Ka-band Technologies for Small Spacecraft Communications via Relays and Direct Data Downlink

National Aeronautics and Space Administration

CubeSat Workshop – 30th Annual AIAA/USU Conference on Small Satellites

NASA Glenn Research Center, Cleveland Ohio/James M. Budinger

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SPACE COMMUNICATIONS SCaN AND NAVIGATION

Outline

- Objectives
- Ka-band background
- Software defined radios
- Ka-band antennas
- Potential data return in Ka-band
- Summary

Ka-band Communications

OBJECTIVES

Objectives

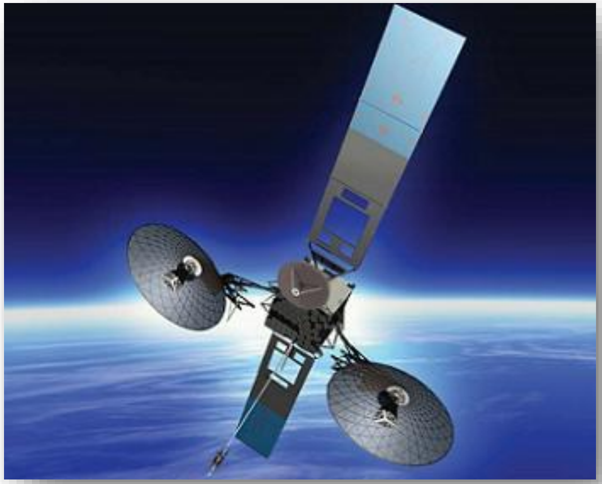
- Develop affordable technologies to ease transition into Ka-band for significantly higher data rates with minimal impact on near Earth missions
  - Ka-band/multi-band ***software defined radios (SDRs)*** and standards for a range of space missions
  - ***Portable waveforms*** for SDRs to reduce cost of development and increase flexibility
  - ***Electronically steered high gain antennas*** to increase data return and eliminate mechanisms and vibration
  - Leverage ***large and small business and university*** capabilities to address unique needs of small spacecraft

NASA Ka-band Communications Infrastructure

KA-BAND BACKGROUND

TDRS Ka-band Single Access Service

- NASA's Tracking and Data Relay Satellite (TDRS)
  - Three generations of spacecraft provide high bandwidth, low latency communications to multiple simultaneous mission spacecraft
  - S-band, Ku-band, and ***Ka-band Single Access (KaSA)*** and S-band Multiple Access services
- KaSA Service via large steerable antennas in auto-track mode
  - ***Return*** (from spacecraft) of mission data and spacecraft telemetry; ***G/T: 26.5 dB/K***; 25.25-27.5 GHz
  - Forward (toward) command and control EIRP: 63.0 dBW; 22.55-23.55 GHz
  - Field of View ± 76.8º E-W; ± 30.5º N-S



Third Generation TDRS K, L, M

NASA Near Earth Network (NEN) Ka-band Tracking Terminal Examples

WS-1 at White Sands New Mexico

- WS-1
  - White Sand Complex
  - 18 m
  - S-, X- and Ka-bands
  - Ka-band ***G/T of 46 dB/k***

AS-3 and AS-1 at Fairbanks Alaska

- AS-3
  - Alaska Satellite Facility
  - 11 m
  - S- and X-bands operational
  - Provisions for Ka-band capability in ~2020
  - Expected Ka-band ***G/T of 40 dB/k***

Commercial Ka-band Tracking Terminal Example

Type 2 Ground Mount on Roof

- Comtech TCS 2.4m X/Y Tracking Terminal
  - Eliminates “keyhole” when spacecraft is overhead
- Ka-band operation
  - 25.5 to 27.0 GHz
  - G/T of ***27 dB/K***

Source: http://www.telecomsys.com/Libraries/Collateral_Documents/XY_Overview_Brochure.sflb.ashx

NASA Near-Earth Mission Frequency Spectrum and Typical Channel Bandwidths

Mission Links	Via TDRS Relays (GHz)			
Space-Space	Forward	Bandwidth	Return	Bandwidth
• S-band	2.025-2.110	0.028	2.200-2.290	0.018
• Ku-band	13.775±.070	0.065	15.0034±.1125	0.250
• Ka-band	22.55-23.55	0.065	25.25-27.50	0.250, >0.650

Mission Links	Via NEN Direct to Ground Links (GHz)			
Space-Earth	Uplink/ Command	Bandwidth	Downlink/ Telemetry	Bandwidth
• S-band	2.025-2.110	0.085	2.200-2.290	0.090
• X-band Earth Science	N/A	N/A	8.025-8.400	0.375
• X-band Space Science	7.190-7.235	0.045	8.450-8.500	0.050
• Ka-band	N/A	N/A	25.50-27.0	0.500 to 1.500

Overlap

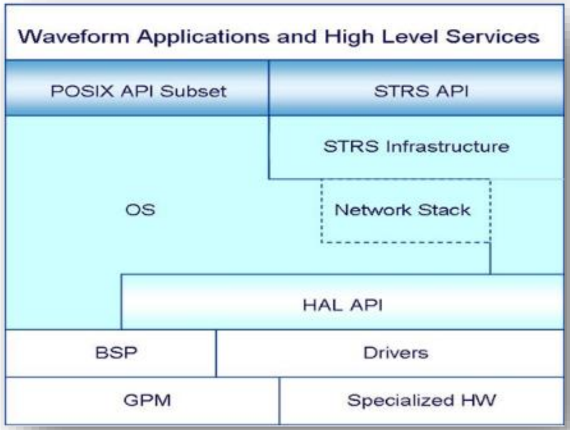
Up to 4x

STRS and Ka-band SDRs

SOFTWARE DEFINED RADIOS

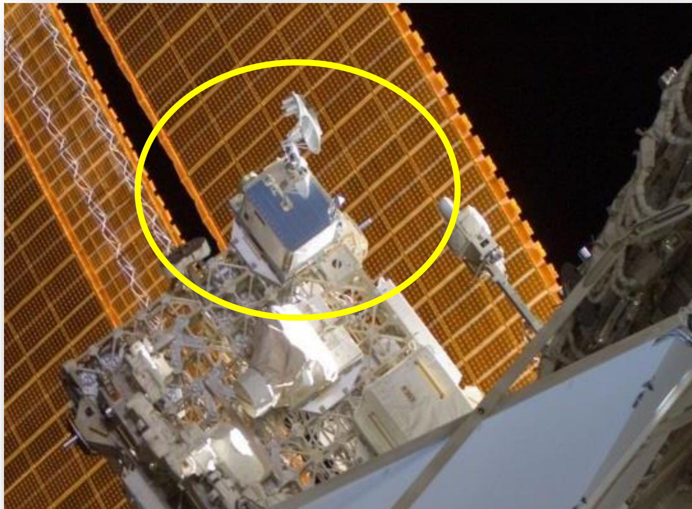
NASA Standard for Software Defined Radios (SDR) for Space Applications

- **Space Telecommunications Radio System (STRS)** Architecture and Standard (NASA-STD-4009)
  - Enables independence of applications from software defined radio platform/hardware
  - Reduces effort to develop, port and share applications waveforms and documentation via repository
  - Applicable to all categories of spacecraft from large platforms to SmallSats and CubeSats
  - Multiple vendors have STRS compliant SDRs or platforms in their product line
  - Others under development via partners and NASA SBIR/STTR Program
  - See https://strs.grc.nasa.gov/



STRS Layers Model

SCaN Testbed on ISSs is Flying Multiple STRS-Compliant SDRs from 3 Vendors



Harris

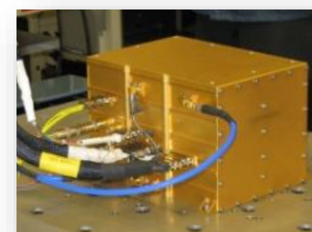
- **Ka-band SDR;** 225 MHz
- >500 Mbps Class
- Virtex IV, PowerPC Proc, DSP (1 GFLOP), VxWorks
- STRS adopted for use in Harris AppSTAR™ software-defined payload architecture

JPL/L-3 CE

- S-band SDR; 6 MHz channel
- 10 Mbps Class
- L-band receive (GPS)
- Virtex II, Sparc Processor, RTEMs

General Dynamics

- S-band SDR; 6 MHz channel
- 10 Mbps Class
- Virtex II, ColdFire Processor (60 MIPS), VxWorks, CRAM (Chalcogenide RAM) Memory



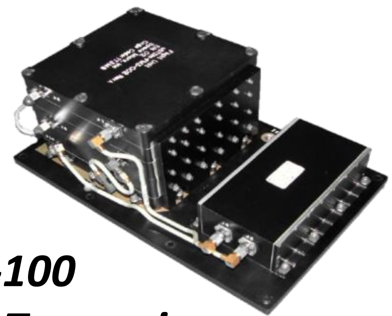
✓ ***SDRs offer economies-of-scale via common hardware, tailored to mission needs via STRS-compliant software***

SBIR/STTR Contracts for STRS-Compliant SDR Technologies

- SBIR-14 Commercialization Readiness Program
  - Software Defined Near Earth Space Transceiver (SD-NEST) [Space Micro]
- STTR-15 Phase I
  - Wideband Autonomous Cognitive Radios for Networked Satellite Systems [Bluecom Systems/U. of New Mexico]
- SBIR-16 Phase I Selections
  - OpenSWIFT-SDR for STRS [Tethers Unlimited]
  - Plug-In Architecture for Software-Defined Radios [Blue Sun]
- [Earlier SBIR SDR Contracts non-STRS Compliant]
  - https://www.nasa.gov/sites/default/files/files/SBIR_SDR.pdf

✓ Watch for the 2017 SBIR/STTR call for proposals in November 2016

Software-Defined Near Earth Space Transceiver (SD-NEST)



µSTDN-100
S-band Transceiver

- ***NASA IRIS, LADEE Missions***

STRS Waveforms
(From Legacy Repository)

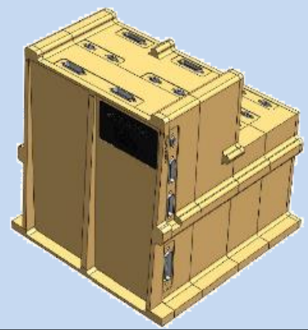
µXTx-100 / 200 X-Band Transmitter

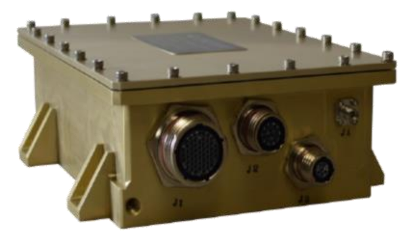
- ***NASA IRIS Mission***

Proton 400k Rad-Hard Processor

- ***NASA MISSE-X Mission***

SD-NEST
STRS-Compliant
Multi-Band Transceiver





µKaTx-300 Ka-band Transmitter

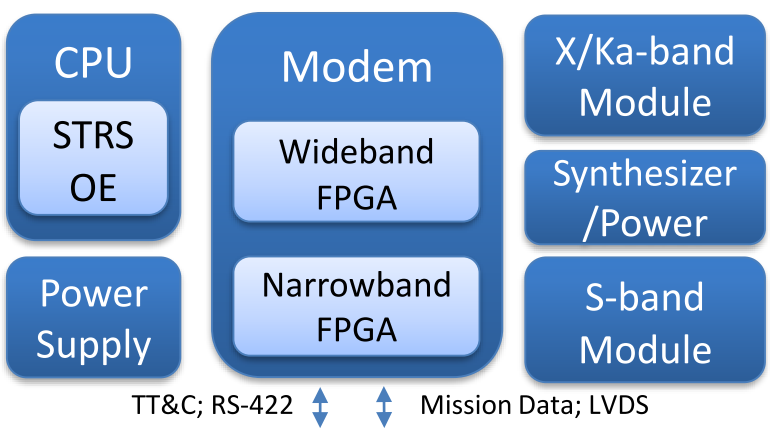
- ***NASA TESS Mission***

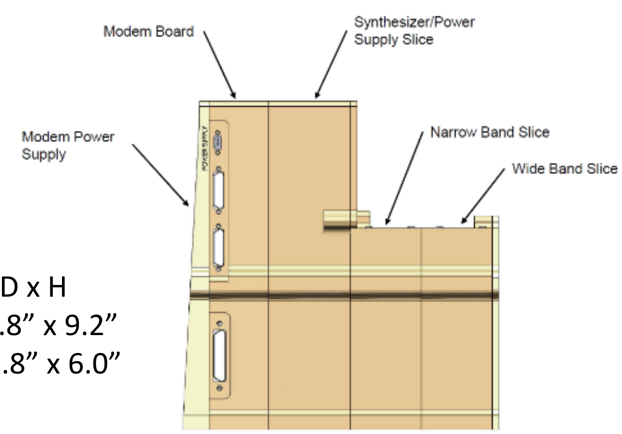
SPACE MICRO

X/Ka Wideband Receivers
(New Development)

Software-Defined Near Earth Space Transceiver (SD-NEST)

- **Frequency agile, multi-band transceiver**
  - Narrowband TT&C over any frequency S-, X- or Ka-bands
  - Wideband data return and forward over X-band (375 MHz) or Ka-band (>650 MHz)
- **Flexible waveform processing**
  - Low-power mode for TT&C alone
  - High-performance mode for high-rate mission data return (>1.2 Gbps)
- **STRS Operating Environment**
  - General-purpose processor available (e.g. P400K) for high-level control algorithms





L x D x H
4.9” x 8.8” x 9.2”
4.0” x 8.8” x 6.0”

✓ Engineering Model Completion in FY17

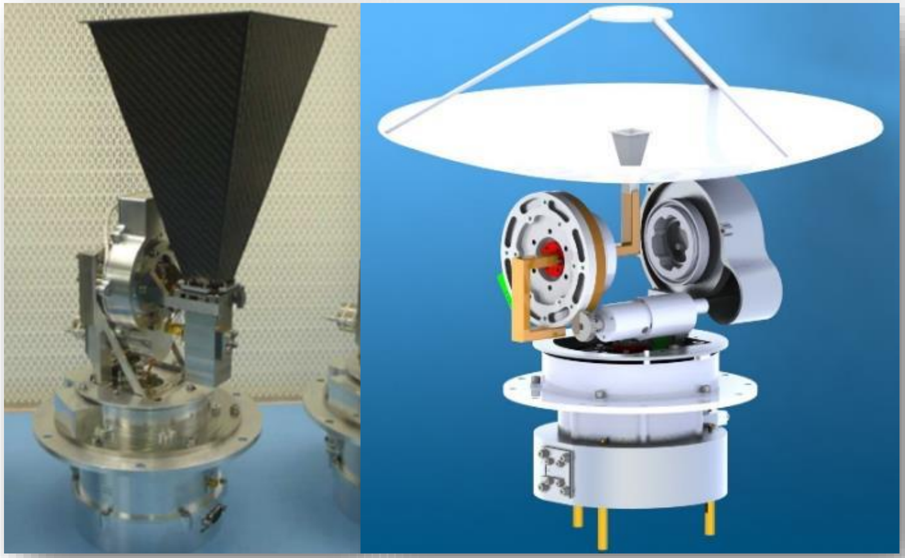
✓ ***Seeking partners for contract option (with cost sharing) for proto-flight model***

Alternatives to Mechanically Deployed or Steered Antennas

KA-BAND ANTENNAS

Mechanically Steered High Gain Antenna Examples

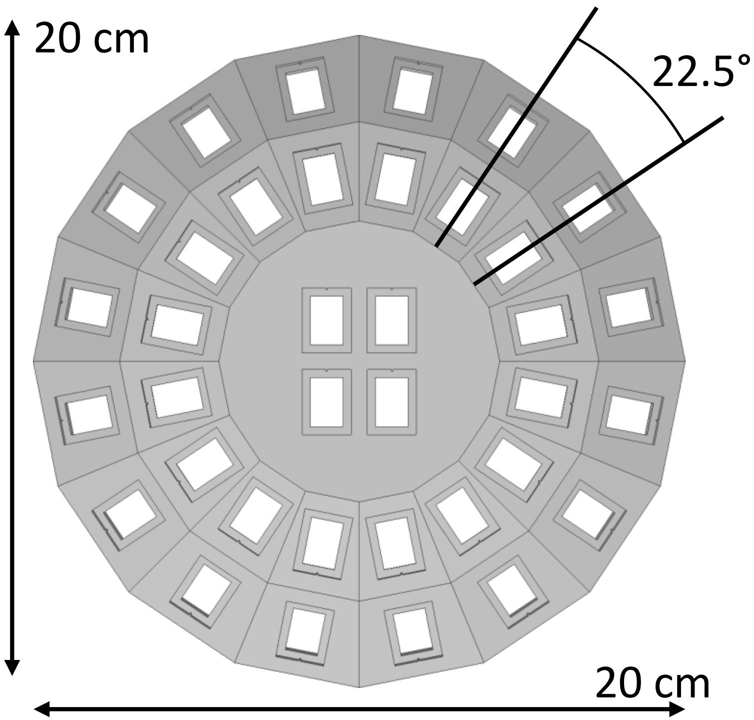
SCaN Testbed Ka-band and S-band Antenna Positioning System (APS)

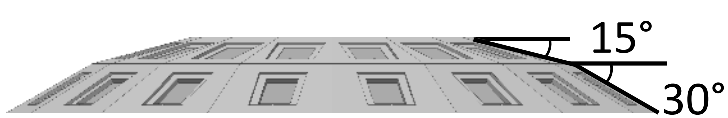


Surrey Satellite X-band (COTS) and Ka-band (Under development) Antenna Pointing Mechanisms (APM)

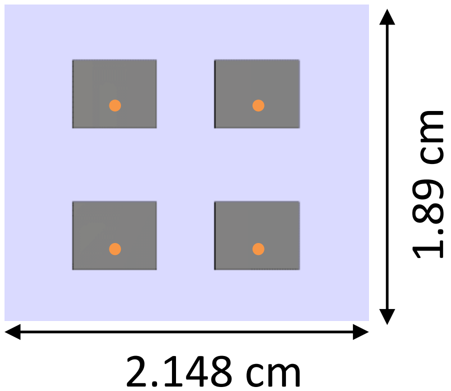
	SCaN Testbed APS on ISS		SSTL X-APM	SSTL Ka-APM
Frequency	25.5 – 27.0 GHz	2.025-2.11 GHz	8.0 – 8.5 GHz	25.5 – 27.0 GHz
Gain	39.8 dBi	13 dBi	18 dBi	30 dBi
Antenna diameter	~46 cm	~25 cm		~30 cm
Overall Dimensions	57 cm x 30 cm x 71 cm		Ø 27.4 x 30 cm	TBD

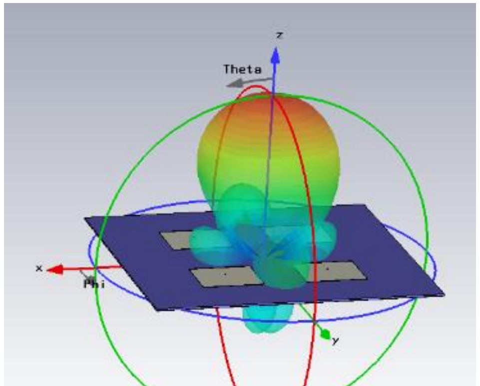
GRC 3-D Printed Ka-band Faceted Dome Array – Concept and Prototype





- 36 Elements (16 at 30°, 16 at 15°, 4 at 0°)
- ~90 degree field of regard (~30° beamwidth)
- Probe Fed Elements 14.4 dBi, 256 MHz BW





SBIR/STTR SmallSat Antenna Technologies Examples

- STTR-14 Phase II
  - Fully Printed Flexible 4x4 Element Graphene–Based Phased Array Antenna; [Omega Optics/U. Texas Austin]

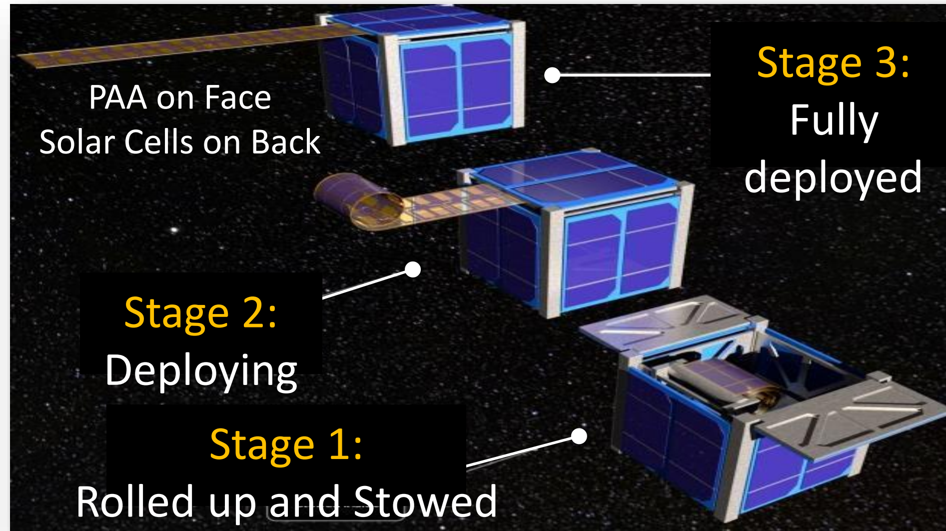
- STTR-16 Phase I Selection
  - Deployable Ka-band Reflect Array Antenna; [Tyvak Nano-Satellite Systems/UCLA]

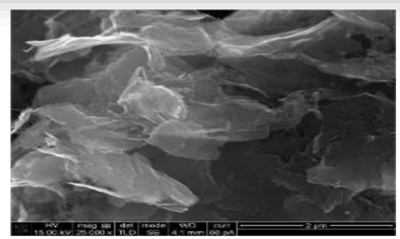
- SBIR-16 Phase I Selection
  - Space Environment Design and Testing; [Kymeta Government Solutions, Seattle, WA]

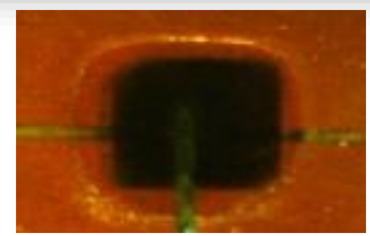
✓ Watch for the 2017 SBIR/STTR call for proposals in November 2016

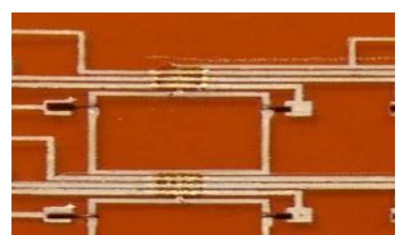
Graphene Based, Flexible, Fully-Printed 2D-Scanning Phased Array – Omega Optics and Texas State University

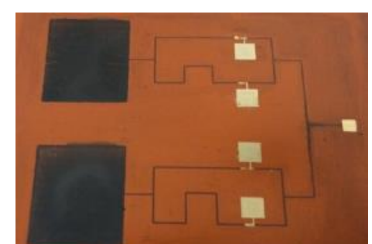
- **Goal**
  - Develop a flexible ink-jet printed Graphene-based 4-bit 4x4 phased array antenna (PAA) at S-band
- **Development Approach**
  - Grow Graphene nano-flakes via CVD and incorporate into Graphene ink
  - Print multi-layer integrated circuits and interconnections on flexible substrates
  - Print Rx/Rx modules from Graphene transistors, phase shifters and amplifiers
  - Test a prototype printed PAA
- **Applications**
  - CubeSat and SmallSat antennas
  - Large deployable phased array antennas
  - Reconfigurable, deployable, conformal, and/or wearable active antennas




Graphene flakes


Inkjet printed transistor


Multilayer interconnect


Printed Graphene PAA

Kymeta Government Solutions, Inc. (KGS) Meta-material Phased Array

CubeSat Antenna

- Frequency: Optimized for 27.0 GHz
- Gain: ~24 dBiC over scan volume
- Electronically steerable; ± 45° range
- Power: <5W

Maturity

- Designed, built, tested, delivered
- Next steps: Modifications for space (SBIR Phase I), flight qualification testing and demonstration mission

SmallSat Antenna

- Simultaneous transmit and receive out of same aperture for X, Ku, and Ka bands
- Capability at Q, V and W bands
- Technology creates potential for economical 6U, 12U, and larger form factors

Maturity

- Initial design target sets identified
- Early modeling and simulation complete
- Seeking a development partner to fund detailed design, build, and test

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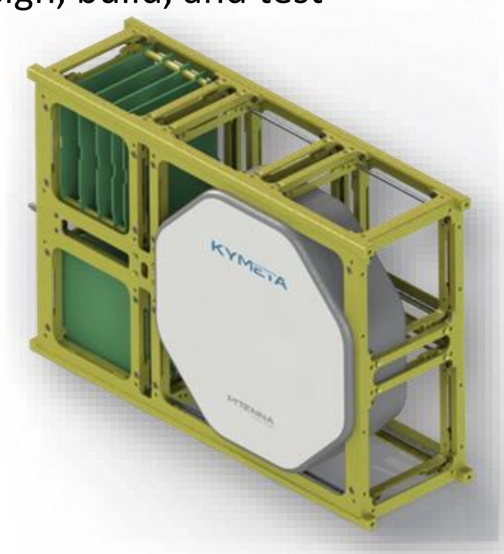
GOVERNMENT SOLUTIONS

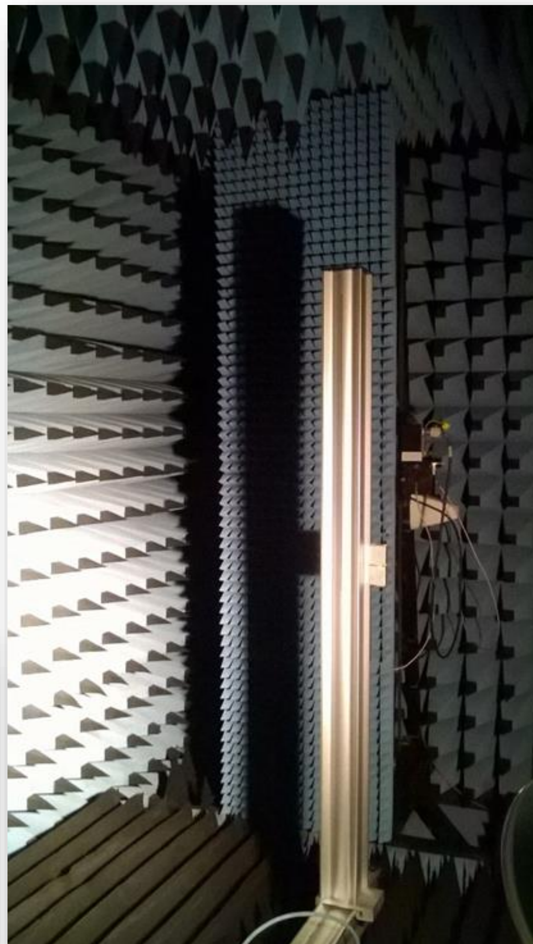


Current NASA Activities with Kymeta Meta-material Phased Array

KGS SBIR Phase I (GSFC)

- Seeks to space qualify CubeSat antenna
  - Define requirements
  - Hardware redesign
  - Antenna redesign
  - Thermal characterization

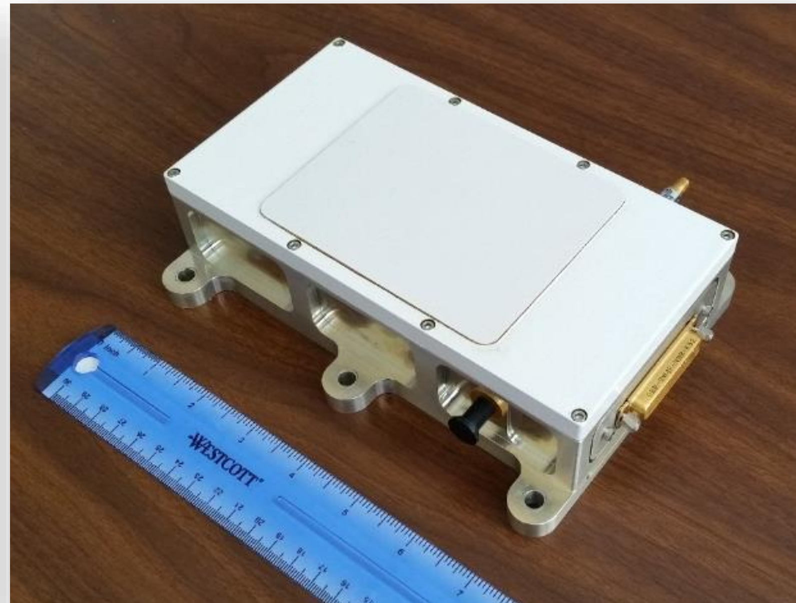
- All of which seek to make the SmallSat antenna space flight-qualifiable



Cubesat Antenna Measurements (GRC)

- Seeks to characterize the metamaterial-based technology beyond its design parameters gain insight into what it can do
  - Leverage antenna measurement systems and talent at GRC to obtain high quality pattern, polarization, power, and steering measurements.
  - Compare against other Ka-band antenna technologies for potential for use on CubeSat and SmallSat missions.

Boeing 256-Element Ka-Band Transmit Phased Array Antenna for GRC and ONR

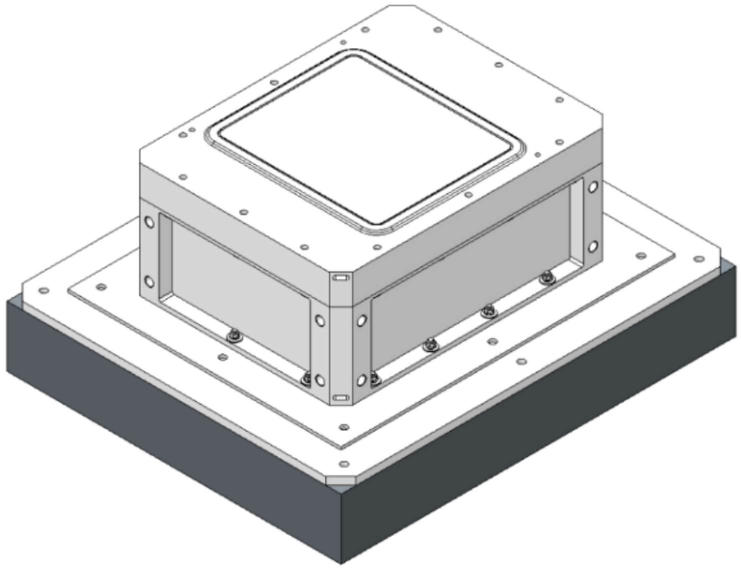


Array Number of Elements: 256 Elements
Band: 25.5-27.5 GHz; > 1 GHz Bandwidth
Beam width: Nominal 5 degrees at -3dB
Gain (CP): 28 dBi
EIRP: Peak 36.5 dBW; 33 dBW@ 60 Degrees
Array Total DC Power: 90 Watts (per beam)
Dimensions: 19 cm x 10.2 cm x 6.5 cm
Mass: 1.8 kg

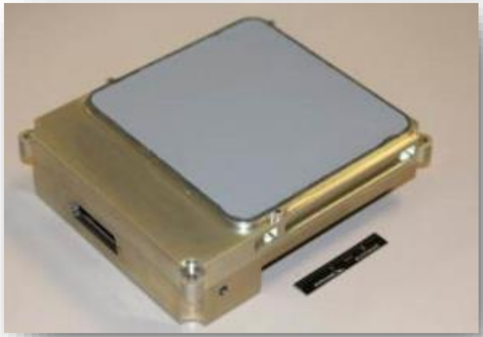
Limitations:
- Lab model over 10 year old design; many components obsolete
- Rad-hard Triquint GaAs MMIC design kit and foundry process retired
- “Brick” design is more expensive to manufacture than “tile” approach

Scalable Ka-band Active Phased Array Antenna (PAA) Design

- Space qualifiable tile PAA design
  - Based on Boeing Wideband Communication and RF Systems Group airborne product line
  - Tile packaging significantly reduces costs and offers higher efficiency than brick design
  - SiGe 0.15 um process; rad-hard by design MMICs to 300 krad (Si)
- Ka-band: 25.25 to 27.5 GHz
  - Right-or left-hand circular polarized
- Wide field of regard: $\pm$ 70°
  - LEO mission to GEO relay or direct to ground
- Easily scalable implementation
  - ***Select 64, 128 or 256 elements for EIRP of 24-, 30- or 36-dBW respectively***
  - Range of user needs, budgets, SWaP constraints
- Potential for data rates up to 3.2 Gbps
  - Performance with DVB-S2 MODCOD to be validated



SmallSat Design Shown with Optional Enclosure for Beam Controller, Power Supply and Thermal Control

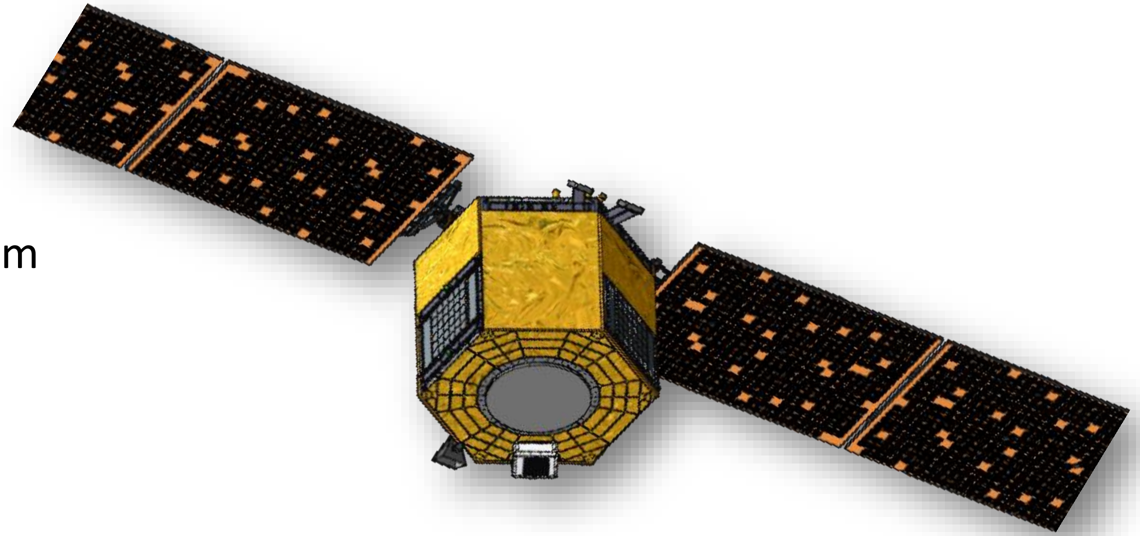


Prototype Tile PAA in Airborne Packaging

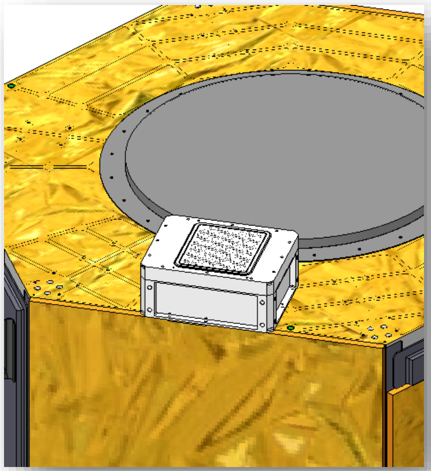
BOEING

Boeing Ka-band Tile Array for SmallSats

- 25.5-27.0 GHz
- $\pm$ 70 degree FOR
- 24-, 30- or 36 dBW
- 22.9 cm x 17.8 cm x 9.6 cm
- 1.8 kg
- <150 W depending on # elements and drive level
- Rad-hard by design
- 8 year design life



Ka-band PAA Shown on Boeing 502M SmallSat Bus



- ✓ 10s to 100s Mbps data rates in affordable, modular PAA packages optimized for SmallSat missions
- ✓ Available with integrated beam controller, power supply and thermal management

BOEING

Comparisons Via GEO Relay and Direct to Ground (DTG)

POTENTIAL DATA RETURN IN KA-BAND

Potential Minimum Data Rates/Return Using Future Tile Phased Array Antenna

Data Return via	Bandwidth	Future Boeing Ka-band Tile Phased Array Antenna		
		64 Element	128 Element	256 Element
TDRS, 26.5 dB/K	225 MHz	900 kbps	3.5 Mbps	14 Mbps
WS-1 Terminal 18.3m, 46 dB/K	500 MHz	830 Mbps	1.1 Gbps	1.1 Gbps
	1.5 GHz	1.5 Gbps	2.9 Gbps	3.3 Gbps
AS-3 Terminal 11m, 40 dB/K	500 MHz	520 Mbps	990 Mbps	1.1 Mbps
	1.5 GHz	940 Mbps	1.9 Gbps	3.1 Gbps
Comtech TCS 2.4m, 27 dB/K	500 MHz	64 Mbps	230 Mbps	500 Mbps
	1.5 GHz	64 Mbps	250 Mbps	820 Mbps

- 1000 km, 98.5º mission, max ranges 38000 km, 2800 km, DVB-S2 MODCOD
- SmallSat DTG data rate ~70x higher than via TDRS; ***~38 Gb/ 10 minute pass***
- Large mission DTG data rate ~235x higher than via TDRS; ***~2Tb/10 minute pass***

Summary and Co-Authors and Contributors

CLOSING COMMENTS

Summary

- Affordable Ka-band communications technologies will enable a new generation of science and exploration missions through increased data return
  – Mission data return rates from 10s of Mbps to Gbps are feasible for range of small and large satellites

- NASA is working with industry and SBIR/STTR program to:
  – Develop STRS-compliant waveforms
  – Advance the technology readiness level of Ka-band SDRs
  – Develop and demonstrate Ka-band space-qualifiable electronically steered antennas

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For your kind attention

THANK YOU!