Studying NASA's Transition to Ka-Band Communications for Low Earth Orbit

David Chelmins, Richard Reinhart, Dale Mortensen,
Bryan Welch, Joseph Downey, and Mike Evans

dchelmins@nasa.gov
+1 (216) 433-3304

NASA Glenn Research Center (GRC)
Cleveland, Ohio, United States

IAC 2014, Toronto, Ontario, Canada

Overview

- **Introduction and Background**

- **Recent Mission Use of 26 GHz Ka-Band**

- **SCaN Testbed**
  - Ka-Band Components
  - SCaN Testbed Radios and Capabilities
  - Ka-Band Tracking Considerations

- **Experiments on SCaN Testbed**
  - Ka-Band Launch Waveform Performance
  - Antenna Pointing Quality Metric
  - High-Rate, Bandwidth-Efficient Waveform

- **Toward the Future: Ka-Band User Spacecraft**

Introduction and Background

- **NASA is considering use of Ka-band for Low Earth Orbit (LEO)**
  - Large data volumes drive the need for higher data rates
  - Short pass times drive the need for more bandwidth and higher-order modulation schemes

- **Int'l Telecommunications Union (ITU) allocations favor Ka-band**
  - S-band space science: ~10 MHz
  - X-band earth science: ~375 MHz
  - Ka-band space-to-space: ~2250 MHz

- **NASA developed the Space Communications and Navigation (SCaN) Testbed to research software-defined radio techniques for Ka-band transition in LEO**
  - First NASA space-qualified Ka-band transceiver (Harris Corp.)
  - Research capabilities for modulation, pointing/tracking, etc.

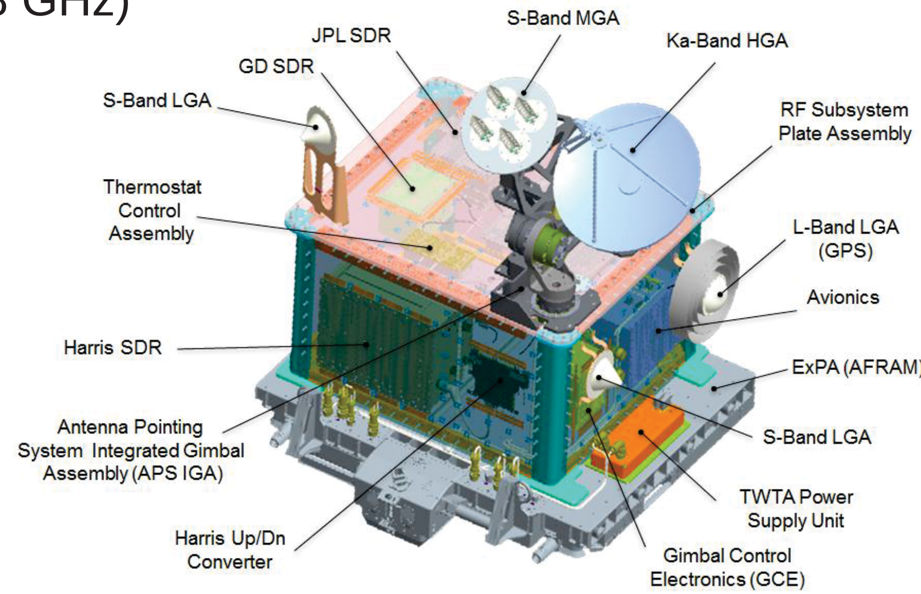
Recent Mission Use of 26 GHz Ka-Band

- **NASA**
  - SCaN Testbed
  - Solar Dynamics Observatory
  - Lunar Reconnaissance Orbiter
- **JAXA**
  - Advanced Earth Observing Satellite
  - Advanced Land Observation Satellite
  - Japanese Experiment Module (Int'l Space Station – ISS)
- **ESA**
  - Envisat (concluded in 2012)

- **Transition to Ka-band has been slow for a number of reasons…**
  - Reusing hardware and systems from previous missions (reduce risk)
  - Increased complexity of narrow-beam antenna pointing

SCaN Testbed (STB) Ka-Band

- **RF Components**
  - Traveling Wave Tube Amplifier (TWTA)
    - L3 Corporation, 40 Watts (25.5 to 25.8 GHz)
  - High Gain Antenna (HGA)
    - 0.5 meter parabolic reflector
    - 39 dB peak gain at 22 GHz receive
    - 39.8 dB peak gain at 25 GHz transmit
  - Integrated Gimbal Assembly (IGA)
    - Waveguide rotary joints
    - 2-axis gimbaled pedestal

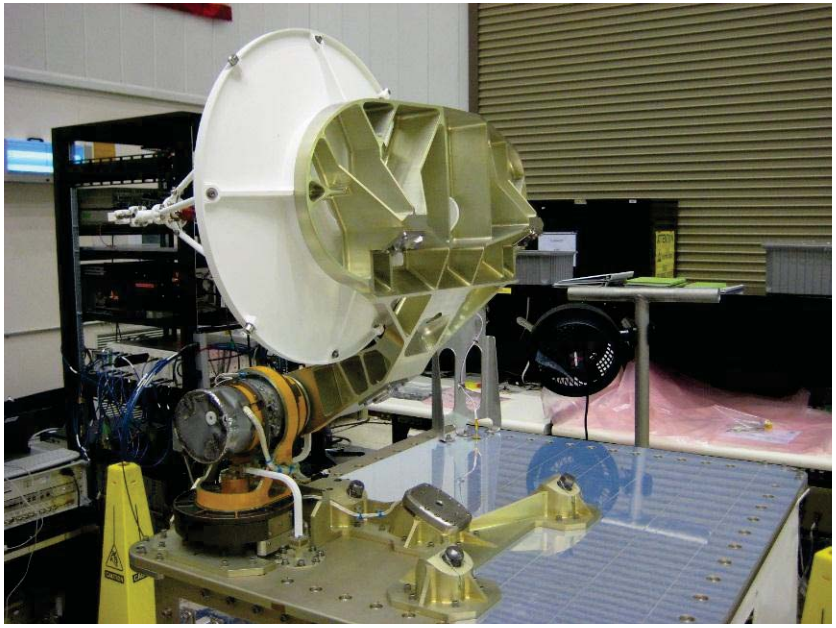


- **Harris Corporation Software-Defined Radio (SDR)**
  - AITech s950 single board computer
  - 4 Xilinx Virtex-IV field programmable gate arrays (FPGAs)
  - Compact Peripheral Component Interconnect (cPCI) chassis
  - Output: ~1 mW at Ka-band with an S-band intermediate frequency

STB Capabilities

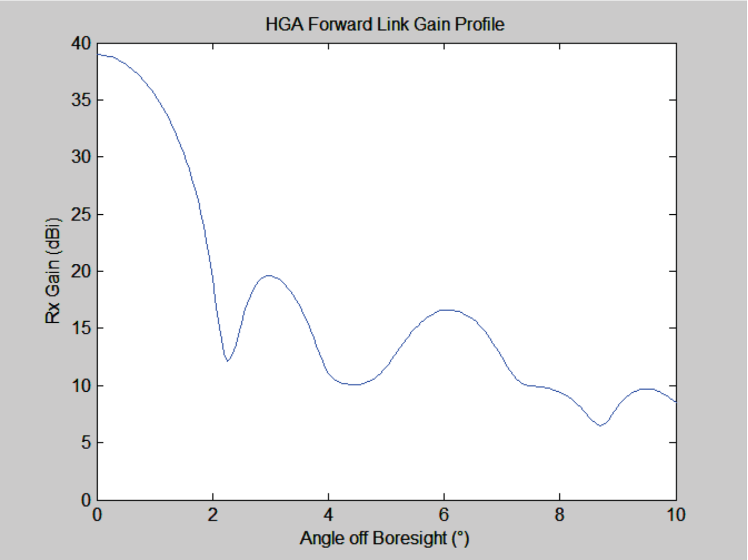
- **SCaN Testbed – studying advanced communications, navigation, and networking applications of SDR for space**
  - Jet Propulsion Laboratory SDR: S-band transceiver, L-band receiver
  - General Dynamics SDR: S-band transceiver

- **NTIA Frequency Allocation and Data Capability**
  - Ka-band: 225 MHz; launch data rates from 1 to 100 Mbps
  - S-band: 6 MHz; launch data rates from 24 kbps to 1 Mbps



STB Ka-Band Tracking

- **SCaN Testbed antenna pointing system**
  - Reprogrammable algorithm
  - Open loop or closed loop
    - Acquisition spiral & autotrack modes
    - Programmable threshold based recv'd power



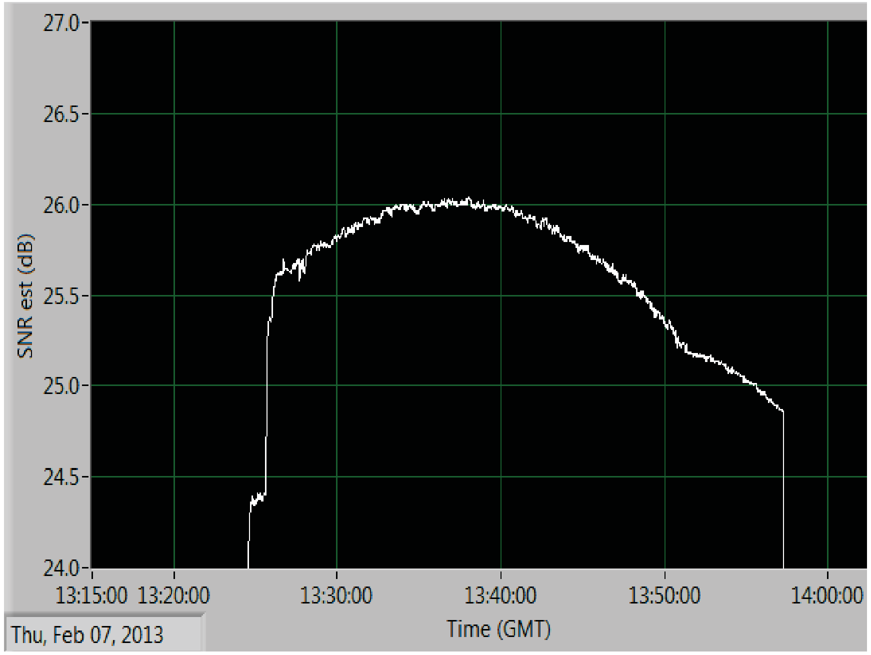
- **Small beamwidth → sensitive pointing**
  - STB 3 dB beamwidth is approximately 1 degree
  - ISS two line element (TLE) staleness tends to create azimuth errors
    - Azimuth error == altitude; elevation error == ascending node
  - ISS truss flexure can induce 1 to 2 degrees of pointing error
    - See Dean Schrage "ISS Truss Flexure Measurement Applying Ka-Band Closed-Loop Tracking", 3rd Annual ISS Research and Development Conference

- **Closed loop is preferred**
  - Many pointing error sources: TLE staleness, truss flexure, attitude uncertainty
  - Open loop is sufficient for high link margin and recent TLEs.

STB Launch Waveform Performance

- **Space-to-space Ka-band links have been evaluated**
  - Full duplex links with NASA's Tracking and Data Relay Satellite System
  - Waveform installed on Harris SDR at payload launch
  - Stable signal with ~2.4 dB margin at 100 Mbps user data rate

- **Successful link demonstrations**
  - No observed bit errors after 40+ minutes at 100 Mbps return link

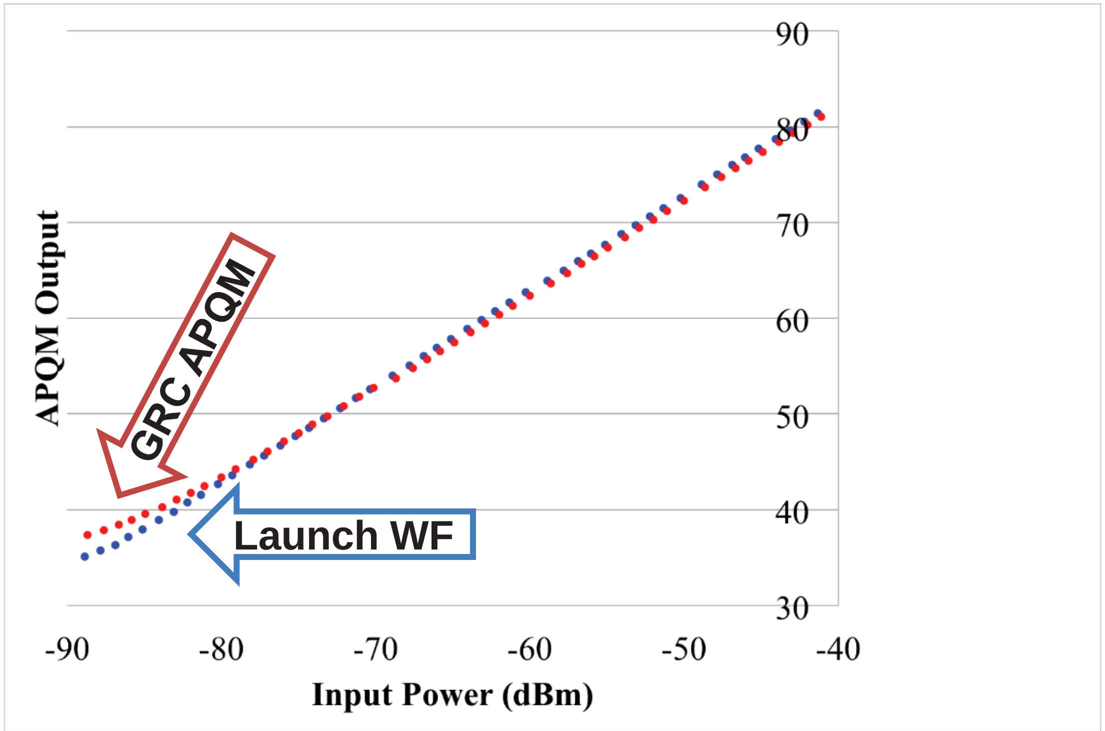


Parameter	Forward Link (SDR Receive)	Return Link (SDR Transmit)
Frequency (GHz)	22.68	25.65
Data Rate (Mbps)	9.5	100
Modulation	BPSK	SQPSK
Convolutional Coding	½ rate	½ rate
Bandwidth (MHz)	38	200
EIRP (dBW)	63	49.2
G/T (dB/K)	2.69	26.51
Required BER	10^{-8}	10^{-8}
Range (km)	43550	
Link Margin	3.0 dB	2.4 dB

STB Antenna Pointing Quality Metric

- **Antenna pointing quality metric (APQM) is important for closed loop tracking.**
  - STB uses a linear signal strength indicator
  - Strong out-of-band signal rejection (noise/interference)

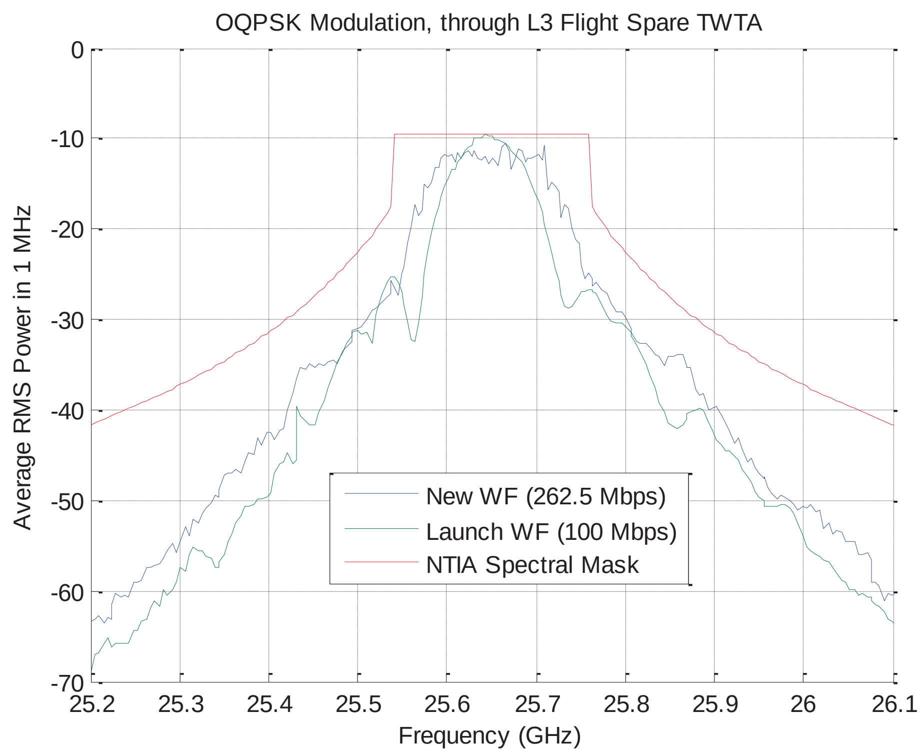
- **Developed an APQM algorithm at NASA GRC**
  - Allows tracking of any modulation type or noise signal



STB High-Rate Bandwidth-Efficient Waveform

- **Objective: Maximize data rate and improve spectral efficiency**
  - Demonstrated 300 Mbps data rate over 225 MHz bandwidth and SQPSK
  - Implements high-order modulation techniques and LDPC coding
    - Gaussian Minimum Shift Keying (GMSK)
    - Pulse-shape filtered M-order phase-shift keying (M-PSK)
    - M-order quadrature amplitude modulation (M-QAM)
  - Implements digital pre-distortion techniques to account for channel issues

- **NASA's Space Network Ground Segment Sustainment Project**
  - TDRSS will support 8-PSK modulation and LDPC decoding
  - Other modulation and coding support can be provided through user modems on-site



Future Ka-Band User Spacecraft

- **Interagency Operations Advisory Group (IOAG) study examined direct-to-ground feasibility of 26-GHz Ka-band from LEO.**
  - Adaptive coding and modulation schemes
  - On-board steerable antennas and pointing algorithms
  - High-rate data interfaces and on-board storage

- **SCaN Testbed can simulate the direct-to-ground environment through antenna mis-pointing.**

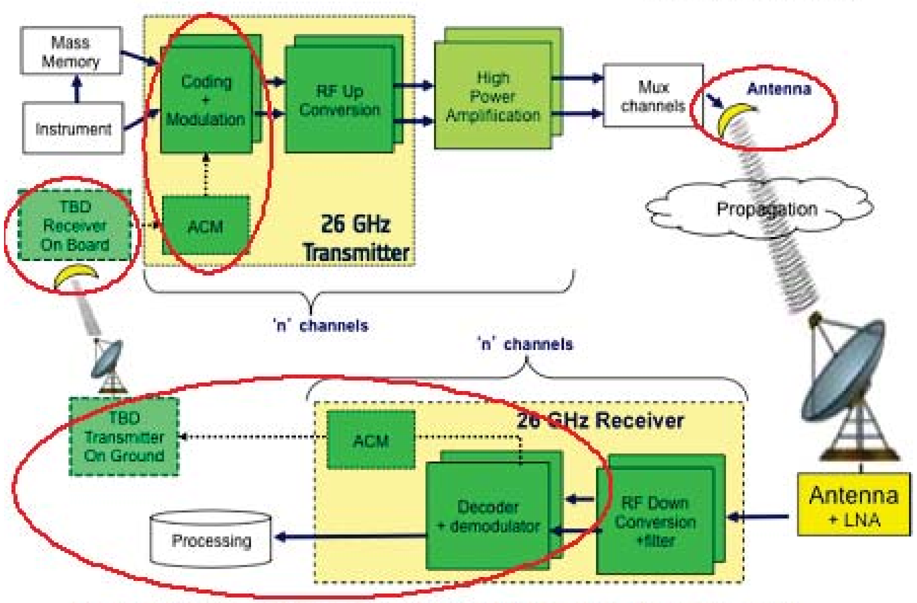
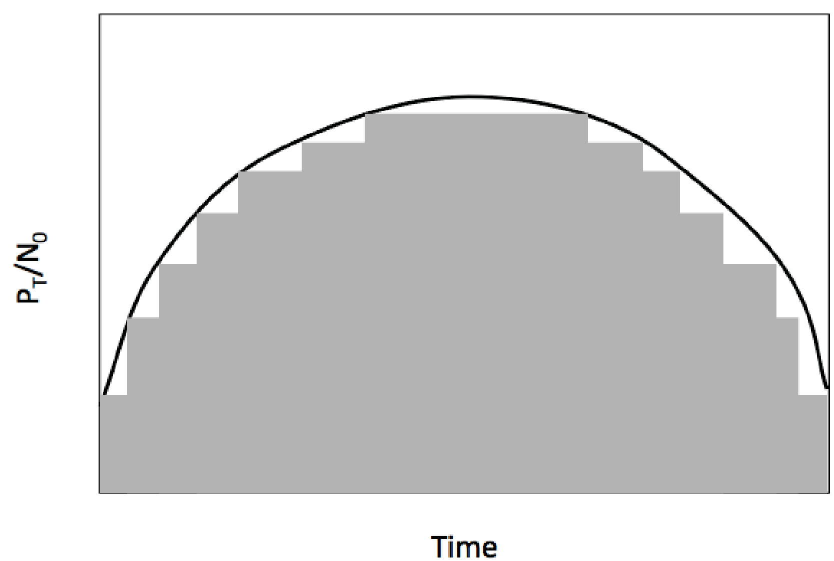


Figure 2-2: Generic functions of the 26 GHz communication system.



Final Remarks

- **Although mission adoption has been slow, full duplex Ka-band is viable for low earth orbit applications.**

- **SCaN Testbed has the capability and location to support ongoing Ka research for LEO.**
  - Antenna pointing and tracking
  - Received power estimation algorithms
  - Modulation and coding

- **More time must be dedicated to study the Ka user spacecraft.**
  - Omni-directional antennas for mission recovery
  - Pointing requirements