Universal Beamforming Technology: Application and Tests

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Introduction

- Beam Pointing of Phased Arrays is not new
  - H/W phase-shifters still used widely
  - Full Digital Beamforming (DBF) is recent
  - ~ 2000, DBF began migrating into RF applications
- In 2004, CDSI designed a DBF TM subsystem
  - Installed on (2) USAF E-9A aircraft in 2008
    - 10 beams, 112 dual-pol elements, S-band, 11dB G/T
    - Replacing 5-beam conventional array (3x bigger)
- Since then, technology continues to advance…
  - We introduce “UBT” architecture/development

Sponsors to date

- Ongoing support from E-9A Program
  - Operational "testbed" for algorithms/operations
- Office Secretary of Defense
  - Test Resource Management Center (TRMC)
    - T&E/S&T Spectrum-Efficient Technology (SET), Edwards AFB, CA.
  - Navy, NAVAIR/NAWCWD Pt. Mugu, CA.
- Goals:
  - Hi-risk/Hi-payoff R&D for T&E
  - Technology transfer
  - Risk Reduction

Background

- Experience with E-9A (operational since 2008):
  - Continuous functionality improvement:
    - Upgrade firmware (once)
    - Upgrade CPU (twice), software (many times)
  - Avoid obsolescence:
    - Entire DBF subsystem (2 racks) is replaceable:
      - Lower cost (ADC/FPGA devices evolve continuously)
      - Higher performance (channels, bandwidth, data rates)
      - Higher reliability (redundancy, fewer devices)
    - Augment antenna array (e.g., add C-band)
      - New S-band array ⅓ size of prior: more weight/space available

“Classic” DBF approach (E9)

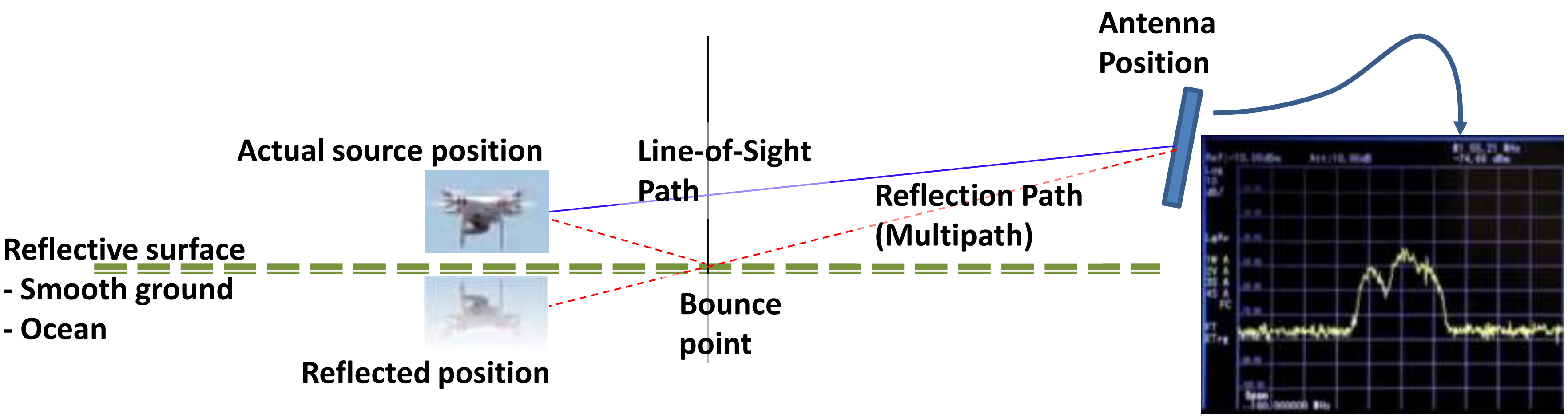
- Each element RF signal is downconverted to IF
  - IF digitized synchronously (ADCs)
  - Processed digitally (FPGAs):
    - Filtering/DDC →baseband “channel-element” streams
      - Tuning frequency, bandwidth
      - Calibration
    - Channel-elements combined into “beam” (each channel)
      - Simultaneous beams: e.g.: Σ,Δ, Polarization, Low SL (weighted)
      - Acquisition: Sequential Search
      - Tracking : Monopulse
    - Final output for each beam can be:
      - Analog IF (70 MHz) or Digital (Clock, Data)

Classic DBF Limitations

- As G/T increases:
  - Elements ↑ : cost increases as diameter^2
  - Acquisition time ↑ : beamwidth^{-2}
- Multipath
  - Destructive interference across array
- If aperture is fixed – (not on pedestal)
  - Scan Loss
  - Grating Lobes (element spacing >0.5λ)

Multipath

- Mechanics of Multipath
  - Line-of-sight (LOS) illumination provides predictable behavior
  - Pointing algorithms usually created using LOS principles
  - Conventional algorithm produces sub-optimal aggregate signal
  - Primary effect: aggregation of bounce path (at random phase)
  - Secondary effects like Aperture Surface waves



Notional Multipath scenario

Damaged spectrum

UBT Improvements

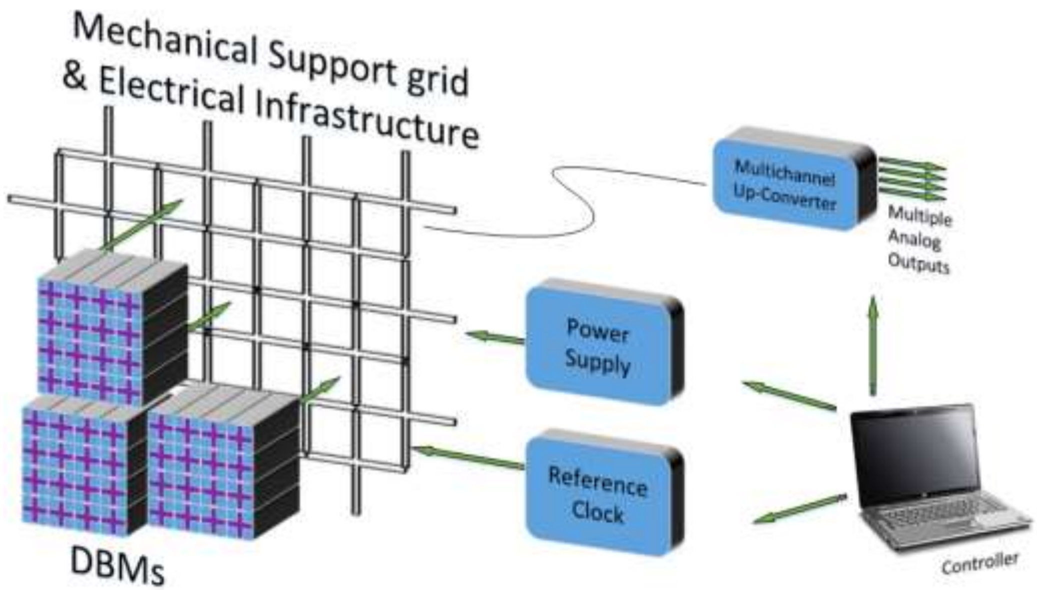
- Digital Beamforming Module (DBM) concept:
  - Reduced cost, increased reliability/flexibility
  - Higher G/T = more DBMs (plug-n-play)
- DBM forms a Generic Intelligent Subarray:
  - Can handle single- or multi-band RF elements
  - Cost of available devices continuously reducing
  - Efficiency of available firmware increasing
- Local intelligence provides many advantages:
  - Optimal SNR, rapid acquisition/tracking
  - Multipath mitigation, conformal/disjoint apertures, …

UBT RF Hardware

- Single-band or multi-band RF elements
  - LNA/LNB, Filters (EMI), limiters, …
  - Many alternative downconversion approaches:
    - Block IF downconversion: entire band of interest (E-9)
      - Can handle many beams in each block with fewer devices
    - Individual beam (frequency) down-converters:
      - Can place beam anywhere in wide RF range (= many devices)
- Can be co-located with RF panel
  - Minimal cable loss

UBT RF Hardware

- UBT uses "Building block" approach: DBMs
  - Digital Beamforming Modules
- DBM contains
  - RF elements
  - Filters
  - Downconverters
  - DBF Processing
  - Interconnection



UBT Firmware

- DBM Firmware performs:
  - Subsystem hardware configuration
    - Channel parameters (tuning, bandwidth)
    - High-level functions (calibration, angle/freq scan, acq/track)
  - Dynamic operations:
    - ADC synchronous sampling
    - Channelization/Filtering (e.g., DDC)
    - DBF processing (algorithms, data transport, combination)
  - Hardware monitoring/control (interface to software)
- Final output Firmware:
  - Digital-to-IF upconversion
  - Any other output processing

UBT Software

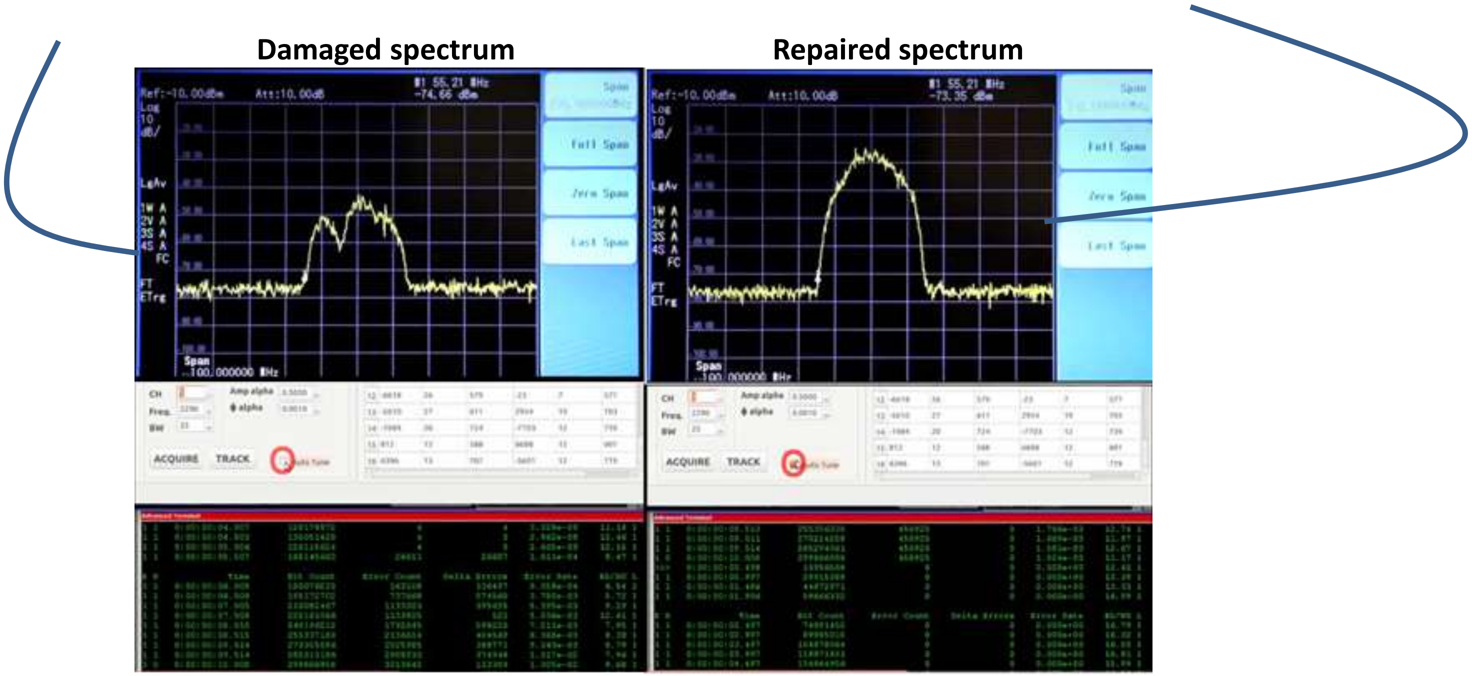
- Subsystem configuration by User
  - Channels, scenarios
- Subsystem monitoring/control
  - Nominal health or fault diagnosis
  - Debug of firmware interface (essential)
- User interface
  - Graphical presentation
    - spectra, scans, maps
- Can be a single host (e.g., laptop)

UBT Digital Hardware

- ADC configuration (depends on RF choices):
  – Higher speed/cost required for “block” approach
  – Lower speed/cost for targeted frequency approach
- FPGA configurations
  – Each DBM: ADC inputs, DBM I/O (data and control)
  – Final Stage: produces digital or IF beam outputs
- DBF processing:
  – DBM intelligence: calibrate/acq/track/multipath
  – Physical: board-stack possible on each RF panel

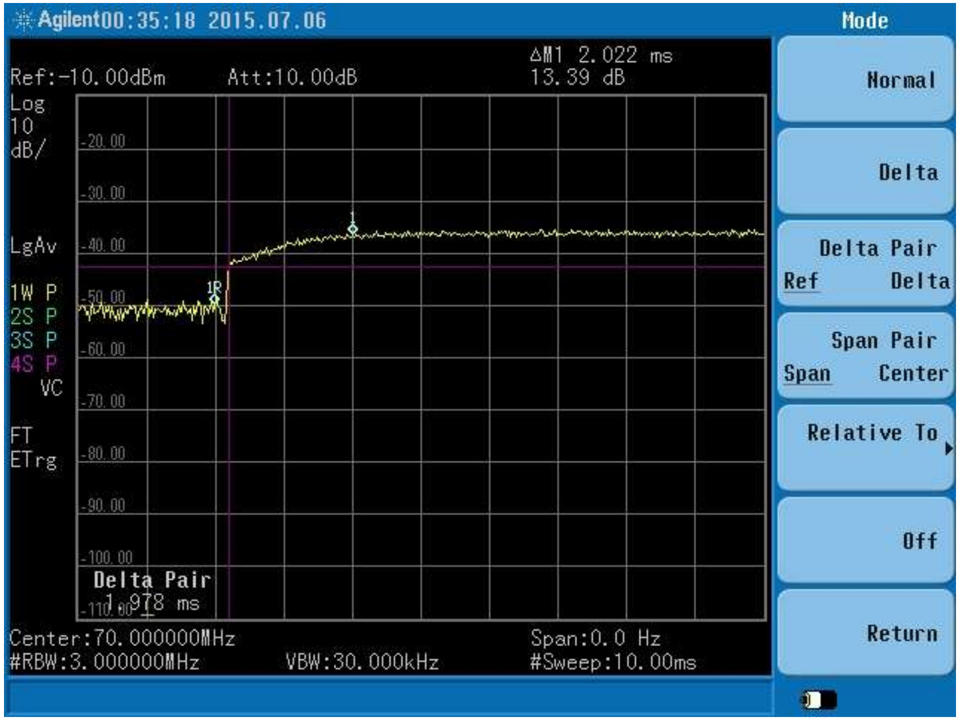
Multipath Resilience

- Multipath scenario was purposely created
  - Mitigation is built into UBT
  - Conventional steering vs. UBT steering



Target Acquisition

- Spectrum Analyzer in Time-trace mode:
  - 13 dB SNR source
  - Tracking ~2 msec after signal appears anywhere in view



UBT implementation

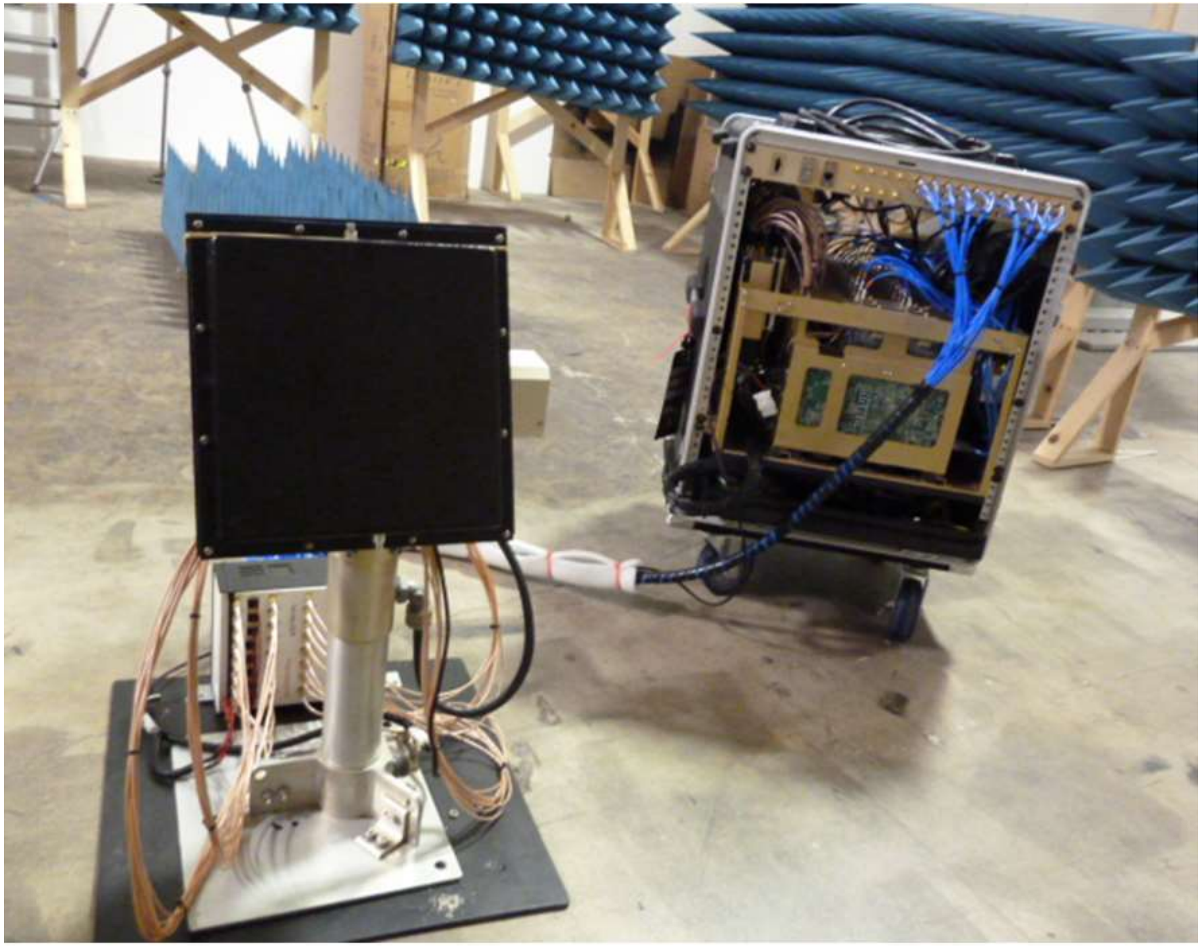
- UBT Phase-1 proof-of-concept goal:
  - Tri-band multi-beam TM subsystem at TRL6
- Brassboard implemented in <12 mos, using:
  - Available COTS multi-purpose boards:
    - FMC transceiver boards + FPGA development boards
  - Available COTS firmware: DDC/filtering/DUC/SERDES cores
  - Prototype tri-band RF panel (First RF)
  - Some custom hardware required for integration:
    - Global Clock/sync/trigger, LO synthesis/distribution

UBT implementation

8” square RF panel:
- 4x4 dual-pol elements
- 1.4–5.2 GHz

Rollaway (4x4 DBM):
- 16 FPGA boards
- 32 FMC boards

Providing:
- 16 dual-pol beams
- 250 MHz bandwidth
- over 0.4–6 GHz
- up to 125MHz/beam



UBT in-house testing

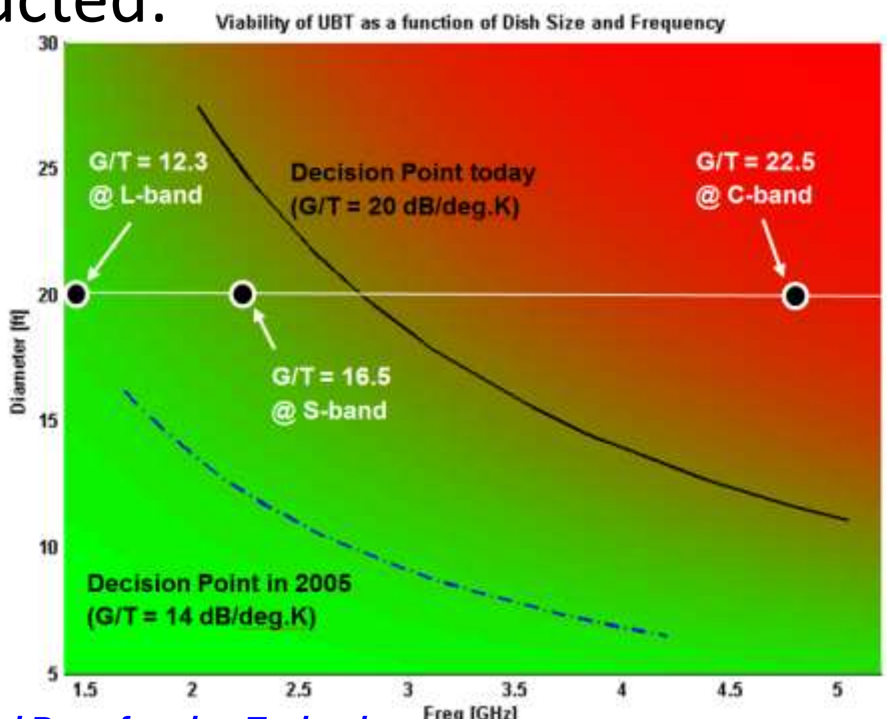
- “Wheel of Death” (WOD)
  - – 6 RF sources mounted on suspended wheel
    - Rotation at 20RPM: >120deg/sec angular rates
  - – One source transmitting SOQPSK at 30Mbps L/S/C
- Small drone: carrying SOQPSK source
- Multi-channel acquire: “instantaneous”
  - – Despite multipath everywhere (indoors)
- Zero BER at 30 Mbps at all angular rates
  - – Inside testing and drone flight (video taken)

UBT testing at EAFB

- UBT set up adjacent to 8’ TM dish at EAFB
  - 3 static sources: pole mounted
  - 1 flying source: 5 Mbps SOQPSK (L/S/C)
    - Flight path (blue) shown on map
- Pulsed interference:
  - Radar sweeps by…
    - Produce short error bursts
    - No front-end filtering installed
- Tracking Results:
  - Zero BER up to 45mi
    - Aircraft-aspect dependent
    - Discounting pulsed interference
    - Near theoretical limit For 8” aperture
  - Multipath mitigation demonstrated from flight-line

UBT vs. Reflector systems

- A specific DBM can be used in various ways, e.g.:
  - 8 beams for dual-pol 4x4 array (individual downconverters)
  - 1 beam for 16x16 single-pol array (different RF cabling)
- Decision-space model constructed:
  - Using today's assumptions
  - Competes with dishes on cost
    - Up to 20' for some cases
    - Could replace dish farm
  - Potential advantages, e.g.:
    - Multi-beam requirements
    - Limited or conformal space



Conclusions

- UBT concept demonstrated: TRL6 brassboard
  - Using available boards/firmware (risk reduction)
- Benefits:
  - Near-theoretical performance
  - Multipath resilience, “instantaneous” acq/track
  - High bandwidth/beam-count combinations
  - DBF has become cost-competitive vs. dishes
    - DBM cost continues to reduce over time
    - Potential ground, sea, airborne applications