Ka-band Modulator Development for the NISAR Mission

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337 Section Seminar Series
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Agenda

- NISAR Mission Overview
- Communication Architecture
- Coverage Analysis
- Ka-band Modulator Specifications
- JPL Flight SDR Developments
- Next-Generation JPL SDR Family
- Modular Hardware Architecture
- Hardware/Software/Firmware Designs
- EM Test Results
- Future Plans
- Acknowledgements

NISAR Mission Overview

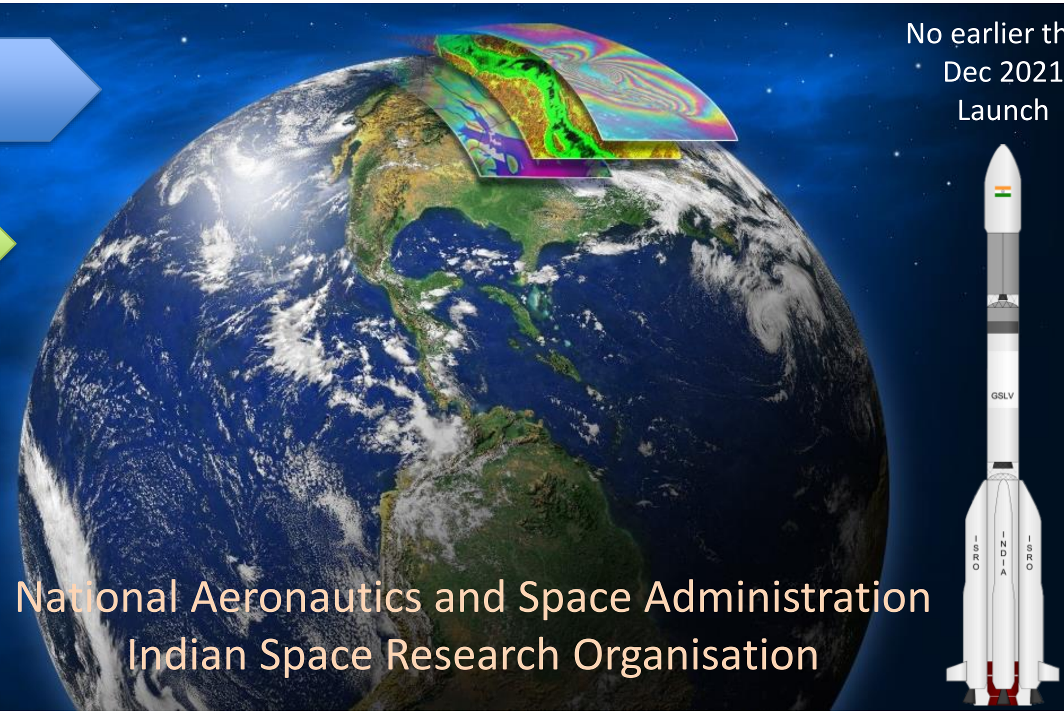
Response of ice sheets to climate change and the interaction of sea ice and climate

Carbon storage and uptake in wooded, agricultural, wetland, permafrost

Likelihood of earthquakes, volcanic eruptions, and landslides, with potential for urgent response and hazard mitigation

Societal impacts of dynamics of water, hydrocarbon, and sequestered CO_2 reservoirs

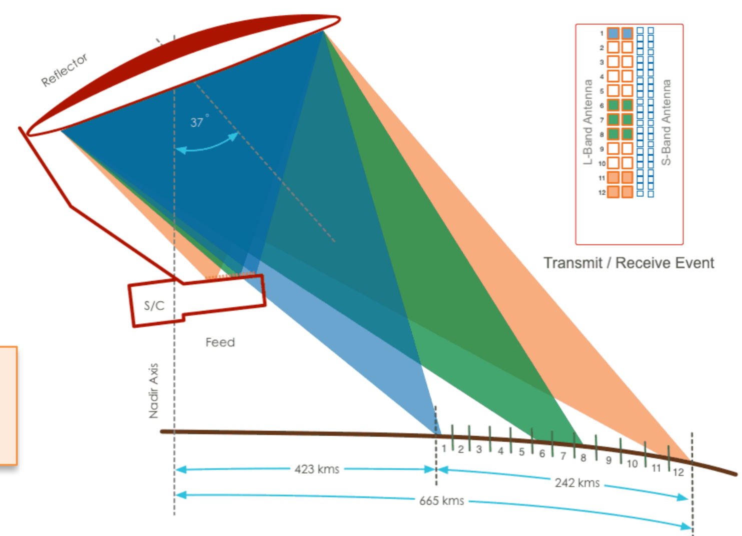
No earlier than Dec 2021 Launch



National Aeronautics and Space Administration
Indian Space Research Organisation

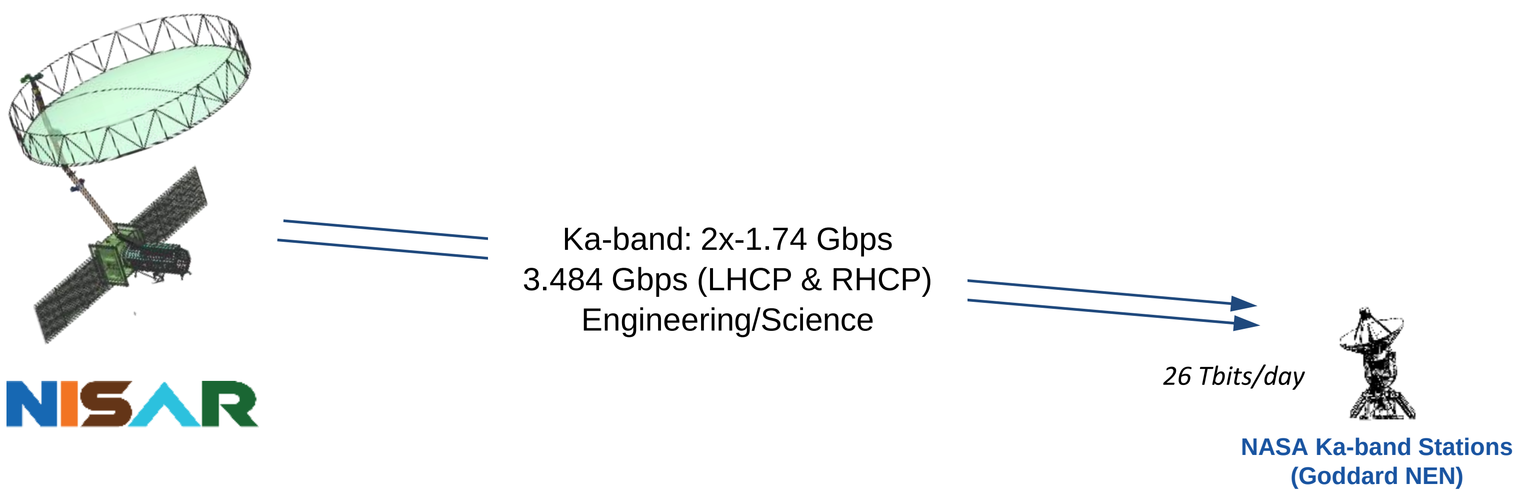
Simultaneous dual-frequency (L-band/S-band) SAR instruments produce data at Gbps speeds, driving the data transfer and storage capabilities (data collection sums to 20-30 Terabits/day)

Driving telecom requirement: ***downlink 26 Tbit/day***



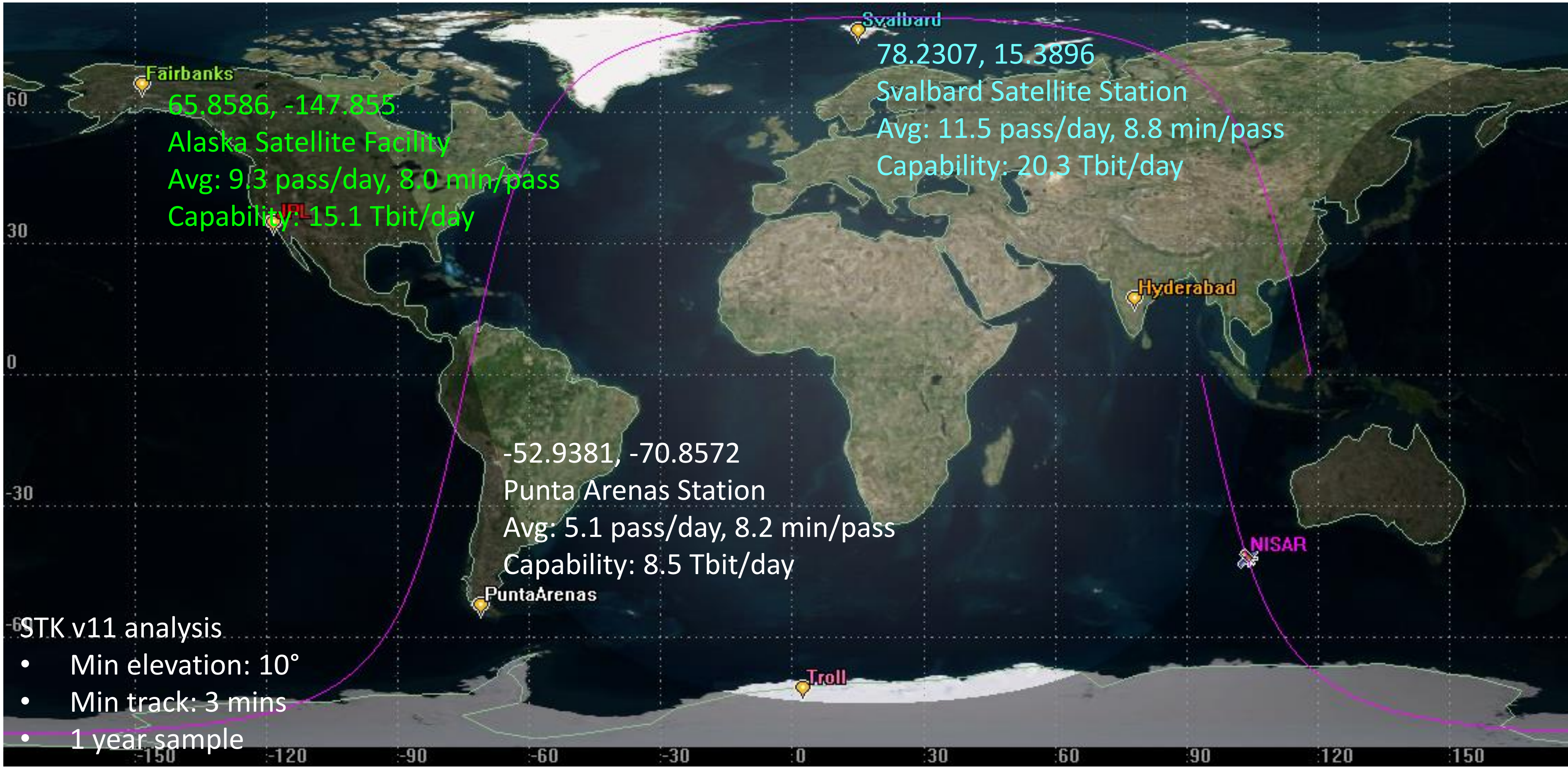
Communication Architecture

- 4.0 Gsps Ka-band downlink
  - Dual-polarization (LHCP/RHCP) downlink system
  - Each chain operating at 1.74 Gbps per channel
- Offset-QPSK modulation with baseband filtering
  - 1 GHz RF low-pass filters on I/Q as well as RRC digital pulse shaping
  - Bandwidth efficient while still offering good Eb/No performance
  - Offset I and Q transitions is resilient to spectral regrowth by saturated amplifiers
- CCSDS LDPC 7/8 encoding
  - High-rate code minimizes overhead while still providing ~8 dB of coding gain
  - Synchronizes with CCSDS AOS framing, sharing single sync marker
  - Pseudo-randomizer to ensure bit transition density



Coverage Analysis

NEN stations to be upgraded with 11.3-m Tri-band (S/X/Ka) full-motion antenna systems



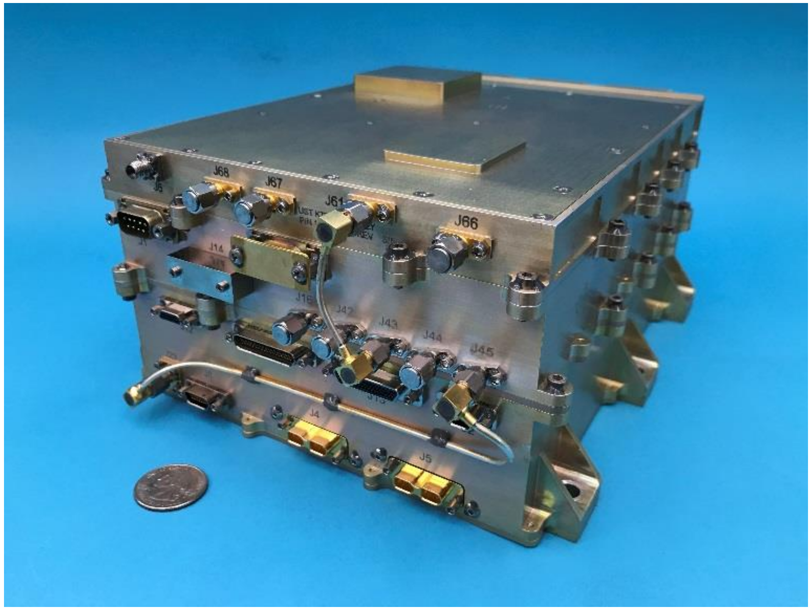
Coverage simulation shows data volume **requirement is met with ~36% margin** using two stations (Svalbard and Fairbanks)

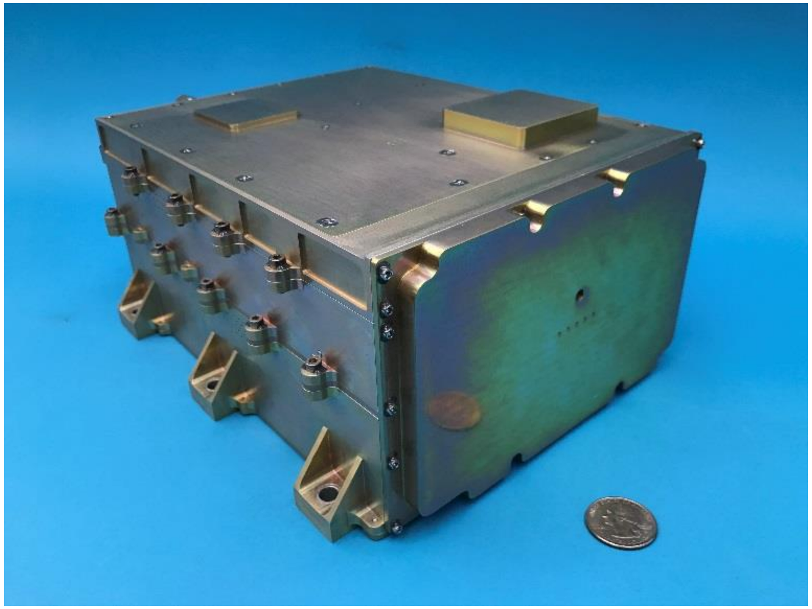
Ka-band Modulator (KaM) Specifications

TX Specs	
Frequencies	Ka-band (25.5 – 27.0 GHz)
Bandwidth	< 1.5 GHz
Coded Data Rates	500, 1000, 2000 Msps
Modulations	QPSK/OQPSK with custom baseband analog filtering
Digital Pulse Shaping	Root Raised Cosine (optional)
Channel Coding	LDPC with Rate 223/255 (~7/8)
RF Output Power	+12 dBm

Environmental Specs	
Flight Allow. Temp	-20°C to +50°C
Dynamics	Random Vibration: 15 Grms Pyrotechnic shock: 2000g
Radiation	50 krad

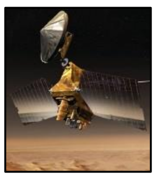
Interface Specs	
Power Consumption	40 W Tx Mode; 20 W Standby Mode
Cmd/Tlm Interface	1553, RS-422, or Spacewire (option)
High-speed Data	TLK WizardLink SERDES (up to 2 Gbps)
Power Interface	22-36 V Unregulated Bus
Mass/Dimensions	4.5 kg / 25 x 20 x 11 cm (L x W x H)





JPL Flight SDR Developments

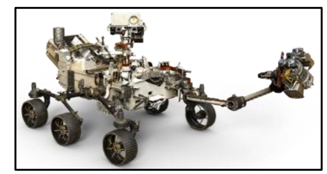
- KaM leverages design features from JPL's previous flight SDRs
  - Stacked module configuration with separate digital, power, and RF modules
  - One-time programmable Housekeeper FPGA and PROM for reliable Safe Mode
  - Xilinx FPGA with in-flight reprogrammable firmware for modem processing
  - SPARC microprocessor with in-flight reprogrammable Application Software


MRO Electra
UHF Relay Radio


MSL Electra-Lite
UHF Relay Radio


CoNNeCT
S-band Radio

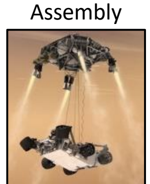

TGO Electra
UHF Relay Radio

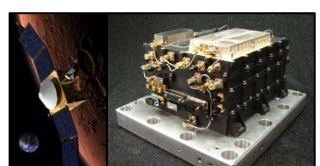

M2020 Electra-Lite
UHF Relay Radio

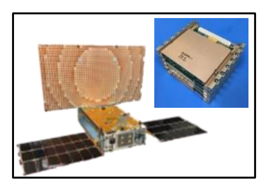
JPL Flight Software-Defined Radio Developments

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

M3
Instrument


MSL Landing
Radar Digital
Assembly


MAVEN Electra
UHF Relay Radio


MarCO Iris Deep-
Space Transponder


M2020 Landing
Radar Digital
Assembly

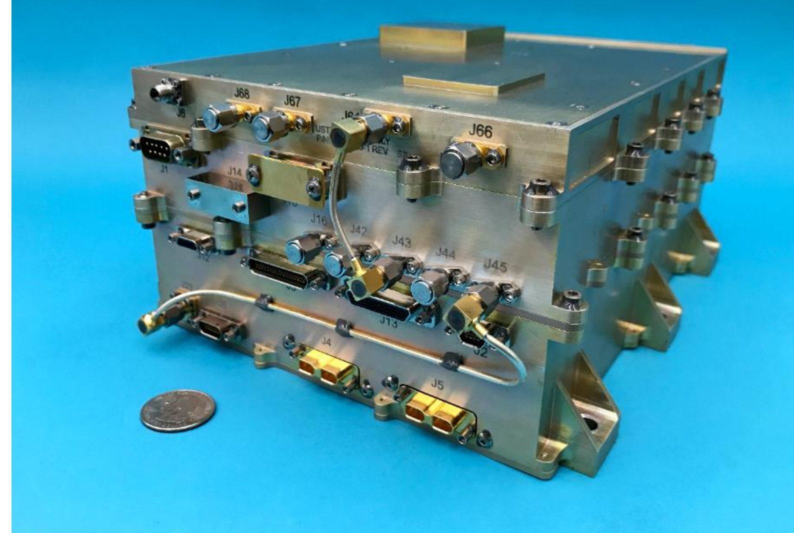

NISAR Ka-band
Modulator


Next-Generation JPL SDR Family

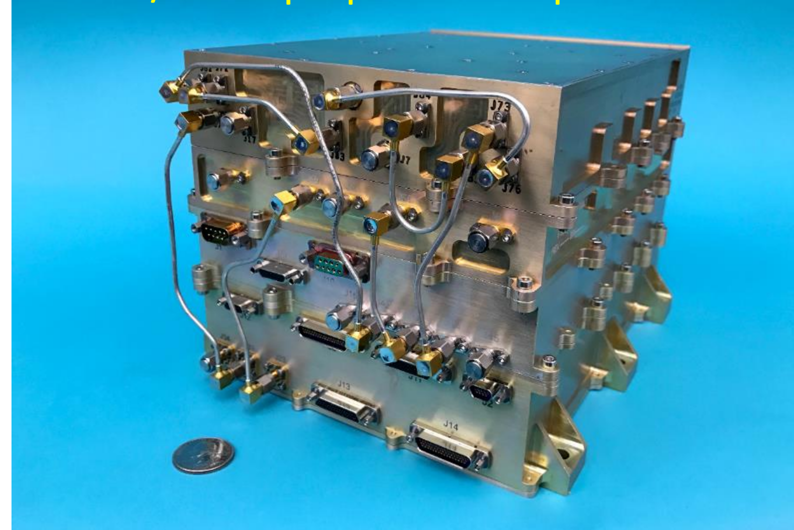
Universal Space Transponder (UST)

- Modular hardware to provide flexibility to meet a large variety of telecom, navigation, and radio science needs with a single radio platform
- Expandability to handle multiple RF links (UHF, S-, X-, or Ka-band), allowing a single unit to support both relay and direct-to-Earth communications for near-Earth or deep space missions
- Significantly higher bi-directional data rates than current space radios to increase mission return data volumes
- Sufficient digital resources to enable advanced modulations, FEC coding, protocols, and navigation techniques
- In-flight reprogrammable to allow new functionality or bug fixes during any mission phase
- Frequency agility to increase flexibility in channel assignments or to avoid EMI

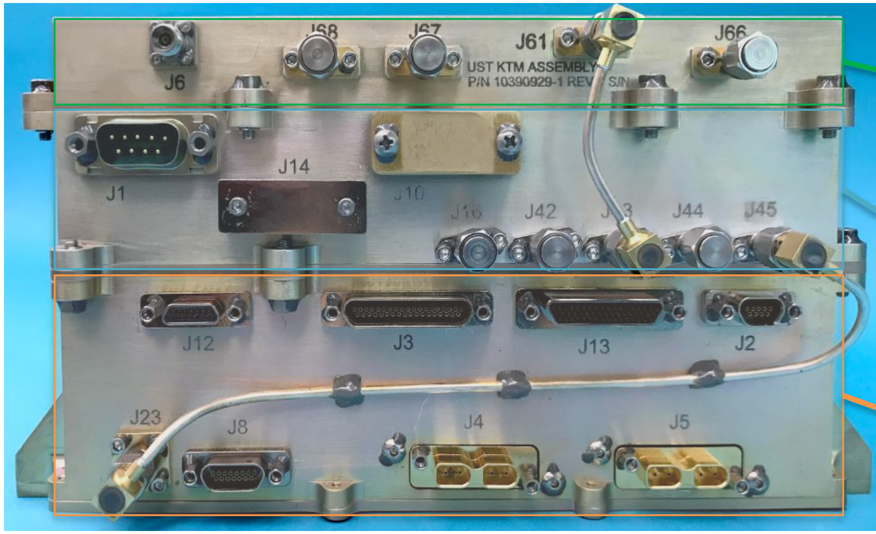
Ka-band Modulator



S/X Deep-Space Transponder



Modular Hardware Architecture



Ka-band Transmit Module (KTM)

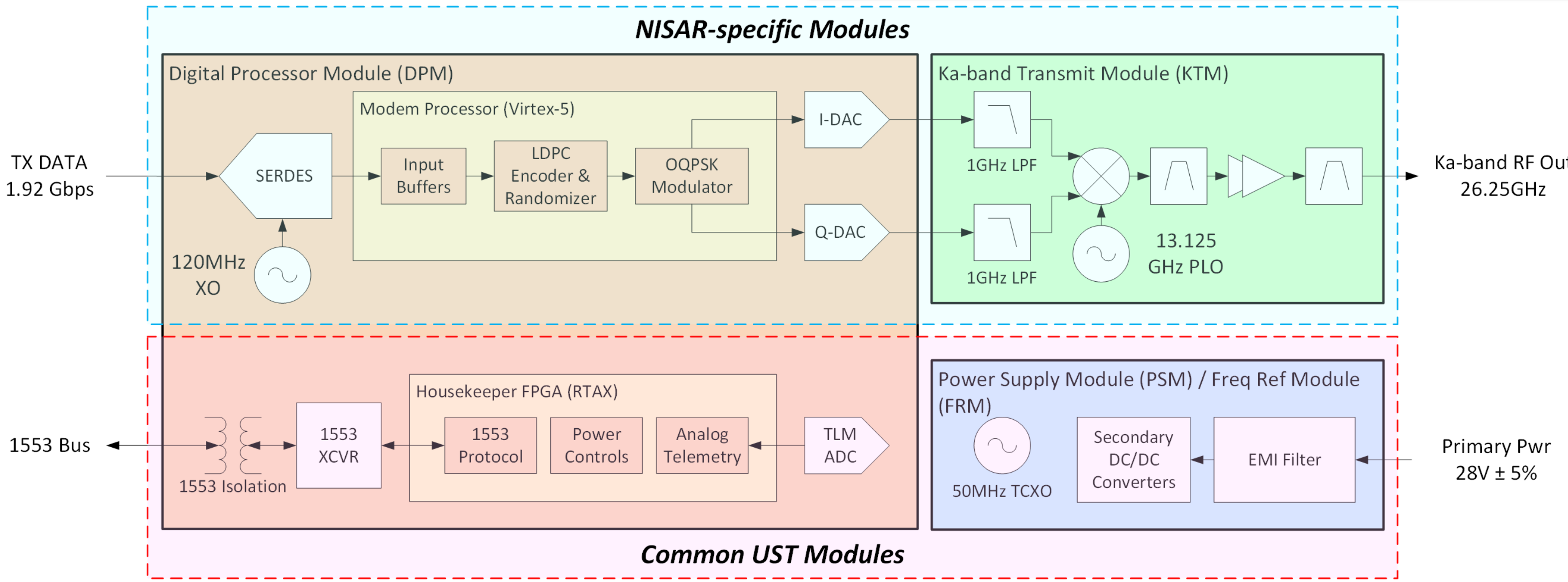
- Modulates I/Q baseband signals onto Ka-band RF Tx
- Provides 2 GHz reference for DACs in DPM

Power Supply Module (PSM) and Freq Ref Module (FRM)

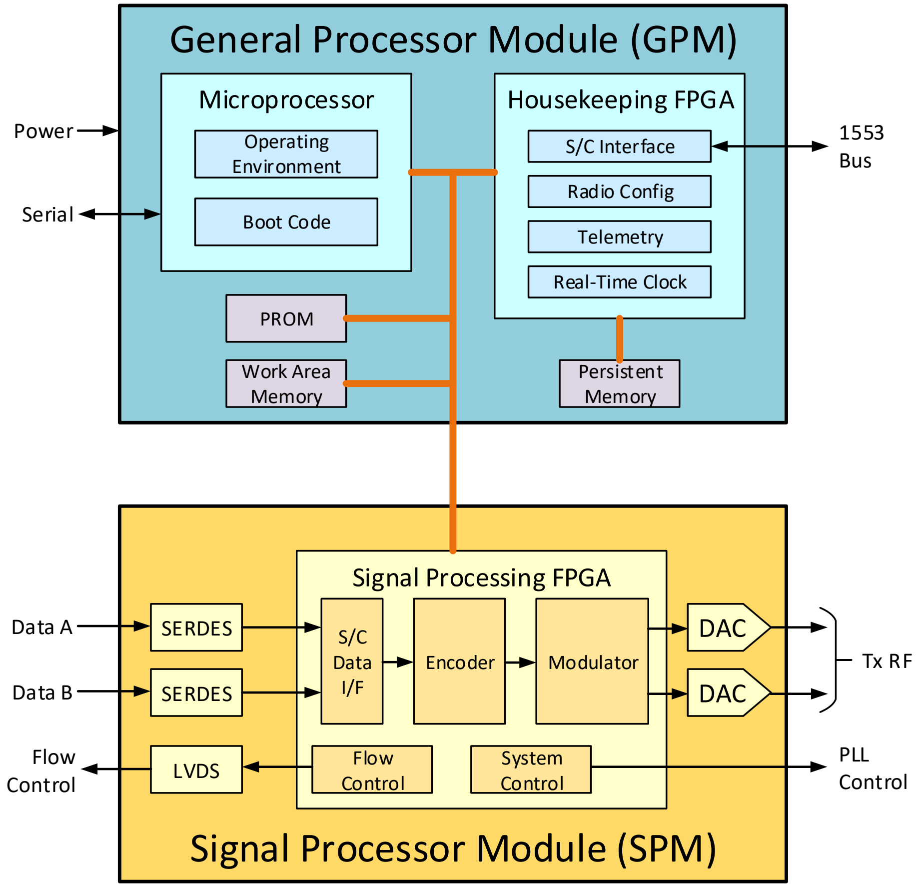
- Converts primary power to secondary voltages
- Provides TCXO frequency reference to other modules

Digital Processor Module (DPM)

- Provides all the digital interfaces with the S/C
- Baseband processing and modulation of Tx data
- Unit housekeeping function and telemetry collection



Digital Processor Module



General Processor Module (GPM)

- Command and telemetry over MIL-STD-1553B, RS-422, or Spacewire interface
- Analog telemetry collection (voltages, temp, etc.)
- Provides storage and management of software and firmware images for all reprogrammable DPM elements
- Configuration and scrubbing interface for Xilinx Virtex-5 FPGA on SPM
- Overall radio management, including PSM and RF module control

Signal Processor Module (SPM)

- High-speed interfaces to Spacecraft SSR via TLK2711 SERDES transceivers
- Virtex-5 FPGA for modem processing
- In-flight reprogrammable
- High-speed DACs for I/Q data
- TX frequency synthesizer programming

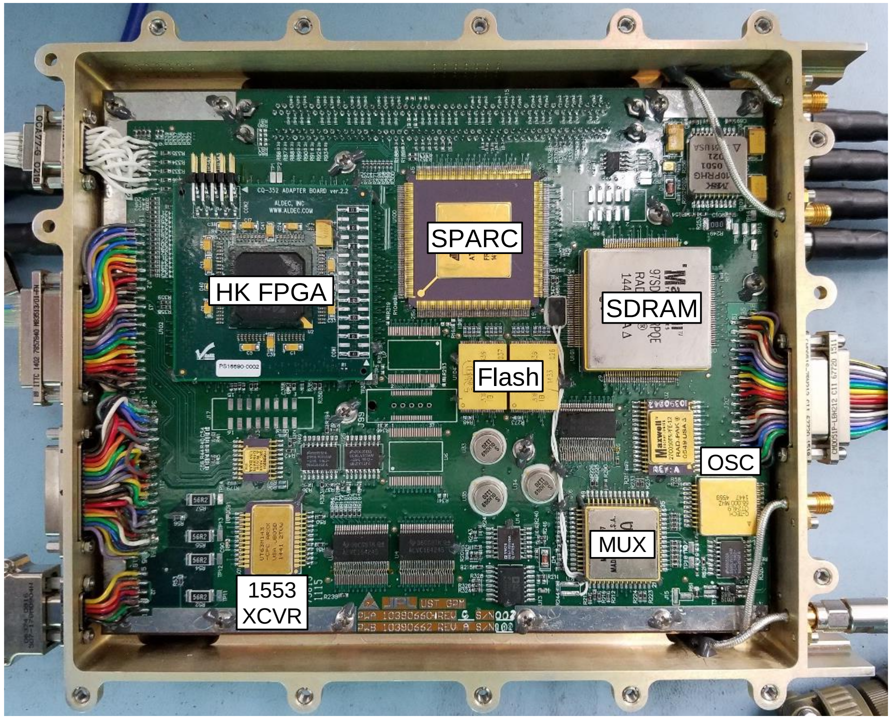
DPM Details

Top side of the DPM (GPM)

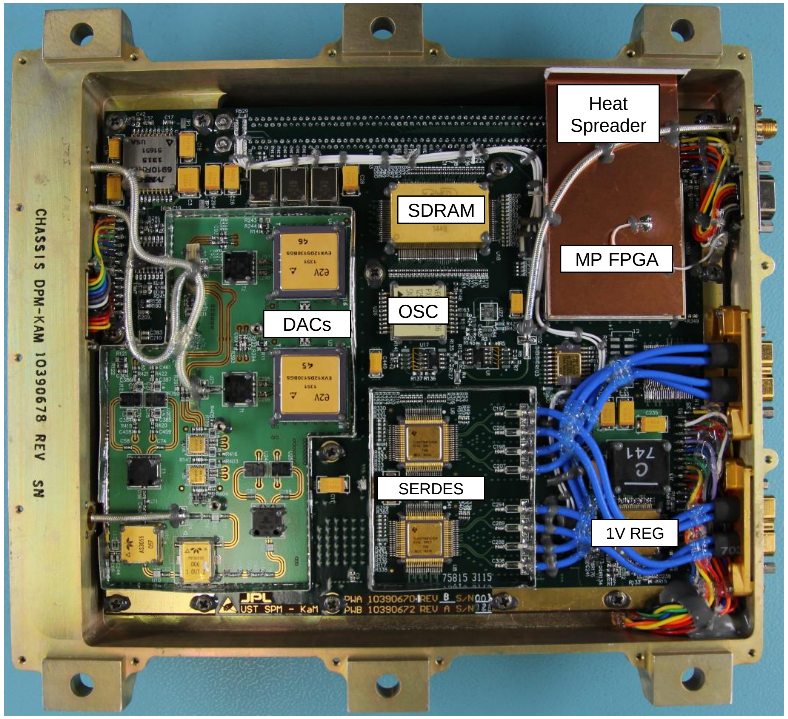
- Housekeeper RTAX FPGA
- SPARC Microprocessor with SDRAM runtime memory and flash NVM for SW/FW storage
- 1553 and SpaceWire/RS-422 interfaces
- Analog MUX and telemetry ADC
- PSM and RF module control outputs

Bottom side of the DPM (SPM)

- Xilinx Virtex-5 Modem Processor FPGA
- Xilinx power sequencing/distribution
- High-speed transmit I/Q DACs
- SSR SERDES transceivers
- 120 MHz SERDES clock
- SDRAM buffer memory



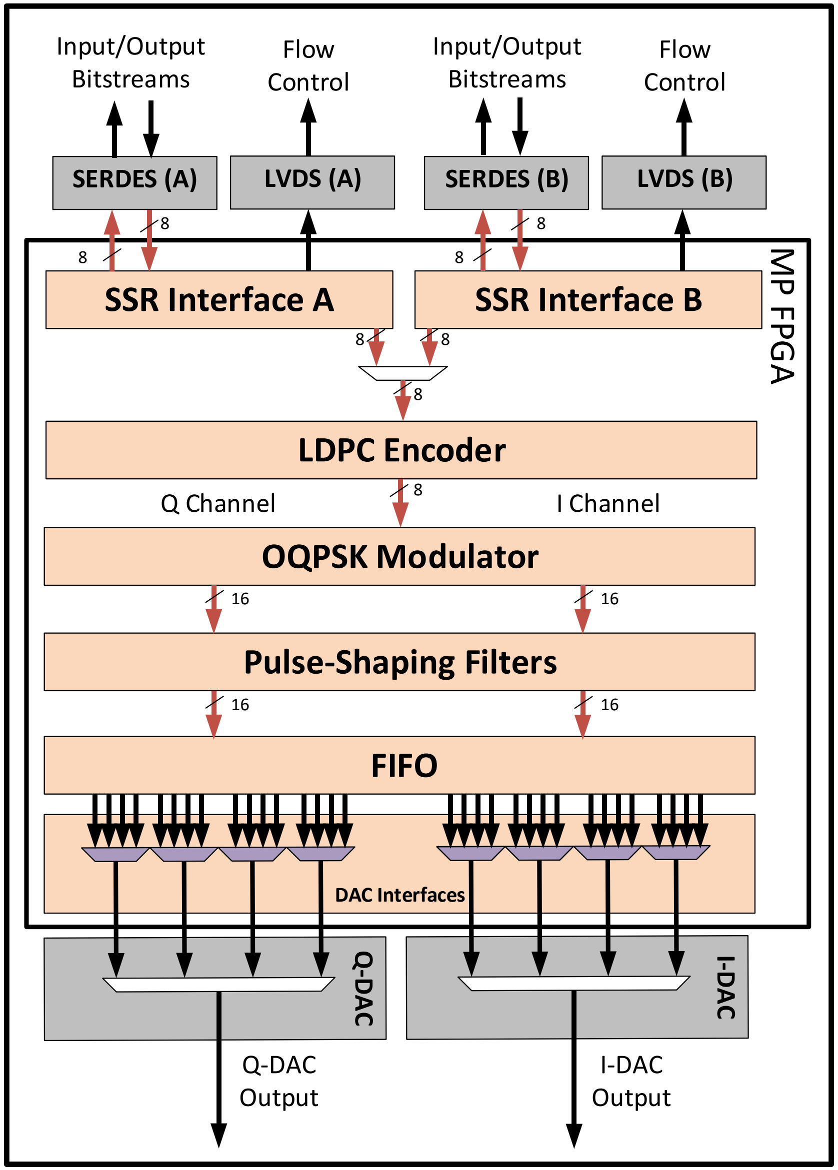
EM DPM Slice Top (GPM PWA Side)



EM DPM Slice Bottom (SPM PWA Side)

Modem Processor FPGA

- All DSP implemented in Xilinx Virtex-5 Modem Processor (MP) FPGA
- High-speed processing with 125 MHz main clock
- 2 Gbps,16-bit parallel SSR interface with 8b/10b encoding and K-codes for AOS frame synchronization
- Parallel CCSDS (860,7136) low-density parity check (LDPC-7/8) encoder with pseudorandomizer and ASM attachment
- Parallel 16-bit OQPSK I/Q modulator
- Parallel Root-Raised Cosine (RRC) pulse-shaping filter with two samples per symbol for inter-symbol interference reduction
- High-speed interface logic to 12-bit DACs with built-in 4:1 multiplexer



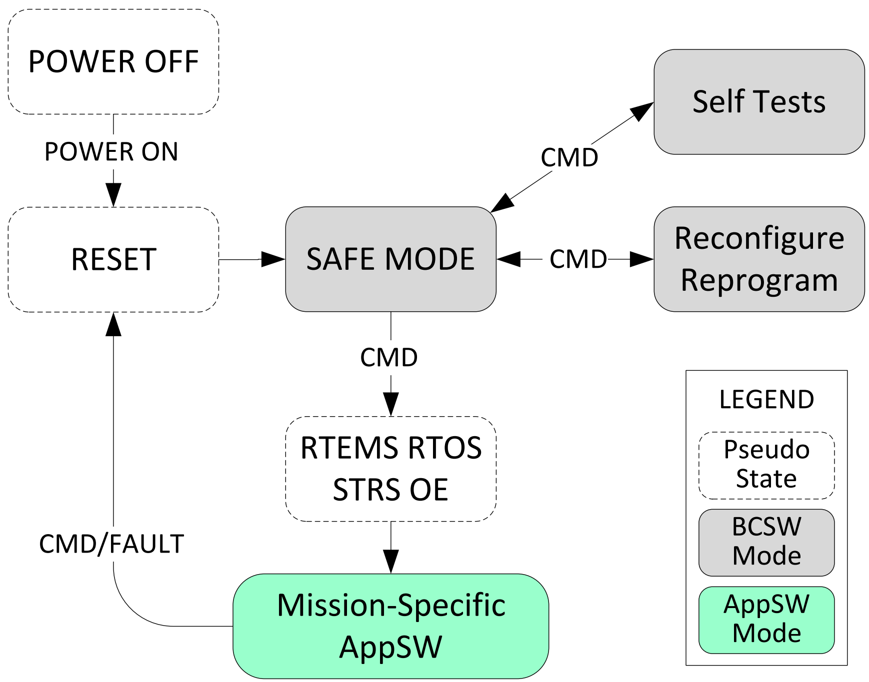
Software

Boot Code Software (BCSW) provides a "Safe Mode" – always available and loaded on power-on or reset from one-time programmable rad-hard PROM

- Telemetry collection and reporting
- Command and control via 1553
- Basic commands for AppSW loading
- Accepts new FW/SW images over 1553 and manages flash storage

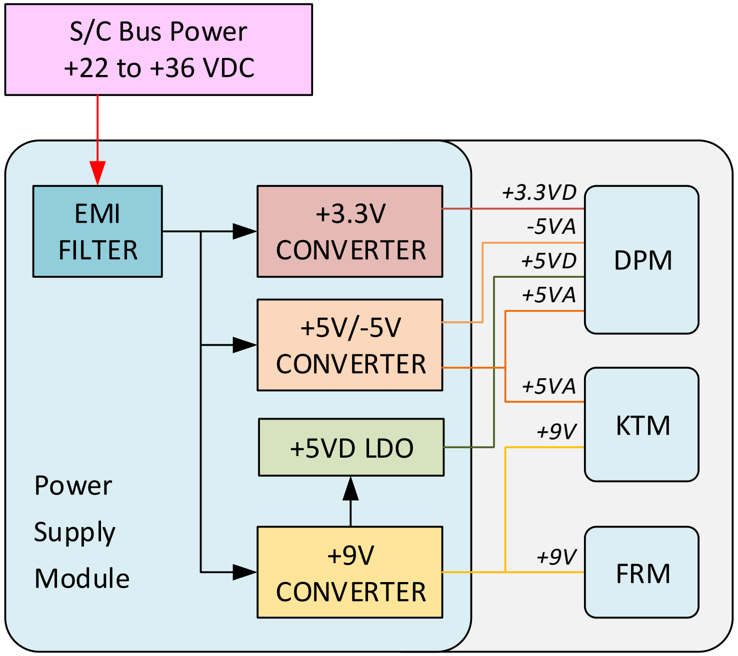
Application Software (AppSW) provides mission-specific functionalities on top of basic BCSW functions – loaded from image in flash memory

- Programs and initializes the Modem Processor FPGA and configures modem parameters
- Configures DACs, memories, and SSR data interfaces
- Real-time amplitude adjustments to compensate for temperature variations



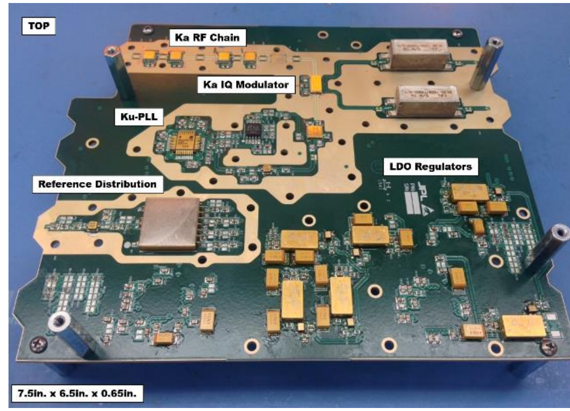
Power Supply Module

- Accepts unregulated 22 to 36V bus power input from Spacecraft
- Provides regulated secondary DC power to other UST modules
- Design is based on a heritage architecture, with the spacecraft power bus passing through an EMI filter and then distributing to various DC/DC secondary converters
- Additional PWB in isolated cavity for TCXO frequency reference distribution
- Split chassis design with DC/DC converters and the frequency reference PWB on one side of a common floor and the power PWB on the other side

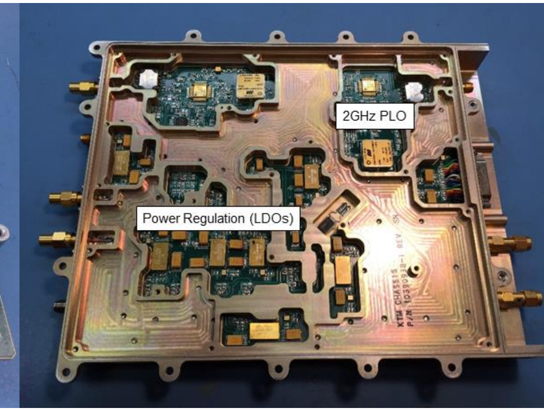


Ka-band Transmit Module

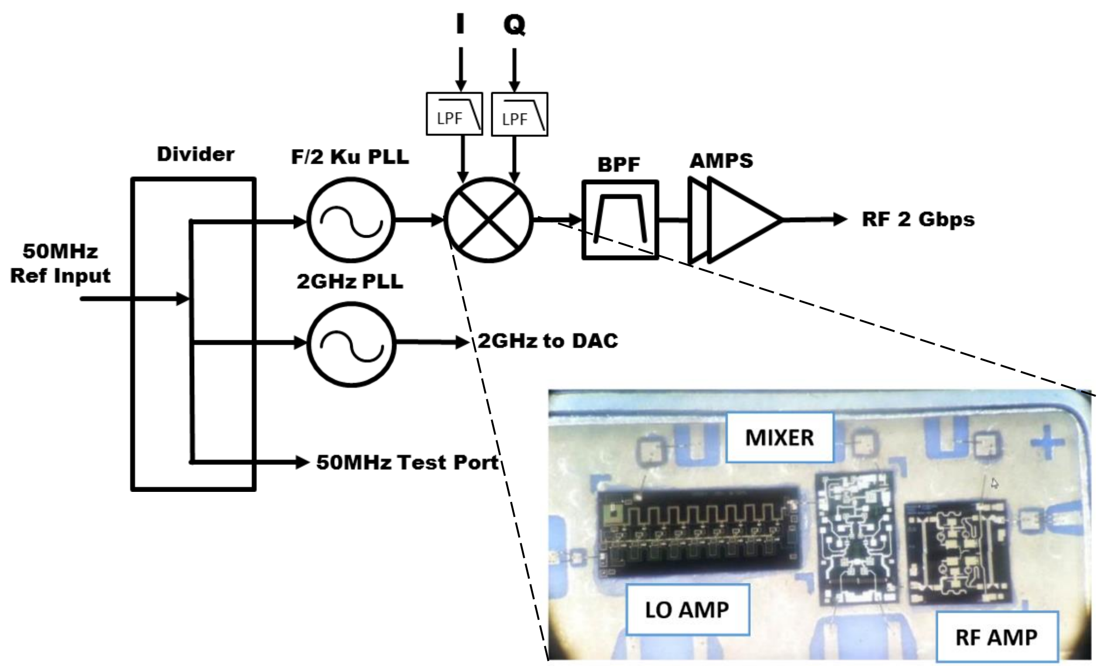
- Ka-band carrier modulated I/Q digital waveforms from the DPM
- Analog baseband filtering for I/Q side-lobe and image rejection
- Custom multi-chip module (MCM) sub-harmonic IQ modulator eliminates need for Ka-band VCO
- Transmit output filtering for harmonics suppression
- On-board frequency synthesizers for DPM high-speed clock and KTM modulator LO
- All surface-mount technology (SMT) hybrids for package-size reduction and lower Ka-band interconnect losses
- Internal clamshell covers to reduce signal crosstalk



Ka-band Transmitter EM PWA (Top View)



Ka-band Transmitter EM Assembly (Bottom View)

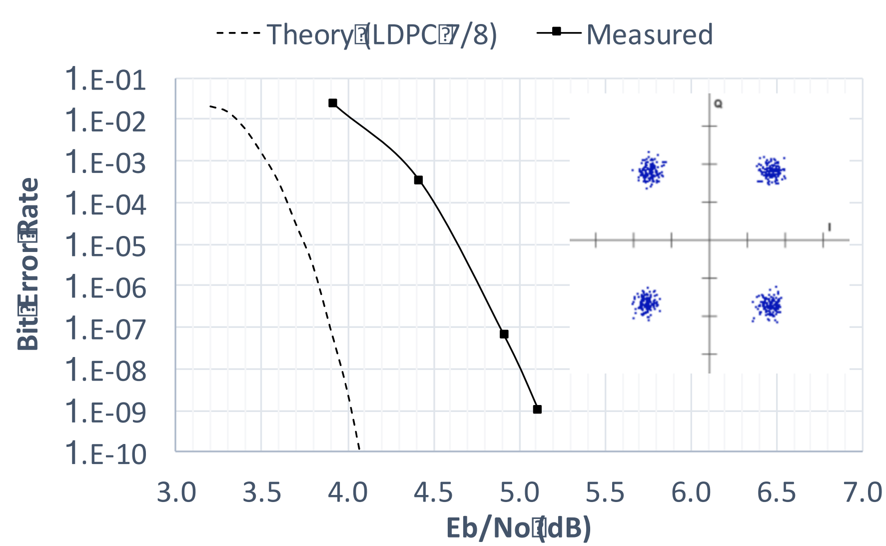


Custom MCM IQ Modulator

EM Test Results

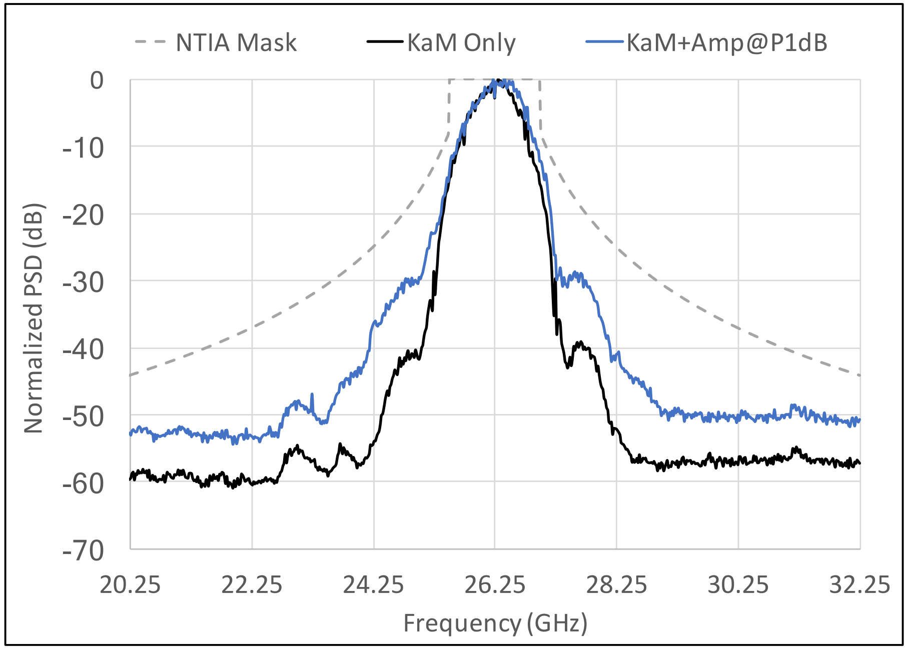
- NASA TRL-6 demonstrated via testing with an engineering model in 2016, including three-axis dynamics, thermal vacuum, and EMI/EMC testing
- All specification met across the allowable flight temperature range
- Compatibility demonstrated with commercial, high-rate ground-station receivers from Zodiac and ViaSat

Parameter	Units	Spec.	Meas.
DC Power Consumption (Tx Mode)	Watts	< 50.0	40.9
DC Power Consumption (Standby Mode)	Watts	< 24.0	19.9
RF Output Power	dBm	> 12.0	12.4
Carrier Frequency	GHz	26.25	26.25
Carrier Phase Noise (1 kHz – 10 MHz)	deg,rms	< 3.6	3.1
Coded Data Rate	Gbps	2.0	2.0
Phase Imbalance	deg	< 5.2	3.5
Amplitude Imbalance	dB	< 1.1	0.4
Spurious Outputs	dBc	< -60	none

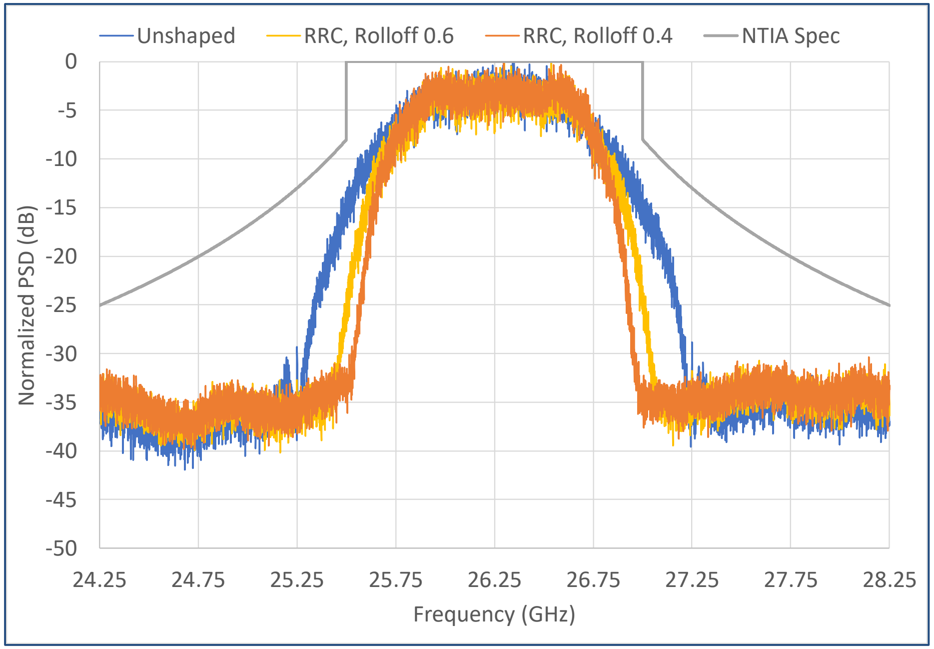


Spectral Compliance and Pulse Shaping

- Consistent with simulations, NTIA compliance was maintained with a saturated, external RF amplifier
- Additional testing with RRC pulse shaping produced improved spectral efficiency and performance for cases without significant saturation



Measured Spectrum Pre- and Post- Saturated Amp



Measured Spectrum with Digital Pulse Shaping

Future Plans

- The NISAR project is currently in the flight hardware build phase with a scheduled launch no earlier than Dec 2021
  - Three flight models of the KaM are currently being assembled at JPL
  - Flight models will be integrated in 2018 and will complete a proto-flight qualification program in 2019
  - JPL will likely select and work with an industry partner on builds for any future missions
- Additional development planned for higher-rate KaM operational modes to achieve ~4 Gbps transmission rate per unit
  - Operating dual SERDES inputs simultaneously for faster transfer from SSR
  - Higher-order modulations such as 16-APSK could increase date throughput at the cost of link SNR
  - Increasing channel symbol rate to 1.3 Gsps with RRC pulse shaping to maintain spectral compliance

Acknowledgements

We would like to thank the following people for their contributions to the KaM development:

Mike Pugh, Igor Kuperman, Carl Spurgers, Fernando Aguirre, Brandon Burgett, Gerry Ortiz, Mike Kilzer, Jimmy Chen, Ian Ruiz, Thaddaeus Voss, Kyle Botteon, Stan Winstein, Scot Stride, Susan Clancy, Anusha Yarlagadda, Kris Angkasa, Steve Allen, Sarah Holmes, Dave Orozco, Kirk Fleming, Thanh Tran, Josh Ravich, Kevin Hischier, John Koenig, Ray Quintero, Vachik Garkanian, Tuyen Ly, Carlos Esproles, Rich Rebele, Brian Custodero, Quintin Ng, Dave Bell, Charles Dunn, Larry Epp, and Dimitrios Antsos