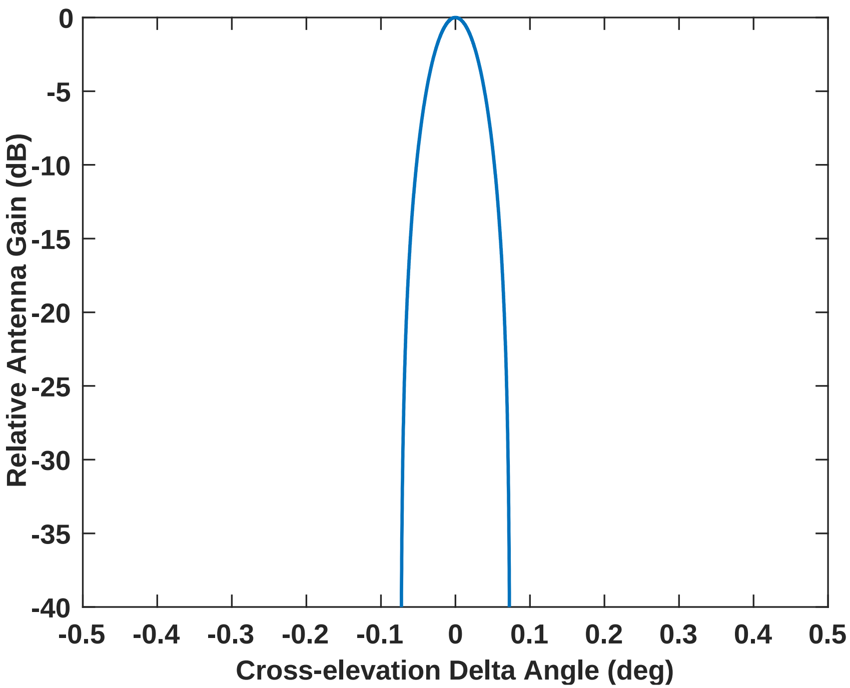
# Software Receiver Architecture



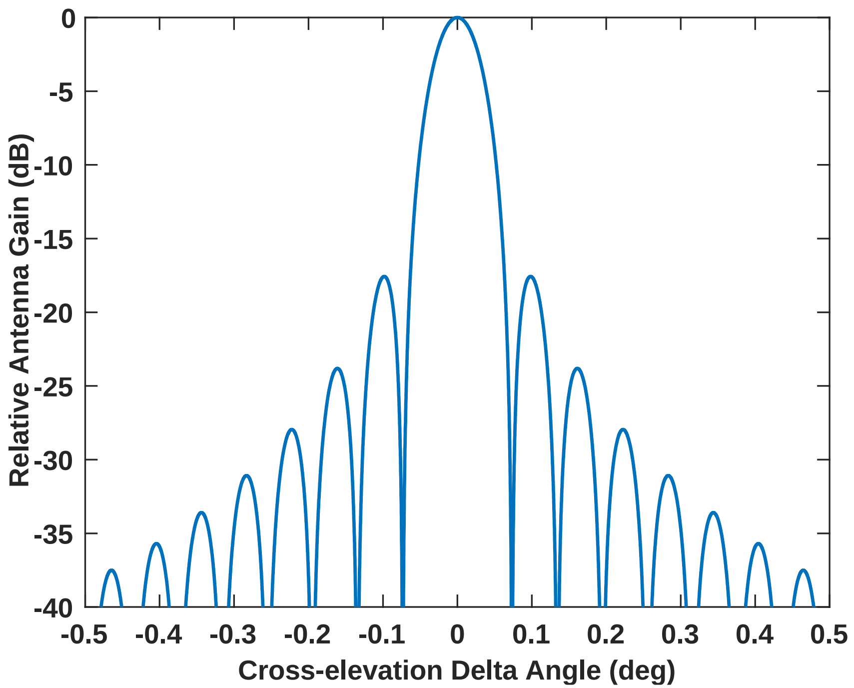

Note: Software Receiver Instances will vary in structure and underlying functions to suit the parameters of each particular spacecraft. **The software receiver for this IRIS waveform requires 8 seconds to process 10 seconds of raw data (1.25x faster than real-time).**

# Antenna Model: The Impact of Side-lobes

Main Beam Only



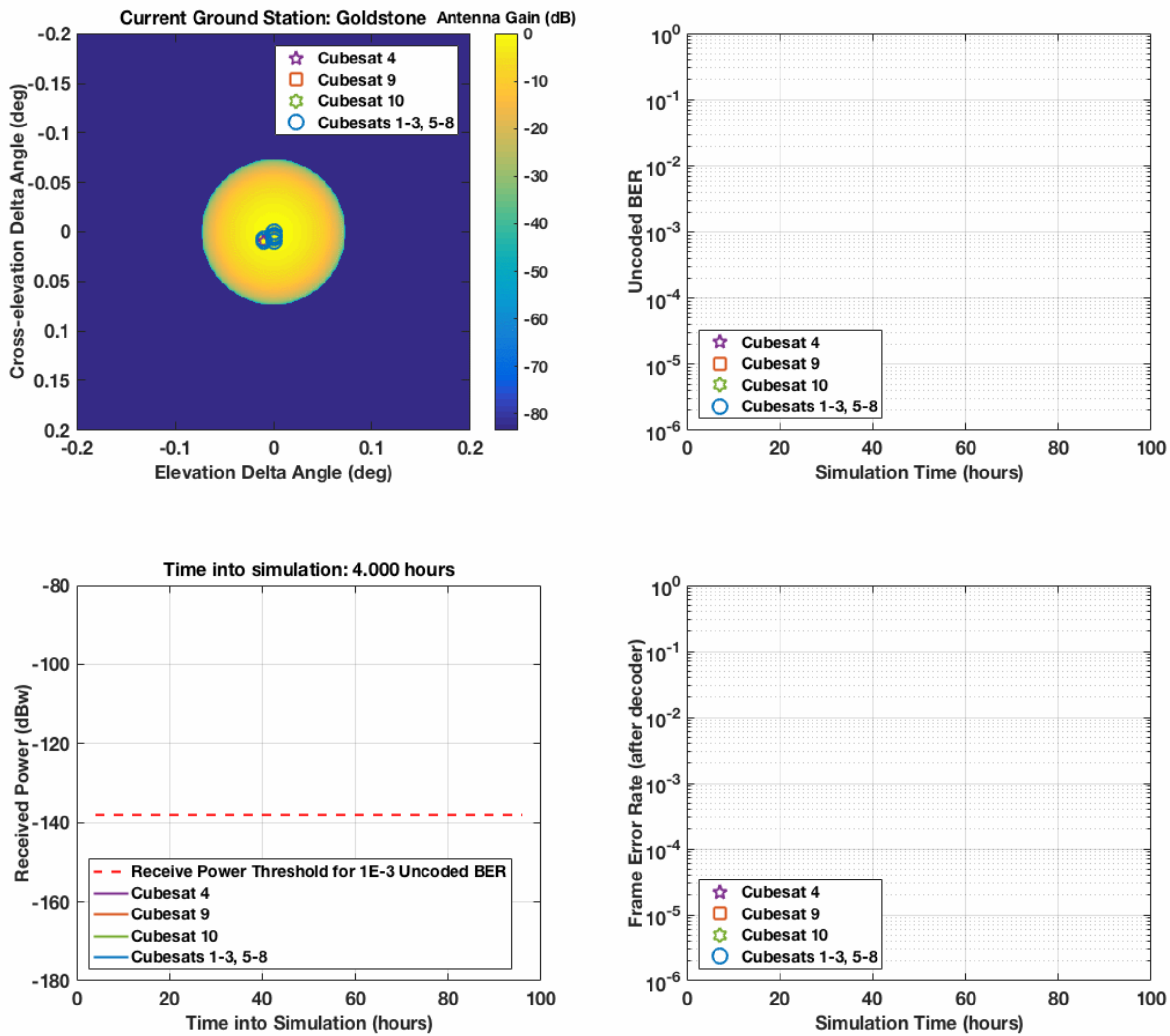

Main Beam with Side-lobes



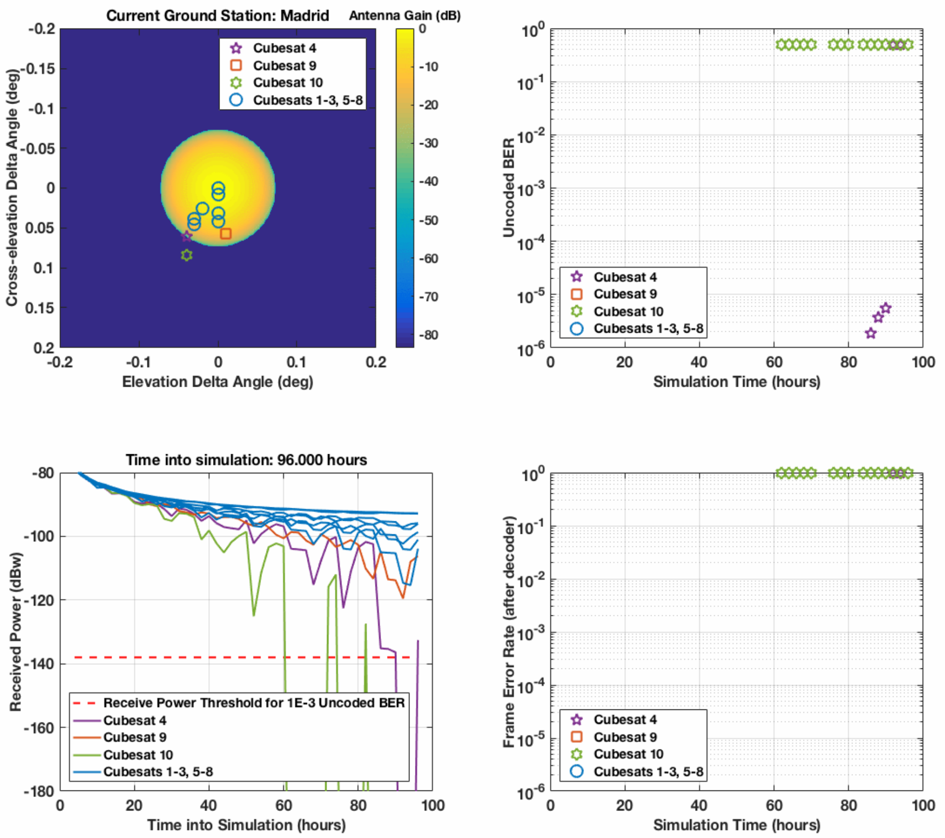

- The main beam is modeled as having a width of 1/10 degree*.
- Outside of the main beam, the first side-lobe is still relatively strong at only 20dB loss.
- Phase flips may occur at side-lobes, but the software receiver should be able to cope.
- Nulls are relatively narrow, and thus receiving cubesats through side-lobes is promising.

* Antenna pattern specification obtained from David D. Morabito <david.d.morabito@jpl.nasa.gov> and David P. Rochblatt (333F) <david.j.rochblatt@jpl.nasa.gov>

# Simulation Results with Main Beam Only Animation

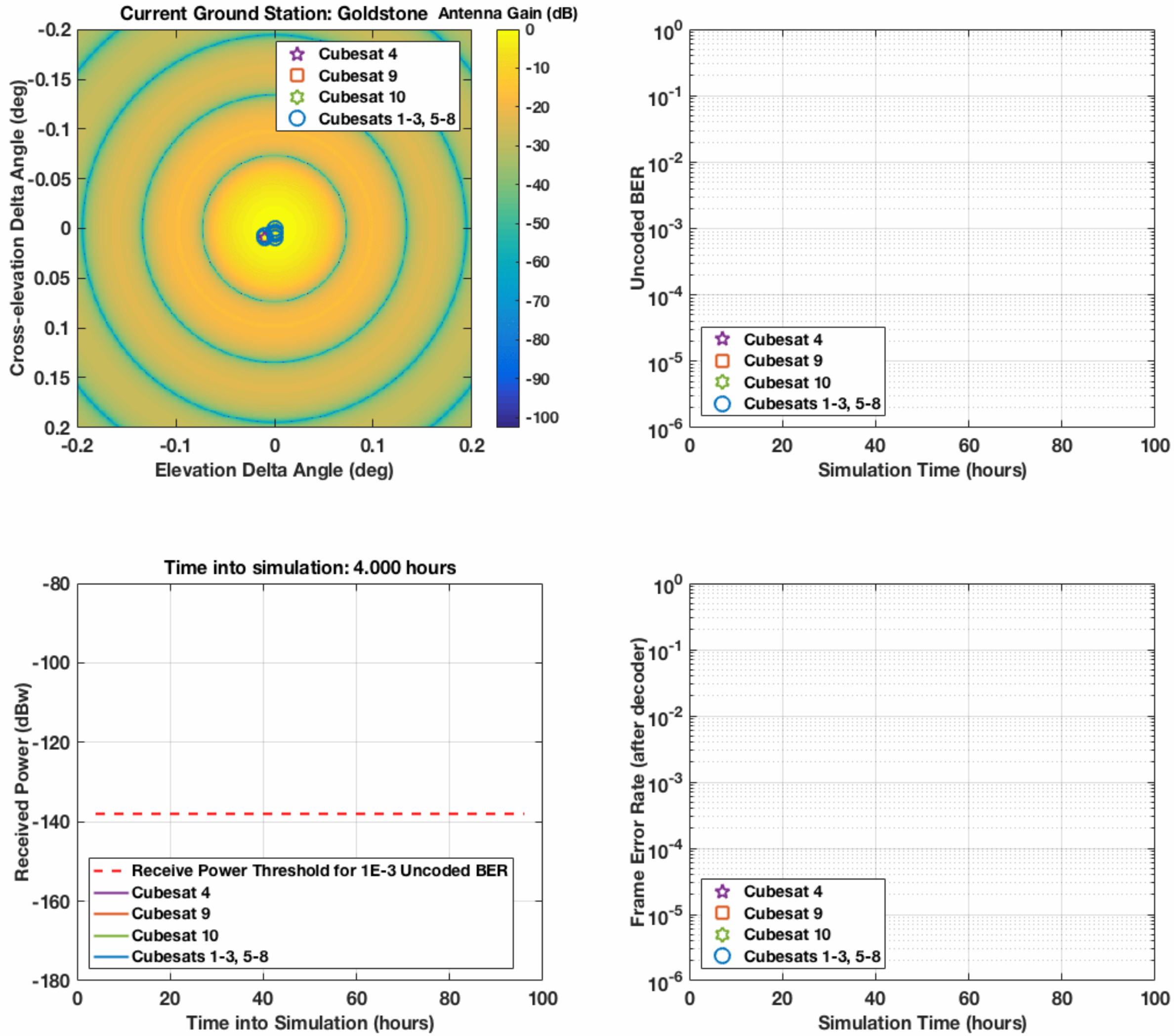


# Simulation Results with Main Beam Only

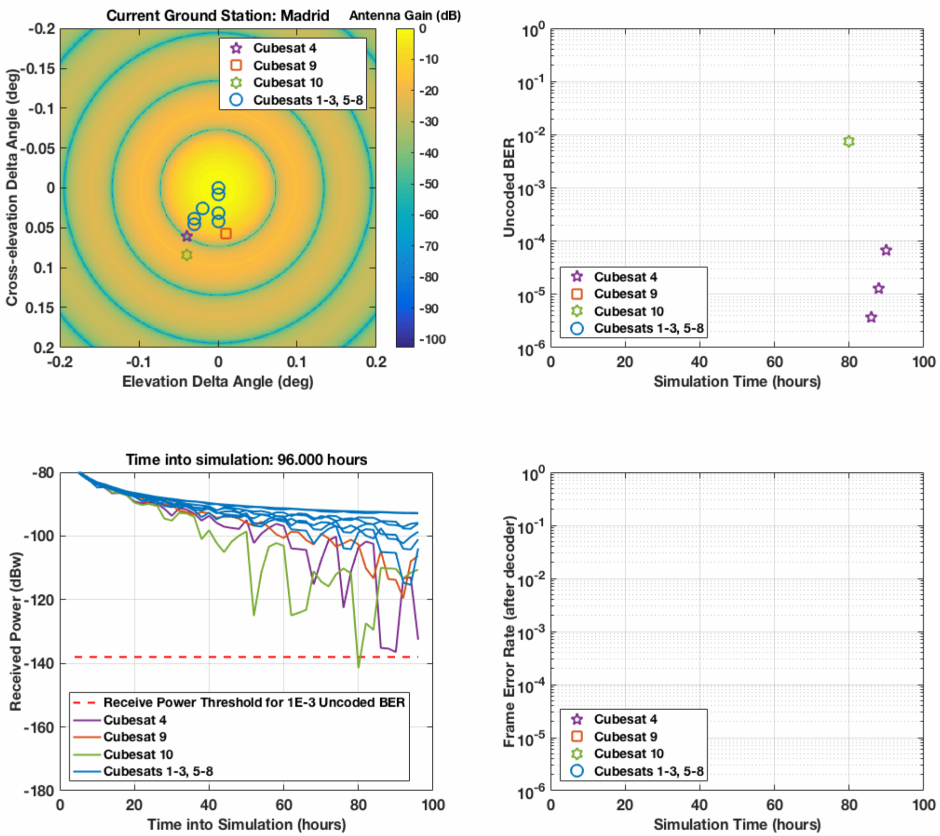



- Out of the 10 cubesats, 8 remained in main beam for duration of simulation.
- Frame errors only occurred once a cubesat completely exited beam.
- Even when cubesat 4 was slowly exiting beam at hours 86-90, frames were saved by the powerful Turbo 1/6 code.

# Simulation Results with Main Beam with Side-lobes Animation



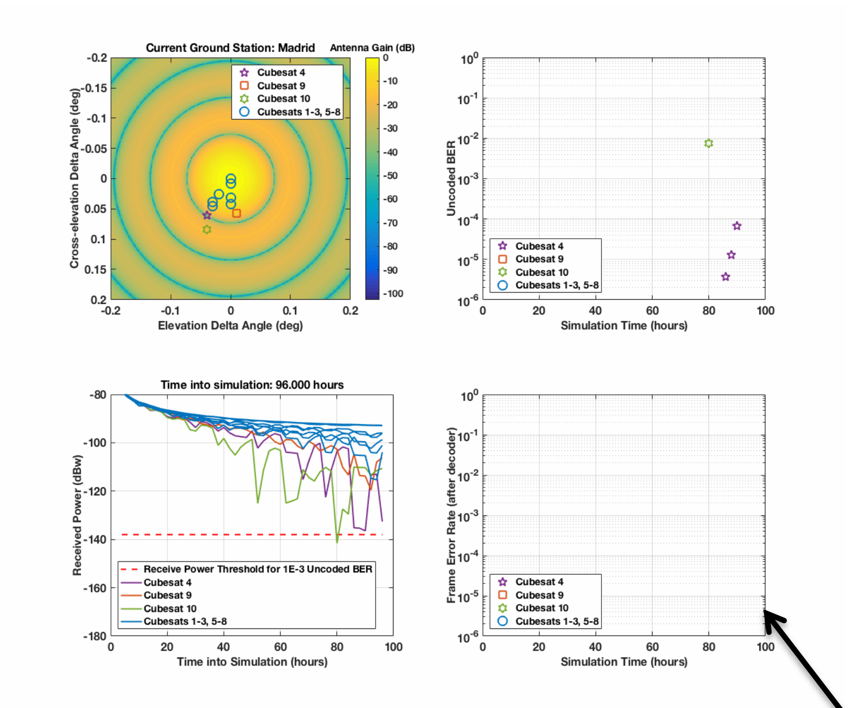
# Simulation Results with Main Beam with Side-lobes



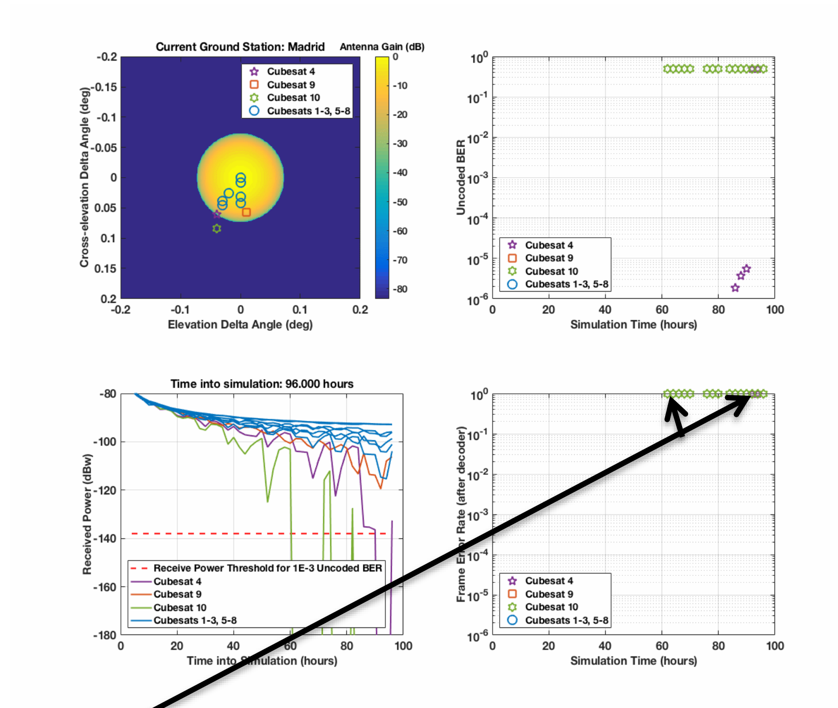

- In 96 hours, cubesat 10 traveled furthest to the first side-lobe, which yielded about 17dB antenna gain loss.
- Frame errors would occur when a cubesat is in a null. This event was not sampled during the simulation (cubesat 10 was close to null at hour 80).
- Even when cubesat 4 was exiting main beam (BER > 0), the frames were saved by the Turbo 1/6 rate code.
- More bit errors will be detected if simulation was more finely sampled to perceive dips when cubesat is in null. But these cases are very brief.

# Performance Improvement

## Main Beam and Side-lobes

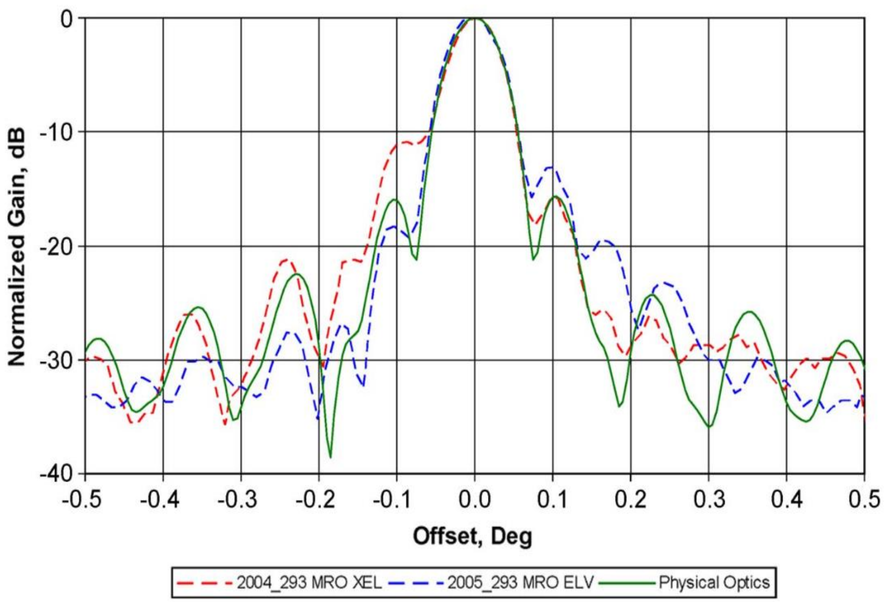


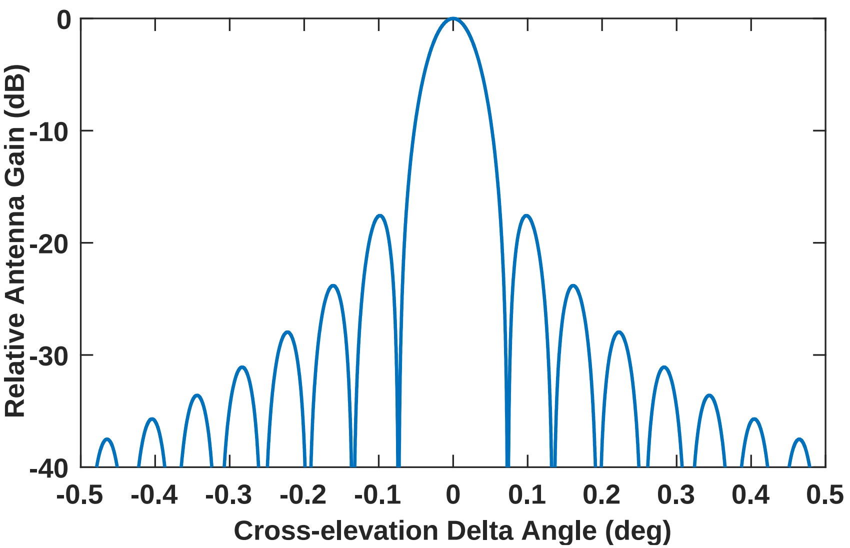

## Main Beam Only




No frame losses vs. multiple frame losses from multiple cubesats for this 2 hour sampling.

# Nulls in Practice




- In practice, nulls are not infinitely deep.
- < 40dB attenuation up to +/- 0.5 degree offset. For near earth or lunar scenarios, this may be acceptable with powerful coding.

D. D. Morabito, W. Imbriale and S. Keihm, "Observing the Moon at Microwave Frequencies Using a Large-Diameter Deep Space Network Antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 3, pp. 650-660, March 2008.

# Conclusions

- Opportunistic MSPA scenario was simulated using lab-collected IRIS waveform.
- Antenna patterns, range, and antenna gain were incorporated to model received powers from different cubesats from the different ground stations (Goldstone, Canberra, and Madrid).
- Over the first 96 hours of EM-1 scenario with no TCMs, 8/10 cubesats were fully successfully demodulated over scenario time samples. The 2/10 failed cubesats failed due to moving outside the main beam, not due to path-loss.
- When taking side-lobes into account, 10/10 cubesats were fully successfully demodulated over scenario time samples.
  - Outages tend to be brief as they only occur when a cubesat is exactly in a null.

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# BACKUP

## An Alternative Simulation Method (1)

- The synthesis and channelization blocks are time and memory consuming.
- Instead, we trace out the BER and FER curves as a function of received power.
- Given the received powers as a function of time (obtained using only geometry, antenna pattern, and EIRP), interpolate the BER and FER curves to obtain expected performance.
- This approach does not take into account the particular time-variant Doppler shifts (a fixed Doppler shift is included).
- This approach can sample the trajectory more finely.

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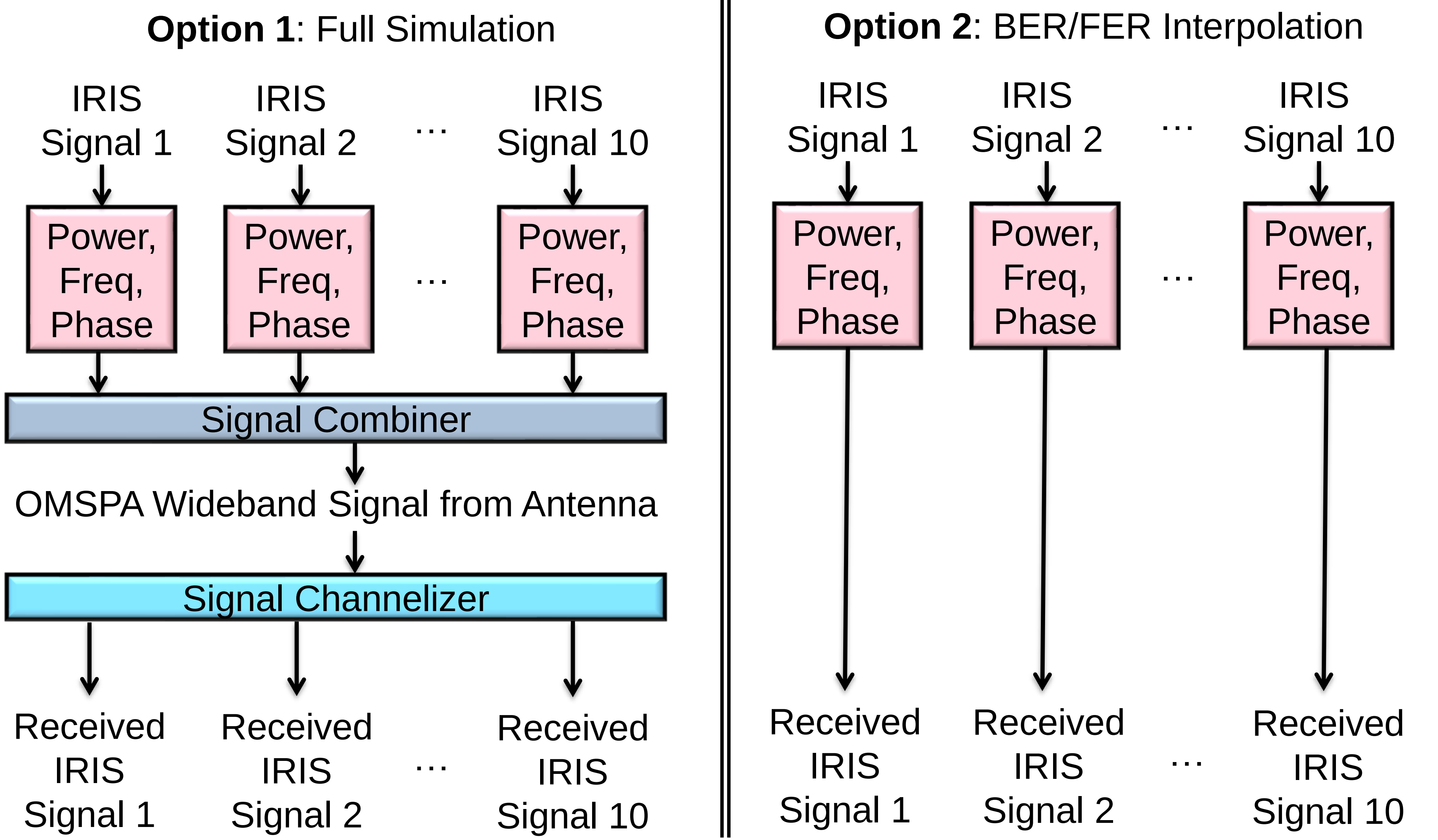
## An Alternative Simulation Method (2)



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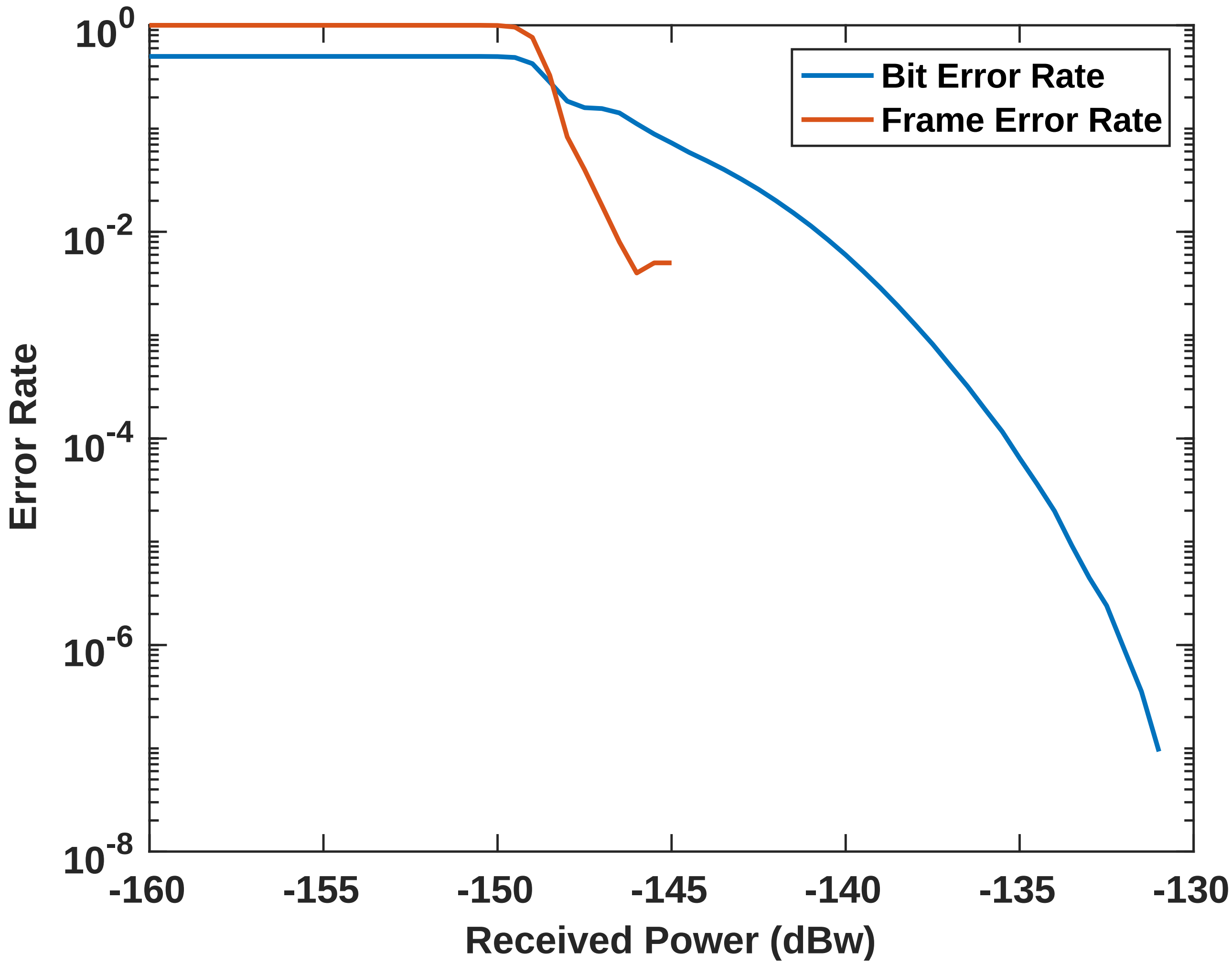
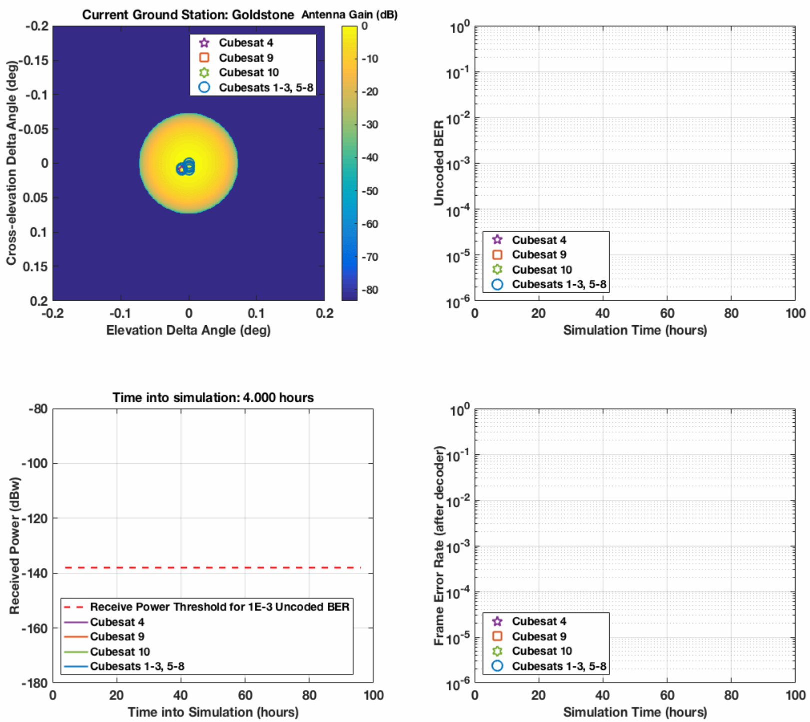
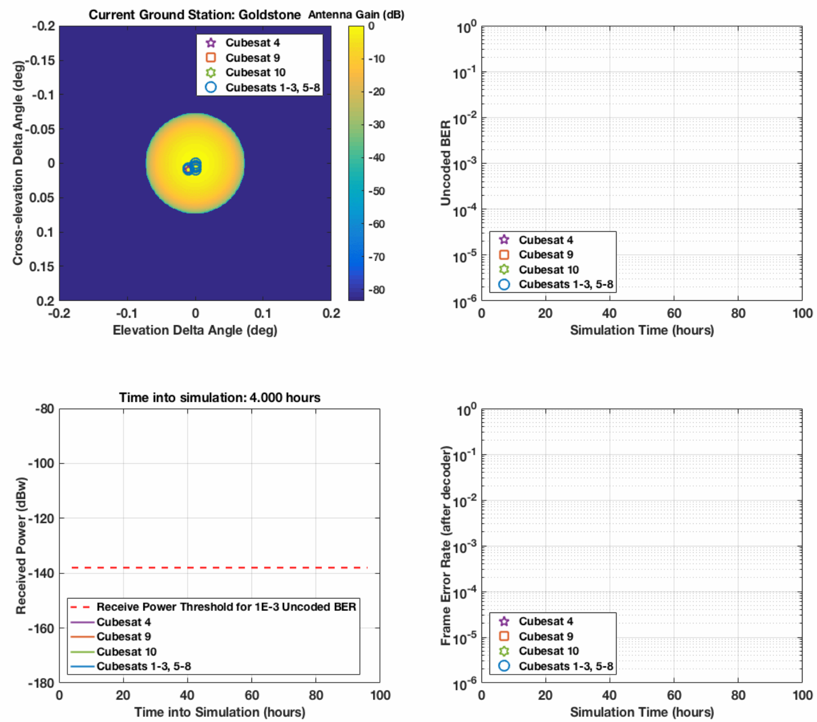
## Simulated BER/FER Curves



# Main Beam Only



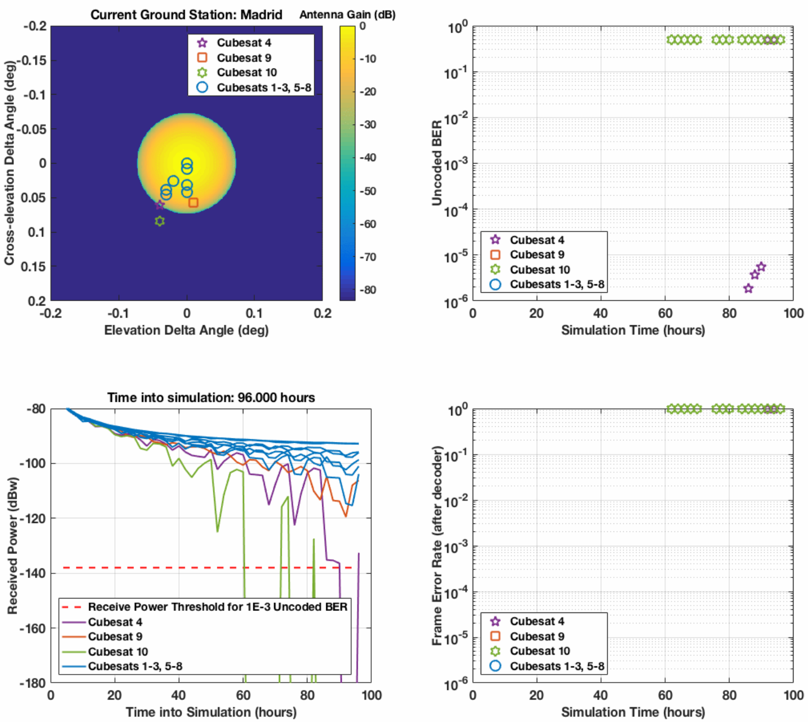

Full Simulation (inc. channelization)



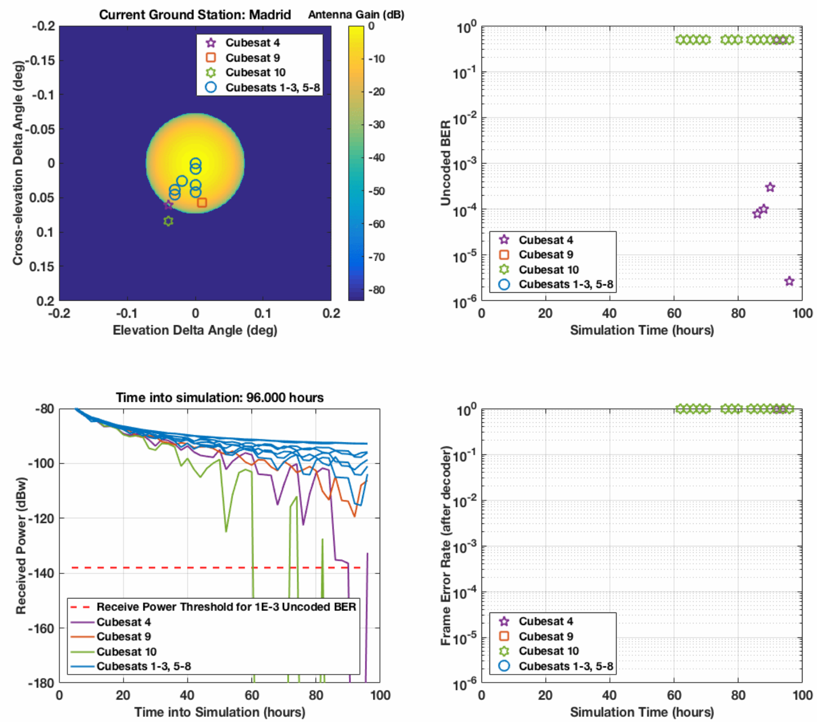

Simulation Approach 2
(BER/FER Interpolation)

# How Simulation Approaches Compare (2)

## Main Beam Only

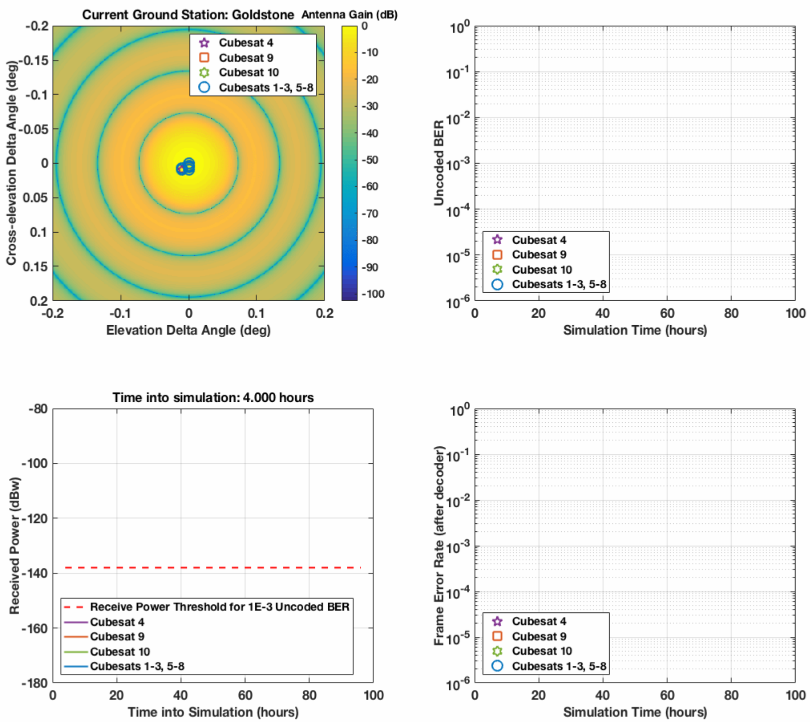



Full Simulation (inc. channelization)

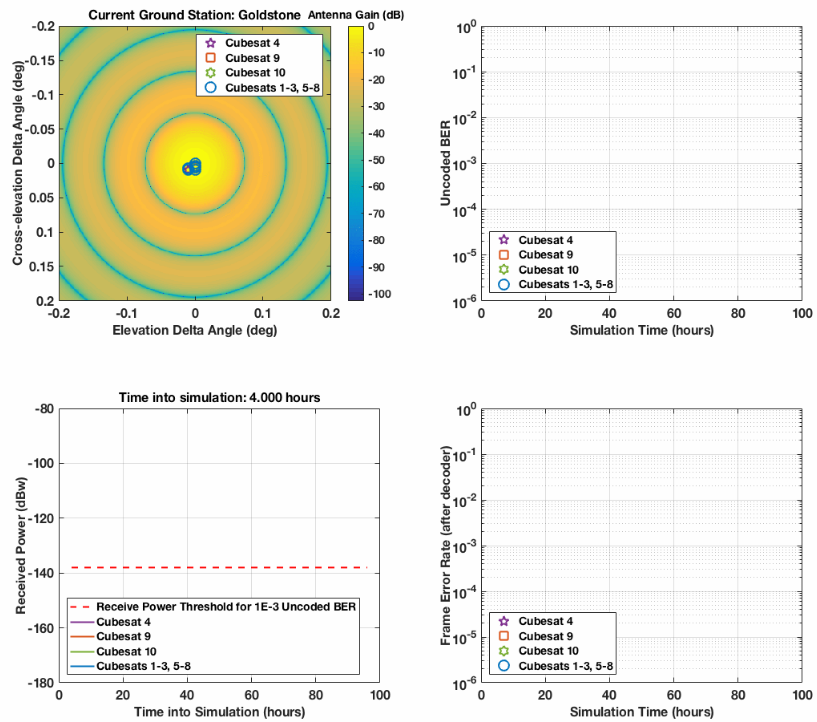



Simulation Approach 2
(BER/FER Interpolation)

# Main Beam and Side-lobes

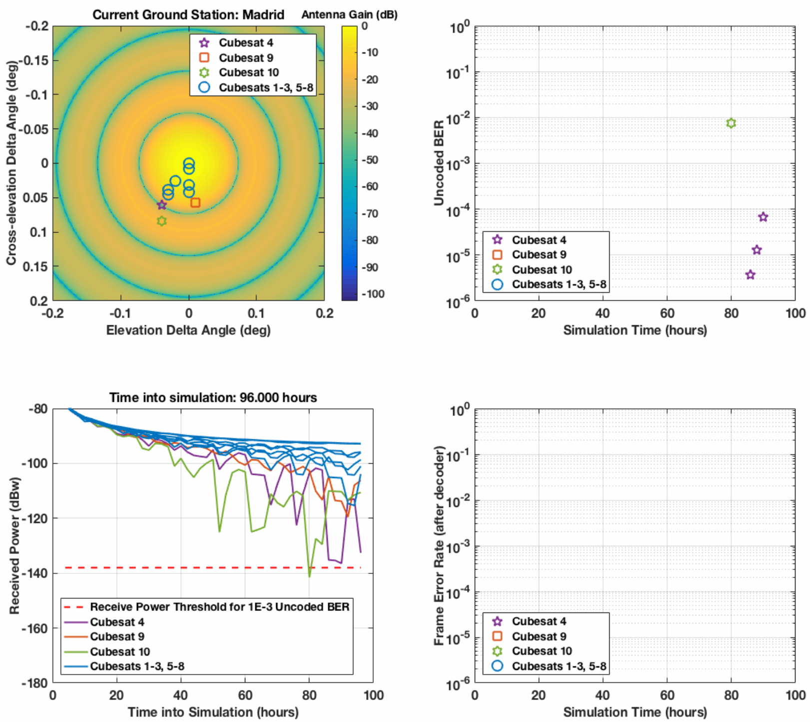



Full Simulation (inc. channelization)

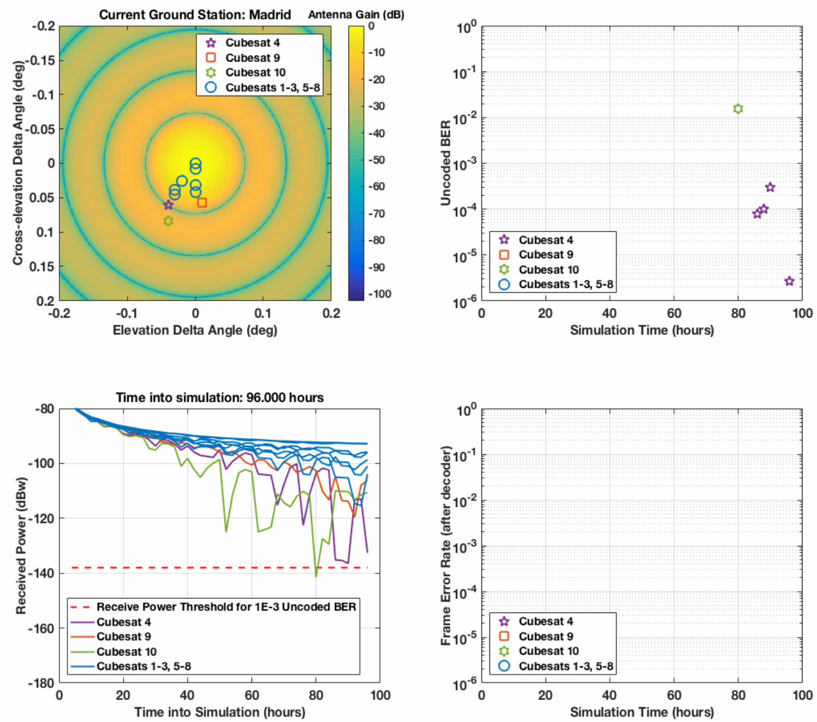



Simulation Approach 2
(BER/FER Interpolation)

# Main Beam and Side-lobes




Full Simulation (inc. channelization)

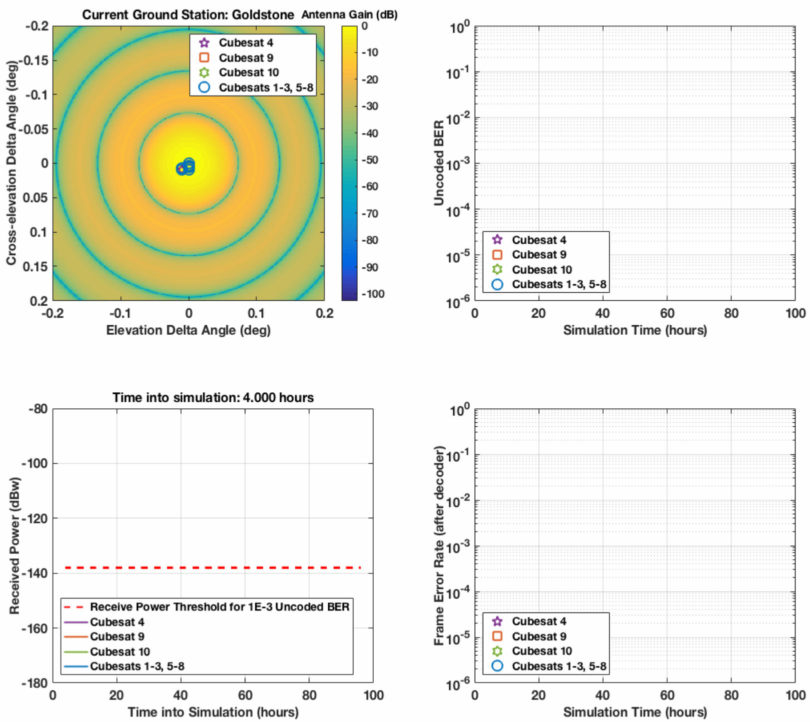



Simulation Approach 2
(BER/FER Interpolation)

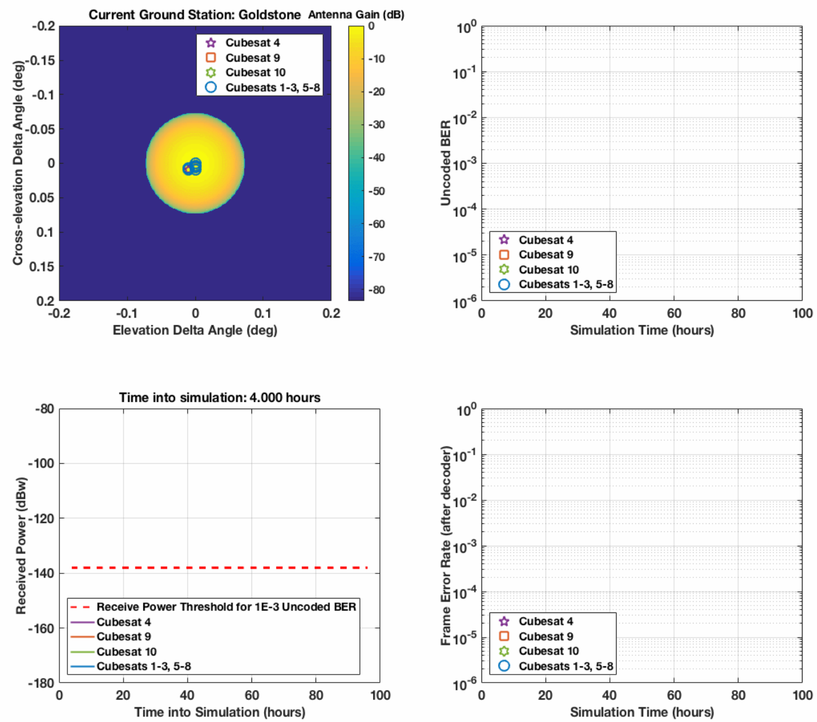
# BACKUP

## Finely-Sampled Performance Curves (1)

### Main Beam and Side-lobes




### Main Beam Only




- These curves are generated by using the received power due to path-loss, antenna gain, EIRP, etc and placing them on the error rate curves on a previous slide.

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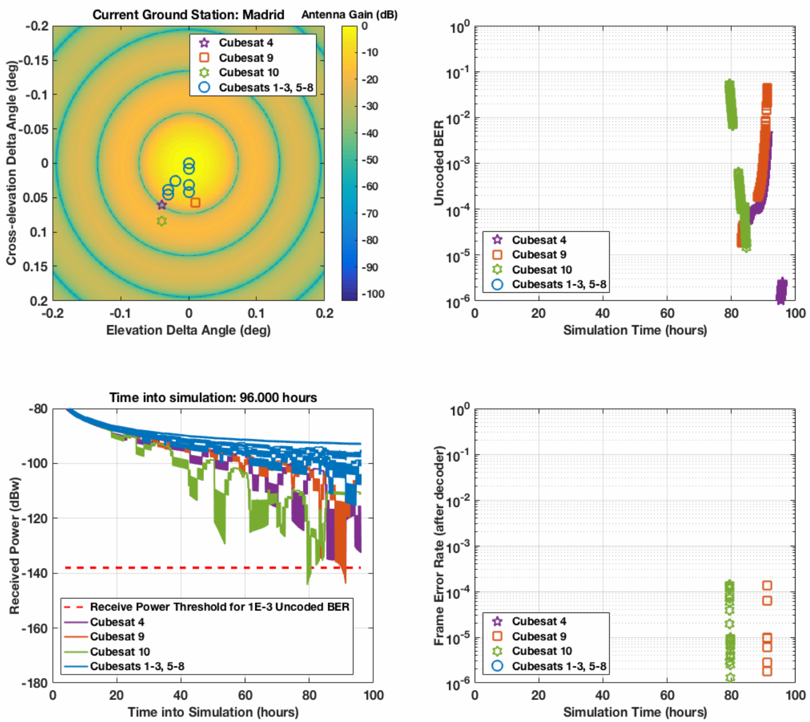
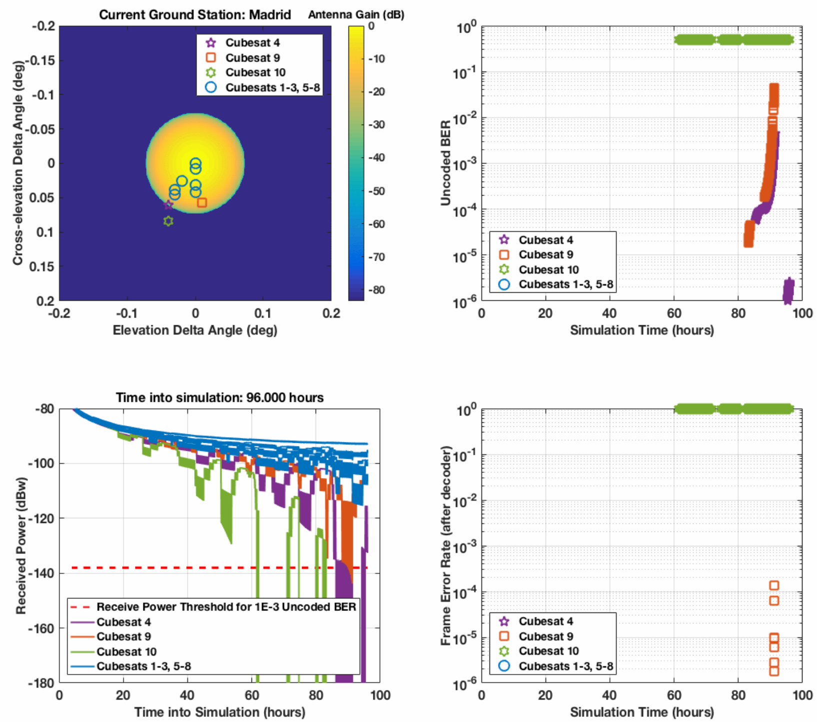
## Finely-Sampled Performance Curves (2)

### Main Beam and Side-lobes




### Main Beam Only




- These curves are generated by using the received power due to path-loss, antenna gain, EIRP, etc and placing them on the error rate curves on a previous slide.
- The simulation resolution is 5 seconds as opposed to the previous 2 hour resolution.

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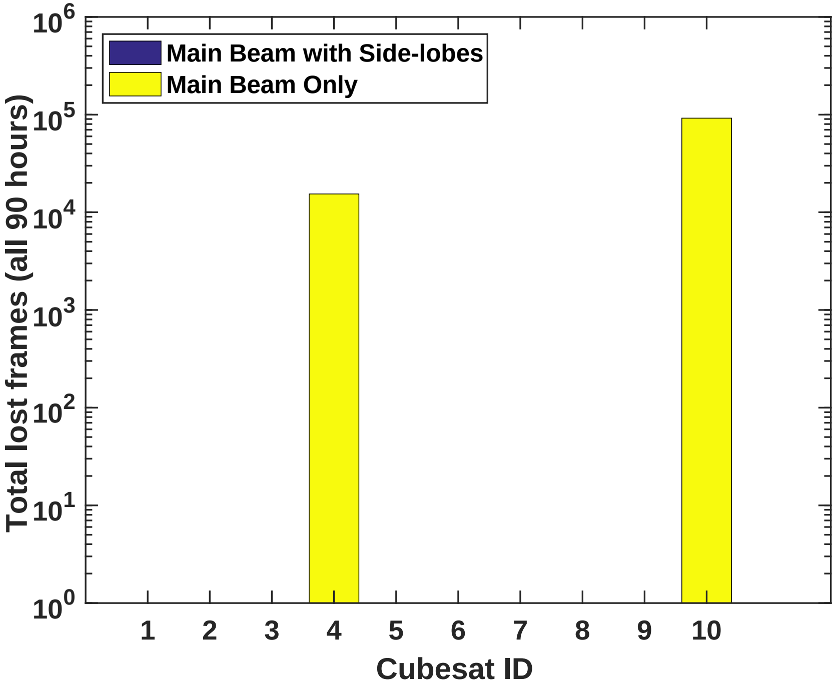
## Total Expected Failed Frames




- Without the use of side-lobes, **8/10** platforms are received for the entire 96 hours without a single frame drop. Frames are dropped due to Cubesats going out of beam.
- With the use of side-lobes, **10/10** platforms are received for the entire 96 hours without a single frame drop. Frames would be dropped due to Cubesats being on received through a narrow null.
- 96 hours accounts for about 310K total frames/cubesat.
- Cubesat maneuver effects are not included.