



The Use of Vacuum Electronic Devices in NASA Missions – IVEC 2020

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A decorative graphic featuring a blue background with a circuit-like pattern of hexagons and lines. On the left, there are large, stylized white letters 'H' and 'M' with a blue circuit pattern inside them. The 'H' has the URL 'www.nasa.gov' written in small black text at its base.

October 21, 2020
NASA's Goddard Space Flight Center
Flight Microwave & Telecommunication Systems Branch

Agenda

- **NASA Missions using Traveling wave Tube Amplifiers (TWTAs)**
 - In orbit
 - In development
 - Summary of mission parameters important for RF Comm System
- **RF Communications System Trade space**
 - Architecture trades
 - System combinations
 - Concepts: EIRPs, data rates, orbits/distances
- **Missions in Development (RF Comm Architecture and RF Comm Systems)**
 - Nancy Grace Roman Space Telescope (NGRST)
 - PACE
- **Spacecraft Design Considerations**
- **Closing Remarks**

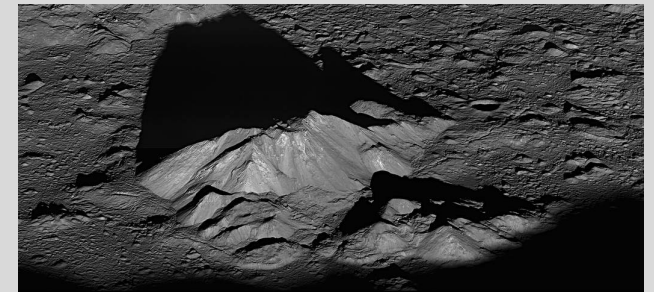


NASA Missions using TWTAs

NASA missions using TWTAs

In orbit

- **Lunar Reconnaissance Orbiter (LRO)**
 - Science: To map the moon's surface. After 1 year of exploration, was extended with additional science objectives.
- **Landsat 8 (previously LDCM)**
 - Science: Continue program's role in monitoring, understanding and managing the land resources needed to sustain human life.



LRO Camera NACs to capture a dramatic sunrise view of Tycho crater

NASA missions using TWTAs

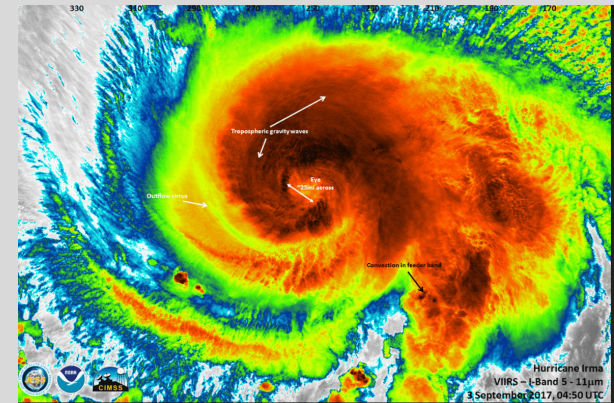
In development

- **Joint Polar Satellite System (JPSS-2)**

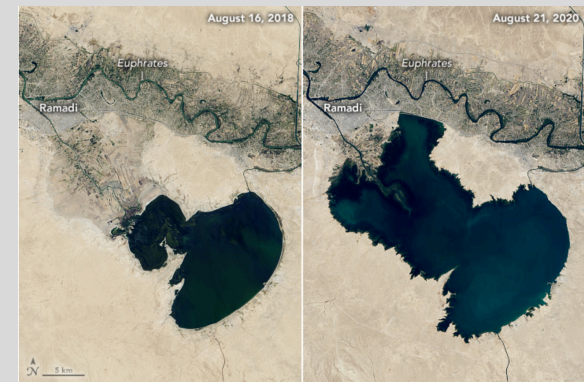
- Science: Provide critical environmental satellite data to support NOAA's ongoing mission to understand and predict changes in the weather, in the oceans and along the coasts, and the climate. Also, to increase the timeliness, accuracy and cost-effectiveness of public warnings and forecasts of climate and weather events, reducing the potential loss of human life and property.

- **Landsat 9**

- Science: Continue program's role in monitoring and understanding land resources.



Hurricane Irma (Infrared Image)



Iraq's Lake Ramadi

NASA missions using TWTAs

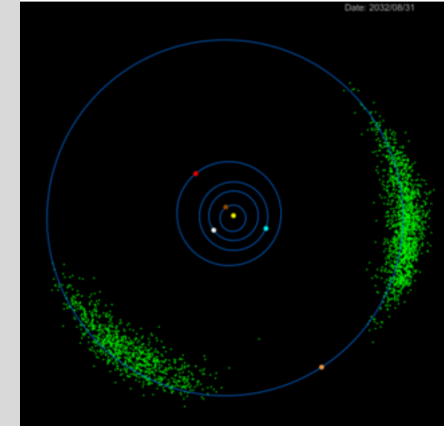
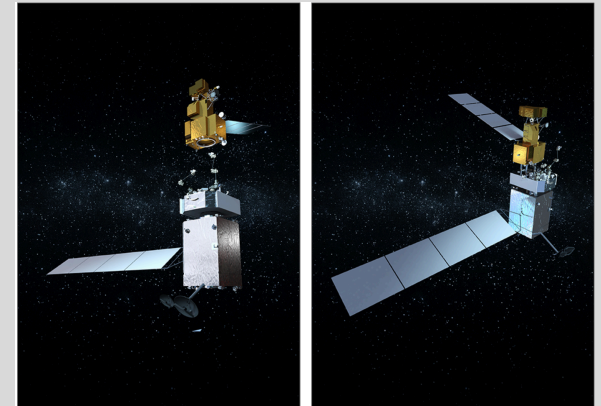
In development

- **On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM 1)**

- A robotic spacecraft equipped with the tools, technologies and techniques needed to extend satellites' lifespans - even if they were not designed to be serviced on orbit.

- **Lucy**

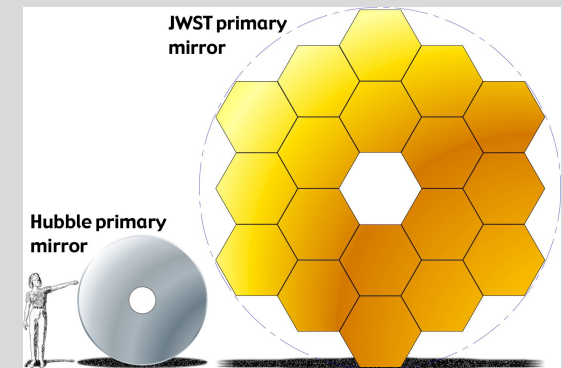
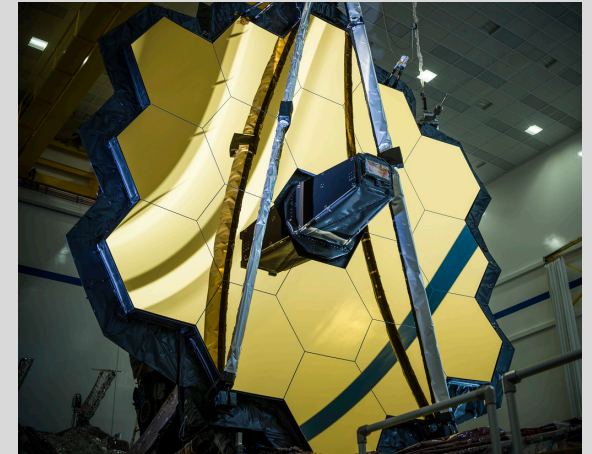
- Science: Will revolutionize our knowledge of *planetary origins* and the formation of the solar system by being the first space mission to study the Trojans. This swarms of Trojan asteroids associated with Jupiter are thought to be remnants of the primordial material that formed the outer planets. The Trojans orbit the Sun in two loose groups, with one group leading ahead of Jupiter in its path, the other trailing behind. Clustered around the two Lagrange points equidistant from the Sun and Jupiter.



NASA missions using TWTAs

In development

- **James Webb Space Telescope (JWST)**
 - Science: Orbiting infrared observatory that will complement and extend the discoveries of the Hubble Space Telescope, with longer wavelength coverage and greatly improved sensitivity. Will look much closer to the beginning of time and to hunt for the unobserved formation of the first galaxies, as well as to look inside dust clouds where stars and planetary systems are forming today.



NASA missions using TWTAs

Summary

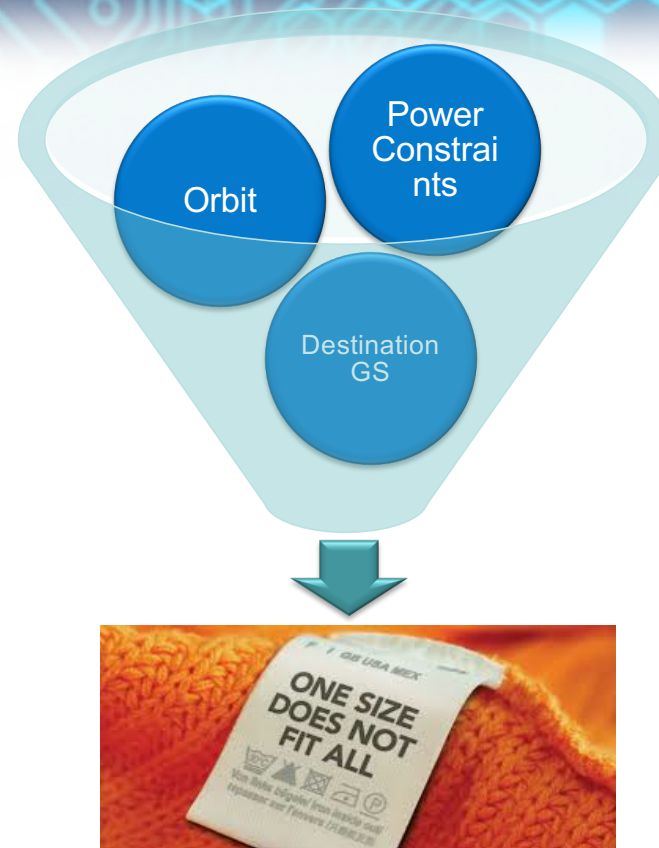
Mission	Science Category	Frequency Band	Orbit/Dist.	TWTA Output Power (W)	EIRP (dBW)	Max Data Rate
LRO	Moon (Planetary)	Ka-band	Lunar Orbit 405,544.1 km	40	55.14	228 Msps
LDCM	Earth	X-band - EES	LEO 705 km	65	17.3	440 Msps
JPSS	Earth	Ka-band	Sun-synchronous 833 km	75	50.5	300 Msps
Landsat 9	Earth	X-band- EES	LEO 705 km	65	17.3	440 Msps
OSAM-1	STMD	Ka-band	LEO 680 km	70	54.15	86 Msps
Lucy	Planetary	X-band DS	Jupiter	25	55.4	705 ksps
JWST	Astrophysics	Ka-band	Lagrange-2 (L2)	52	53.57	28 Mbps



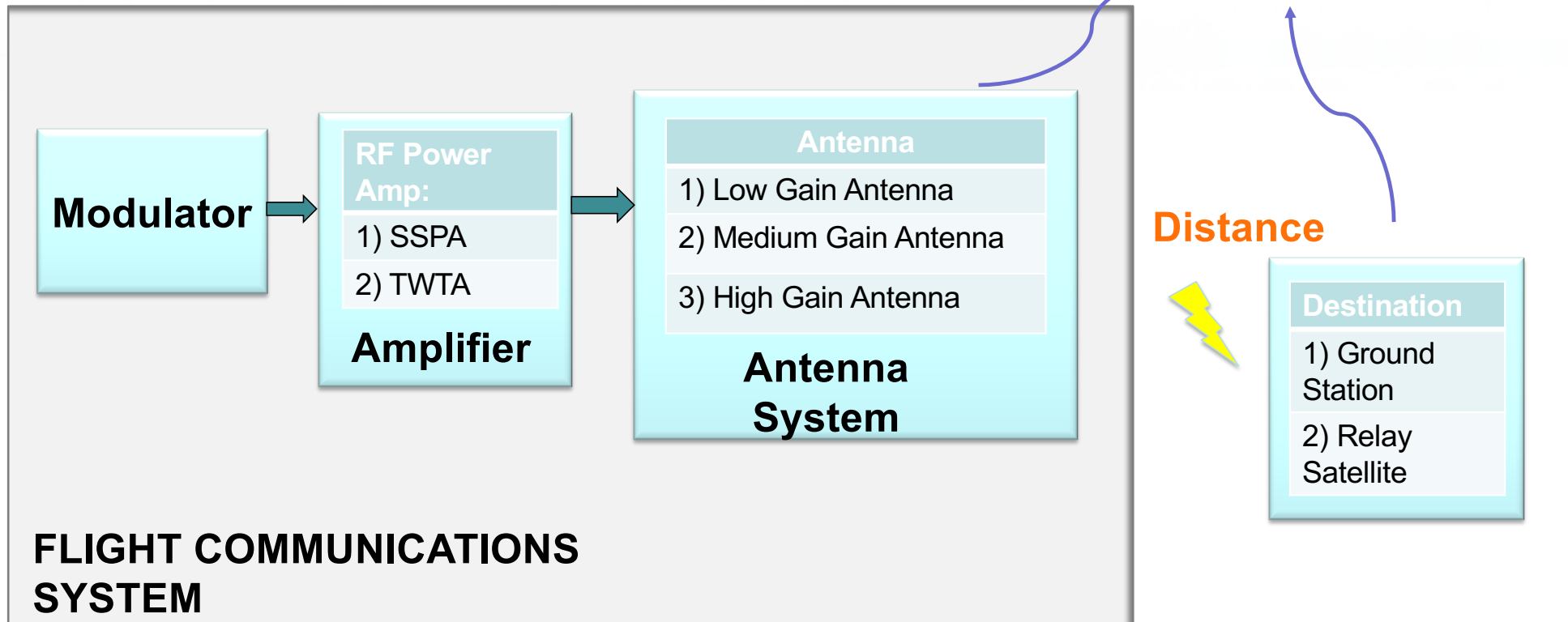
RF Comm System trade space

RF Comm System trade space

A mission's communication system selection depends on many things, such as:



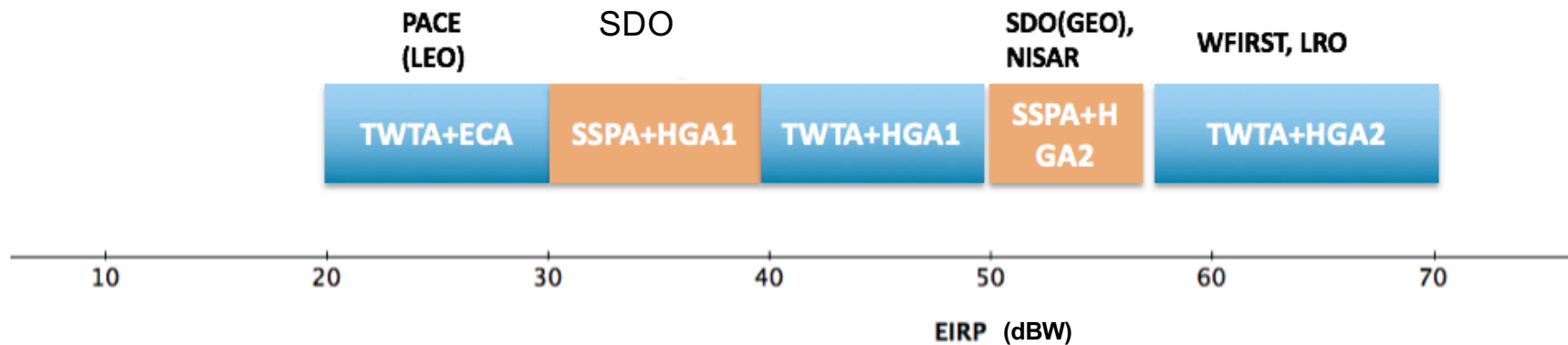
RF Comm System trade space Architecture



RF Comm System Trade Space

System Combinations/EIRP(Ka-band)

Effective Isotropic Radiate Power (EIRP) = Transmit Power + Antenna Gain – Passive Losses



RF Comm System Trade Space

System Combinations to achieve data rates/distances

Mission	Orbit –to- Destination	S/C EIRP (dBW)	Data Rate	Hardware Combination
DESDYnl (pre-phase)	LEO-to-SN	60	1.0 Gbps	TWTA + HGA ₂
WFIRST (pre-phase)	GEO-to-NEN,	40	1.2 Gbps	SSPA + HGA ₂
NISAR	LEO-NEN		2.0 Gbps x 2	
PACE	LEO-to-NEN	23	1.2 Gbps	TWTA + ECA
NGRST	L2-to-NEN	63	up to 600 Mbps	TWTA + HGA ₂
JPSS	LEO-DTE LEO-TDRSS	~52	263 Mbps	TWTA + HGA ₂



Missions in Development

NGRST and PACE Mission Architectures

Tech Development and Mission Infusion

NGRST (Nancy Grace Roman Space Telescope)

- NGRST is a NASA observatory designed to settle essential questions in the areas of **dark energy, exoplanets, and infrared astrophysics**. NGRST will have two instruments, the Wide Field Instrument, and the Coronagraph Instrument.
 - The Wide Field Instrument will have a **field of view that is 100 times greater than the Hubble infrared instrument, capturing more of the sky with less observing time**. As the primary instrument, the Wide Field Instrument will measure light from a billion galaxies over the course of the mission lifetime.
 - Example: 432 HST pointing, vs 2 NGRST pointing for a large area survey

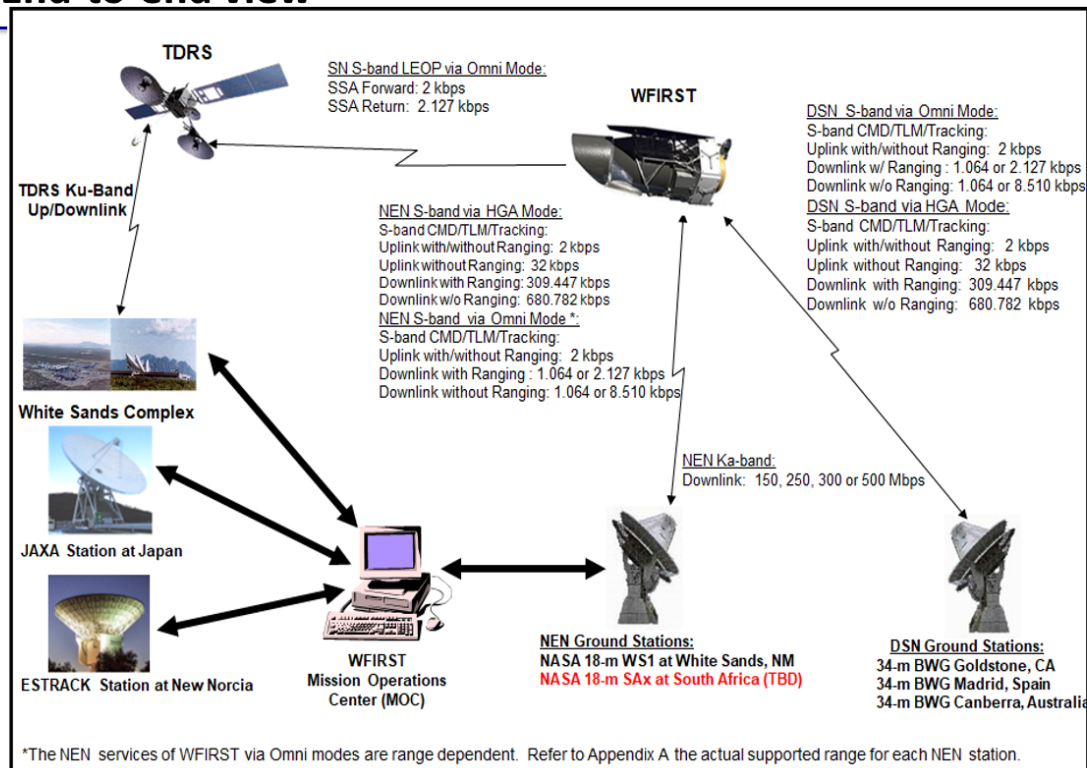
Missions in Development

NGRST: RF Comm Architecture



RF Comm Subsystem Design

End-to-end view



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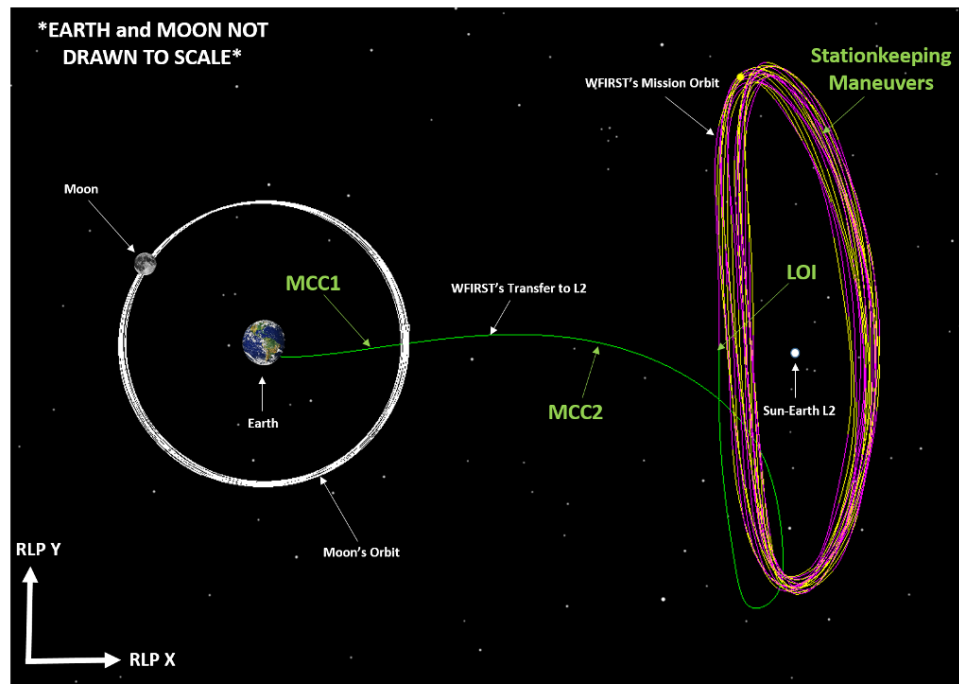
Missions in Development

NGRST: RF Comm Architecture



RF Comm Subsystem Design

WFIRST Orbit Trajectory



MCC: Mid course correction maneuver

LOI: L2 orbit insertion maneuver

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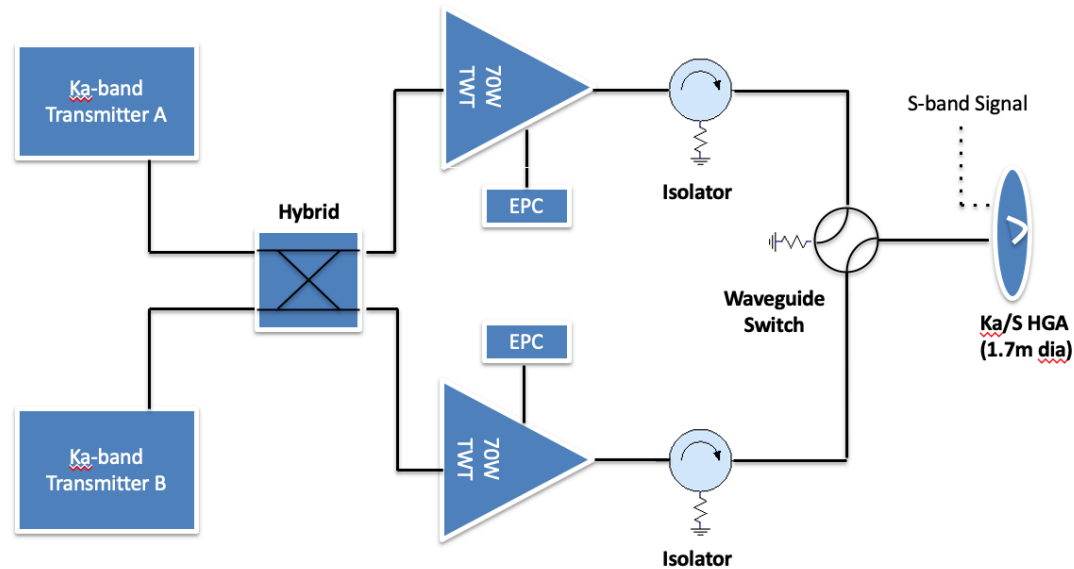
Missions in Development

NGRST: Ka-band RF Comm Subsystem



RF Comm Subsystem Design

Architecture: Ka-band



WFIRST RF Comm EPR

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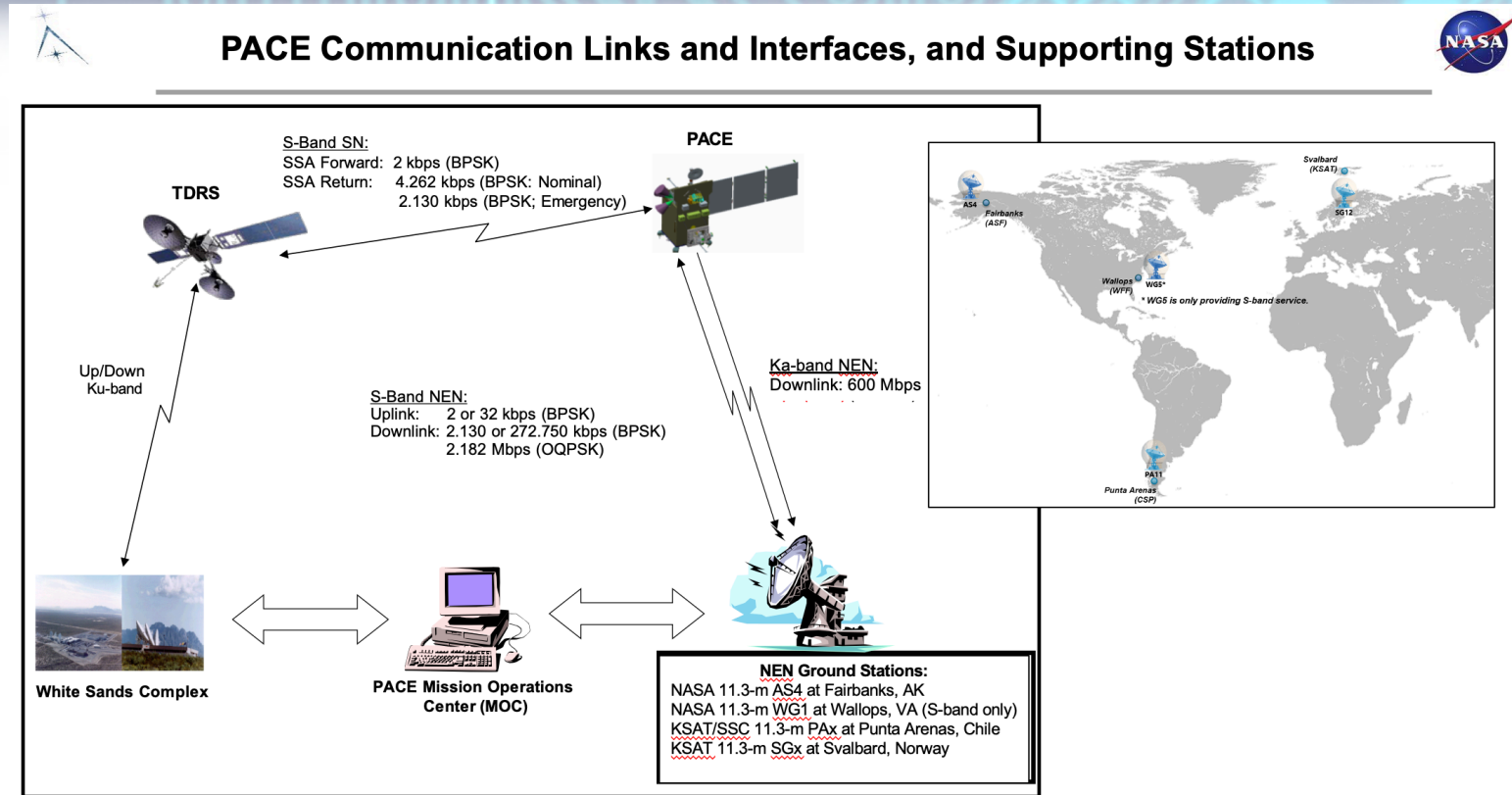
Missions in Development

PACE (Plankton, Aerosol, Cloud, ocean Ecosystem)

- PACE will advance the assessment of **ocean health** by measuring the distribution of phytoplankton, tiny plants and algae that sustain the marine food web. The ocean's health is important for maintaining the health of the Earth – and the ocean's health starts at its smallest inhabitants, **phytoplankton**.
 - By taking in carbon dioxide, these microscopic plants and algae play an active role in moving carbon from the atmosphere into the ocean.
- It will also continue systematic records of key atmospheric variables associated with **air quality** and Earth's climate.
- PACE represents will provide an unprecedented view of the ocean without the blind spots of previous sensors.

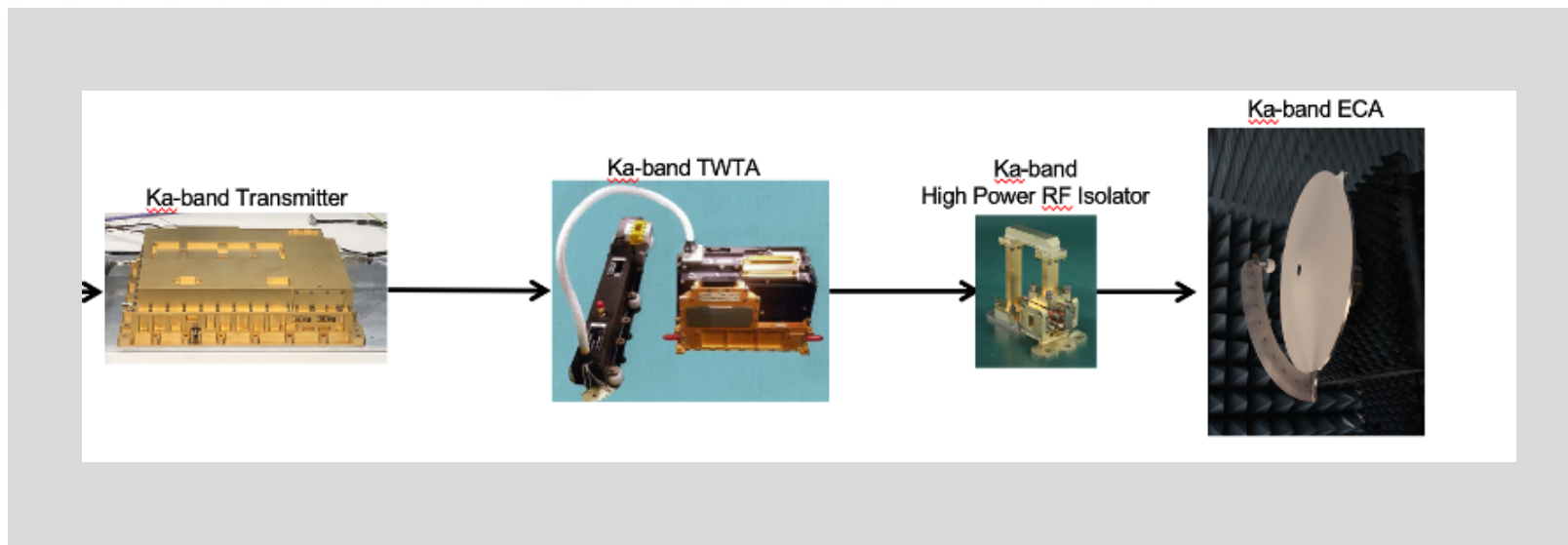
Missions in Development

PACE: RF Comm Architecture



Missions in Development

PACE: Ka-band RF Comm Subsystem



Missions in Development

EIRP/ RF Output Power/ Data rate

NGRST case:

Data Rate (Mbps) for a 1.7 m HGA:

	70 W TWTA		100 W TWTA		150 W TWTA	
Margin	3 dB	1 dB	3 dB	1 dB	3 dB	1 dB
10-20 deg	145	230	207	328	310	820
Above 20 deg	241	383	345	547	518	476

PACE case:

Data Rate (Mbps) for a fixed ECA:

	35 W TWTA	70W TWTA	140 W TWTA
Margin	1 dB	1 dB	1 dB
Data rate @ 10 deg EL	600	1200	2400



Spacecraft Design Considerations

Spacecraft Design Considerations

Interfaces

1. Power Consumption

- Burden on the power subsystem
- Life of Tube (cathode degradation) => Mission Life [reliability]
 - is best when High Voltage is kept ON to minimize thermal gradients in EPC and tube

2. Thermal Interface

- The higher the RF output power, the higher the heat dissipation, and this needs to be designed for.
- Needs to be kept as stable as possible to prolong life of TWTA.

3. Electrical Interfaces

- Power service must handle in-rush current

4. Location: Magnetic fields to/from nearby components must be considered, including proximity of TWTAs themselves.

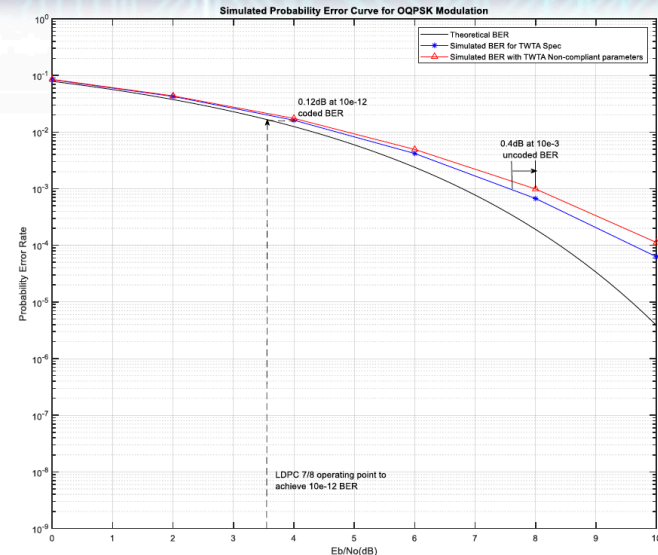
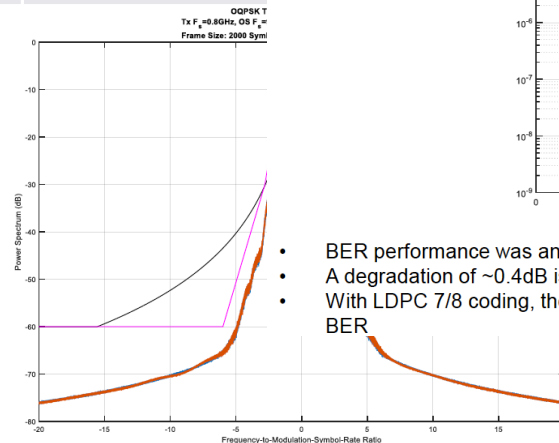
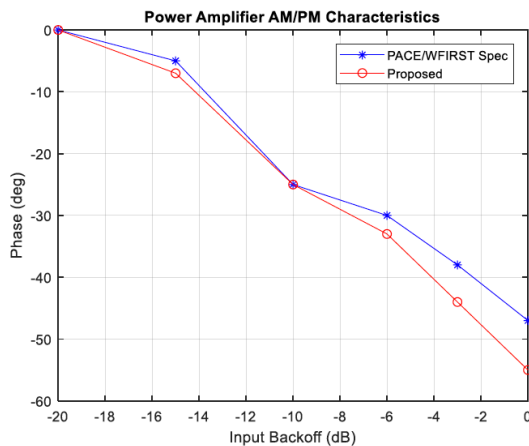
5. TWTA telemetry and how to use those operationally

- Flight Software (Failure Detection and Correction)

Spacecraft Design Considerations

Contributions to transmit signal Integrity

- Signal output phase shift
- Am to PM conversion
- Signal Gain Flatness
- Spurious (in-band and out-of-band)
- Others



- BER performance was analyzed with all the proposed non-compliant parameters combined
- A degradation of ~0.4dB is observed at 10⁻³ error rate on the uncoded channel
- With LDPC 7/8 coding, the degradation from baseline specifications can be derived to be about 0.12dB at 10⁻¹² BER

- Meets NTIA and SFCG spectrum requirements. Impact on BER performance due to proposed AM to PM characteristics will be analyzed.

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Closing remarks

- Presented on several NASA missions and their science objectives
 - All the pictures are available online.
 - Please go the specific mission's website if you want to know more.
- Shared the trade space for RF Communications architectures and when TWTAs come into play.
- Presented the RF Comm architectures for some of our NASA missions in development.
- Shared some spacecraft design considerations.

THANK YOU for the invitation! 😊

