Advanced Propulsion, Power, & Comm.
for Space, Sea, & Air

Improving CubeSat Communications

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TUI & Comm? History and Motivation

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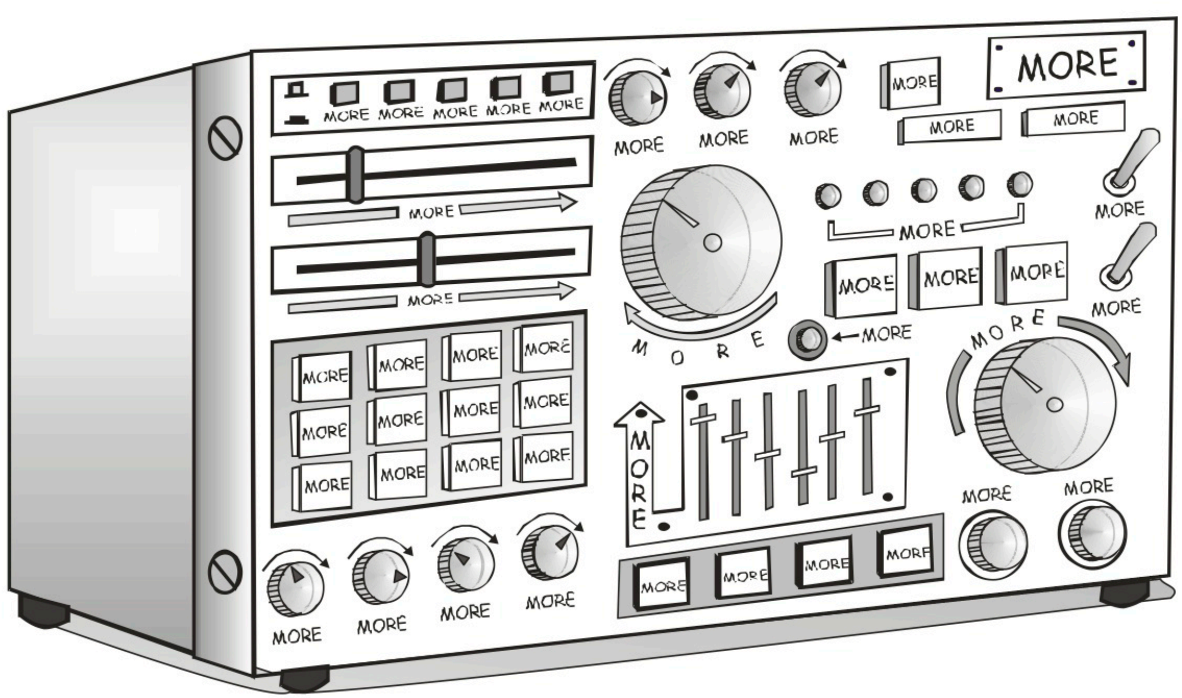
- **First TUI SDR was designed for relative navigation**
  - Tethered CubeSats
    - Relative position important for tether dynamics knowledge and active control
- **Also useful for**
  - Fractionated Spacecraft (e.g. DARPA F6 clusters)
    - Collision avoidance
    - Relative position knowledge for orbit maintenance
    - Aid in pointing higher gain apertures
  - Distributed Sensing systems
    - Relative position knowledge for orbit maintenance
    - Timing for synchronized sampling
    - Knowledge of sensor baselines and orientations
- **Antennas developed with radio for complete comm solution**

Desired CubeSat Comm System

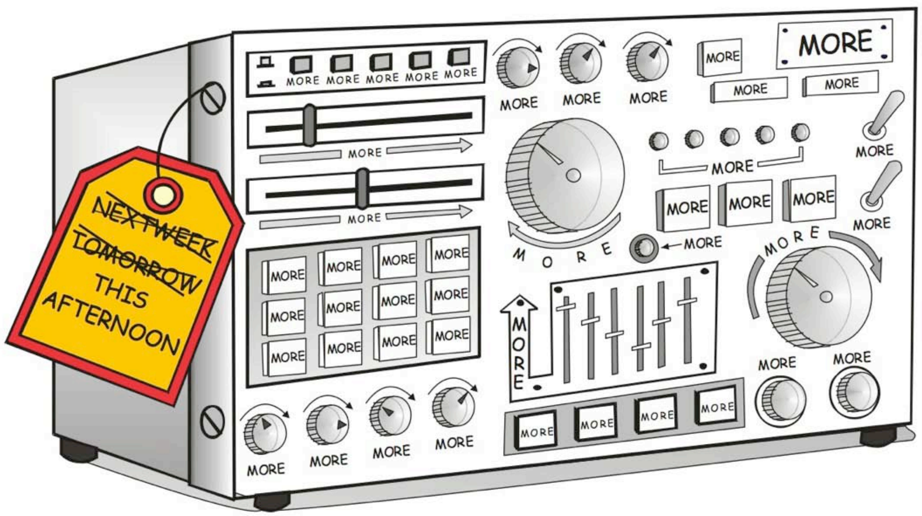
- **CubeSat Designers Dream**
  - Greater data throughput
    - Higher Data Rates
    - More Ground Stations
  - Lower Data Latency
  - Low/Acceptable SWaP-C
    - Spacecraft Radio
    - Spacecraft Antenna
    - Ground Station
    - Operations

BETTER!

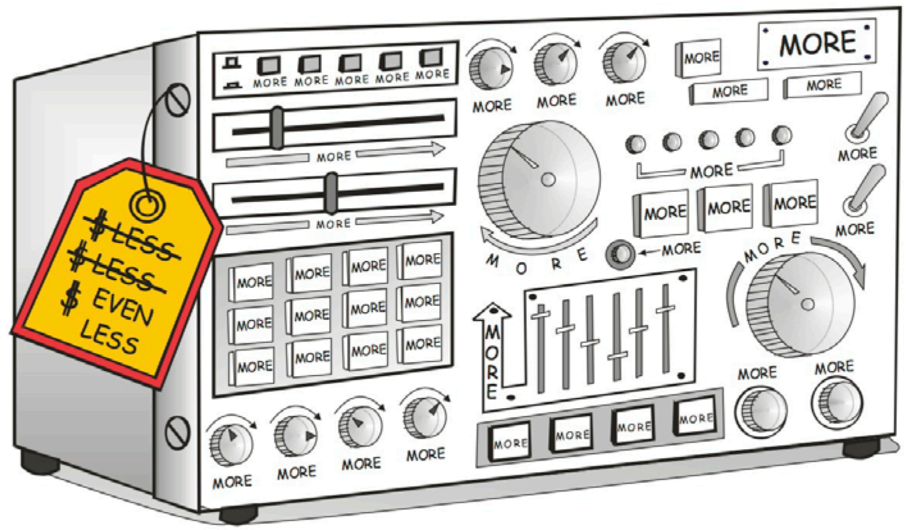


We also want…

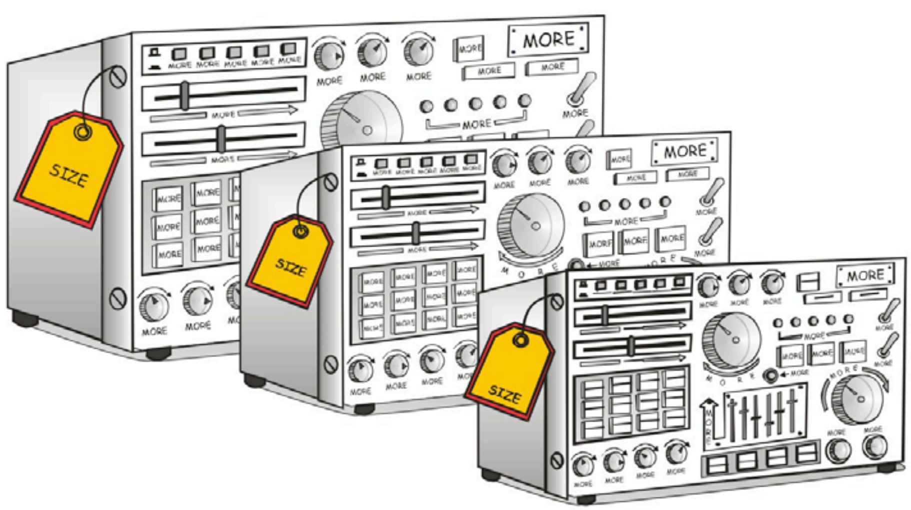
FASTER!



CHEAPER!



and…. SMALLER!



Some Factors Limiting Data Throughput

- **System Configuration 1: Omni <-> Omni**
  - TX: omni antenna (transmit power constant)
  - RX: omni antenna
  - RESULT: *Data rate decreases* with increasing frequency
- **Configuration 2: Omni <-> High-Gain**
  - TX: omni antenna
  - RX: high-gain (directional) antenna with fixed aperture size
  - RESULT: *Data rate independent* of frequency
- **Configuration 3: High-gain <-> High-gain**
  - TX: high-gain (directional) antenna with fixed aperture size
  - RX: high-gain (directional) antenna with fixed aperture size
  - RESULT: *Data rate increases* with increasing frequency
- **CONCLUSION: Higher gain antennas, with higher operating frequencies, produce *higher data rates***

80W PEAK POWER (@1AU)

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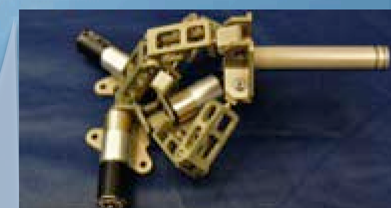
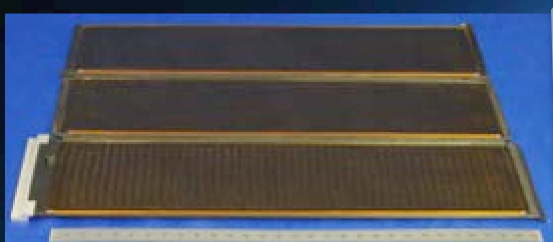
SunMill™ Deployable, Steerable Solar Array For 3U Cubesat Structures

High power, highly capable missions: Enabled

- 0.45U system volume (incl. controller)
- Spectrolab CIC laydown heritage
- Fully customizable panel length
- Available for order
- Full hemispherical pointing





0-g Panel Deployment Testing

0-g Gimbal Testing

Historical CubeSat Data Rates

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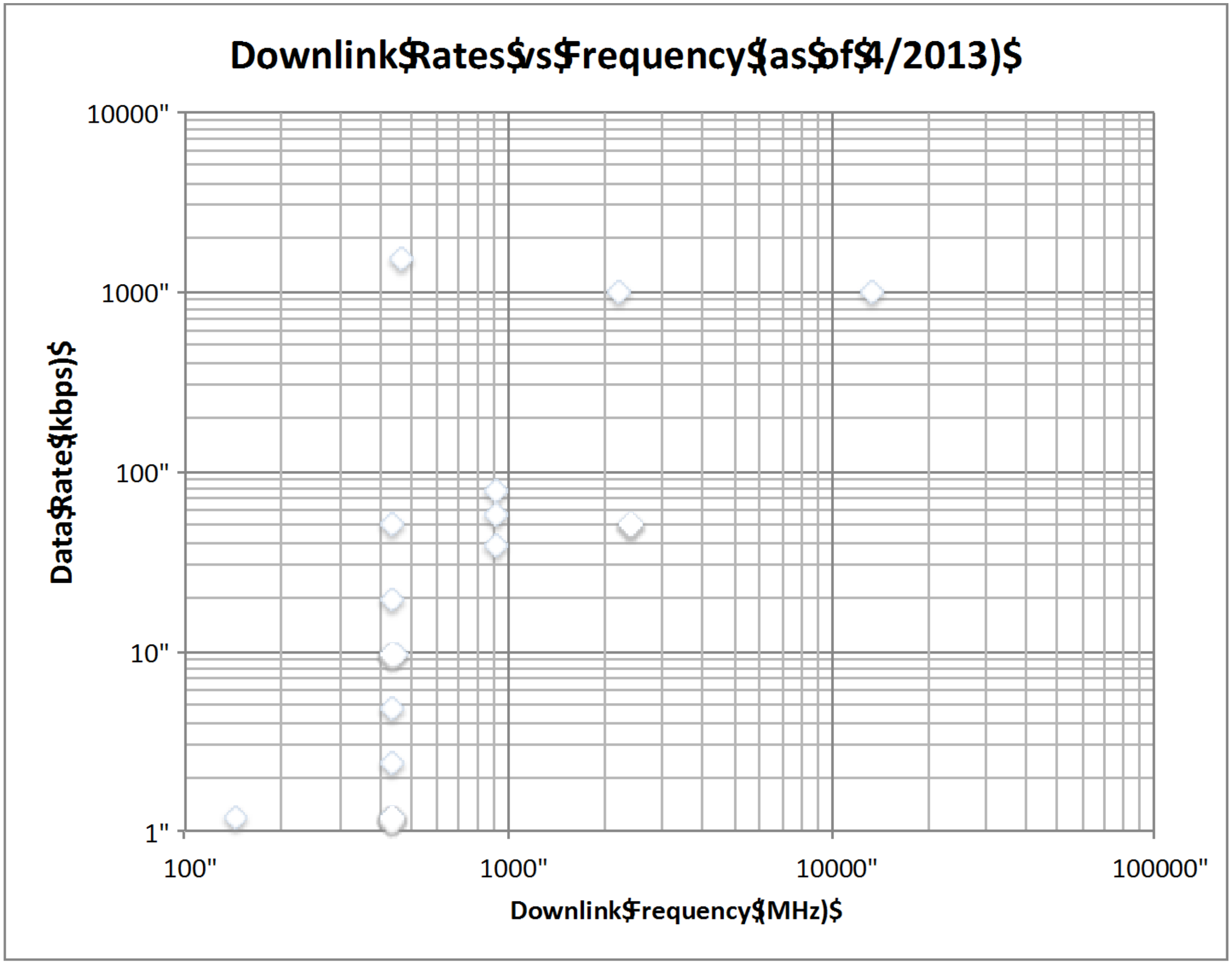
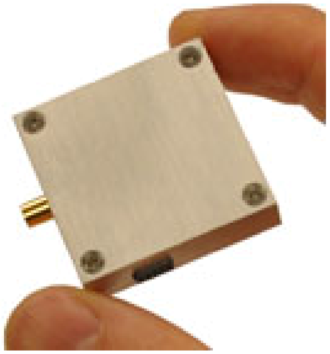
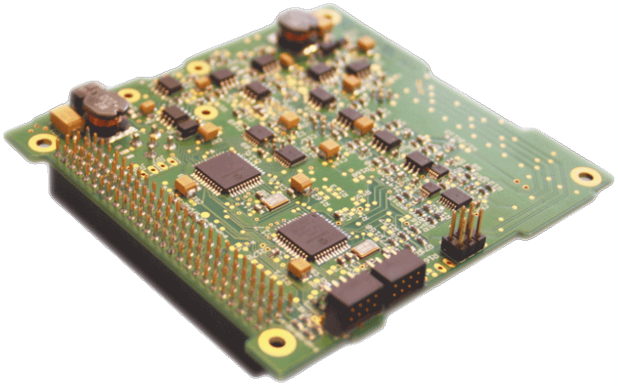
- **CubeSats launched to date shows trend of higher data rates at higher downlink frequencies**



Moving to higher frequencies

- **Most downlinks at ≈ 437 MHz**
- **Some (not all) radio options to move to higher frequencies**
  - S-band (e.g. 2.2-2.3GHz, 2.4-2.5 MHz)
    - Astrodev Beryllium: 10s to 1000s of kbps
    - Clyde Space STX: 2 Mbps
    - ISIS TXS: up to 100kbps
  - X-band (8.0 – 8.4 GHz)
    - Syrlinks EWC27: 2.8 to 100Mbps
    - CNES: up to 50Mbps
  - Ka-band
    - JPL ISARA: up to 100Mbps
    - Antarctic Broadband: 16Mbps transponder
    - TUI's SWIFT-HPX: 100Mbps (in development)

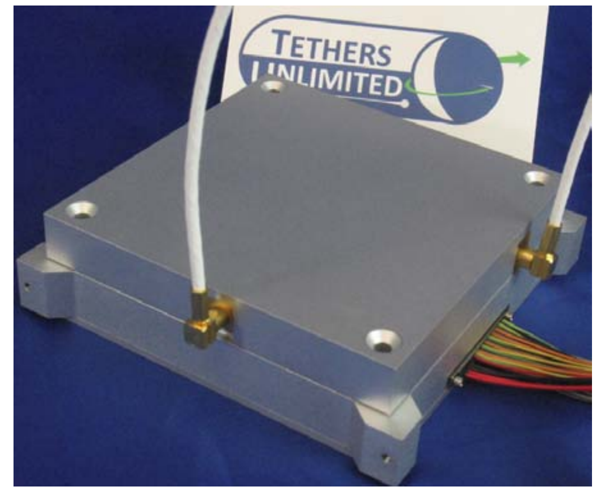


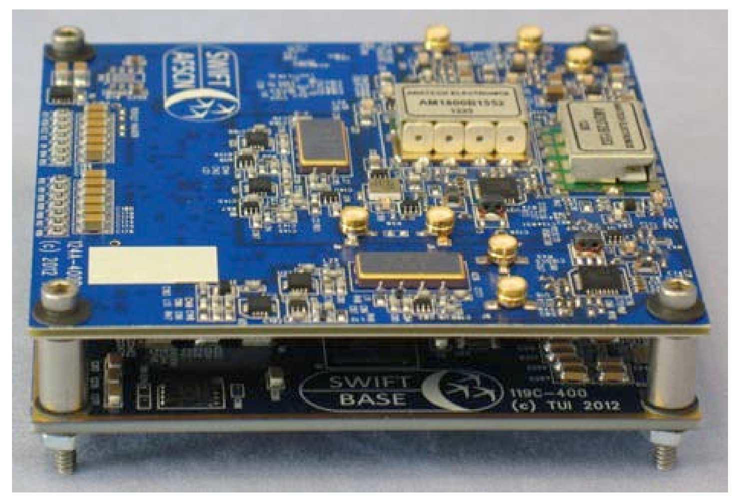


SWIFT-AFSCN(/NEN/USB) radio

- **Dual-band Receiver**
  - SGLS: 1760-1840 MHz carrier range
  - USB: 2025-2100 MHz carrier range
    - Up to 1Mbps command uplink (ICD limited)
- **Transmitter**
  - S-band: 2200-2300 MHz, >30dBm (1W) output
    - AFSCN rates to 10Mbps, and NEN up to 20Mbps
    - Hardware can support up to 100Mbps
- **Encryption capabilities**
  - Internal AES-256
- **Coherent turn-around ranging**
- **SWaP**
  - Size: □82 x 25 (H) mm (0.25U) boards
    □86 x 35 (H) mm in enclosure
  - Mass: <0.4kg
  - Power
    - 3.2W single channel receive only
    - 6.9W transmit only
    - 10.3W transmit and dual channel receive

SWIFT AFSCN





SWIFT-HPX Crosslink

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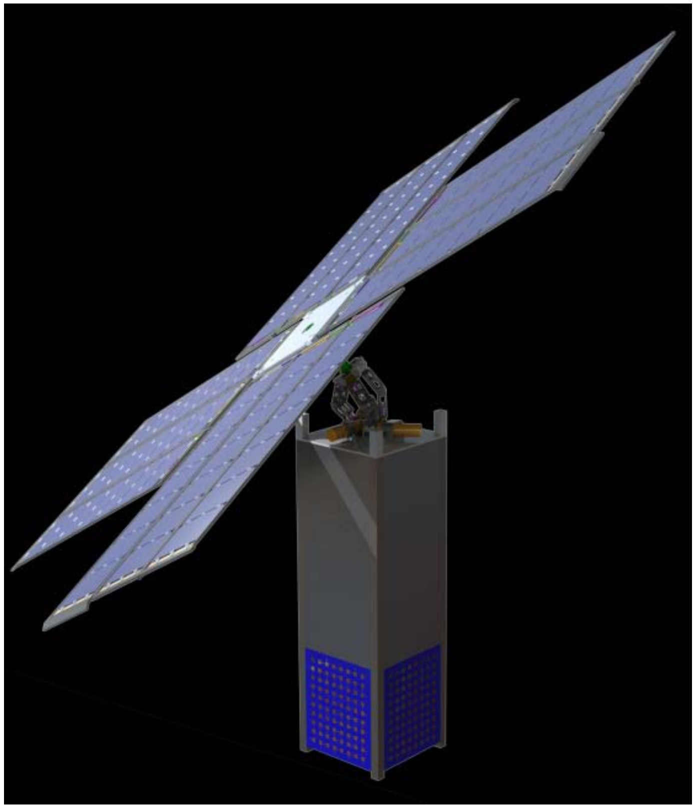
- **SWIFT-HPX will provide CubeSat-scaled crosslink communication**
  - 100Mbps crosslink at Ka-band frequencies with 1W TX output
    - 100Mbps @ 100km range
    - EESS/SRS ITU frequency allocations
  - Can also close downlink to ground stations with >12m diameter dish antennas
- **System needs high-gain antenna**
  - Ka-band patch antenna array with >24dBi of gain that fits on CubeSat face (83x100mm)
  - Requires 1˚ pointing

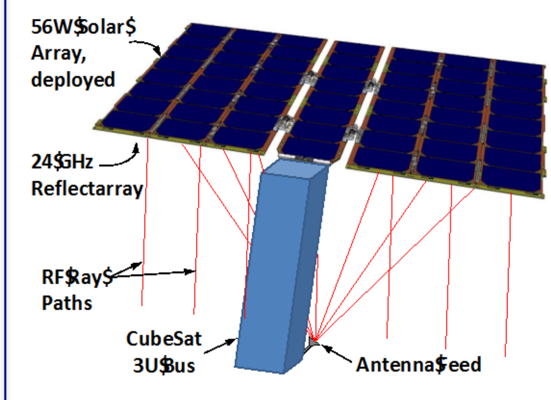


Notional 3U CubeSat with two RHCP 83x100mm Ka-band patch antennas for multi-beam coverage (e.g. to allow for multiple intersatellite crosslinks without attitude maneuvers).

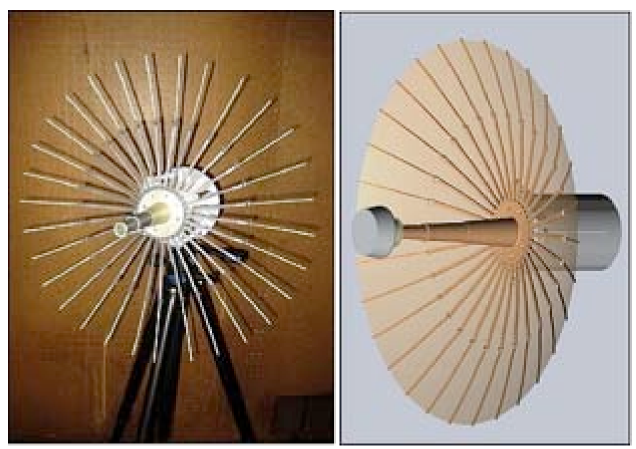
High gain antenna also needed

- **Due to limited electrical power available on the CubeSat platform, and especially beyond LEO, high-gain antennas needed to close links**
- **Deployable antennas provide high gain, albeit with addition mission risk**
  - Pointing required to close link
- **Non-deployable antennas may provide sufficient gain to close up/down links at reasonable rates**
  - Patch antennas are low risk, and easy to integrate

Miniature Deployable High Gain S-band Antennas
18 dBi gain, 50 cm DIA
Boeing system pictured above; NGC system demo'd on Mayflower CubeSat



JPL ISARA Ka-band Antenna


USC SERC Aenas Deployable Antenna

Medium Gain Antenna

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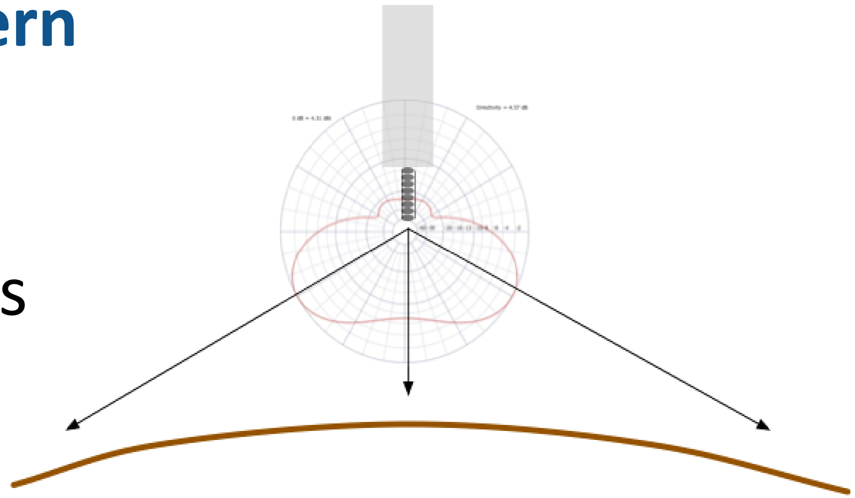
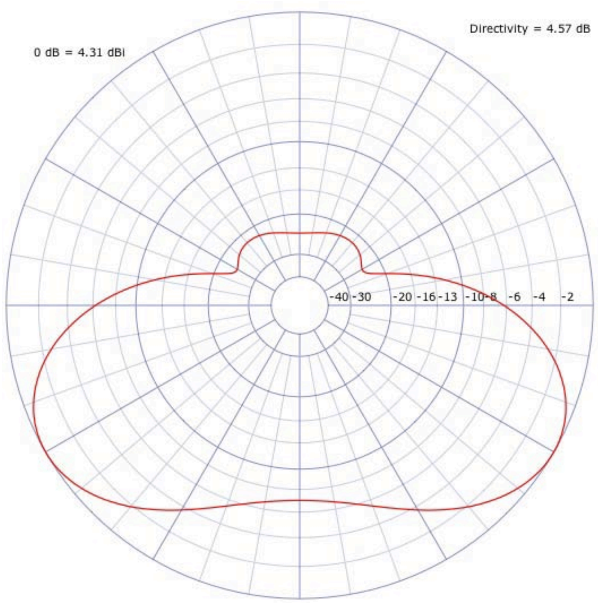
- **Range-compensating/isoflux pattern**
  - Can reduce/eliminate signal strength variations due to line-of-sight path length changes during a pass
  - At 700km ≈10dB variation with 10˚ elevation at antennas ±62˚

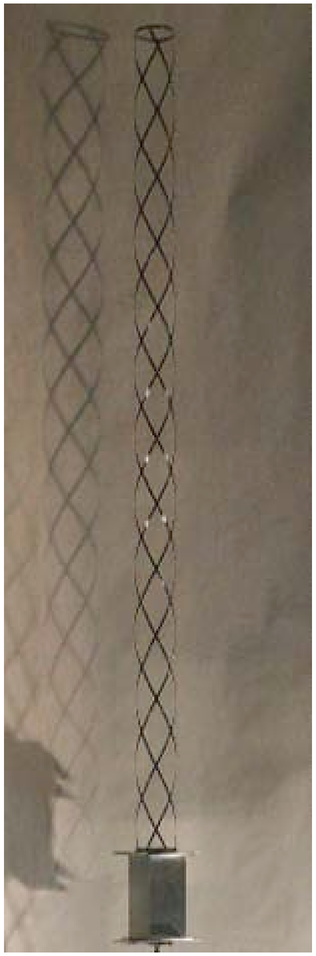


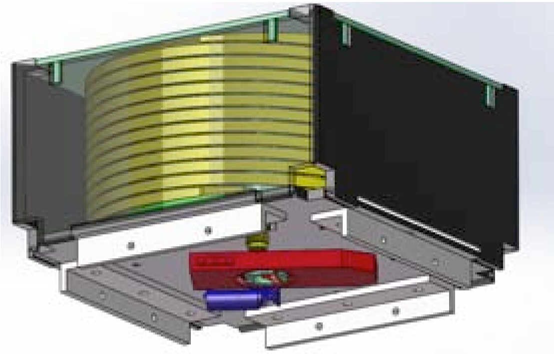
- **Quadrifilar Helical Antenna (QFHA)**
  - Pattern readily shaped to isoflux by varying antenna geometry
  - Circularly Polarized with very good axial ratio in main beam
  - Fairly insensitive to ground planes and surrounding structures



TUI Deployable UHF Antennas

- **Initially design for LEO SATCOM**
  - Range-compensating/isoflux pattern to provide coverage over the entire Earth FOV
  - Quadrifilar helical antenna (QFHA) produces desired gain pattern with good circular polarization
  - No pointing required if spacecraft is gravity gradient stabilized
    - Additonal mass can be place on tip of antenna for more stability
- **UHF Deployable Antenna Module**
  - Stowed Volume: Less than 0.5 U
  - Deployed size ≈ 1.5 x 0.07 Ø m
  - Mass: < 0.45 kg
  - Peak Gain: > 4 dBic
- **UHF High-gain (> 14dBi) helical antenna in development**





Maximizing Channel Throughput

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- **Communication standards such as DVB-S2 use Variable Coded Modulation (VCM) or Adaptive Coding Modulation (ACM) modes to optimize downlink capacity**
- **Variable Bit Rate (VBR) is simpler and still fairly efficient**
  - Requires full-duplex comm and
  - Adaptive Radio Technologies, LLC Firehose Radio
    - Designed to maximize bits/Joule
    - Up to 10Mbps downlink rate at USB frequencies

MODulation	CODing	Spectral Efficiency (info bits/symbol)	Data Rate (Mbps)	Eb/No (dB)	Gross Bit Rate (Mbps)	Info bits (Mbps)
QPSK	1/4	0.49	20.43	-5.4	83.33	20.83
QPSK	1/3	0.66	27.35	-4.3	83.33	27.78
QPSK	2/5	0.79	32.89	-3.3	83.33	33.33
QPSK	1/2	0.99	41.20	-2.0	83.33	41.67
QPSK	3/5	1.19	49.51	-0.8	83.33	50.00
QPSK	2/3	1.32	55.09	0.1	83.33	55.56
QPSK	3/4	1.49	61.98	1.0	83.33	62.50
QPSK	4/5	1.59	66.13	1.7	83.33	66.67
QPSK	5/6	1.65	68.94	2.2	83.33	69.44
8PSK	3/5	1.78	74.16	0.7	125.00	75.00
QPSK	8/9	1.77	73.60	3.2	83.33	74.07
QPSK	9/10	1.79	74.53	3.4	83.33	75.00
8PSK	2/3	1.98	82.53	1.8	125.00	83.33
8PSK	3/4	2.23	92.84	3.1	125.00	93.75
16APSK	2/3	2.64	109.88	2.9	166.67	111.11
8PSK	5/6	2.48	103.27	4.6	125.00	104.17
16APSK	3/4	2.97	123.61	4.2	166.67	125.00
8PSK	8/9	2.65	110.25	5.9	125.00	111.11
8PSK	9/10	2.68	111.63	6.2	125.00	112.50
6APSK	4/5	3.17	131.90	5.0	166.67	133.33
16APSK	5/6	3.30	137.51	5.6	166.67	138.89
32APSK	3/4	3.70	154.30	5.7	208.33	156.25
16APSK	8/9	3.52	146.80	6.9	166.67	148.15
16APSK	9/10	3.57	148.64	7.1	166.67	150.00
32APSK	4/5	3.95	164.65	6.7	208.33	166.67
32APSK	5/6	4.12	171.65	7.3	208.33	173.61
32APSK	8/9	4.40	183.24	8.7	208.33	185.19
32APSK	9/10	4.45	185.54	9.1	208.33	187.50

Adaptive Rad
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Applications

- CubeSats and small satellites
- UAVs and rovers
- Harsh environments
- Remote Sensing

Data Rates

- Adaptive high-speed downlink:
  - 10 Mbps peak

Summary

- **Higher frequency and higher gain antennas (both spacecraft and ground station) improve throughput**
- **Deployables enable higher throughput**
  - Deployable solar arrays for power
    - Enables greater power for data transmission
  - Deployable antennas for higher gains (especially at higher operating frequencies)
- **Dynamic modulation, coding and/or data rates maximize channel throughput**


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