

Jet Propulsion Laboratory
California Institute of Technology

Protection of Deep Space Missions from RFI caused by EESS Missions

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Introduction

- The 8025-8400 MHz band, used by Earth Exploration Satellite Service (EESS) to downlink data, is adjacent to the 8400-8450 MHz band used by deep-space missions for downlinks from Space to Earth
 - ITU defines deep space to be anywhere that is farther than 2 million km from the Earth
- Adjacent band emissions from EESS satellites can interfere with the extremely sensitive deep space earth stations
 - The 8400-8450 MHz band is vital to deep-space missions and is heavily used
 - By the end of 2022, over 30 deep space missions will be using this band
- A protection criterion of -221 dBW/Hz is established by the ITU-R Recommendation SA. 1157 to protect the deep-space earth stations in the 8400-8450 MHz band
- ITU-R Rec. SA.1810 recommends that in order to minimize the need for operational coordination, EESS satellites should utilize appropriate techniques to prevent unwanted emissions exceeding the deep space ITU-R protection criterion in the 8 400-8 450 MHz band
 - Use of the 25.5-27 GHz band by Earth exploration-satellites should be considered if RFI in X-band cannot be avoided

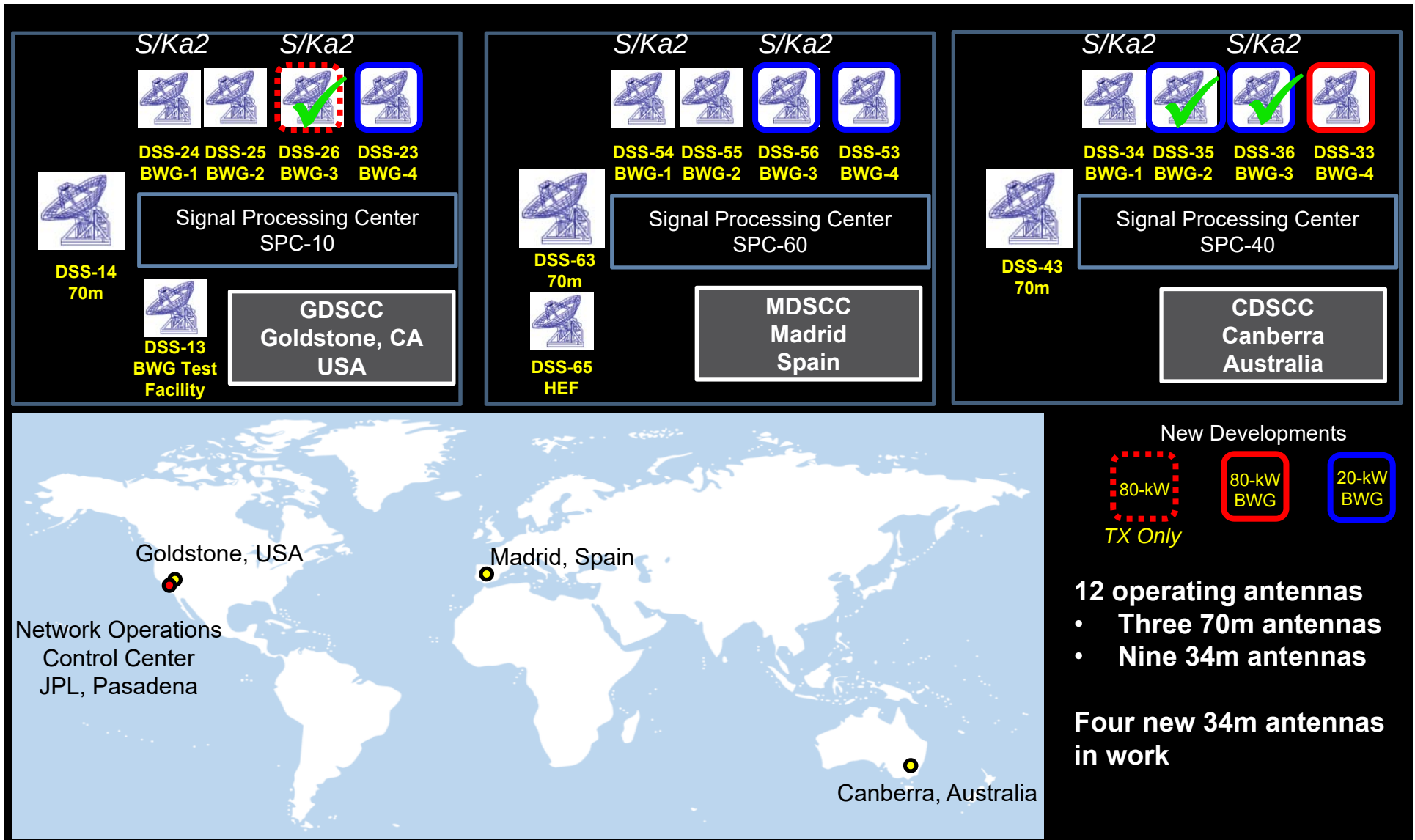
Deep Space Earth Stations

- Deep space missions use very large antennas with extremely sensitive receivers
 - Currently NASA operates nine 34-m and three 70-m antennas in USA, Australia, and Spain
 - ESA operates three 35-m antennas in Spain, Australia, and Argentina
 - Other administrations that operate deep space antennas include Japan, Russian Federation, China, Germany, Ukraine, and India
- Deep space antennas are unique
 - Capture information from spacecraft with the world's most sensitive receivers
 - Utilizes high power transmitters to uplink commands to deep space missions and to operate a planetary radar system
 - Provide the data that enables precise deep space navigation
 - Have the most stable operational clocks and ultra-precise frequency and timing systems

DSN Goldstone Deep Space Communications Complex

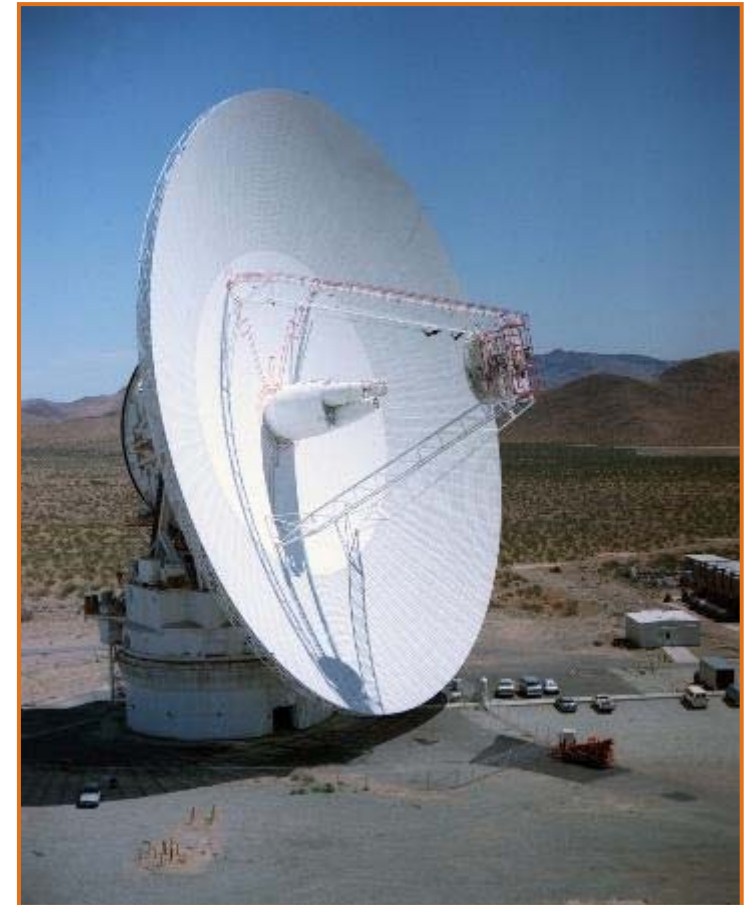


Deep Space Network



Deep Space Missions Operating Environment

- Deep space antennas are ultra-reliable with $> 99\%$ proficiency
- The cost of deep space missions range from several hundred millions to several billion dollars
- It takes 5-10 years or more to plan, develop, and launch a mission to another planetary body
 - The stakes are always very high
- Deep space mission are unique – usually no second chances, no re-dos – one of a kind missions with critical events that must succeed on the first try
 - The ITU protection criteria allows interference only 0.001 percent of time for weather anomalies, no line-of-sight interference
- Examples include extraordinarily difficult planetary landings (e.g., Mars Exploration Rovers, Mars Science laboratory, Mars 2020 Rover)



Why Deep Space Missions are so susceptible to RFI?

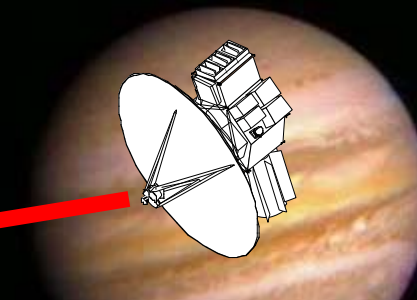
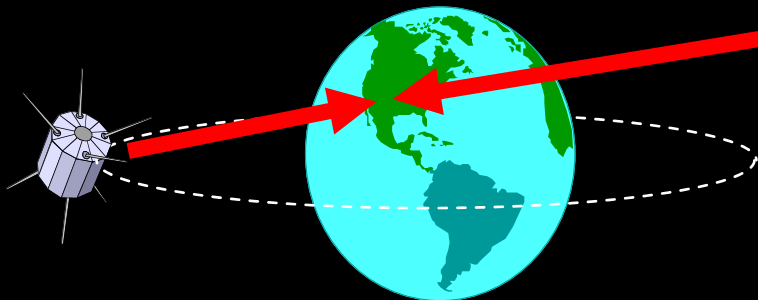
Communications difficulty increases as the square of the distance

Communicating with Voyager (VGR-1) is 250 billion times harder than GEO

VGR-1 transmit power: *less than 20 watts*

DSN 70-meter antenna received power from VGR-1 :

< 1-billionth-billionth watts



Deep space signals are extremely weak and the large deep space antennas must be in radio quiet regions, preferably at higher elevations

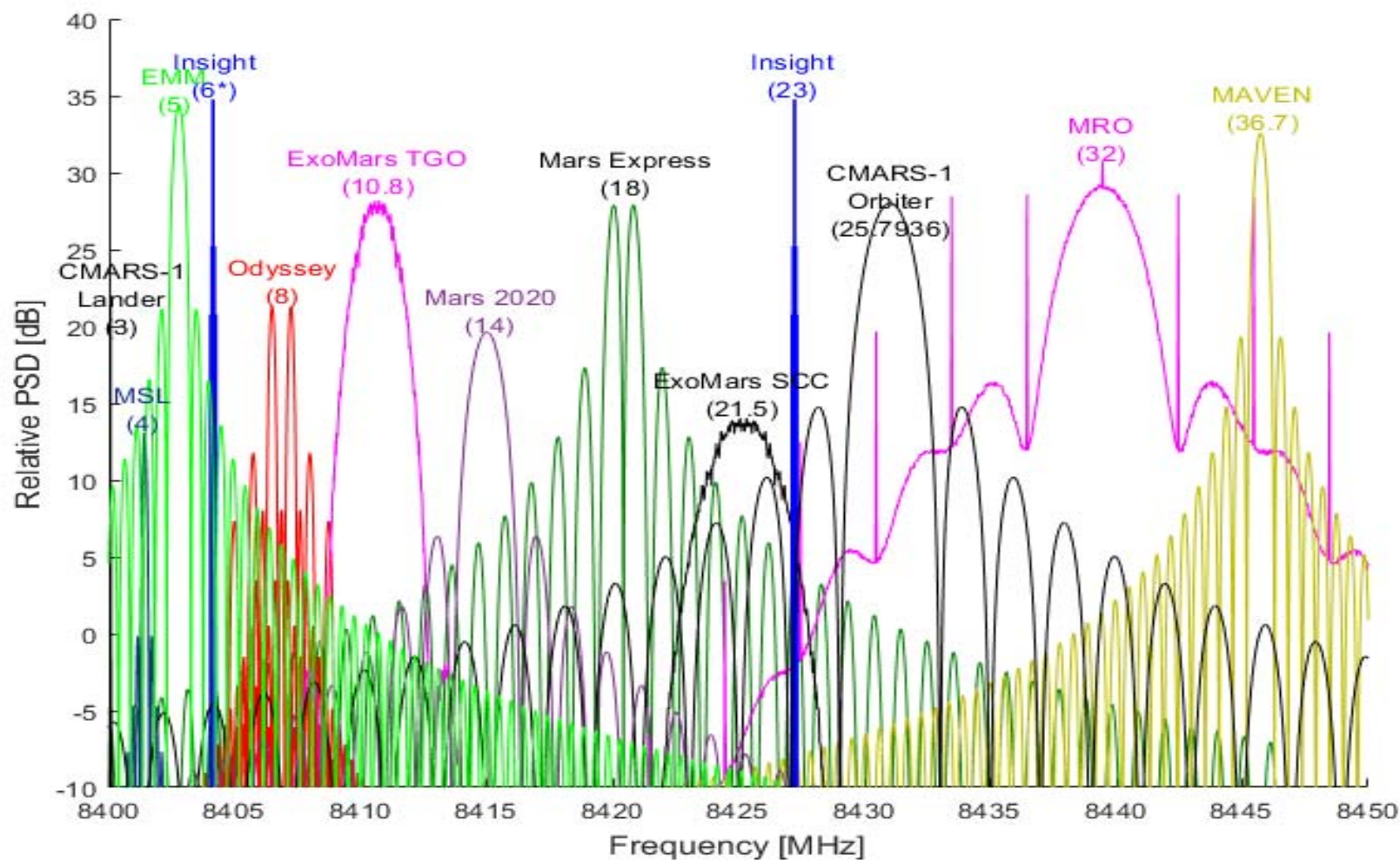
Relative Difficulty

Place	Distance	Difficulty
Geo	4×10^4 km	Baseline
Moon	4×10^5 km	100
Mars	3×10^8 km	5.6×10^7
Jupiter	8×10^8 km	4.0×10^8
Pluto	5×10^9 km	1.6×10^{10}
VGR-1	20×10^9 km	2.5×10^{11}

Characteristics of Deep Space X-Band Downlinks

- Deep space X-band downlink signal are extremely weak (can be -255 dBW/m².Hz) or lower)
- To ensure the integrity of deep space data, deep space missions employ
 - Large aperture
 - Very low noise receiver front-end
 - Robust error correction code
- The ITU protection criterion of -221 dBW/Hz is equivalent to an increase of 1 dB in noise floor.
 - 1 dB loss is unacceptable for some missions; within NASA, -231 dBW/Hz is used to protect deep space X-band downlinks.
- Location of deep space stations – strategically placed to provide 24 hr/day coverage
 - NASA's Deep Space Network (DSN) has complexes in Goldstone, California, Madrid, Spain, and Canberra, Australia
- In addition to telemetry data, deep space X-band downlinks are used for radio science experiments
 - Characteristics of received signal such as signal strength, phase, etc. are used as observables.
 - Difficult if not impossible to distinguish between an interference event or a natural phenomenon

X-band Congestion in Mars Region-Status in 2025



EESS Out-of-Band Interference to Deep Space X-Band

- EESS satellites are typically in near polar low-Earth orbits
- EESS downlinks typically have much higher flux density per bit than deep space downlinks
- Interference to deep space downlinks are typically characterized by brief interference events that occur many times a year
 - Example:
 - A 150 Mbps (QPSK) EESS satellite at the 705 km sun-sync orbit with an isoflux antenna and transmitting at 20W
 - EESS satellite exceeds the deep space protection criterion at a deep space station ~ 700 sec/yr, but
 - $700 \text{ sec/yr} = 35$ interference events with average event duration of 20 seconds
 - while an interference event is short, the impact on the affected deep space downlink can last much longer!

Different Mechanisms of EESS Adjacent Band Interference

Interference from RF front-end saturation

- The output of deep space X-band downlinks RF front-end can be suppressed if the EESS interference is sufficient

Interference from discrete spectral lines

- Discrete adjacent band emissions are typically caused by imperfection in the EESS transmitter design or ranging tones
- Very low power discrete spectral lines near the center frequency of a deep space downlink from the EESS adjacent band emission can cause deep space tracking loops to lose lock

Interference from rise in deep space noise floor

- Sidelobes from the modulation of EESS satellites can cause a rise in the noise floor of deep space X-band downlinks
- Interference affects a deep-space receiver's tracking loop performances and data integrity, as well as antenna pointing

Effect of EESS Adjacent Band Interference on a Deep Space X-Band Downlink (I)

- Interference can cause a deep space receiver to lose lock during the interference event. The receiver will need to reacquire the weak deep space downlink, which can take many minutes
- When receiver is out-of-lock in a DSN tracking station, an operator has to recognize an anomaly and reinitiate the acquisition sequence
- DSN receiver acquisition may require
 - Loading predict to estimate the relative location and velocity of the spacecraft
 - Antenna pointing acquisition
 - Perform FFT to get accurate estimate of downlink carrier frequency
 - Carrier tracking loop acquisition
 - Subcarrier tracking loop acquisition
 - Symbol tracking loop acquisition
 - Frame synchronization

Effect of EESS Adjacent Band Interference on a Deep Space X-Band Downlink (II)

- It can take hundreds of seconds for various carrier and symbol tracking loops to acquire lock
- For frame synchronization, a frame is typically around 10,000 bits. Depending on the error correction code used, it can take around 400 seconds for frame synchronization for a downlink rate of 100 bps.
- About 15 minutes is needed for a deep space receiver to re-acquire for a 100 bps downlink after an interference event and much longer for weaker links
- In practice it will take much longer than 15 minutes to resume tracking due to the fact that the operators do not know why the receiver lost lock
 - Usually the operators suspect an equipment malfunction and will try to check all the antenna equipment
 - When all the equipment proved to be working normally then an RFI will be suspected

Operational Impacts of EESS Interference on Deep space Antennas (I)

Antenna Pointing

- DSN station's antenna pointing is aided by the knowledge of relative motion of a deep space spacecraft and the antenna
- Conscan (conical scan) is a close-loop tracking algorithm that uses carrier power to noise spectral density to finely adjust the pointing of the antenna to correct small pointing errors caused by wind and/or atmospheric effects
- A rise in noise floor due to EESS adjacent band emission can cause Conscan to deviate from the intended target and cause the antenna to lose track of the spacecraft

Ranging

- Ranging is used to determine the location of a spacecraft and is performed by measuring round-trip or one-way delay of range signal
- Each range sequence takes several minutes to perform and a gap in a ranging sequence renders the whole sequence useless

Operational Impacts of EESS Interference on Deep space Antennas (II)

Telemetry

- Significant amount of data may be lost
- Some data may be lost permanently

Radio Science

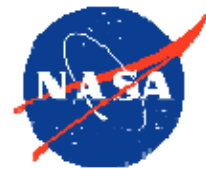
- Critical measurements, such as occultation and atmospheric study, can be lost when receiver is out-of-lock
- When receiver remains locked, it may be difficult if not impossible to distinguish an interference event versus an observed natural phenomenon

Techniques to Prevent RFI from EESS Missions to Deep Space Missions

- EESS missions can use the following techniques to avoid RFI to deep space missions
 - Use on-board filtering to reduce out of band emissions below the ITU Protection Criterion for deep space missions
 - Use bandwidth efficient modulation and coding techniques
 - Use large geographical separation between EESS and deep-space Earth stations
 - Use low sidelobe high gain satellite antennas, and if high gain satellite antennas are not practicable, isoflux antennas should be considered instead of omnidirectional antennas
 - When operating in a non broadcasting mode, radiate only when transmitting data to one or more earth stations
 - Avoid using broadcast modes whenever practicable or, if unavoidable, consider the use of a portion of the lower half of the 8025-8400 MHz band
 - If the above methods are not available or sufficient to protect the deep space missions, use the 25.5-27.0 GHz band, particularly for wideband links

Conclusion

- ITU-R has established a protection criterion of -221 dBW/Hz for the 8400-8450 MHz band
- Average fractional interference time of EESS adjacent band emission to a deep space X-band downlink is small, but it consist of many short interference events
 - Each can cause the deep space downlink to lose tracking time of fifteen minutes or more.
- Interference impacts the operations of deep space antennas in the following areas
 - Antenna pointing
 - Telemetry
 - Radio science
 - Ranging
- Many techniques are available and should be used by EESS missions to reduce their out of band emissions



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