ITEA TIW May 2022

Applications of Universal Beamforming Technology

Authors: Anand Kelkar (CDSI), Mark Radke (SET)

DISTRIBUTION STATEMENT A. Approved for public release; Distribution is unlimited 412TW-PA-22162

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Introduction

- TRMC has funded development of Universal Beamforming Technology at CDSI
- Mr. Mark Radke has been with Spectrum Efficient Technologies at Edwards AFB since 2008.
  - SET has been responsible for the development of several key technologies
    - LDPC , STC for SOQPSK, Network Telemetry etc.
- Mr. Anand Kelkar is a founder of CDSI: founded in 2006
  - 30 yr. USG advisors – reduce cost, increase performance, reliability
  - Developed the first airborne TM digital beamforming phased array (**we think**)
    - Fielded in 2008 – 'Bleeding edge' technology – still needs 'touch'
  - State of the art (and hardware) has increased multi-fold since then
  - Current technology in use in several applications – thank you TRMC/S&T/SET/ASTRO
- CDSI currently operates in a 15K sq.ft facility in Simi Valley, CA

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

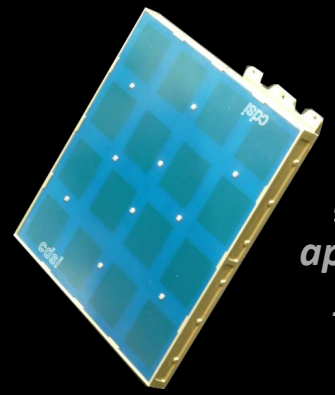
Some background

- Classic Telemetry (TM) collection terminology
  - Antenna control unit (ACU)
  - Automatic Gain Control (AGC)
  - Detection Threshold
  - Fixed-beam antenna apertures – dish, spiral, helix >> phased array
  - Agile-beam antenna apertures >> phased array (‘steerable’ antenna elements)
  - Phased array >> Electronically Scanned Antenna >> Analog, Digital Beamforming
  - Digital Beamforming >> Adaptive Digital Beamforming
- Universal Beamforming Technology (UBT)
  - Digital Beamforming Module (DBM)
  - Adaptive solution to efficient TM collection
  - System of DBMs – focus of this presentation

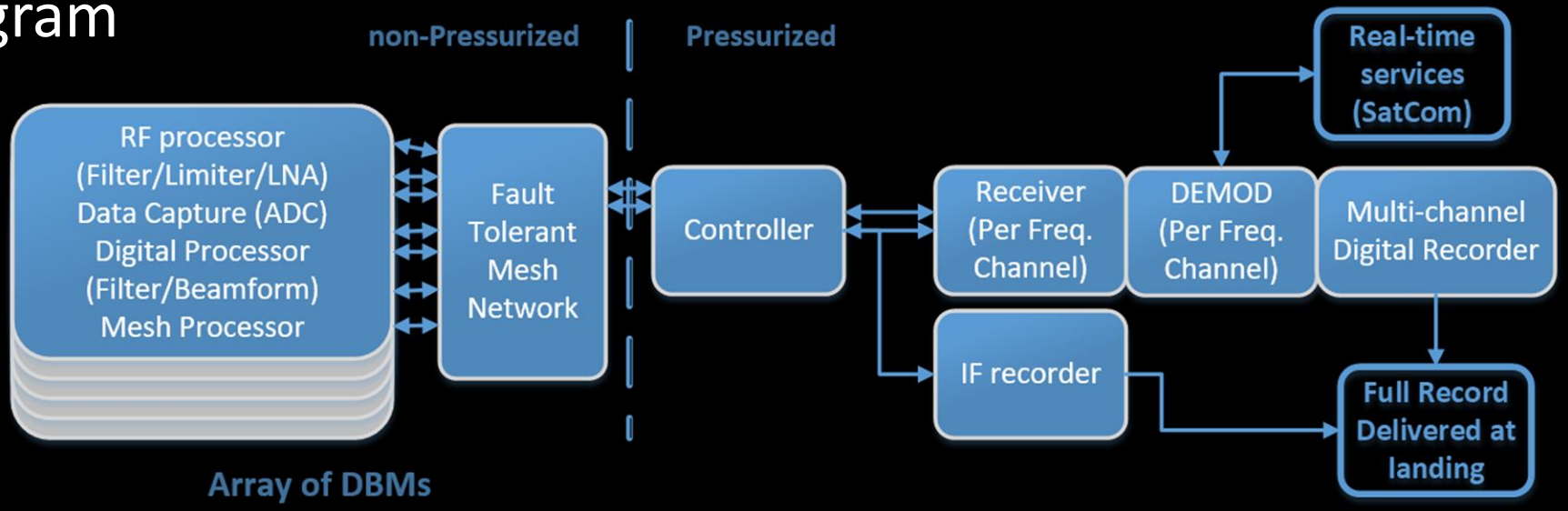
CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Some more background

- Currently fielded systems (airborne)
  - Antenna IF output >> IF recorder & Receiver/DEMOD
  - DEMOD >> Digital recorder
- Up soon: TM/IP from antenna
- Basic block diagram



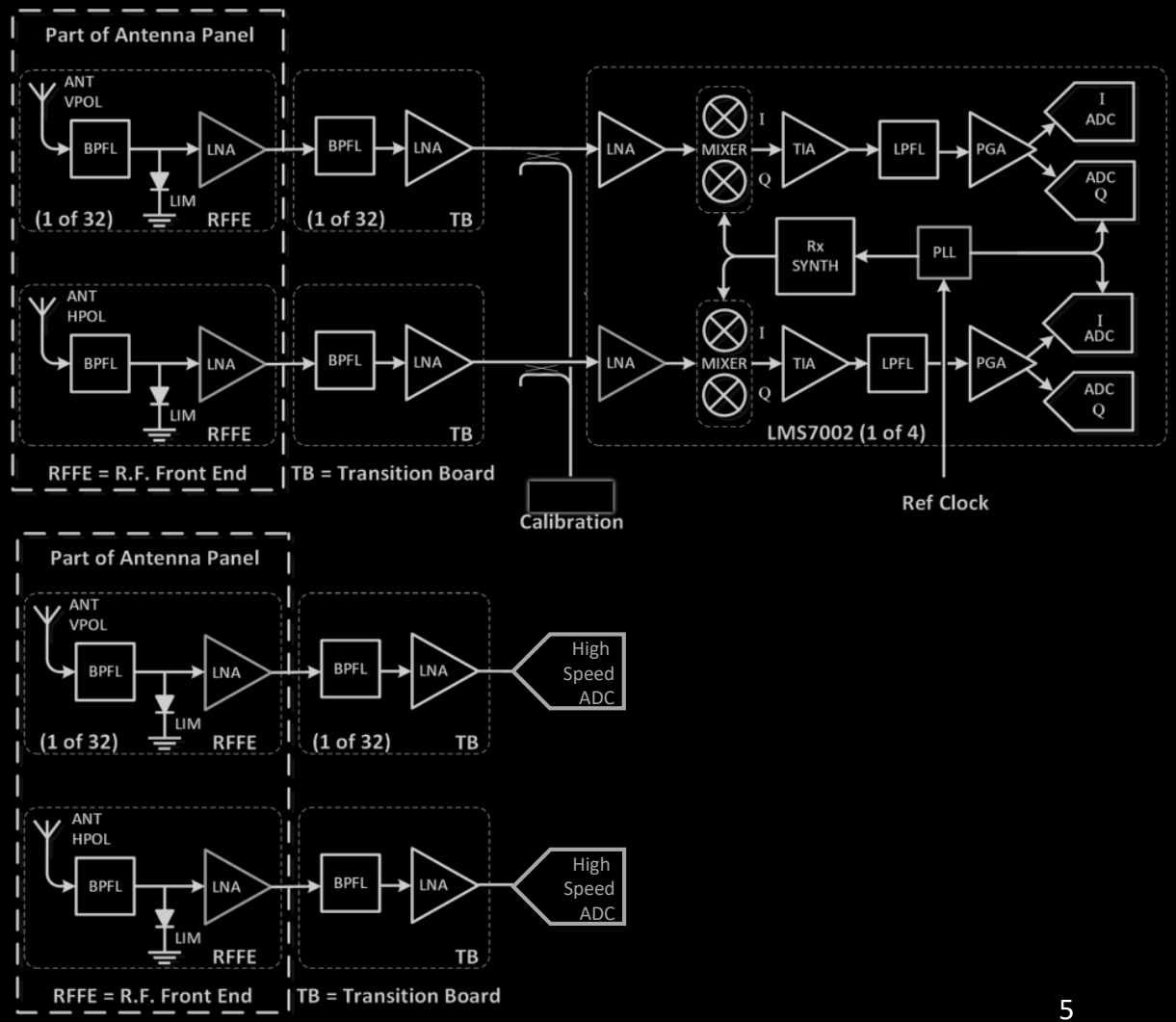
S-band DBM *approximately 10.5" square and 2" deep*



CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Few words about the DBM

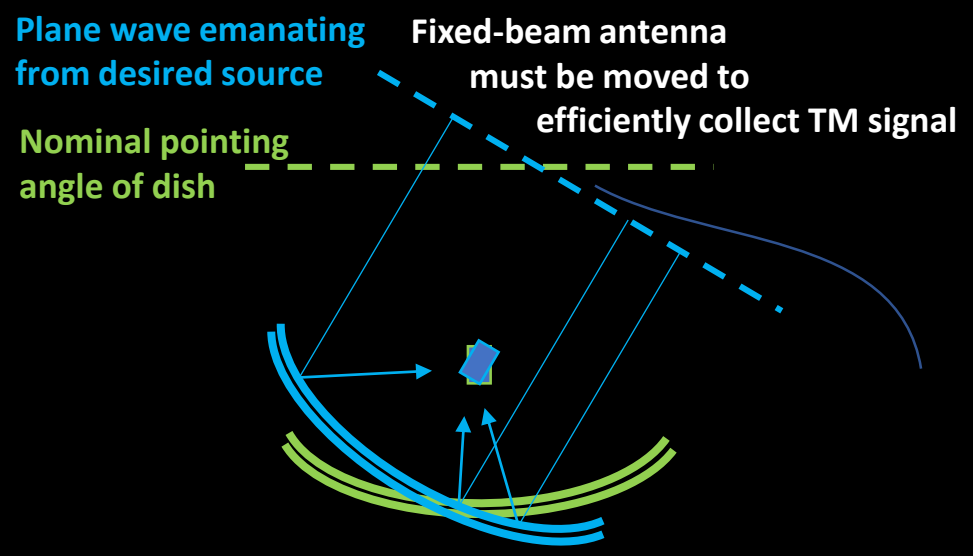
- Digital Beamforming Module (DBM)
- CDSI Fielded (v2.0): S-band only
  - 16 elements/DBM
  - 2 Downconverter (DC chains) /element
  - ~60 DBM application in use ~ 1900 DC chains !
  - All DC chains MUST be synchronized
  - Integration challenge is the DC chain
  - ~20 active components/chain before ADC
  - Drifting analog components - **HARD**
  - Development of the 'Auto-track' function
- Next up v(4.0): L/S and C-band
  - NO DC chains /element
  - ADC digitizes filter/LNA/amplifier output
    - Stable, **EASY**



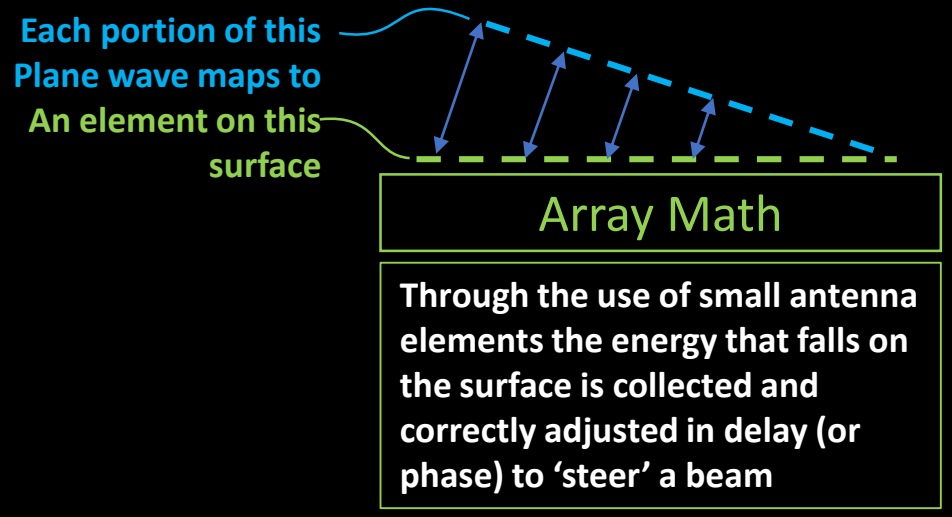
CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

How does the DBM work?

- An emulation of a dynamic fixed-beam antenna ??
  - NO… actually solving a challenge we are currently using dishes for
  - Efficiently collect RF signals that impinge on a surface



Fixed-beam Antenna

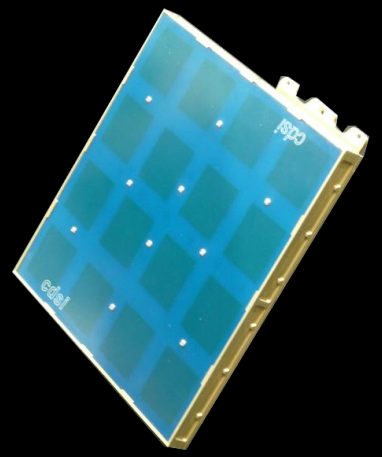


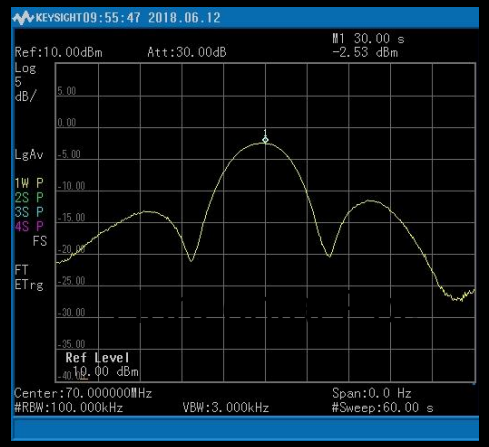
Agile-beam Antenna

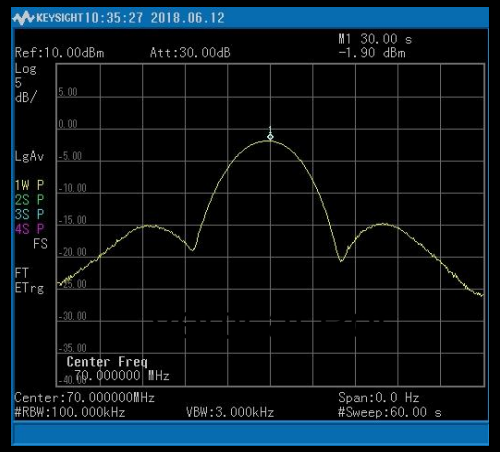
CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

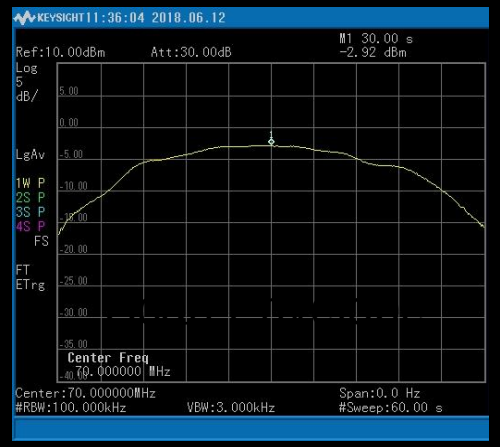
Digital Beamforming Module

- DBM contains 16 elements (4x4 configuration)
- When element phases are steered and held = Fixed aperture
- When element phases are allowed to steer = Steered
- Fixed mode for aperture shown: 3dB Beamwidth: ~30º at boresight
- Fixed aperture – something has to move antenna to point correctly
- Steered mode: Scan envelope: 110º wide at -3dB points
- Steered aperture – antenna is fixed, only the beam moves









CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

…and a system of DBMs

- S-band DBM system fielded, (L-band system almost delivered)
  - Weighs ~ 5.5 (6.5) lb., consumes about 55W
  - Square antenna ‘tiles’ ~ 10.5” (13.5”) square, 2” deep
  - Has been qualified for flight in specific airborne environments
  - Information is digitized directly behind element → fed to FPGA
  - Beamforming performed in FPGA, data + control/status rides on SERDES mesh
  - Mesh-based data transport supports graceful degradation
  - Extensive debug and data capture capabilities developed and deployed
  - Current technology in use by DoD and other Gov’t agencies (ISAR)
- L/S and C-band DBMs on the horizon, due Q1CY23

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Comparing DBMs to other tech

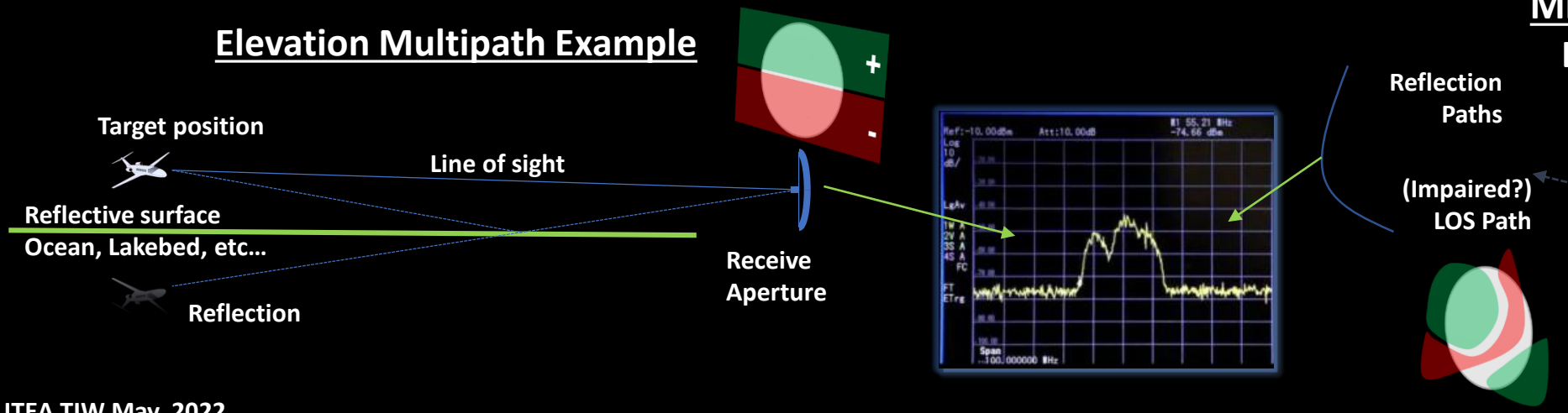
- Adaptive Digital Beamforming solution solves several classic problems
  - Classically steered antenna challenges (analog and digitally beamformed)
    - RF plumbing – VSWR, phase shifter packaging, cost, bandwidth
    - Insufficeintly modeled RF effects produce 0.5 – 1 dB inefficiency (mutual coupling ++)
    - Needs designate to prevent full scan volume search (big acquisition time)
    - Acquisition threshold for Eb/N0 is at least 7-10 dB + for 90% confidence acquisition
    - Search-acquire/track → disambiguate sidelobe track… more elapsed time, limited dynamics
    - Conformal and non-contiguous antenna solutions get very complicated
    - Multipath is handled with Draconian measures (track limit clipping, 10 – 20 dB margins etc.)
  - Universal Beamforming Technology (UBT): Adaptive beamforming
    - https://en.wikipedia.org/wiki/Adaptive_beamformer discusses several adaptive techniques
    - Mutual coupling effects are mostly overcome as normal course of processing (get 0.5 – 1 dB back)
    - Adaptive processing handles conformal and/or non-contiguous apertures without much difficulty
    - Multipath problems are significantly mitigated for sub-symbol delays

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

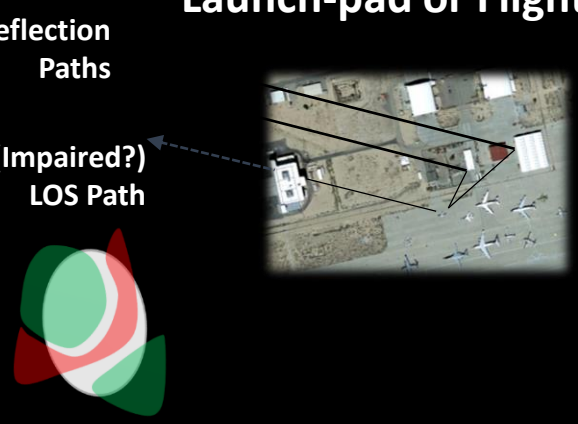
Did someone say Multipath?

- Mechanics of Multipath
  - Line-Of-Sight (LOS) illumination provides predictable behavior
  - Pointing algorithms usually created using LOS principles
  - Conventional steering algorithm can produce sub-optimal output
  - Primary multipath: aggregation of bounce paths (random phase w.r.t. LOS path)
  - Secondary multipath: aperture surface waves/mutual coupling
  - Particularly problematic collecting TM over flat terrain

Elevation Multipath Example



Mixed Multipath conditions
Launch-pad or Flight-line?

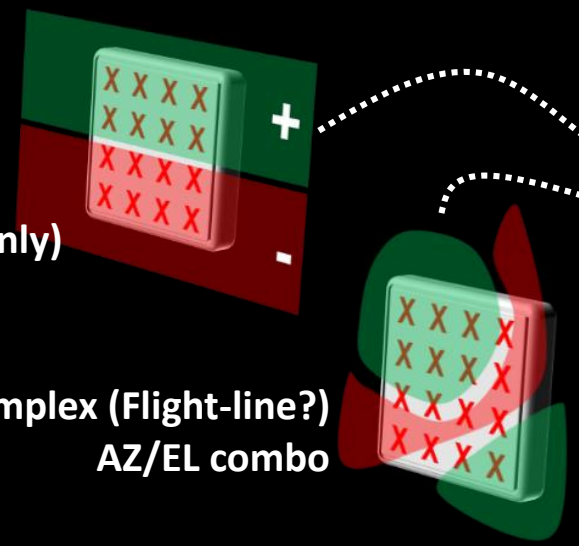


CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Multipath effects

- Monolithic apertures: Fixed-beam, classically steered arrays (analog & digitally beamformed)
  - Nothing to do but sweep Multipath into budget (10 dB ??)
  - This translates directly into antenna aperture size !!!

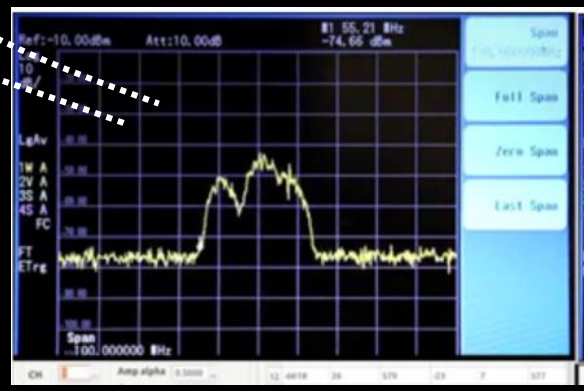
- With Adaptive Digitally beamformed apertures (UBT)
  - Acknowledge that multipath creates phase inconsistencies
  - Solution: Maximize SNR: element-level control, include mitigation such as spatial diversity
  - Reduce penalty to much smaller number (3 dB ??)



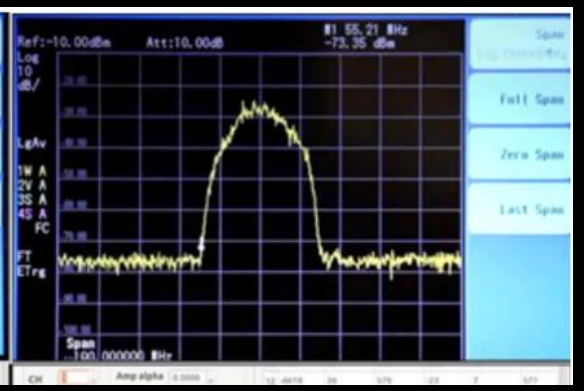
Long Range
(Typically Elevation only)

Complex (Flight-line?)
AZ/EL combo

Monolithic Processing



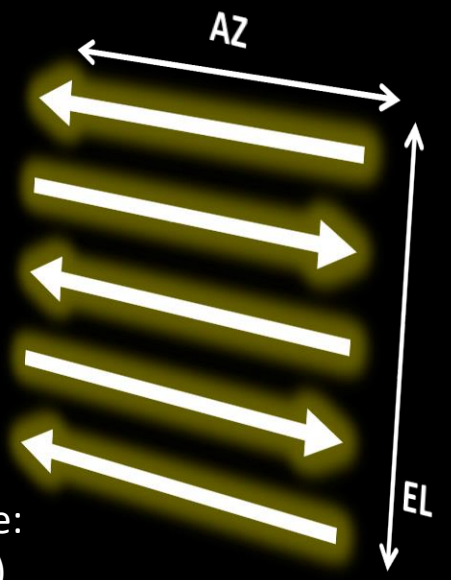
Element-Level (UBT)



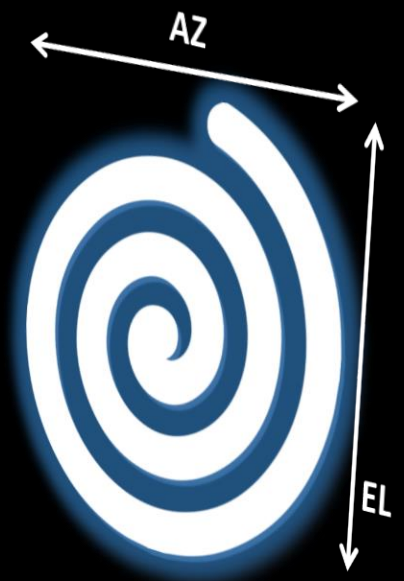
CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

How does UBT work better?

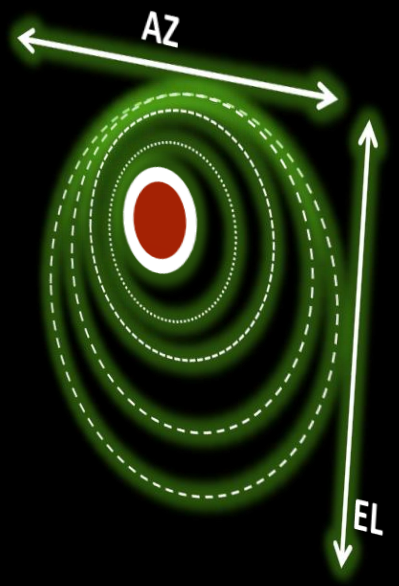
- Beamforming approach defines signal acquisition strategies
  - Classical steering operates on AGC feedback to ACU/beam-steering compoiter
- UBT uses SNR maximizing process involving all antenna elements
  - Removes first order need to know target position



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



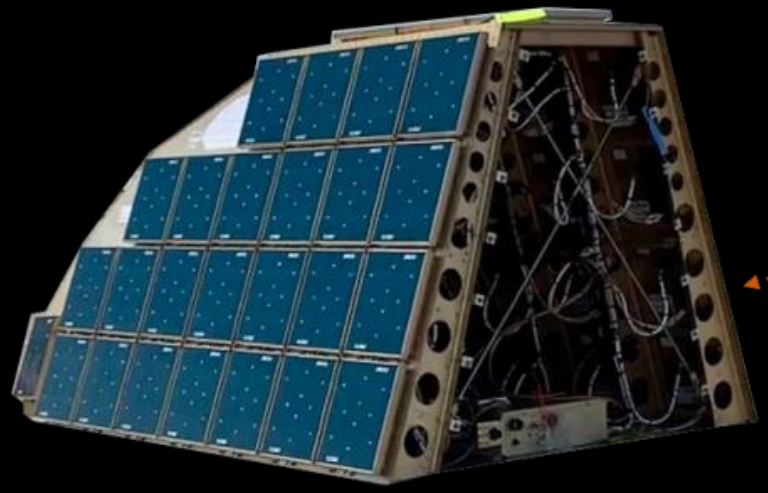
UBT Acquisition time:
1 ms for typ. TM source @ 50 mi
100 ms @ >200 mi
Track rate: >120°/sec



CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

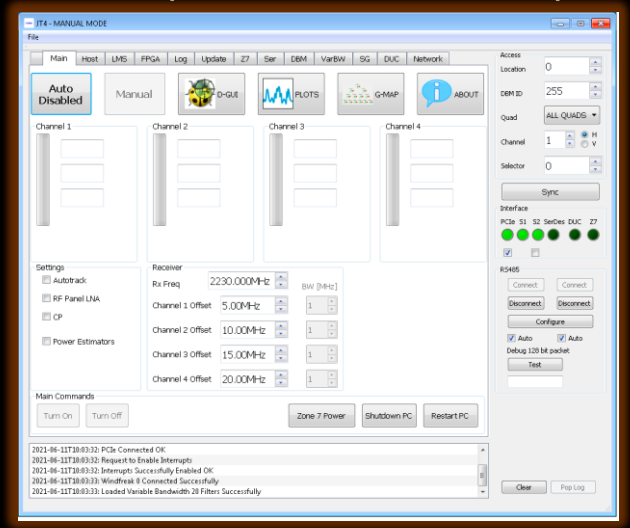
Demonstrated Use case

- DBM array
  - Designed for specific airborne applications
  - Horizon-horizon view
  - Remote Operation demonstrated
  - SATCOM control/status capable



Satcom Link
(narrowband)

Remote GUI
(@ control station)

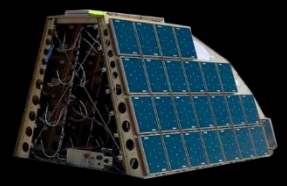


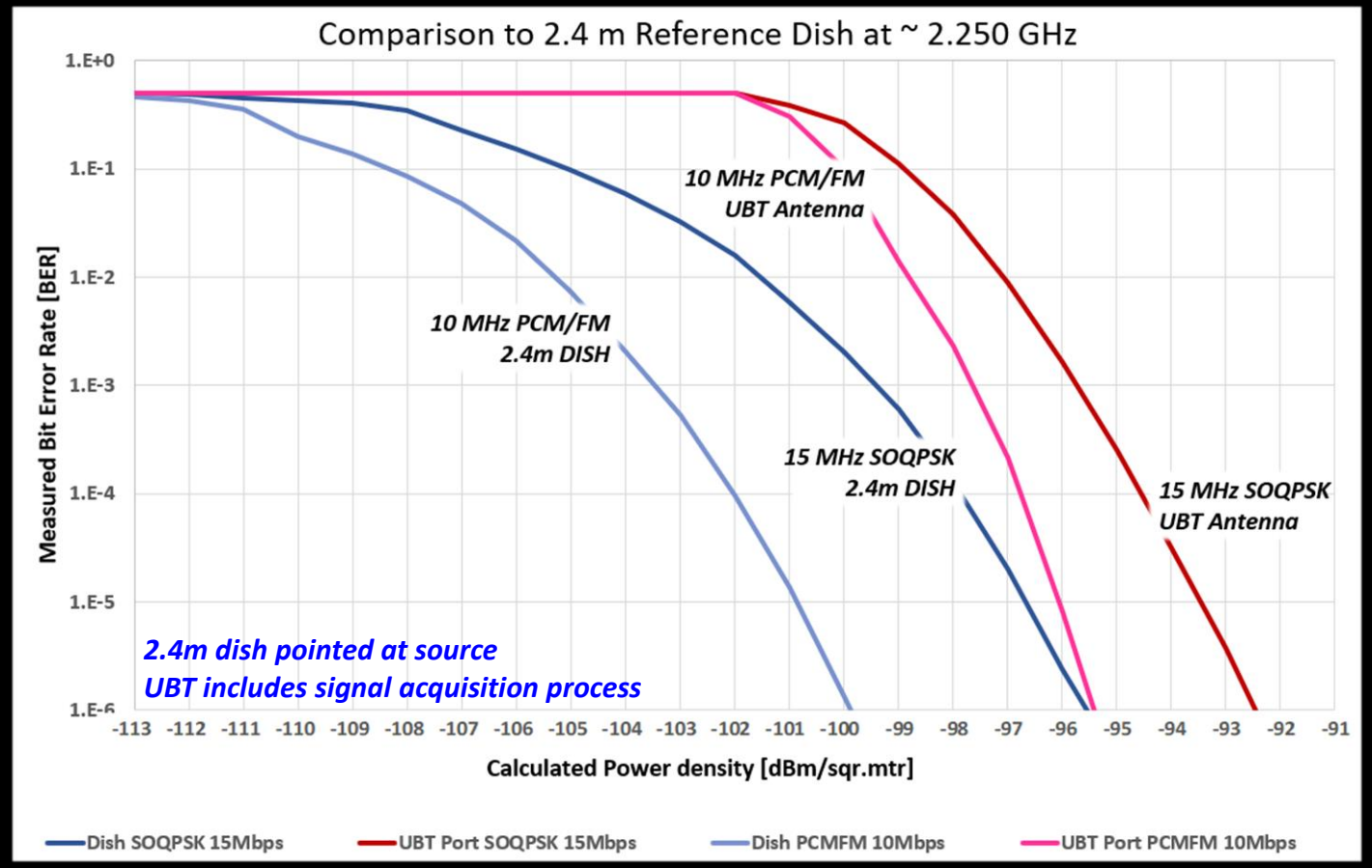
CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Currently fielded

~50 sq.ft

~18 sq.ft





- Non-contiguous, Non-planar
  - Runs autonomously
  - No designate required
  - Measured peak G/T ~ 6.5 dB/K
  - Measured peak Gain ~ 16 dBi/panel –or– ~ 30 dBi for one side of full array

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Mapping to tangibles

- TX power 5W
- TX gain = -10 dBi (10th percentile)
- Misc. losses = 6 dB
- Freq = 2.3 GHz

- Anticipated range with < 1E-6 BER (conservatively)

		# DBMs					
		1	2	3	9	16	64
BW [MHz]	1	100	141	173	300	400	800
	2	71	100	122	212	283	566
	3	58	82	100	173	231	462
	5	45	63	77	134	179	358
	10	32	45	55	95	126	253
	20	22	32	39	67	89	179
	40	16	22	27	47	63	126
		Range [mi] while maintaining < 1E-6 BER					

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

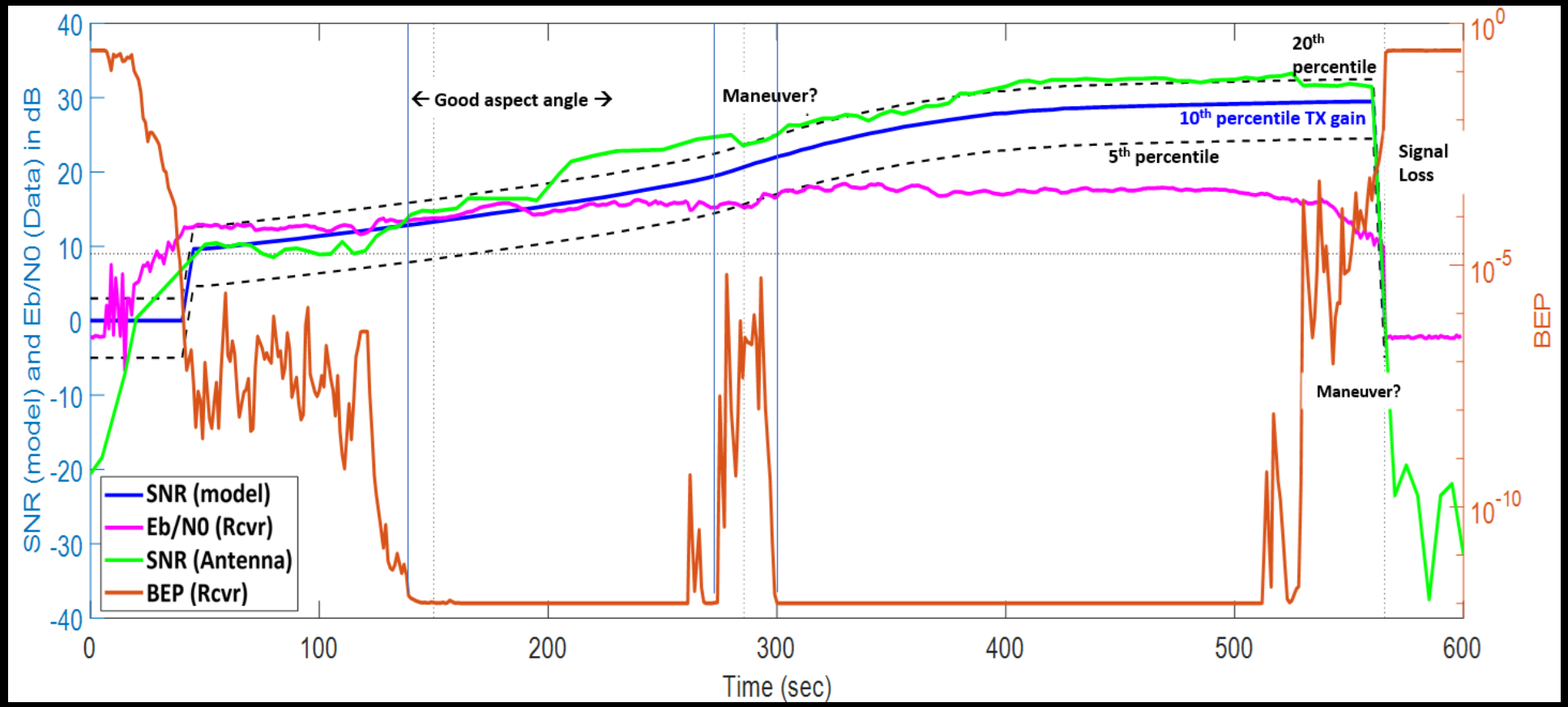
Other considerations

- Scenario Planning Tools for un-manned operations
  - Airborne use case may require
    - Several simultaneous sensors
    - Several simultaneous targets
  - Many time-sensitive constraints will apply (Lat/Lon/Alt, sun loc'n etc.)
  - Determining position of the sensors for max coverage is imperative
  - CDSI has developed planning tools to evaluate potential scenarios
    - Including Ground-based and Sea-borne assets
  - Various engagements 'scored' through Monte-Carlo simulation
  - Allows engagement evaluations long before mission executes
    - Outcomes are often counter-intuitive

CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Measured mission data vs Model

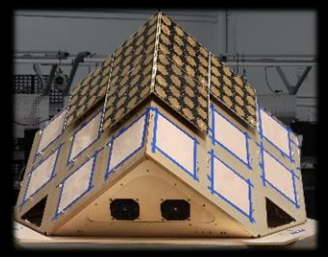
- Measured data was extracted from on-board logs after landing
- Model compared well with measured data

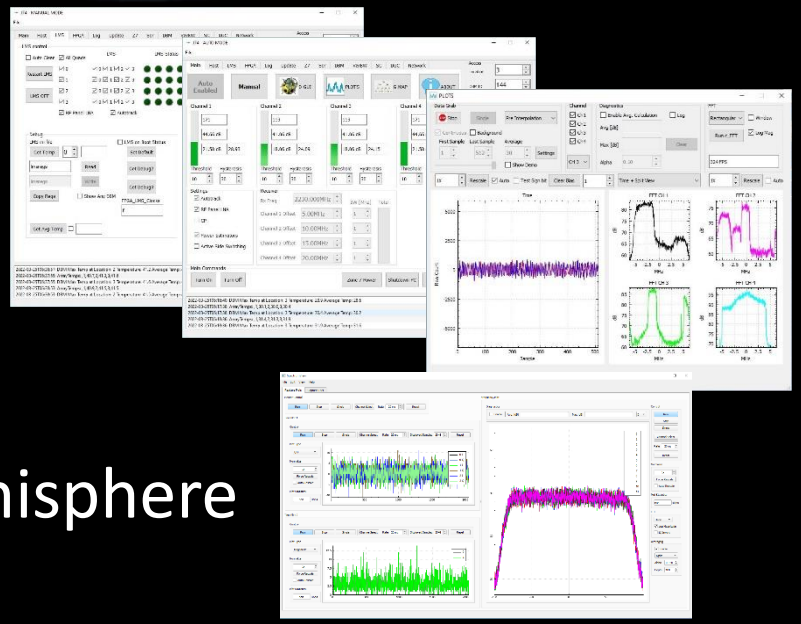


CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Other Applications

- Search & Rescue (SAR) antenna
  - Resides at LUT in Cospas – Sarsat network.
  - GPS/Galileo/Glonass bands
  - 12 – 24 simultaneous beams
  - Precision Time-of-Arrival requirements
  - Beamwidth and sidelobe control
  - Low elevation scan angle requirement
  - Axial ratio requirement
  - Shape allows relatively constant G/T over hemisphere
  - LOTS of integration controls and tools





CDSI™
CREATIVE DIGITAL SYSTEMS INTEGRATION

Summary

- Performance
  - Universal Beamforming Technology (UBT) squeezes max gain (& G/T) out of aperture
  - Adaptive beamforming used in UBT has an inherent advantage over previous approaches
- Simultaneous Multi-Vehicle Tracking
  - Unsurpassed capabilities with sheer number of simultaneous beams (30+ planned)
- Remotely Operable / Low Maintenance / Unmanned
  - Currently supporting airborne TM collection
- Low Cost
  - UBT claims to be lowest cost solution for tracking multiple independent vehicles
- Graceful degradation
  - Individual failures in antenna will not bring down the system.
- Flexible
  - UBT is designed to be expanded – want more sensitivity? – add more DBMs