Iris Deep-Space Transponder for SLS EM-1 CubeSat Missions

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Logan, Utah, USA
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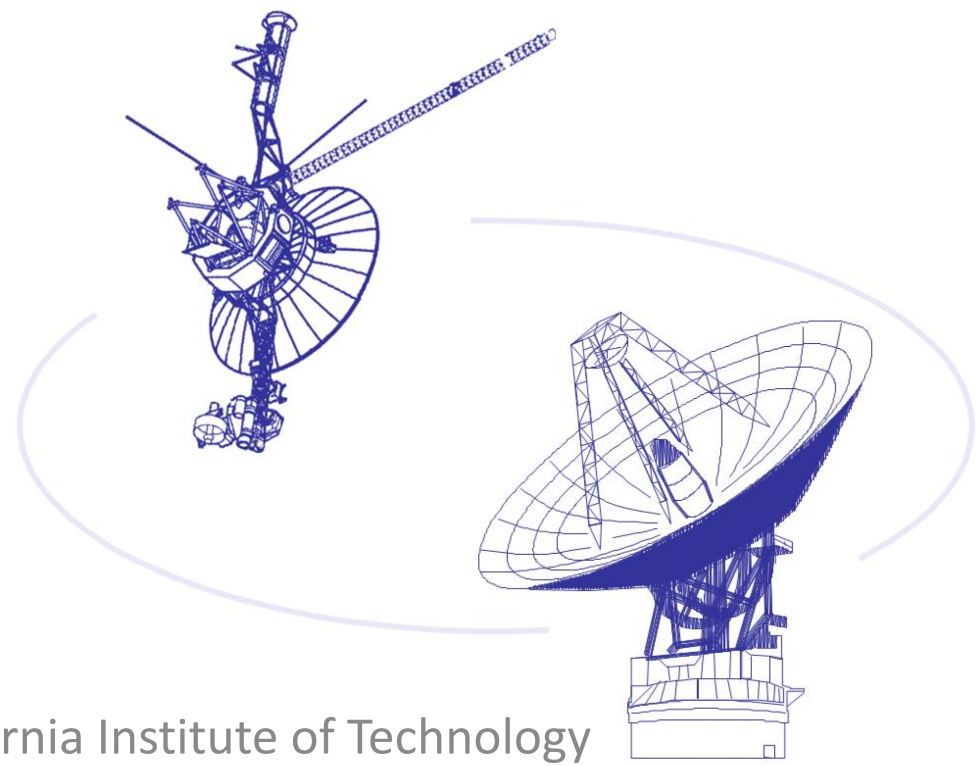

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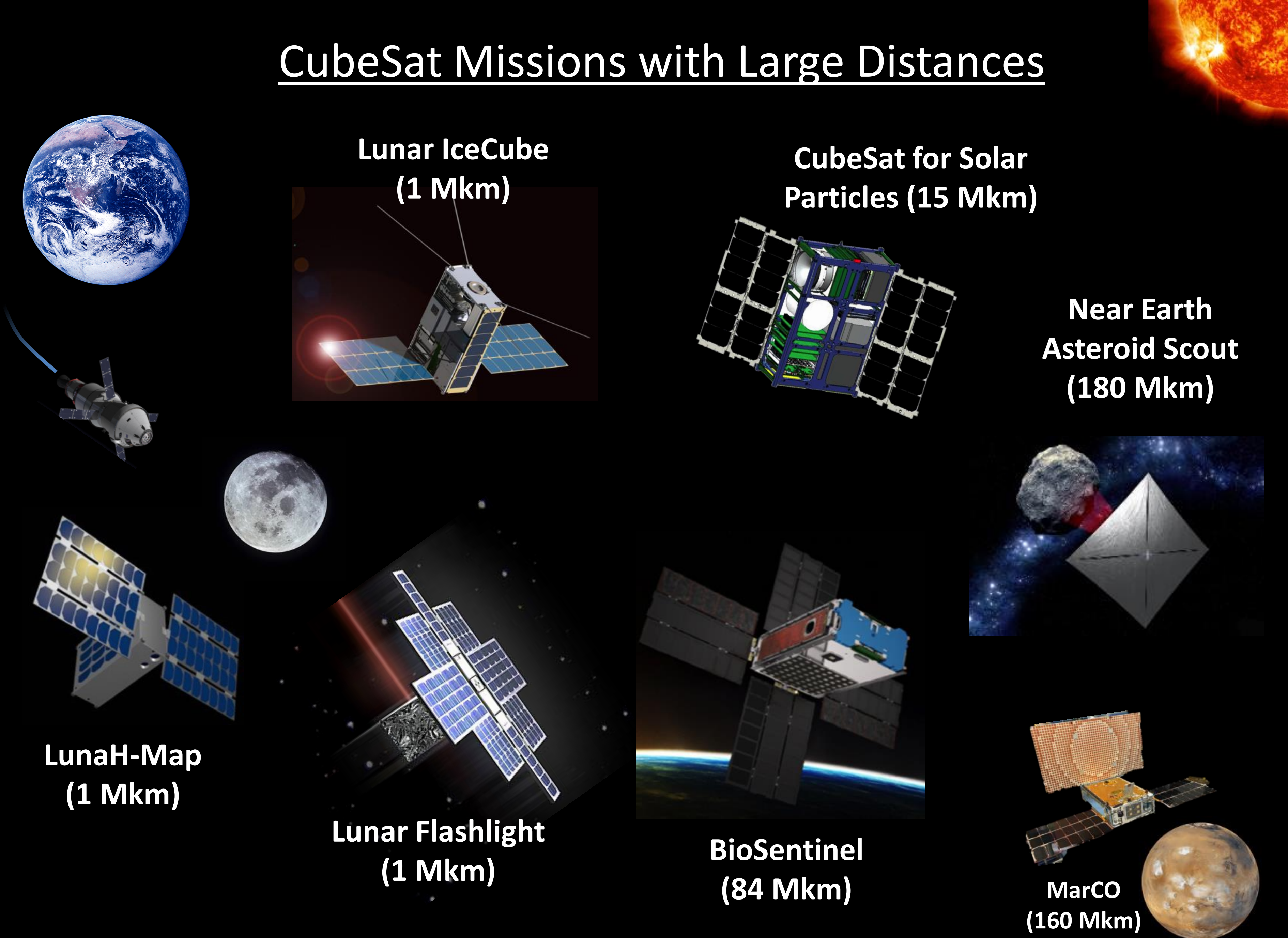
CL#TBD

Outline

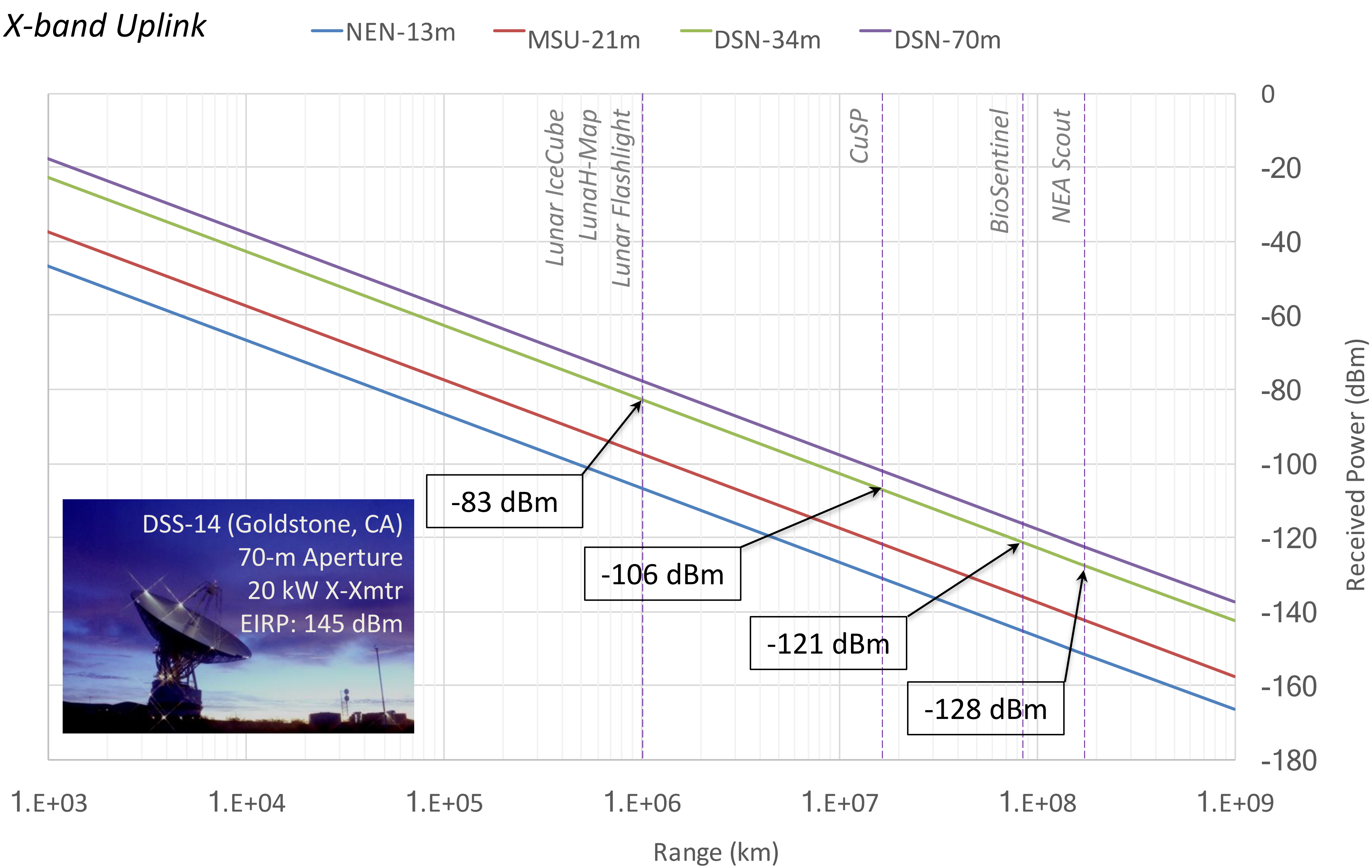
- CubeSat Missions with Large Distances
- Iris Deep-Space Transponder
- Design and Architecture
- Typical Transponder Performance
- Future Work

CubeSat Missions with Large Distances



*IMAGES NOT TO SCALE

Overcoming Large Distances



Iris Deep-Space Transponder

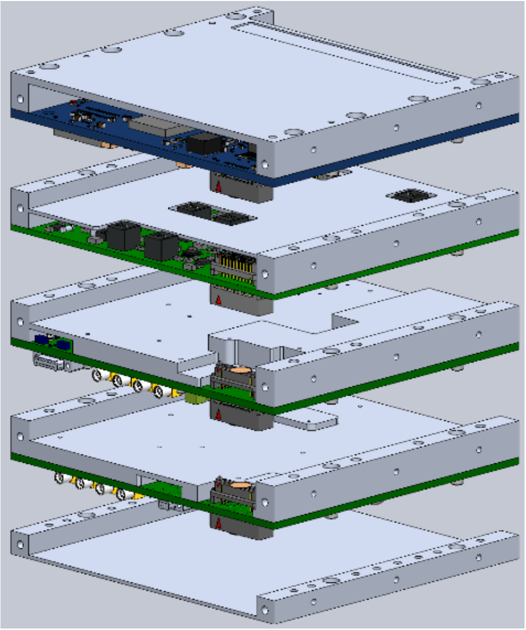
Iris Specification	Spec Value
Processor	Xilinx Virtex-6 w/ Leon-3FT
Uplink/Downlink Frequencies	7145 – 7235 / 8400 – 8500
Turn-around Ratio	880/749
Downlink Symbol Rates	62.5 bps – 6.25 Msps
Uplink Data Rates	62.5 bps – 8 kbps
Modulation Waveforms	PCM/PSK/PM w/subcarr, PCM/PM w/ biphase-L, BPSK
Telemetry Encoding	Convolutional (r=1/2, k=7) Reed-Solomon (255,223) I=1 or 5 Turbo (1/2, 1/3, 1/6) Concatenated codes
Receiver Noise Figure	< 3.5 dB
Carrier Tracking Threshold	-151 dBm @ 20 Hz LBW
RF Output Power	> 3.8 W
Navigation Support	Doppler, Sequential/PN Ranging, Delta-DOR
Transmit Phase Noise	-110 dBc/Hz @ 100 Hz, -117 dBc/Hz @ 1 kHz -126 dBc/Hz @ 10 kHz, -127 dBc/Hz @ 100 kHz
Oscillator Stability	0.001 ppm @ 1 sec
Mass / Volume	< 1 kg (X/X only); 0.56 U (ex. SSPA/LNA)
Power Consumption	12.0 W Rx-only 16.0 W full Tx/Rx (No SSPA), 33.7 W (w/ 4W SSPA)
Power Interface	9 – 28 Vdc
Environmental	AFT: -20°C to + 50°C; > 23krad; 14.1 Grms RV

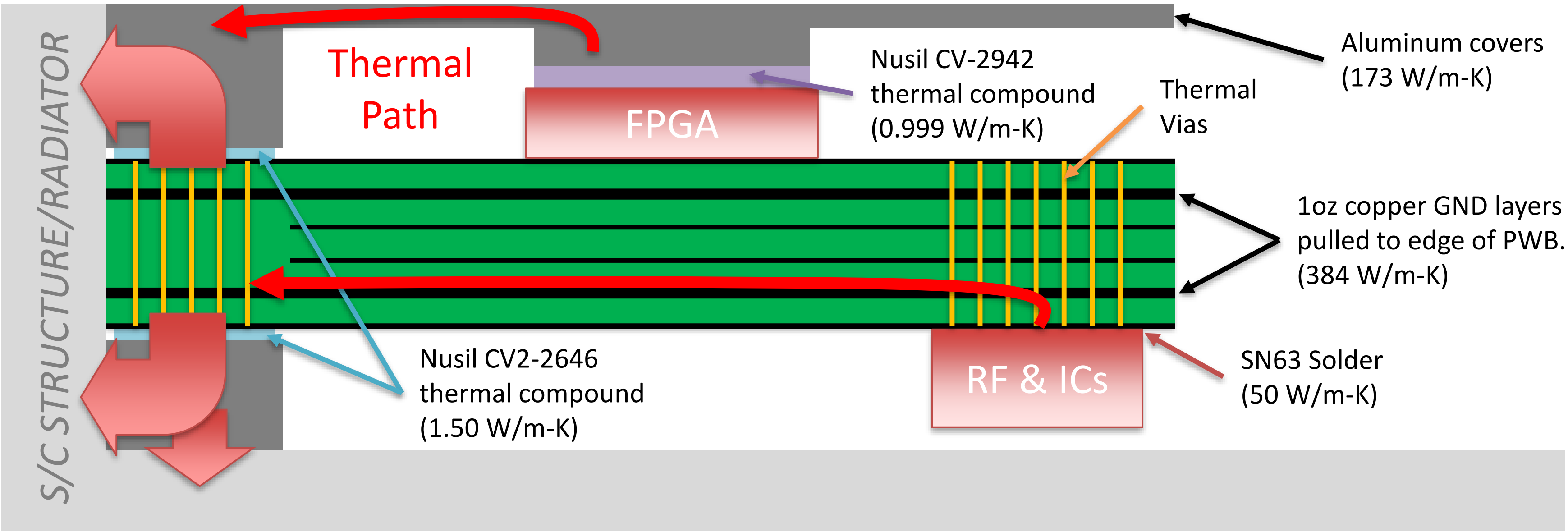
Key Updates in Iris V2.1

- FPGA with embedded processor
- 30% volume reduction
- Higher data rates
- Expanded encoding support
- Increased receiver sensitivity
- Radiation tolerant design

Hardware Design Considerations

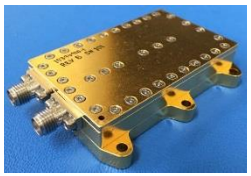
- Modular hardware built of slice elements
  - NASA-STD-4009 (Space Telecom Radio System) guidelines
  - Slices are interconnected with stacking connectors
  - RF modules are generic to allow future designs with other frequency bands (UHF, S, Ka)
- Radiation tolerant up to 23 krads; no destructive SEL.
- EMI covers/shields to minimize radiated emissions
- Emphasized efficient thermal design





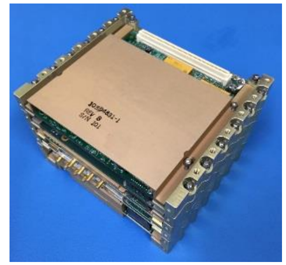
Top-Level Block Diagram

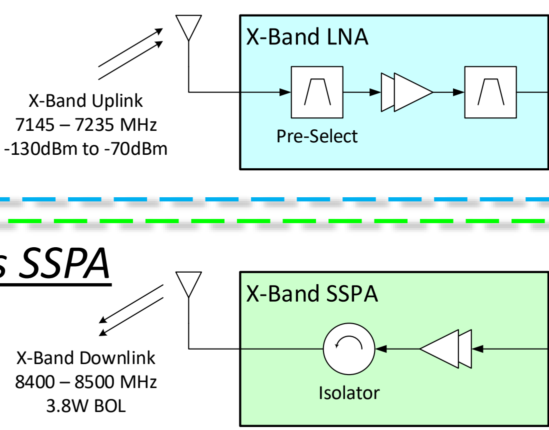
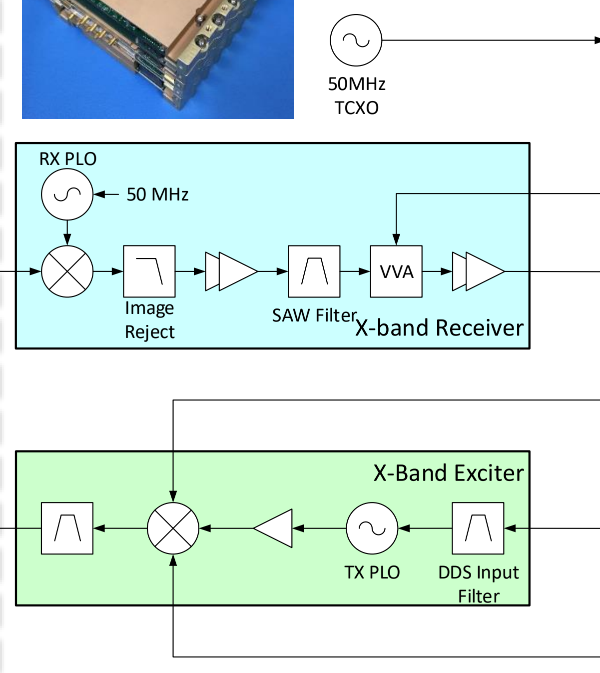
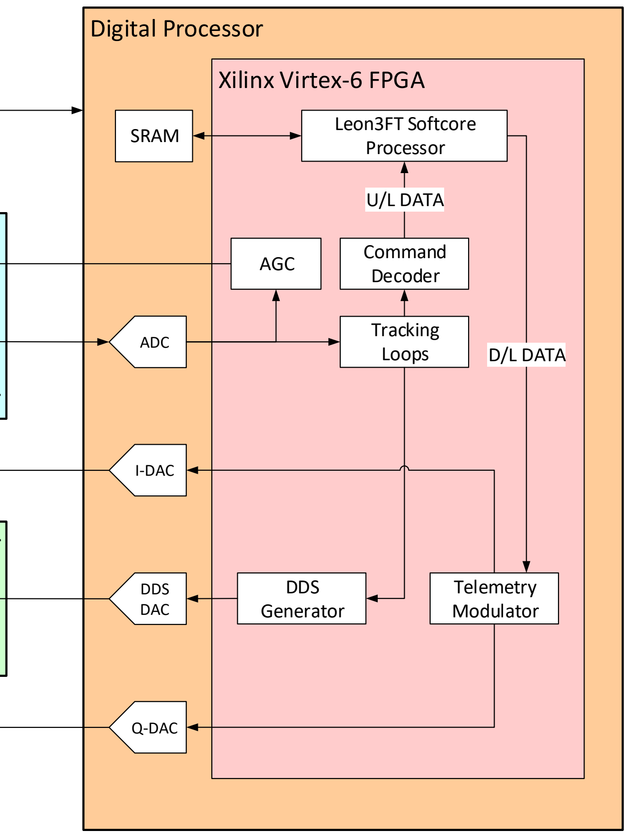
Iris LNA



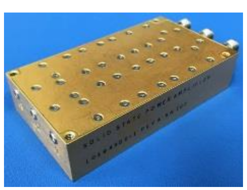
Modular MIC assembly
- Reduce noise figure by shortening cable length from antenna
- Separate gain cavities between LNA and Rx (risk of oscillations)

Iris Transponder Stack



Iris SSPA



Modular MIC assembly
- Provide superior heat dissipation path to structure/radiator
- Chip-and-wire assy to reduce losses for higher efficiency

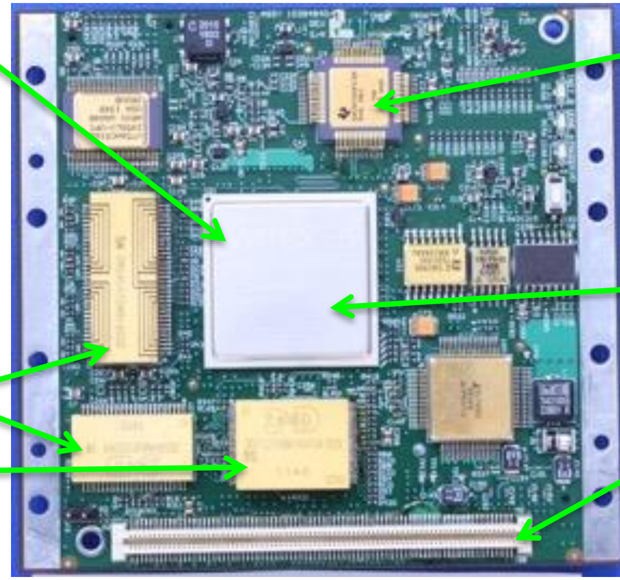
Modular stacked-slice assembly

- Superheterodyne receiver with single-downconversion stage to 112.5 MHz IF
- Digitally closed tracking loops (carrier, subcarrier, symbol)
- Direct Digital Synthesis (DDS) reference for downlink carrier Doppler tracking
- Baseband telemetry modulated direct at X-band
- Embedded softcore processor (Leon3-FT) for configuration and protocol mgmt

Digital Processor

Xilinx Virtex-6 FPGA
Leon-3FT softcore processor
SEL tested up to 37 MeV-cm2/mg
TMR logic and EDAC protected
Reprogrammable/Reconfigurable

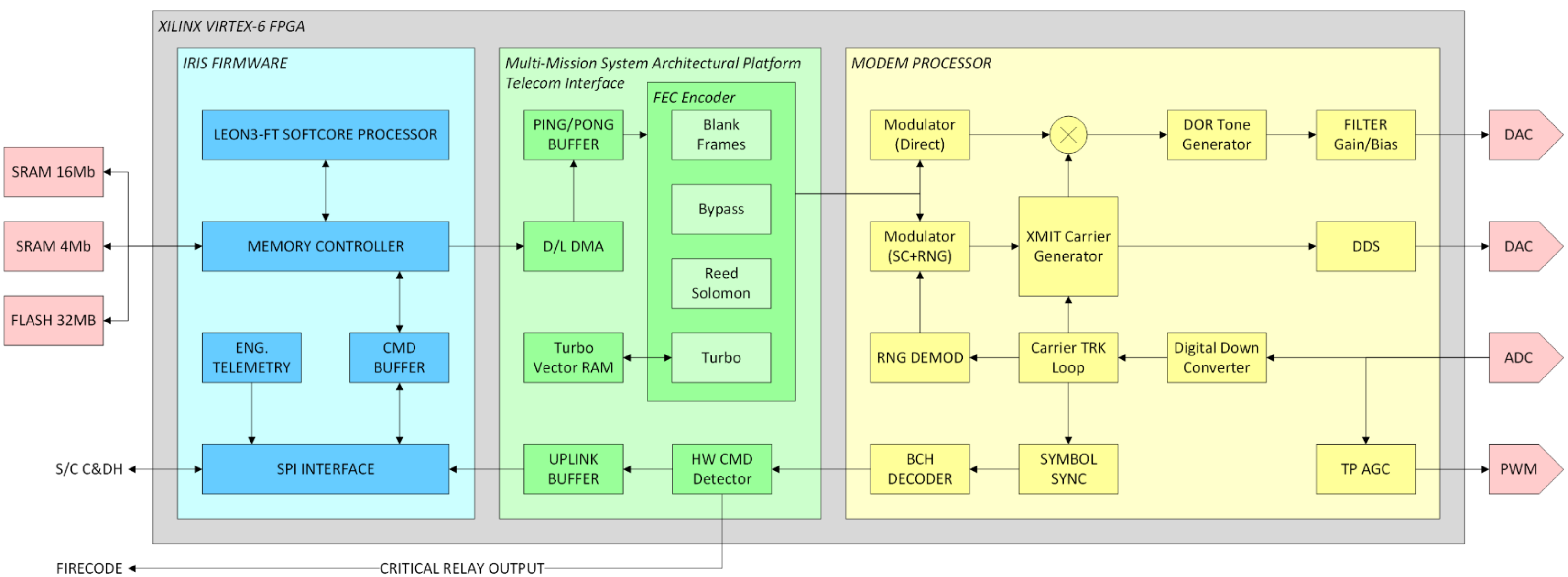
Rad-Hard Memory
2 MB SRAM program memory
32 MB NVM for multiple software images and configuration files



14-bit DDS DAC
Doppler carrier tracking for transponder functions

Modem Processor
Telecom Interface

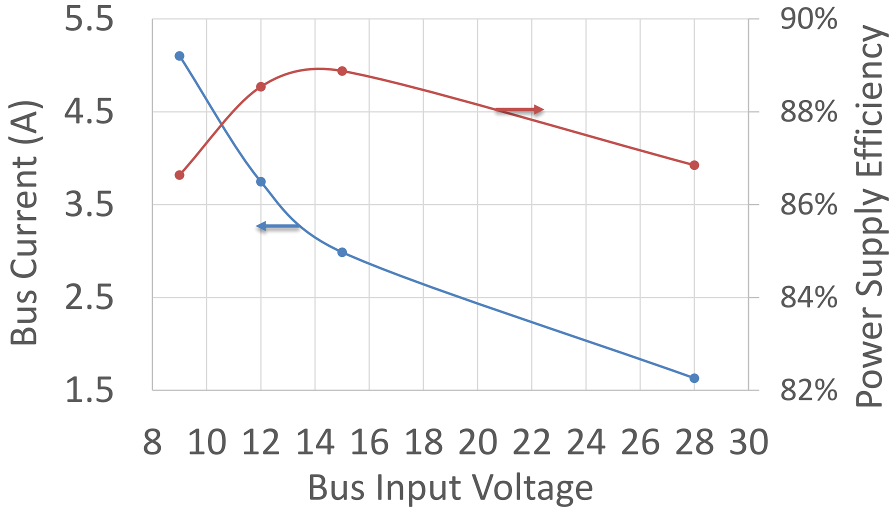
Tyco-160 Bus connector
1 MHz Serial-Peripheral I/F
Expandable for SpaceWire



Power Supply Board

Previous Iris models were for low radiation environ. (Mars ~2.9 krads). Design update necessary for EM-1

Part No.	High Dose Rate Radiation Test Result
LMZ34002	Hard failures at 14-16 krads (biased)
LT1964	Total functional failure by 50 krads
LT3082	No degradation/failures up thru 50 krads
LT3433	Functional failures at 17-21 krads (biased)
LT8570	Output degraded 2% at 7 krads
LT8610	No degradation/failures up thru 50 krads
LT8613	No degradation/failures up thru 50 krads

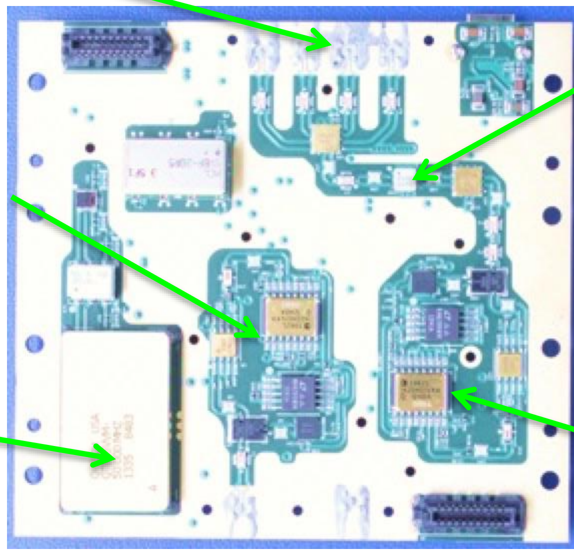


Key Power Supply Board Specs

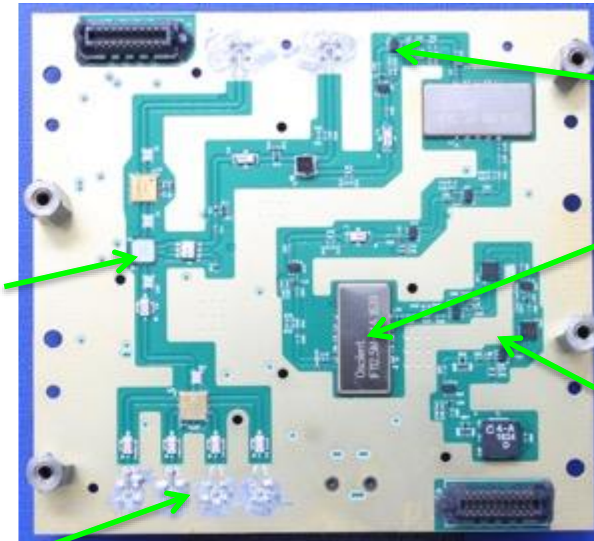
- Bus input range 8 – 28 Vdc
- 36 Watts full-load capability
- High converter efficiency > 86%
- 13 secondary analog/digital voltages

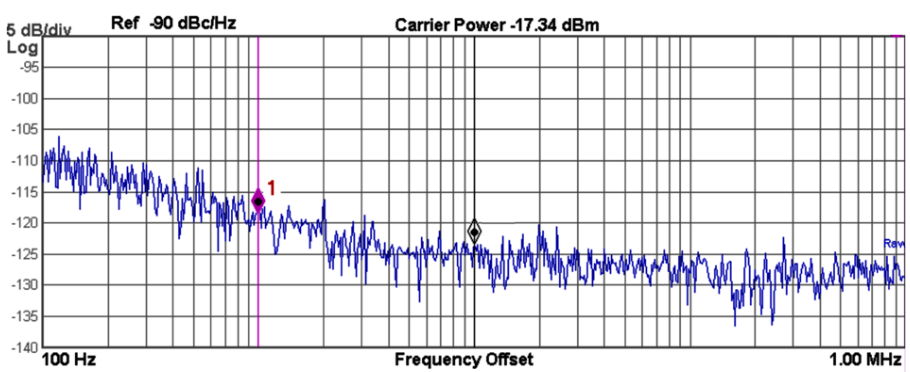
X-band RF Boards

X-band Exciter

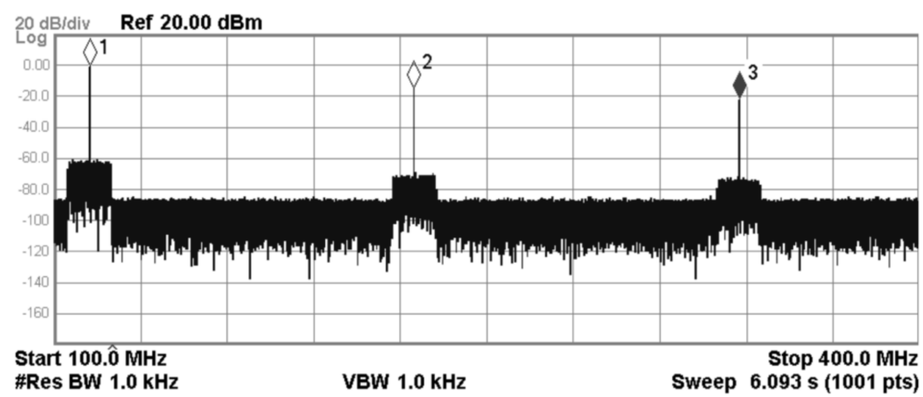


X-band Receiver





Transmit carrier phase noise at X-band



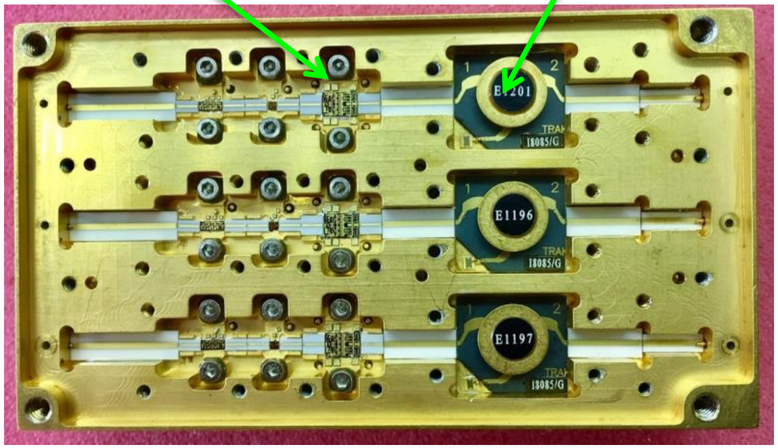
IF Spectrum at high SNR input

X-band RF Modules

GaAs MMIC Pwr Amps

X-band SSPA

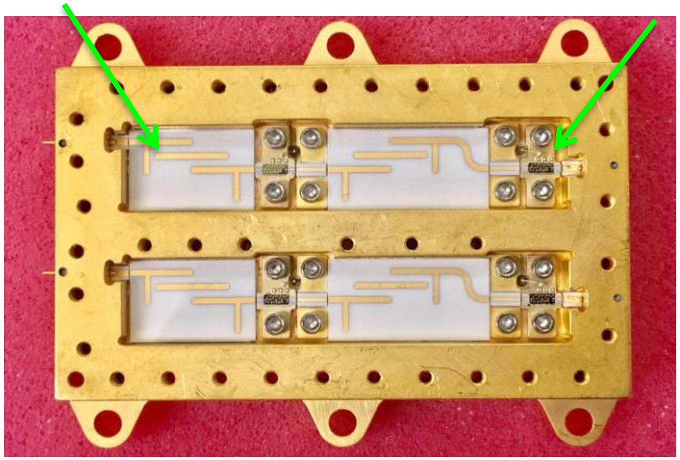
Isolator

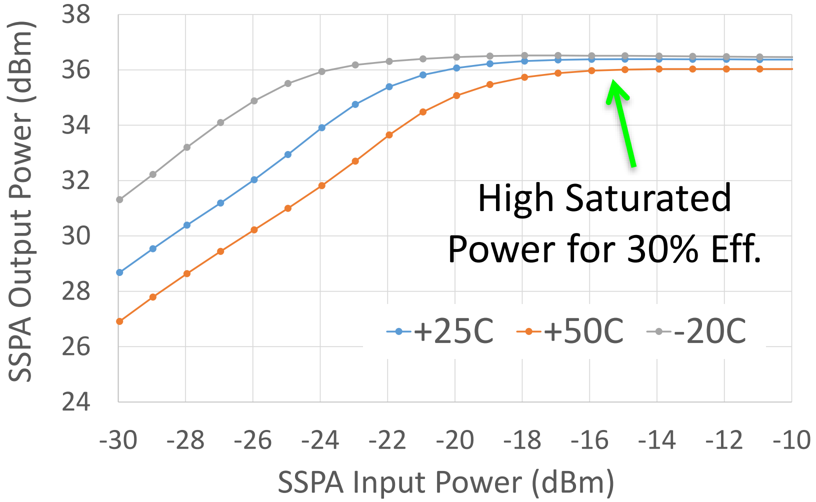


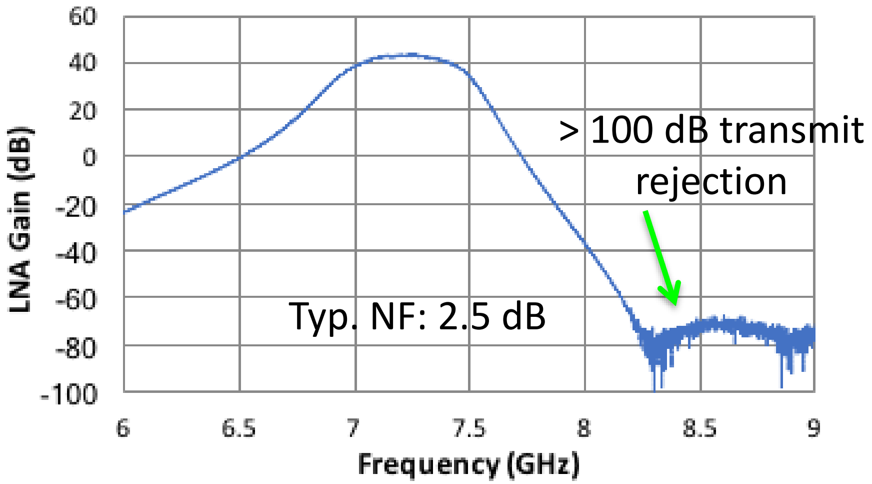
Ceramic printed BPFs

X-band LNA

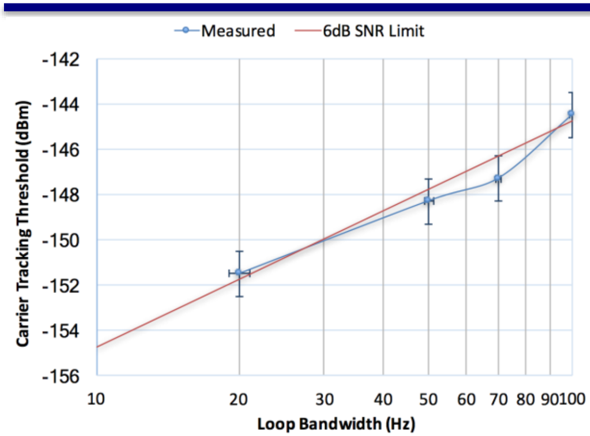
GaAs MMIC LNAs



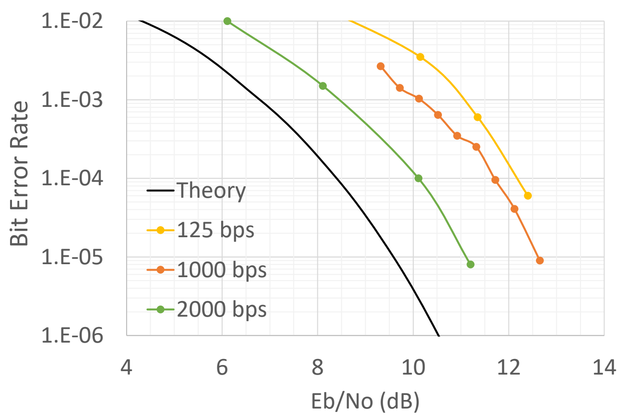




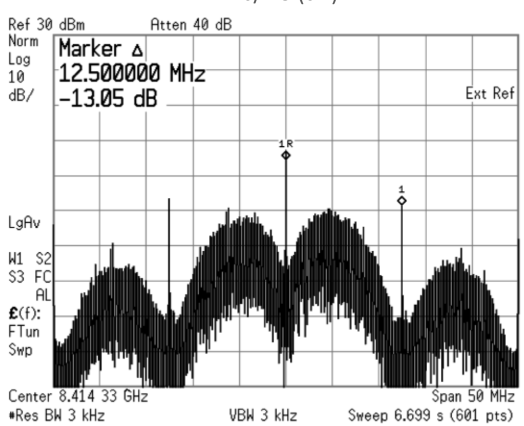
Typical Transponder Performance



- Receiver characterization shows stellar performance comparable to commercial transponders.
- Low loop bandwidth is desirable for low signal levels, but sensitive to frequency dynamics.



- Typical uplink receiver Bit Error Rates on a 16 kHz sine-wave subcarrier at 1.5 radian mod index.
- Further performance improvements can be made with modem processor parameter optimization.



- High-rate testing shows spectrum of a direct-carrier modulated 6.25 Msps waveform with Manchester encoding.
- I/Q imbalance seen as spurious outputs at nulls can be eliminated by software tuning.

Future Work

- Upcoming Iris V2.1 Qualification Tests
  - Complete ambient characterization
  - Environmental tests: TVAC, Vibe, EMI/EMC
  - DSN Compatibility Testing at DTF-21 Facility

- Future Enhancements
  - Delay/Disruption Tolerant Networking
  - Pseudo-noise regenerative ranging support
  - Advanced higher-order modulation schemes (QPSK, 8PSK, etc.)
  - State-of-the-art Forward Error Correction Algorithms (LDPC)
  - Other frequency bands (UHF, S, Ka)

Conclusion

- Upcoming EM-1 CubeSat missions face challenging deep-space telecom system requirements.
- Thorough slice-by-slice design description of the Iris Transponder was presented.
- Comparable transponder performance demonstrated.
- Software defined radios as “smart radios” are leading the pathway to enable rapid technology infusion.

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