Enabling Software Defined Radio Technology for High Performance Coordinated Constellations

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

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TUI's History and Motivation

- **First TUI SDR was designed for relative navigation**
  - Tethered CubeSats
    - Relative position important for tether dynamics knowledge and active control
  - Fractionated Spacecraft (e.g. DARPA F6 clusters)
    - Collision avoidance
    - Relative position knowledge for orbit maintenance
    - Aid in pointing higher gain apertures
  - Distributed Sensing systems
    - ***High rate/low latency data exchange***
    - Relative position knowledge for orbit maintenance
    - Timing for synchronized sampling
    - Knowledge of sensor baselines and orientations

SWIFT-RelNav Enables Cluster Operations

- **Spacecraft subsystem that will enable a 'flock' of satellites to operate as a coordinated cluster**
  - Relative Position and Orientation for Formation Flight
    - Provide reference data for cluster-based sensors
  - Cluster Synchronization and Timing
    - Essential for coordinated operations and coherent measurements
  - Inter-satellite communication
    - Data exchange for cluster-based sensors

	Kinematic GPS w/ UHF link	TUI's "Raw" RelNav
Relative Ranging Precision (1-σ)	0.1 m	**<0.1 m**
Relative Velocity Precision (1-σ)	10 mm/sec	**5 mm/sec**
Relative Attitude Precision (1-σ)	N/A	**1˚**
Relative Timing Precision (1-σ)	10 nsec	**3 nsec**
Comm Data Rate(BER≤10^{-6})	0.0192 Mbps	**>12 Mbps**
Range of Operations	< 10km	**<10 km**

SWIFT-RelNav provides improved relative navigation, timing, and inter-sat comm over GPS-based methods to enable precision cluster flight and coherent sensing.

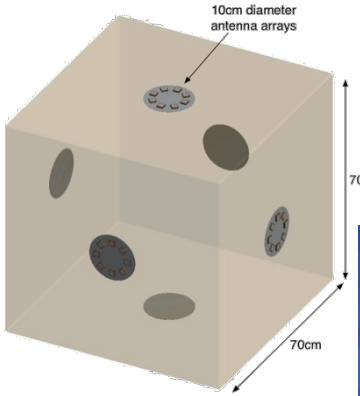
SWIFT-RelNav System Overview

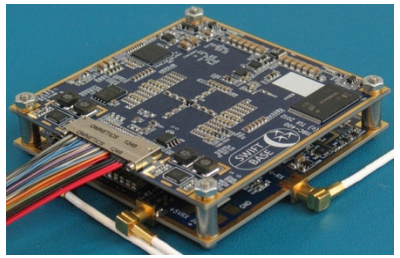
- **Objective**
  - Provide cluster navigation, communication, and timing
- **Performance Targets**
  - RF-Based Relative Range & Heading sensor
  - < 0.1m range precision (1-σ)
    - RF time of flight measurements
  - < 1° attitude precision (1-σ)
    - Pseudo-Doppler Direction Finding for heading
  - Crosslink data rate > 12 Mbps (BER < 10^{-6})
  - Timing synchronized to < 3 ns (1-σ)
  - No sensor pointing required
  - No external references (i.e. GPS) required
  - Scalable to a large number of spacecraft
  - Specified performance up to 10km operating range

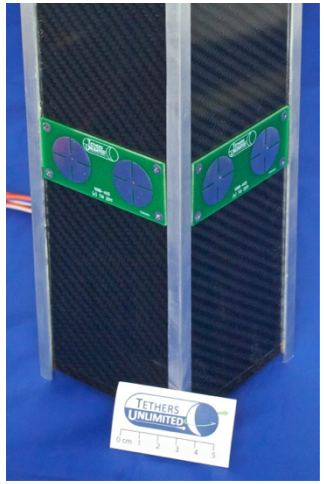
SWIFT RelNav

RelNav Configurations

- **Microsat-scaled RelNav System**
  - Radiation-hardened subsystem for LEO microsatellite (≈100kg)
    - Includes multiple antenna arrays (nominally 6) to ensure full sphere field of view
- **CubeSat RelNav System**
  - Simplified antenna array configuration to minimize footprint on 3U CubeSat
  - Include single antenna array to measure relative attitude in one dimension
    - Measures azimuth in what is nominally local horizontal FOV
      - Assumes long axis is nadir pointed
    - Use of highly integrated COTS parts to reduce avionics SWaP
      - Does not affect ranging, timing, or communications performance







	MicroSat RelNav	CubeSat RelNav
Size	15x15x7.5	10x10x3.5
Mass	2.1 kg	0.38 kg
Power	2.4W avg.* 7.5W peak	1.4 W avg.* 5.0W peak

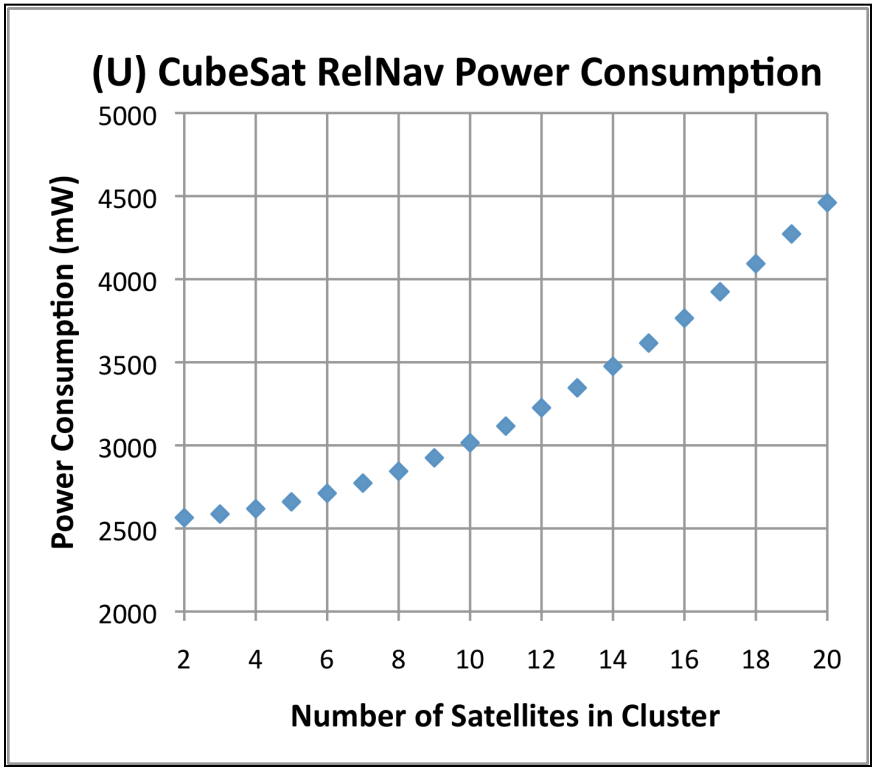
** 3 satellites in cluster, 1 Hz update rage, 3Mbps communications (25% of time after nav)*

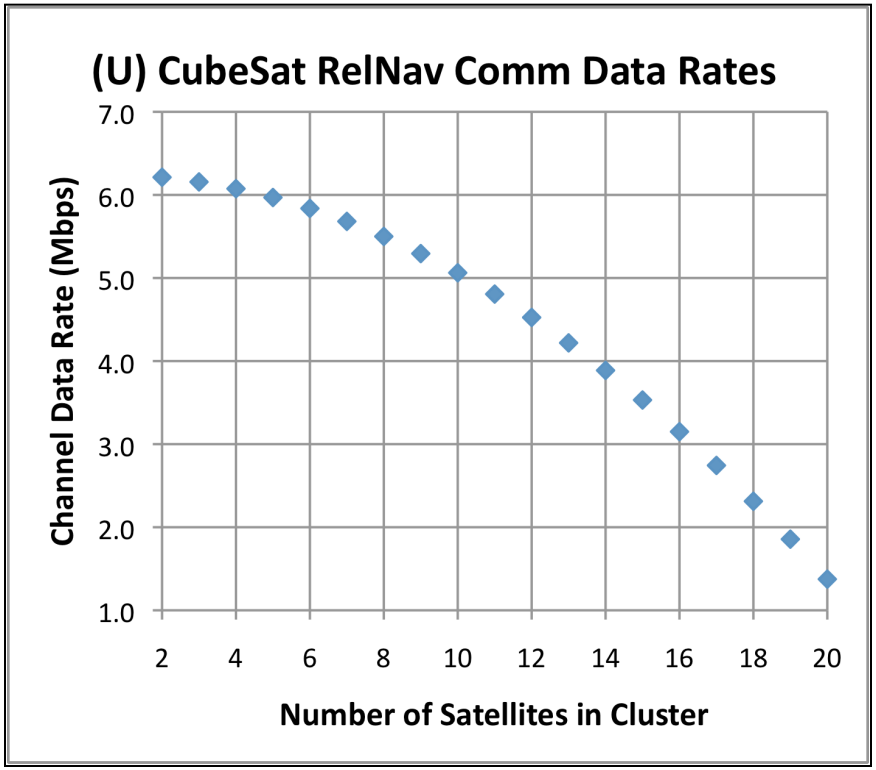
RelNav Communications Bandwidth

- **SDR Enables Multiple Modes of Communication**
  - High rate data communications: > 12Mbps
    - >11dB SNR provides 10^{-7} bit error rate (BER)
    - Forward Error correction can be added to reduce BER at lower SNRs
    - Zero-overhead ranging
      - Must include bi-directional communication
  - Low-rate data communications: ≈ 400kbps
    - Ranging at greater distances
    - Enhanced precision ranging
  - If needed, Multiple Access techniques can be used
    - Increased throughput and lower latency in large clusters at the expense of greater transmitter power

CubeSat RelNav Operating Profile

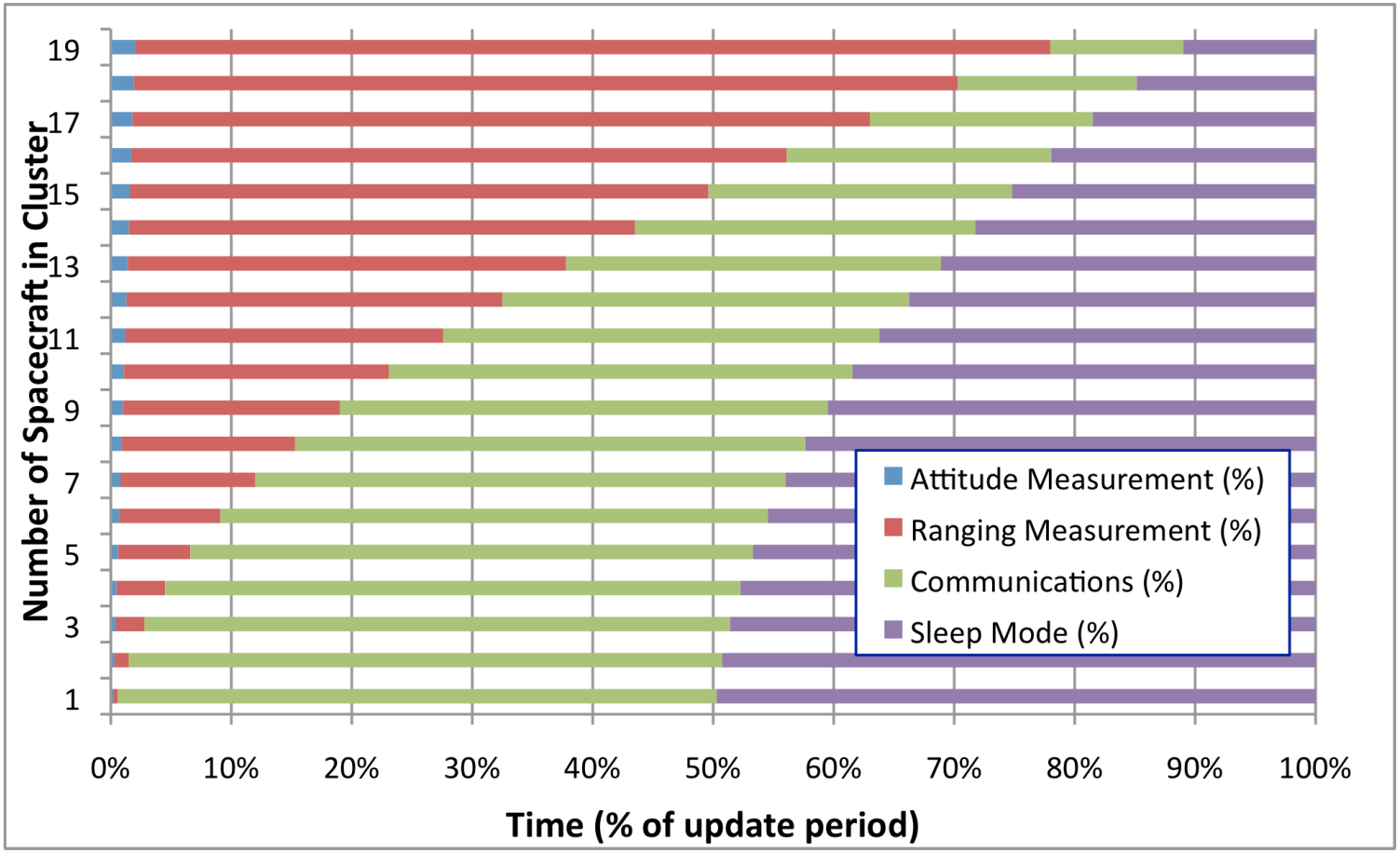
- **Operating Parameters**
  - System measures attitude and range between all satellites in 2 seconds (0.5 Hz update rate)
  - 50% of time remaining after measurements used for data comm





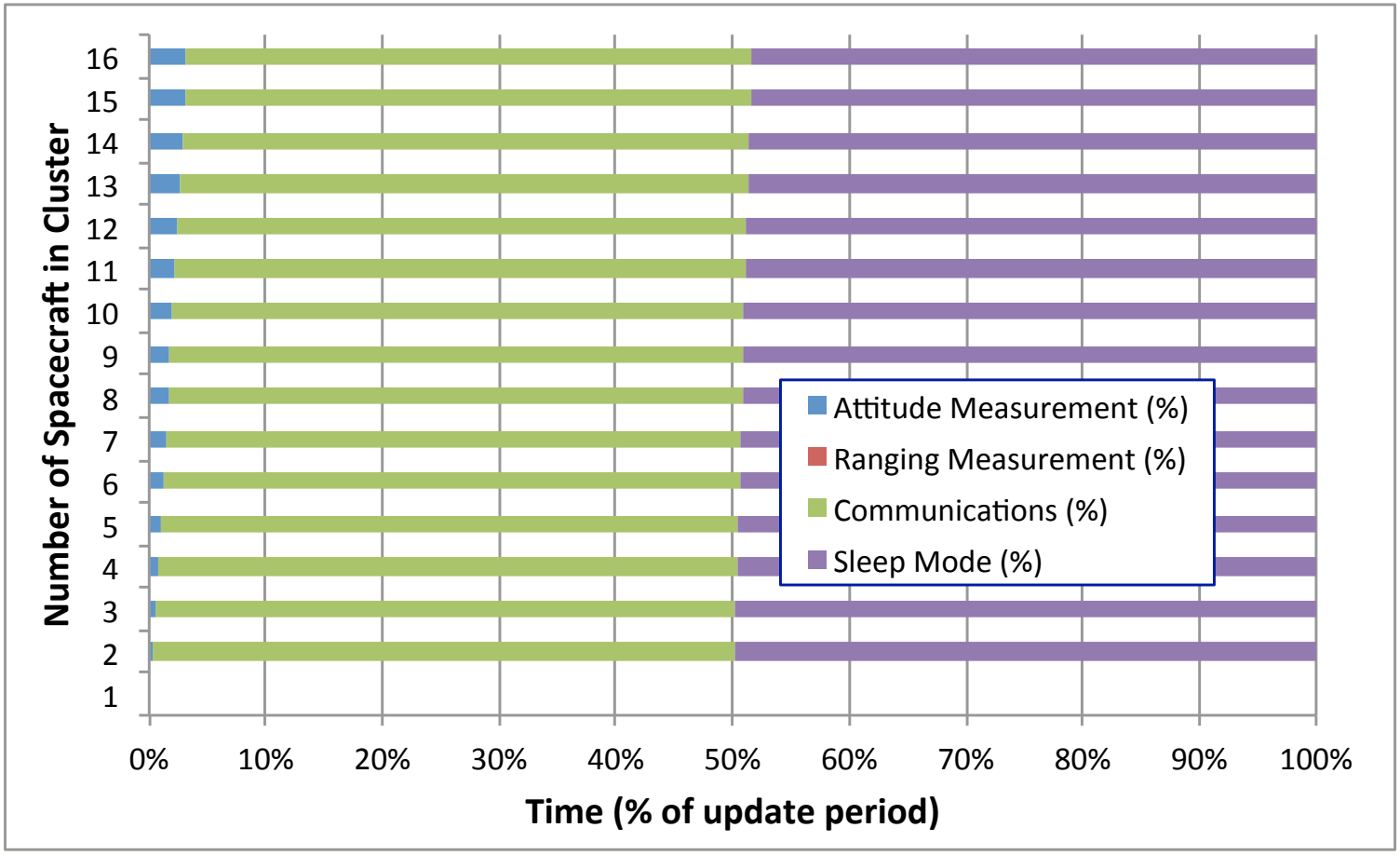
CubeSat RelNav Operating Profile

- **Operating Parameters (low-rate data ranging only)**
  - System measures attitude and range between all satellites in 2 seconds (0.5 Hz update rate)
  - 50% of time remaining after measurements used for data comm



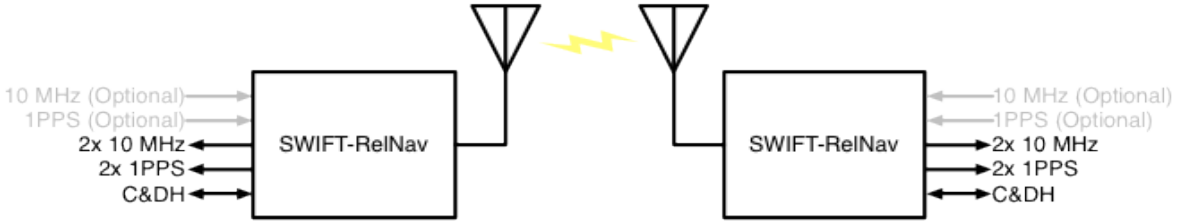
CubeSat RelNav Operating Profile

- **Operating Parameters (high-rate data with zero overhead ranging)**
  - System measures attitude and range between all satellites in 2 seconds (0.5 Hz update rate)
  - 50% of time remaining after measurements used for data comm

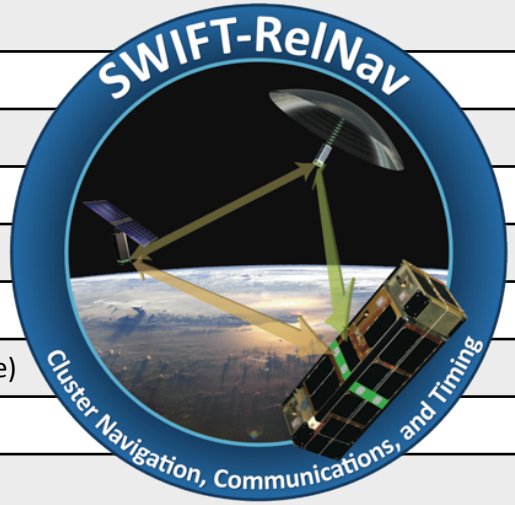


SWIFT-RelNav Summary

- **Cluster navigation, communication, and frequency/timing synchronization**
  - Multiple synchronization modes
  - GPS not required, but 1PPS can be used



Specification	Performance
Measurement Rates	1 Hz for 3-element cluster
Relative Range Precision	< 0.1m (1-σ)
Relative Attitude Precision	< 1°(1-σ) (coverage is antenna array dependent)
Relative Time Synchronization	< 3ns (1-σ)
Crosslink Data Rate	> 12 Mbps
Specified Operating Range	< 10km (for crosslink)
Size	□82mm x 35mm—0.35U (□82mm x 25mm—0.25U without case)
Mass	0.3 kg (w/o antennas)
Power	2.5-4 W average, 7 W peak



Enabled Cluster Missions

- **Science Measurements**
  - Enables scientists to separate temporal from spatial variations
  - Crosslink enables on-orbit data (pre-) processing to reduce data downlink requirements
- **Multi-point measurements**
  - Atmospheric/Ionospheric/Magnetospheric in-situ measurements
  - Coordinated remote sensing measurements
    - Interferometric SAR (InSAR) for improved vertical resolution mapping
- **Rendezvous and docking missions**
  - Robotic Servicing
  - Sample retrieval

SWIFT-SDR Architecture

- Architecture is comprised of hardware, firmware, and software elements
- Standard, modular interface to radio front ends allow system to have frequency and bandwidth flexibility
- Common software interface enables rapid development and implementation of alternate channelization, configuration, modulation/demodulation, and operating schemes
- Flexible user interfaces enhance testing as well as reduce integration challenges

SWIFT-HPX in Development

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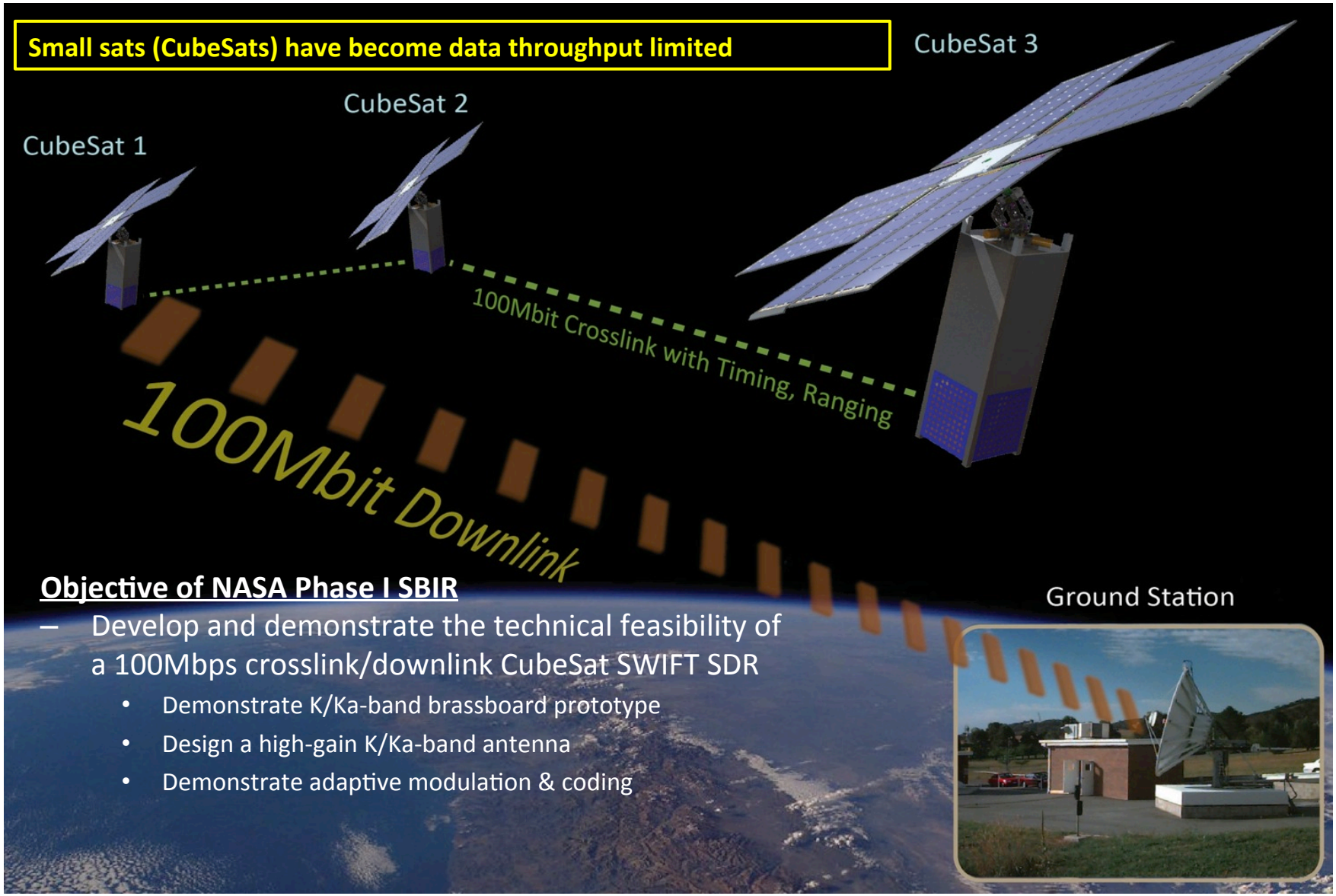
Small sats (CubeSats) have become data throughput limited



Objective of NASA Phase I SBIR

- Develop and demonstrate the technical feasibility of a 100Mbps crosslink/downlink CubeSat SWIFT SDR
  - Demonstrate K/Ka-band brassboard prototype
  - Design a high-gain K/Ka-band antenna
  - Demonstrate adaptive modulation & coding

Advanced Component Technologies for Small Spacecraft

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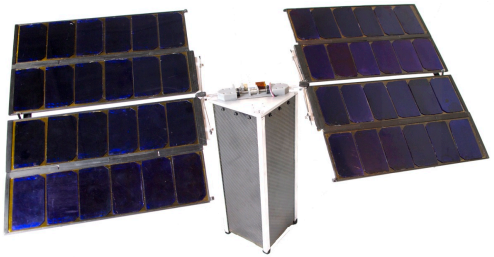
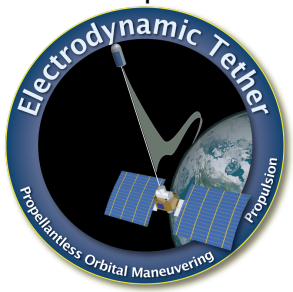


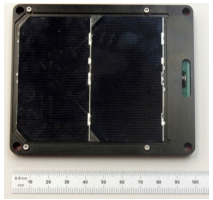
SunMill™
50 W and 80 W Deployable Solar Arrays for CubeSats

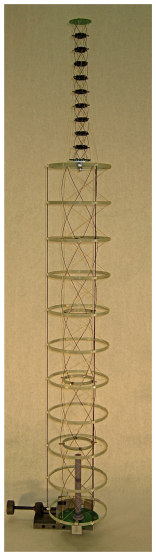
PowerCube™:
Integrated Propulsion, Power & Pointing for CubeSats

microPET™ - Propellantless Electrodynamic Tether Propulsion Module



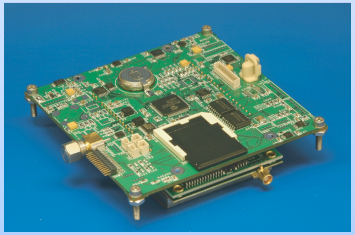
Terminator Tape™
Satellite Deorbit Modules





Deployable Antennas

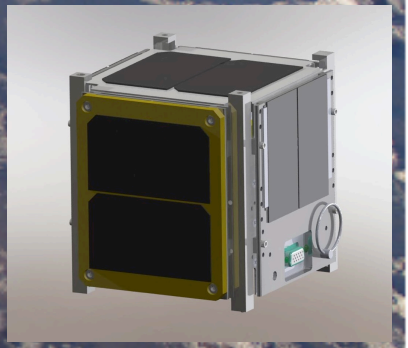
SWIFT™ CubeSat Radios
- SWIFT-RelNav – relative nav, x-link
- SWIFT-AFSCN – SGLS/USB
- SWIFT-TacSatComm - UHF&S-band
- SWIFT-WRX – Wide-band receiver



KRAKEN Robotic Arm
for CubeSats & Nanosats

Last, but not least….

…Yes, we still develop space tethers!



CubeSat Deorbit Module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