CDSI CREATIVE DIGITAL SYSTEMS INTEGRATION

Digital Beamforming Phased Arrays for Telemetry Tracking Applications

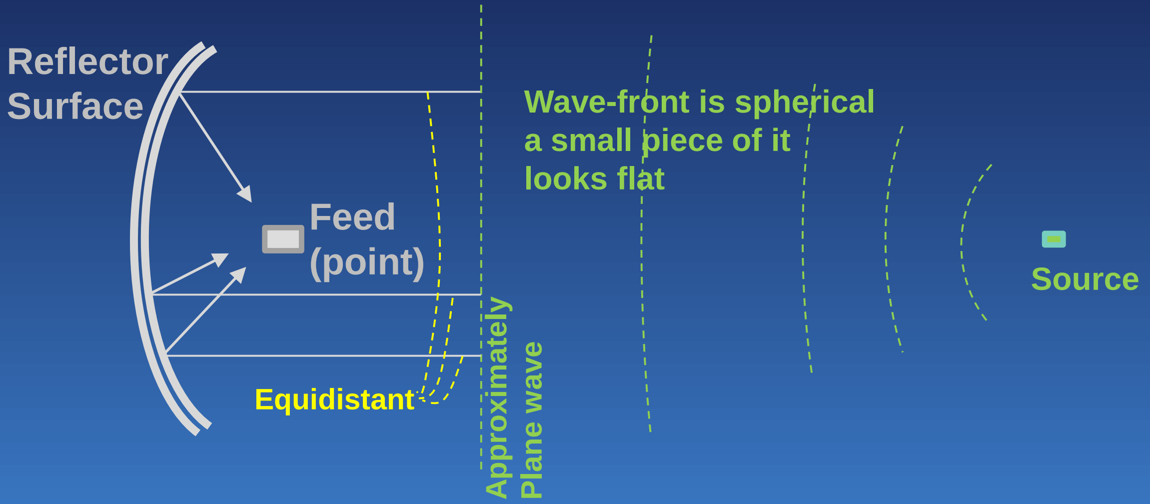
July 2021

Agenda

- Antenna discussion
  - Relationship between Reflectors and Phased arrays
  - Digital beamforming as a special case of Phased Array
- Challenges for Telemetry (TM) in an evolving test environment
  - Increased demands for simultaneous multi-vehicle tracking
  - Cost: equipment, sustainability, manpower, & maintenance
  - C-Band Transition = Smaller beamwidths = tighter motion control
- Exploring applications
  - Development history
  - Digital Beamforming Modules (DBM's)
  - Airborne, Ground Applications and current capabilities
- Q & A

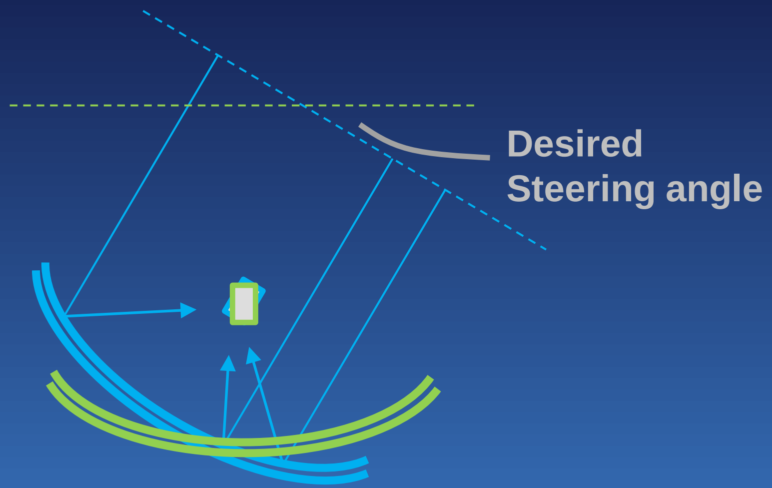
Antenna Discussion

- Parabolic reflector antenna:
  - Equidistant from a point (focus) and a line (plane wave)
  - Focuses all intercepted energy to focal point (feed)
  - Inherently a wideband device
  - Bandwidth limited by materials, tolerances & components

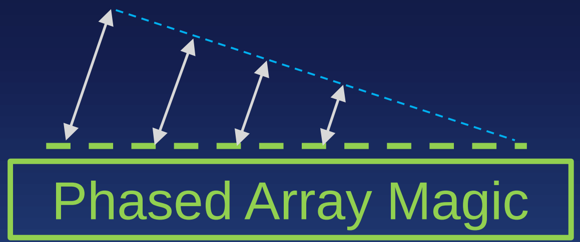


Antenna Discussion

- Steering a beam on a parabolic reflector antenna
  - Move reflector so that the feed aligns with a plane wave from another (desired) direction
- Steering a beam on a phased array antenna
  - Change something (phase or group delay) to match the expected angle-of-arrival of plane wave



Reflector Antenna



Through the use of small antenna elements the energy that falls on the surface is collected and correctly adjusted in delay (or phase) to produce max. output

Phased Array Antenna

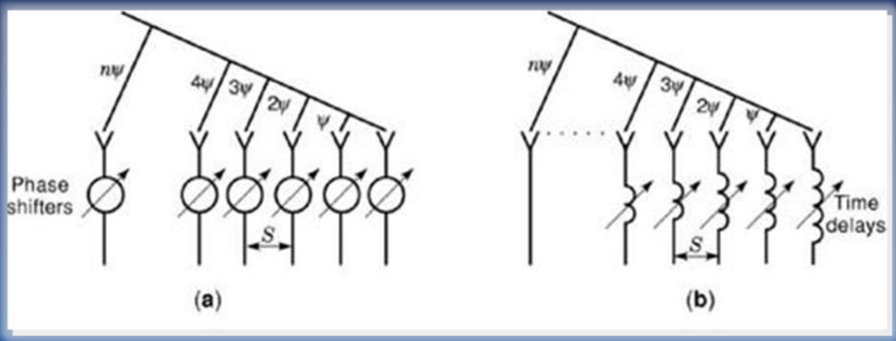
Antenna Discussion

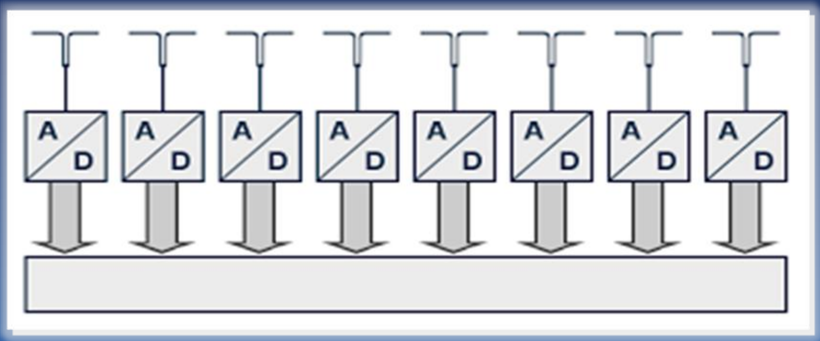
Analog Beamforming:

- ↑ #beams = ↑ h/w

Digital Beamforming:

- ↑ #beams = ↑ FPGA
- Today:
  - >50 beams from 1 aperture





Challenges for TM today

- Multiple simultaneous sources
  - High velocity: Booster & Payload with multiple sources on each
  - Medium velocity: Multiple simultaneous aircraft (dogfight scenarios ~10)
  - Swarms: Large number of simultaneous independent sources (~50)
- Miscellaneous considerations
  - Shrinking spectrum = Spectral re-use in neighboring ranges
    - Airborne TM antennas easily detect ground-based tests across ranges
  - Low grazing angle acquisition (multipath, diffraction)
    - May require classified pointing designate = big cost for portable systems
  - C-Band Transition
    - 50% smaller beamwidths = 4x acceleration = bad news for dish re-use

Addressing Challenges for TM today

- Multiple simultaneous sources
  - Dish technology requires an individual dish for each spatial source
    - Phased Array solution is better suited
  - Classic phased array solution for swarm scenarios is impractical
    - Digital Beamforming (DBF) solution is the only alternative

- Miscellaneous considerations
  - Shrinking spectrum = Spectral re-use in neighboring ranges
    - DBF provides options for waveform-specific discrimination
  - Low grazing angle acquisition (multipath, diffraction)
    - Adaptive DBF provides an agile toolbox for signal fade mitigation
  - C-Band Transition easily accommodated by phased array antennas
    - Beamwidths translate to Tracking loop constants

Exploring Applications
DBF Development History

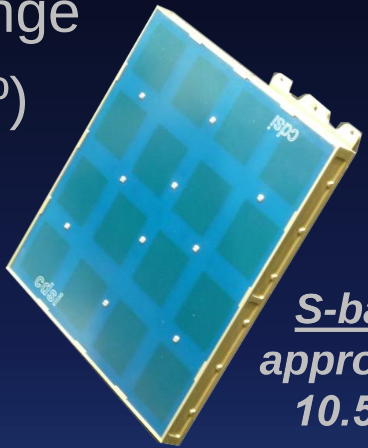
- In 2004 CDSI was in a sub-contractor role
  - Classic Phased Array implemented via Digital Beamforming
    - 10 dual-pol beams = 224 RX chains. Deployed 2008
    - Extremely bleeding edge. Required skilled operators
    - Achilles heel: Big SWaP: ~31w/dpe (dual-pol element)
- In 2011 CDSI was selected for the AirPA program
  - Goal was risk reduction for airborne Phased Array development
  - CTEIP funds, USAF Pgm. Mgmt
  - Classic Digital Beamforming approach, lower SWaP ~ 10w/dpe
- In 2014 BAA for Universal Beamforming Technology (UBT)
  - Resulted in Digital Beamforming Modules (DBMs)
  - TRMC → T&E (S&T) Funds, SET (ASTRO) Pgm. Mgmt

Exploring Applications
DBF Development History

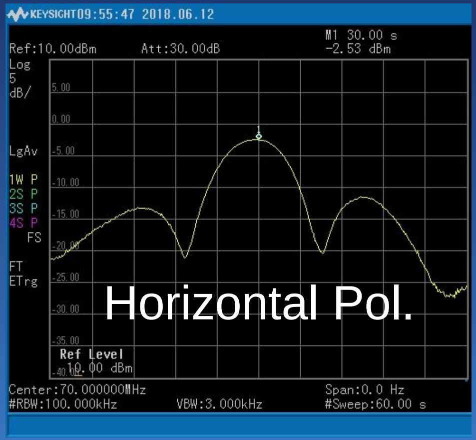
- In 2017 CDSI produced first DBM (S-band)
  - Adaptive Phased Array implemented via Digital Beamforming
  - Independent 'Tiles' that can be inter-connected
  - (Relatively) Low SWaP ~4w/dpe
  - SNR-optimizing steering algo. = no tracking designate required.
  - TM output as Analog (IF or RF) -OR- as digital stream (I/Q)
  - Bleeding edge issues still lurking
- Bleeding Edge has healed (2021)
  - 2nd iteration design (reduction of spurious signals, etc…)
  - Environmental survivability (vib., temp, altitude)
  - Better FPGA algorithms
  - Operational considerations (User interface)
  - ~150 DBMs produced

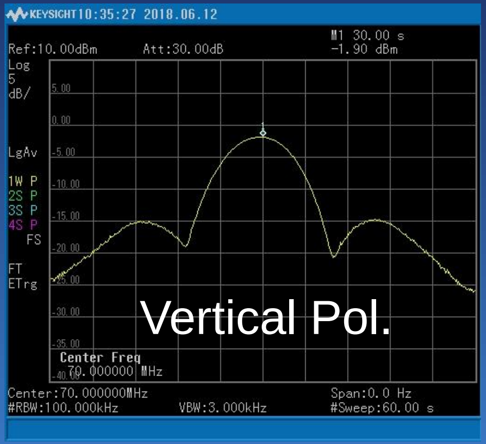
Exploring Applications DBM description

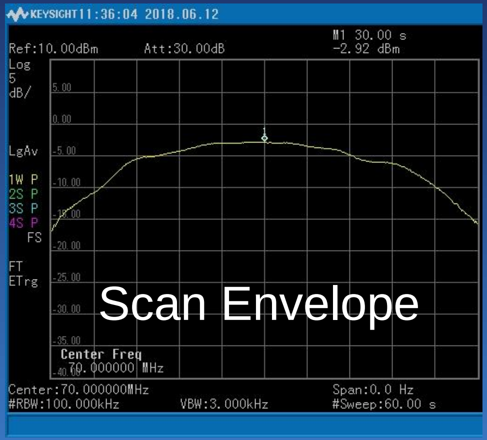
- DBM (4x4 elements) measured in antenna range
- Both Horizontal & Vertical Polarization (+/- 90º)
  - 3dB Beamwidth: ~30º at boresight
  - Scan envelope: 110º wide at -3dB points
  - Modeled Gain = >15.5 dBi (G/T = -7 dB/K)
  - DBMs add linearly in an array
  - G/T for 10 DBM array = -7 dB/K+10Log(10) = +3 dB/K



***<u>S-band DBM</u>* approximately 10.5” square and 2” deep**







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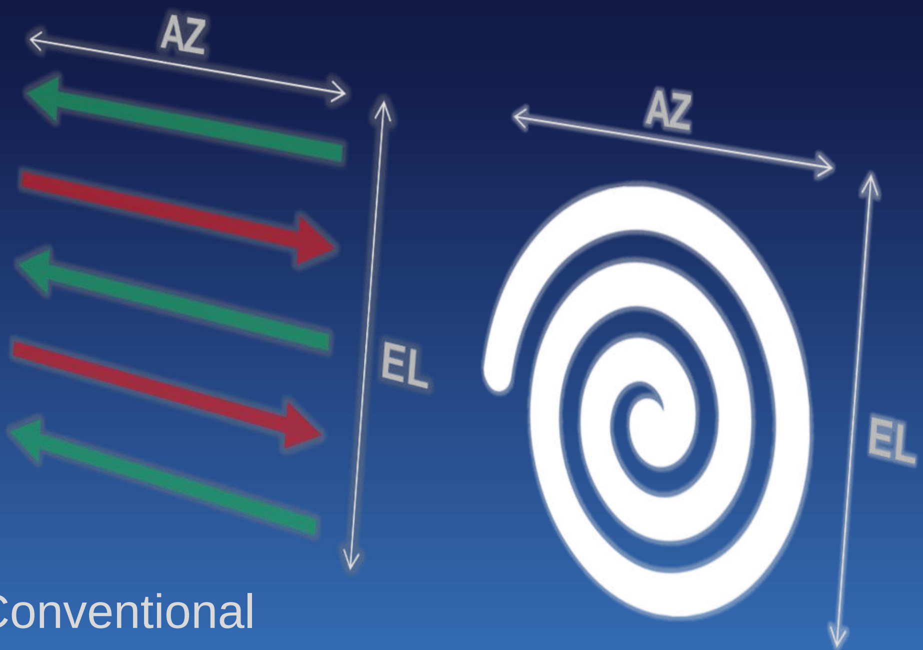
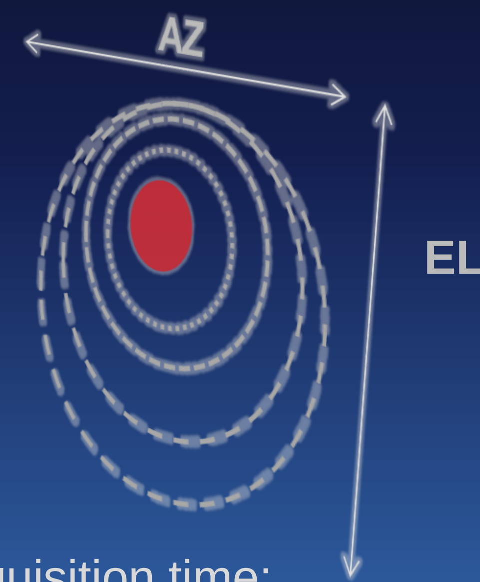
Exploring Applications Performance details

- Conventional Beamforming requires acq./track strategies
- UBT is able to use unconventional adaptive processes
  - Removes first-order “need to know” target position
  - Reduces hardware cost



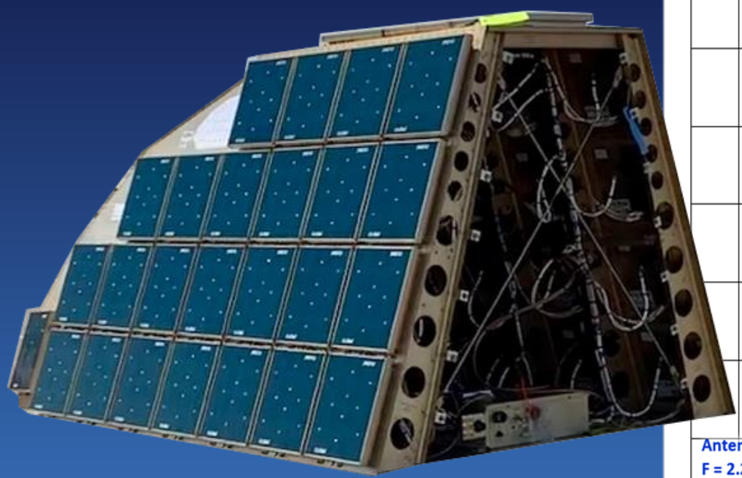
Conventional
Acq./Track time, rate: Variable (secs, °/sec)

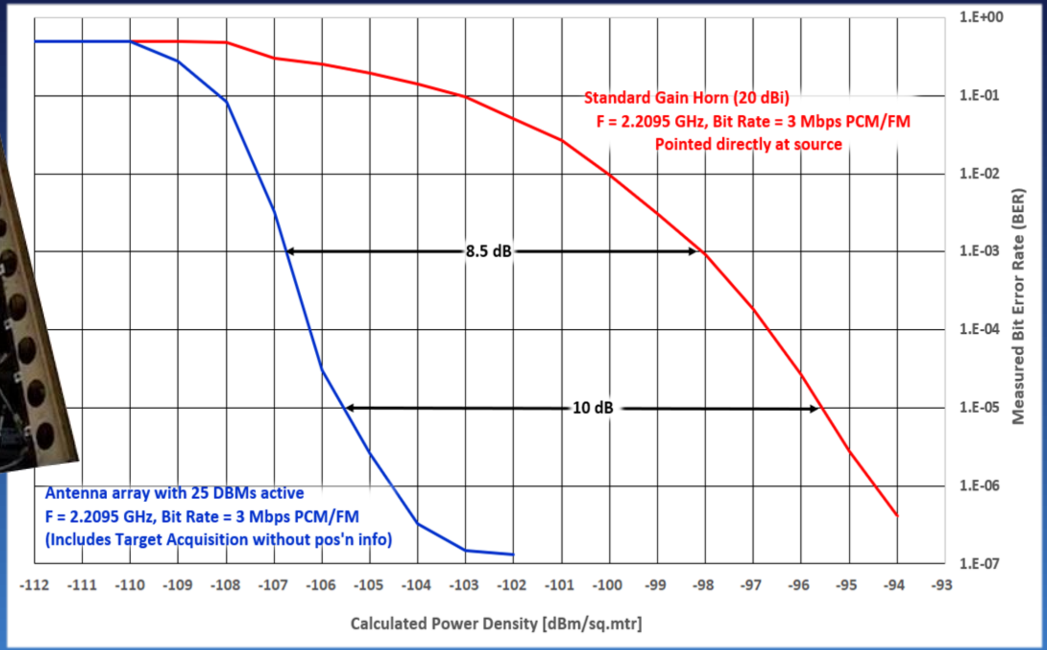


UBT Acquisition time:
1 ms for typ. TM source @ 50 mi
100 ms @ >200 mi, all sizes
Track rate: >120°/sec

Exploring Applications Performance Comparison

- Non-contiguous, Non-planar array mounted on aircraft
  - TM system running autonomously (side selection, switching etc.)
  - No designate required for signal acquisition
  - Measured peak Gain ~ 16 dBi/panel –or– 30 dBi for full array
  - Measured peak G/T > 6.5 dB/K

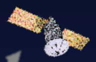




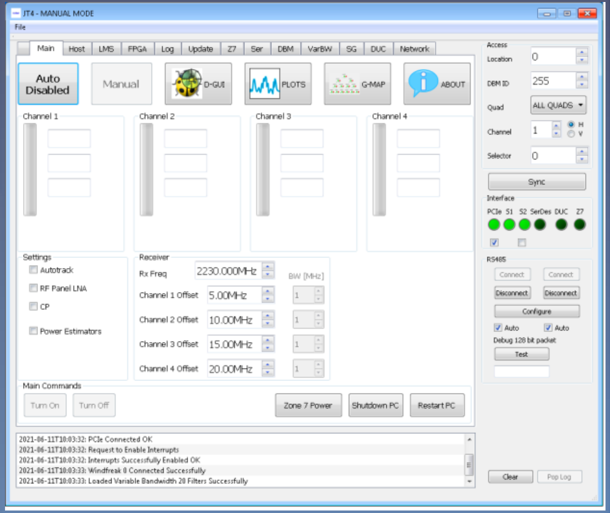
Exploring Applications Airborne TM

- DBM array
  - Can fit in RQ-4 nose
  - Non-contiguous
  - Non-planar
    - Conformal
  - Horizon-horizon view

Satcom Link



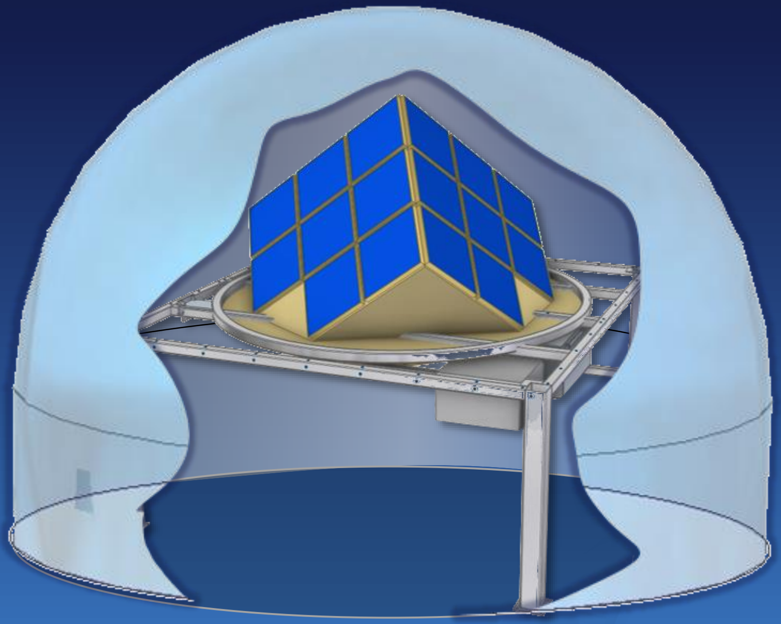
Remote GUI (@ control station)



Exploring Applications Ground-based system

- Designated Beam pointing (no auto-track)
- Hemispherical Coverage: G/T is within 2.5 dB.
- G/T can be increased by adding DBMs
- 24 simultaneous beams
- Precision Time-of-Arrival

Custom GUI developed through API



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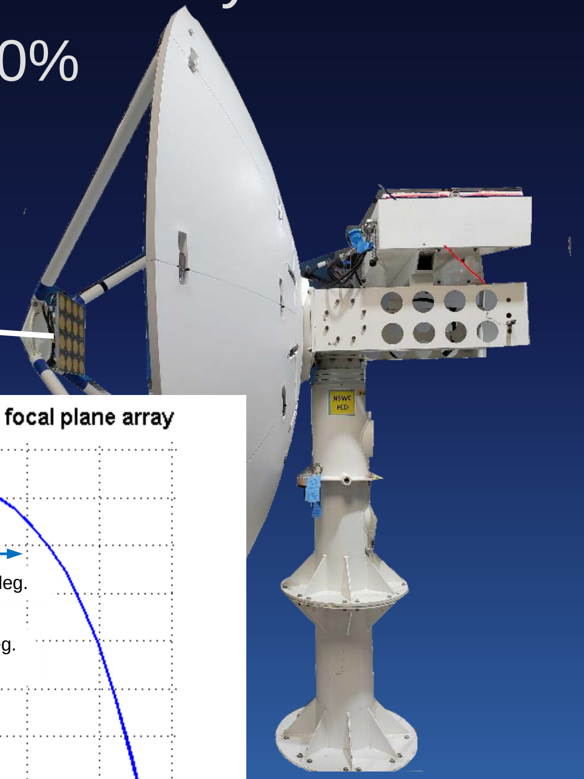
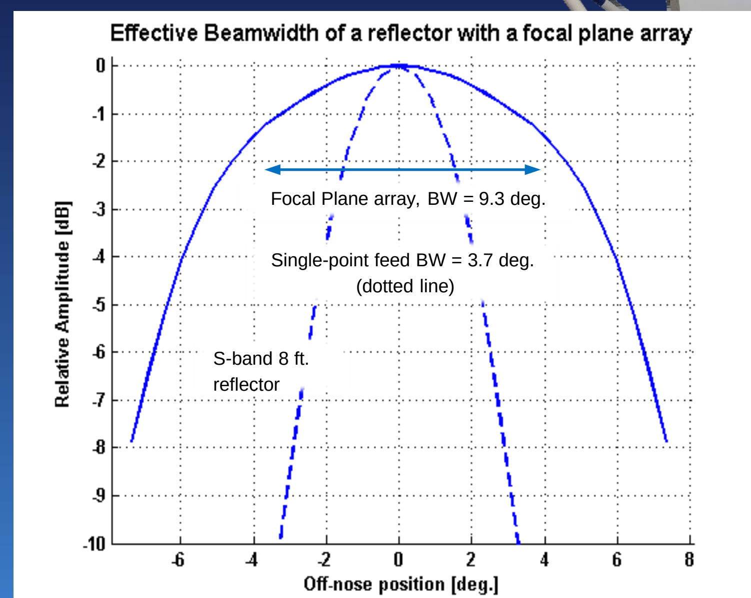
Exploring Applications L/S → C-band upgrades

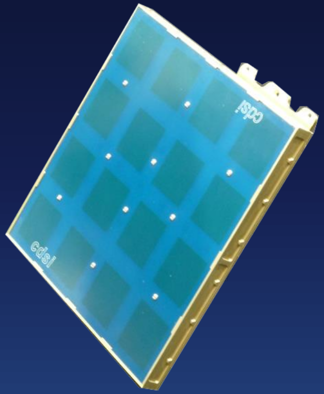
- Migration to C-band has challenges for reflector systems
  - S to C-band shift reduces beamwidth by 50%
  - 4X power is required for dynamic targets
- DBM placed at feed position…
  - Beamwidth 2.5x
  - Acceleration reduced
  - DBM compensates
  - Dynamics for S-band pedestal will suffice for C-band upgrades





Current technology

- Commercial Transceiver chips (MIMO) + Cyclone V FPGA
- S-band DBM (v2.X) – 16 dual-pol elements, 10.5” x 10.5” x 2”, 5 lbs.
  - Operates 2.2 – 2.4 GHz, multi-beam
  - 1 → 20 MHz/beam, all within 50 MHz



- Software/Firmware/Processing/Connectivity
  - Multipath mitigation – adaptive
  - Works stand-alone or in an array to increase gain or coverage angle
  - Unmanned remote operation utilizing existing networks.
  - Can be steered to point or can optimally ‘find’ source.
- SWaP currently at ~ 3.5W/dpe (dual-pol-element)

Coming soon

- Hybrid analog/digital: RFSoC-based DBM
- L/S-band DBM (v4.1) – 16 dpe, approx. 12” x 12” x 3”, 5 lbs.
  - 1.42 → 1.53 + 1.75 → 1.85 + 2.2 → 2.4 GHz, consumes 50W
- C-band DBM (v4.2)– 64 dpe, approx. 10.5” x 10.5” x 3”, 6 lbs.
  - Operates 4.4 → 5.2 GHz, consumes 75 W
  - Multiple simultaneous spatial beams (>60)
  - Variable bandwidth – 1 → 120 MHz/beam
- Software/Firmware/Processing/Connectivity
  - Same as v2.X
  - Fiber optic connection capable
- SWaP currently at ~ 3.5W/dpe (L/S-band), < 3W/dpe (C-band)

Summary

- Availability of fast, compact analog/digital/hybrid technology has moved the bar for antenna products.
- Antenna and signal processing domains now intersect in the Digital Beamforming space.
- CDSI has developed a building block that lands in this intersection
- We call it a Digital Beamforming Module (DBM)
  - Operates Stand-alone or as part of an array
  - Allows spatial shaping of G/T
  - Non-planar, non-contiguous surfaces
  - Native Transmit capability exists