Taking on the Dual-Pol Phased Array Challenge: Demonstration of the CPPAR Concept

Development of a Mobile Cylindrical Polarimetric Phased Array Radar System with Frequency-Based Elevation Beamsteering and a 192 Channel S-Band Radar Backend

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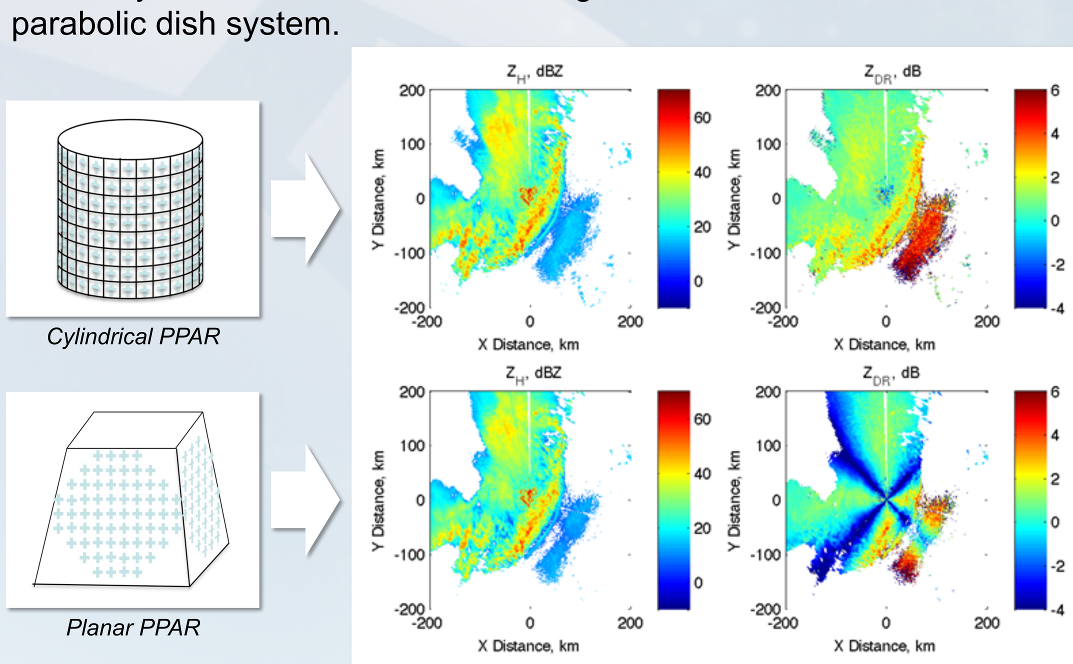
Advantages of Cylindrical PPAR over Traditional Planar PPAR

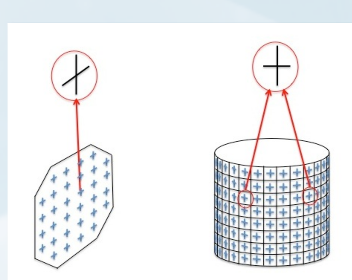
Traditional phased-array radars are comprised of a small number of large planar faces which are arranged to form a 360 degree field of view. This is more straightforward from a manufacturing standpoint and works quite well for non-polarimetric and tracking/detection applications, but significant problems become apparent when the same methodology is applied to dual-pol weather radar applications. The two main problems are azimuth scan losses between the planar faces and the large polarization bias which occurs when the beam is steered away from the principal planes. Both the former and the latter can be compensated for, but not without an unrecoverable degradation in sensitivity and polarimetric performance. Without a more innovative approach, a future MPAR system could become a downgrade from the current WSR-88D parabolic dish system.



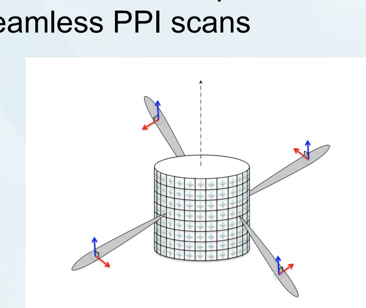
Sensitivity loss > 7.5 dB

Polarization bias > 6 dB

The cylindrical polarimetric phased array radar (CPPAR) has been proposed as a way to deliver both the polarimetric performance needed for weather applications and the fast-scanning capabilities required by a multi-function phased array radar (MPAR).



Adds a "commutating scan" option to PPAR capabilities which enables:
•Azimuth scan-invariance for high-quality, quantitative polarimetric radar measurements with no scanning losses
•No scanning loss - higher efficiency through full utilization of the aperture and no need to sensor large amounts of data to form seamless PPI scans
•Simple/efficient scalar polarimetric calibration
•Polarization orthogonality in all beam directions
•No need for face-to-face matching
•Multiple beams can commutate simultaneously

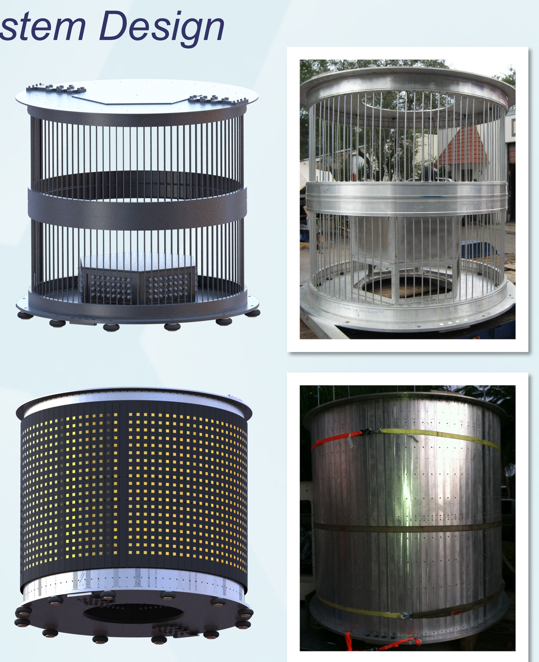


✓ All functionality of four-faced PPAR is preserved
✓ Seamless transition from WSR-88D with no degradation in performance

OU/NSSL CPPAR Demonstrator

Mechanical System Design

Precision Cylindrical Antenna
- 2m diameter with 1mm tolerance
  - Precision diameter achieved using large vertical lathe
- Access to inside/outside surfaces
  - Hatch door for inside access
- PCB antennas mounted to rigid machined channels which also form continuous ground plane
  - Pattern of aluminum clamps and u-channels form rigid structure
- Antennas connect to electronics through replaceable bulkheads
- Vibration isolation preserves structural integrity and precision



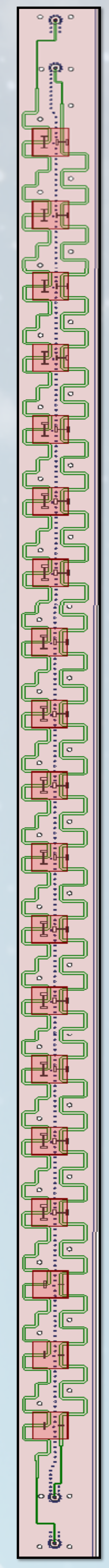
Radar Electronics Enclosure
- 14,000lb GVWR dual-axle trailer
- 7 x 32U shock-mounted racks with full access to all sides
- Power/control/antenna cable routing integrated into structure
- Ports for power/data/cal signals
- Dual 13,000 BTU HVAC units

Extremely Flexible System
•Electronics can control any type of array (192 s-band channels)
•Plans for planar array demo (with column arrays and without)
•Other possibilities…
  - Cylindrical dual-pol imaging radar
  - Cylindrical near-field scanner
  - Active arrays (add control/power to bulkheads)

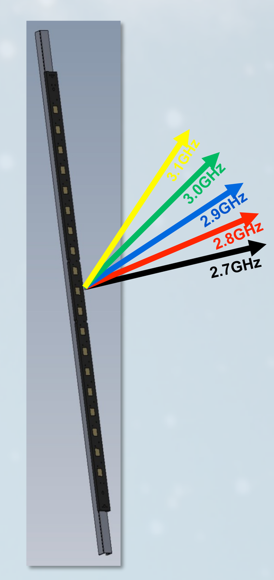
Dual-Polarized Frequency-Steered "Column" Array Antenna

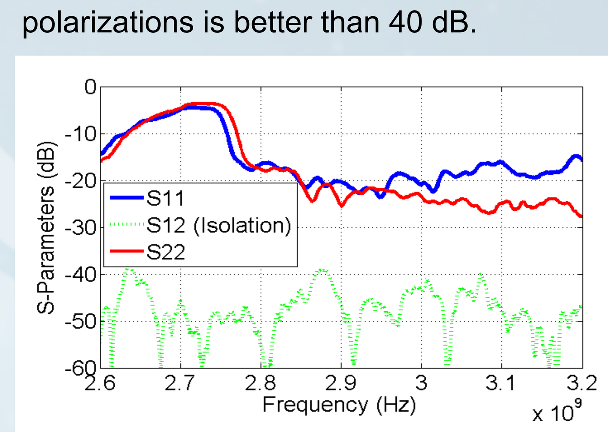
A 19-element, 1.5 m long, 65 mm wide series feed array antenna with 5 PCB layers is designed and manufactured. The array antenna operates in the frequency band of 2.7 to 3.1 GHz. The material used for the antenna is Taconic TLX-8 with a dielectric constant of 2.55. The antenna consists of the radiating patches, parasitic patches, two main transmission lines, and two ground planes.

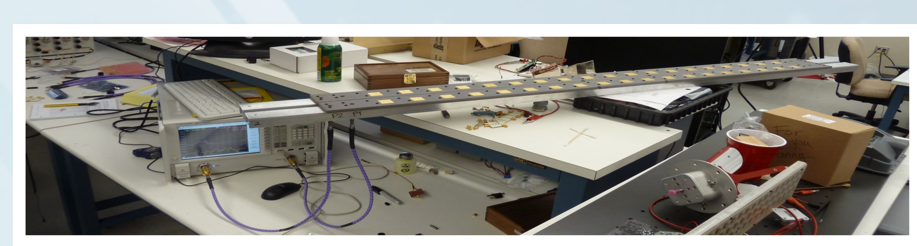
The desired power is coupled through the aperture in the ground plane on third layer. The left and right lines excite the horizontal and vertical polarizations, respectively. The element to element phase shift is controlled by the length of the main transmission lines. The phase shift criterion dictates the distance between the elements. The element spacing, d, is 70 mm for this design. However, the electrical length of transmission lines from element to element is 2λ. By changing the frequency the phase shift between the elements is changed and the beam is scanned.



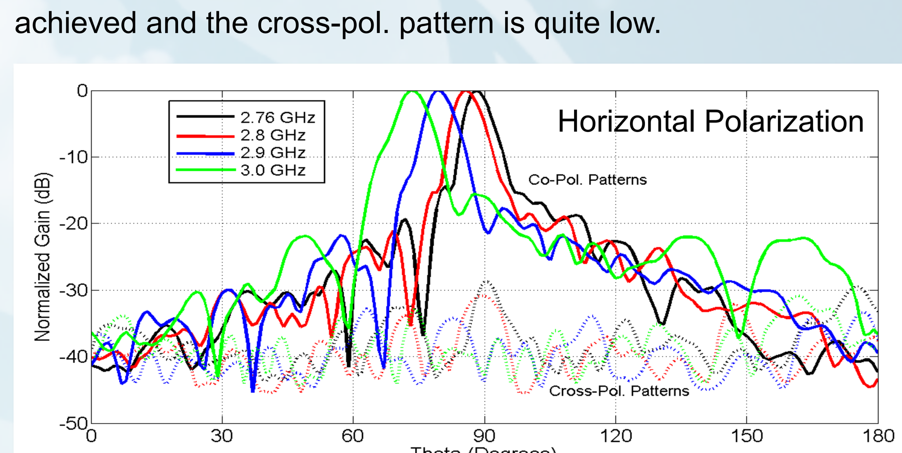
The measured S-parameters show that the desired return loss is achieved and the isolation between Vertical and Horizontal polarizations is better than 40 dB.

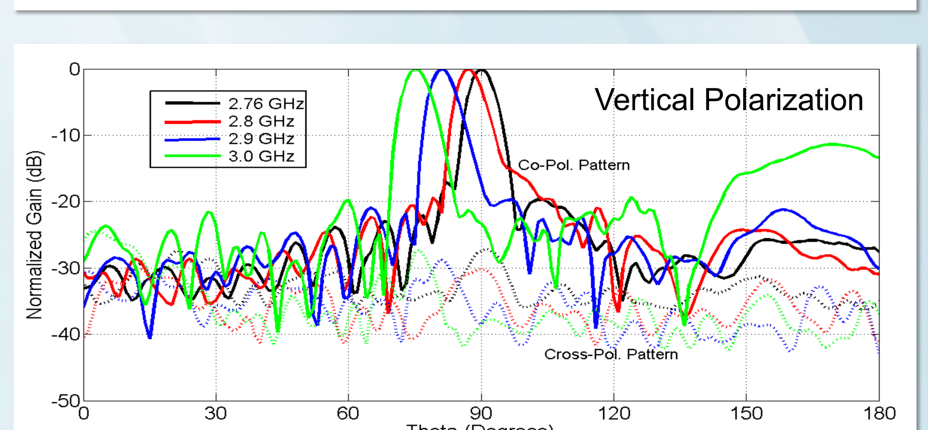




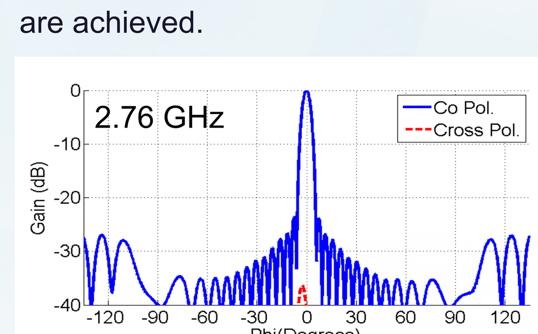


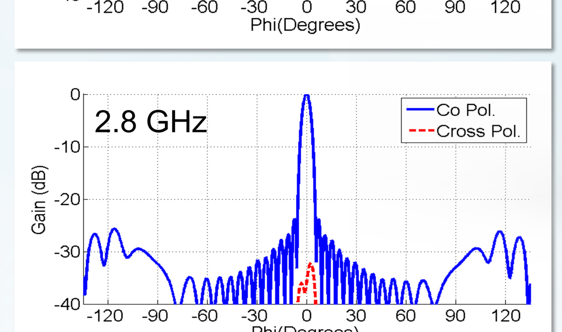
The radiation patterns of the antenna at different frequencies are shown bellow. It can be observed that the desired SLL levels are achieved and the cross-pol. pattern is quite low.

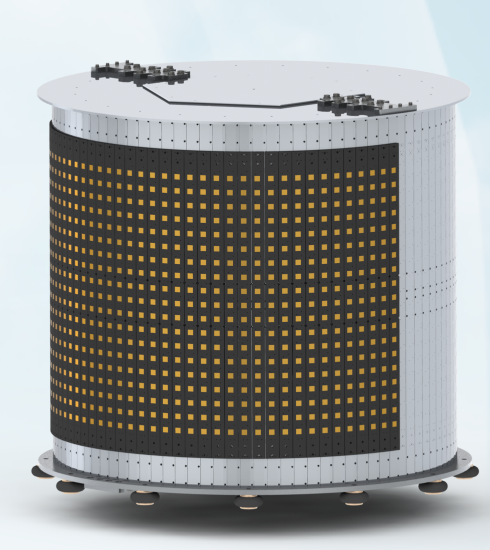




96 antenna columns mounted on the surface of a cylinder can cover the whole cylinder. The column to column spacing is 65 mm. The cylindrical antenna array configuration and the azimuthal radiation patterns of the antenna are shown below. The beam is formed from a 90° sector with 24 active antenna columns. Taylor amplitude distribution is applied to the antenna columns. It can be seen that the desired sidelobe levels and low cross polarization patterns are achieved.

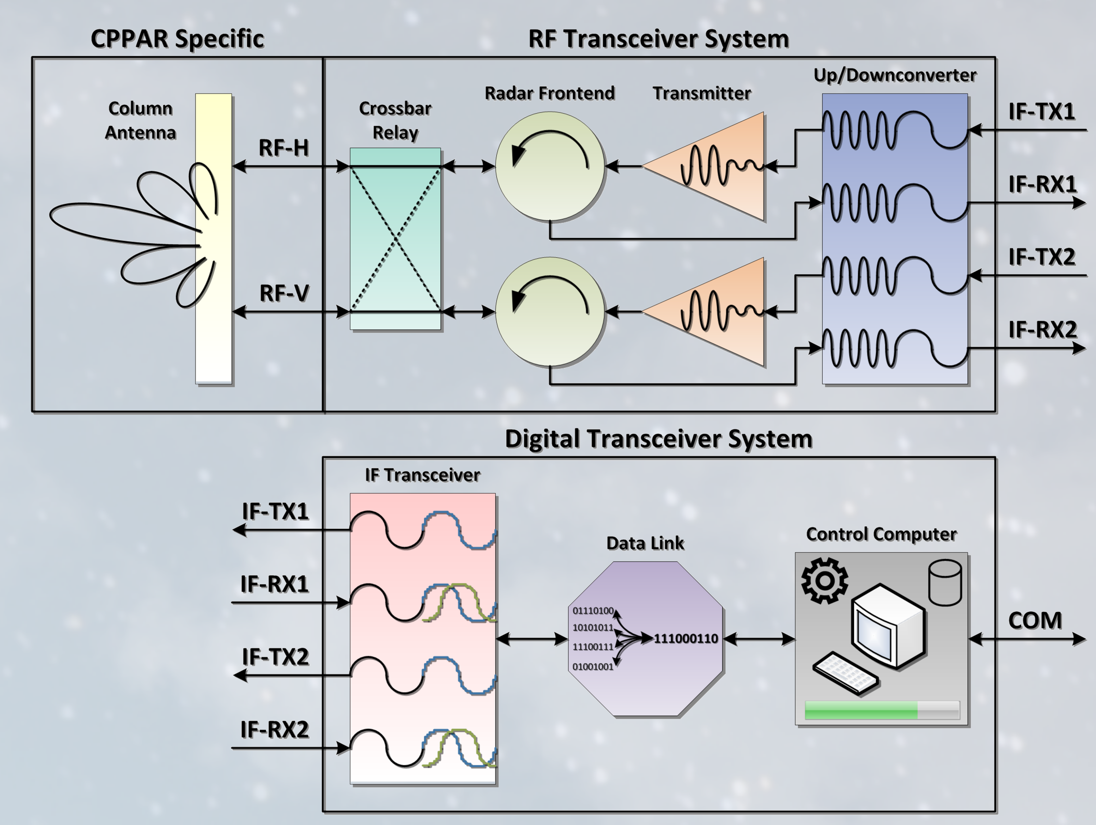






CPPAR Antenna with 180°Populated

192 Channel Capacity S-Band Radar Backend Electronics



CPPAR demonstrator channel block diagram

Distributed Control and Monitoring

Each intermediate frequency (IF) transceiver acts as a real-time controller for two channels and can monitor the unique ID and operational health status of each radio frequency (RF) transceiver sub-module. If a component requires maintenance, the operator will be notified and the channel can be automatically disabled, if necessary, to prevent damage from occurring.

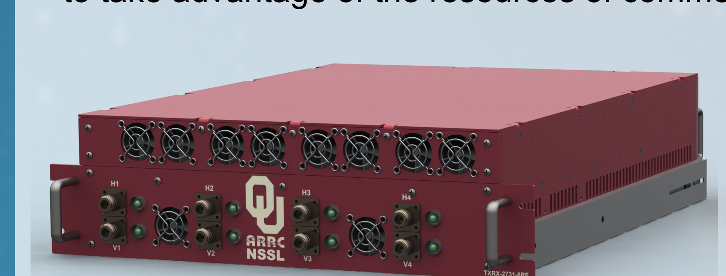
A common reference clock and a synchronization procedure are required to align all of the transceivers. After this power-up synchronization is performed, subsequent commands will be executed simultaneously to ensure radar coherency.

The transmitted pulse is fed back through the receiver to measure and correct for distortions introduced by the transmitter. This closes the loop to enable innovative transmit signals to be used which may be sensitive to unaccounted-for distortions and removes the need to calibrate for each waveform.

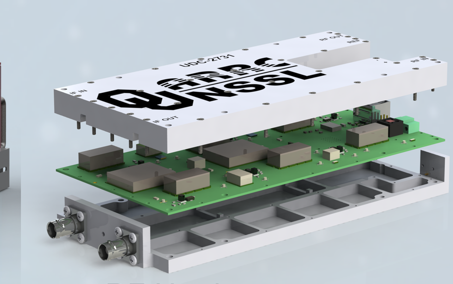
Modular System with Custom Hardware

Through the use of robust modular hardware and decentralized real-time control, the number of system channels may be increased without complicating the overall system architecture. This allows many hundreds of channels to be transmitted, received, and synchronously processed independently and simultaneously.

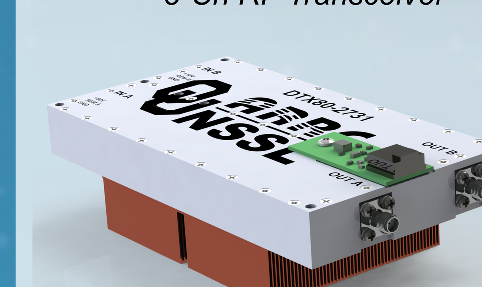
Data from multiple IF transceivers are aggregated at the data link and control computer levels to reduce the number of processing nodes and to take advantage of the resources of commercial processing platforms.



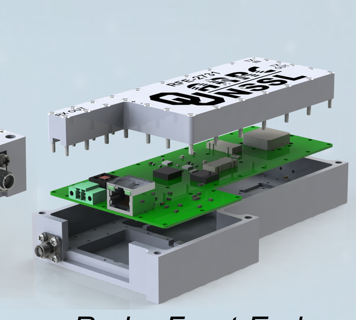
8-Ch RF Transceiver



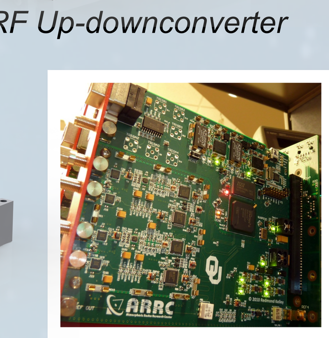
RF Up-downconverter



80W GaN Dual Transmitter



Radar Front-End



2-Ch IF Transceiver

CPPAR Demonstrator Calculated System Performance

General	
Operating Frequency Range	2700 - 3100 MHz
Instantaneous Bandwidth	30 MHz
Sensitivity (w/o pulse compression)	20 dBZ @ 15 km (4 μs PW)
Sensitivity (w/ pulse compression)	20 dBZ @ 50 km (100 μs PW)
Antenna	
3-dB Beamwidth	4.5°(90°Active Aperture)
Polarization	Dual-Linear
Cross-Polarization Level	< -30 dB
Elevation Scan Range	0 - 20°(2.7 - 3.1 GHz)
Transmitter	
Peak Power	1.5 kW (24 x 80W - Loss)
Pulse Width	1-100 us
Maximum Duty Cycle	15%
Receiver	
Minimum Gate Spacing	15 m
Maximum Data Throughput	200 Mbps per Channel

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