Implementation of a Far-Field Tower for Calibrating a Dual-Polarization Planar Phased-Array Radar

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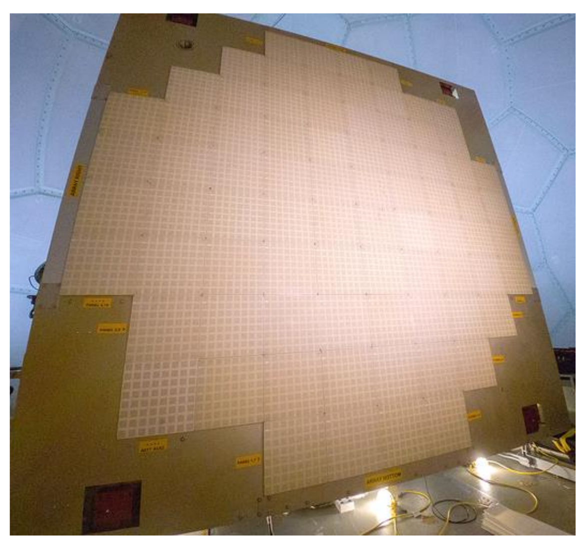
Abstract

The NOAA National Severe Storms Laboratory is currently in the calibration and test phase of the Advanced Technology Demonstrator (ATD), a full-scale, S-band, dual-polarization, active planar phased array weather/air traffic radar. Calibration to achieve satisfactory polarimetric performance remains among the greatest risks for dual-polarization phased array weather radars, as uncalibrated H- and V-channel beams do not necessarily illuminate the exact same volume and electronic steering introduces cross-polar components that bias dual-pol variable estimates. To produce reliable polarimetric variable estimates, it is critical that the H- and V-channel beam peaks are spatially aligned for all scanning angles and that steering-dependent cross-polar patterns are accurately measured and accounted for.

To support these measurements, a 45 m tower was erected in the far field of the ATD, 425 m to the north. Atop the tower is an S-band standard gain horn on a motorized platform that allows it to rotate about its axis, enabling measurements in horizontal or vertical orientation. Although the tower location is fixed, measurement at any electronic steering angle is possible by mechanically positioning the ATD antenna such that the steering angle of interest points toward the calibration tower. An equipment shelter local to calibration tower contains a network of switches and other RF equipment to route signals and adjust power levels in support of multiple modes of measurement (e.g. transmit only, receive only, two-way with delay, single element measurement). This shelter is connected to the ATD by underground network and RF-over-fiber links. Using a dedicated processor and a custom interface board to control the tower equipment, intricate multi-part measurement strategies can be automated in the ATD software (for example, collecting H- and V- channel beam peak measurements for hundreds of steering angles). This poster focuses on the implementation of the calibration tower infrastructure to support all desired measurement types, including challenges and mitigations resulting from preliminary measurements.

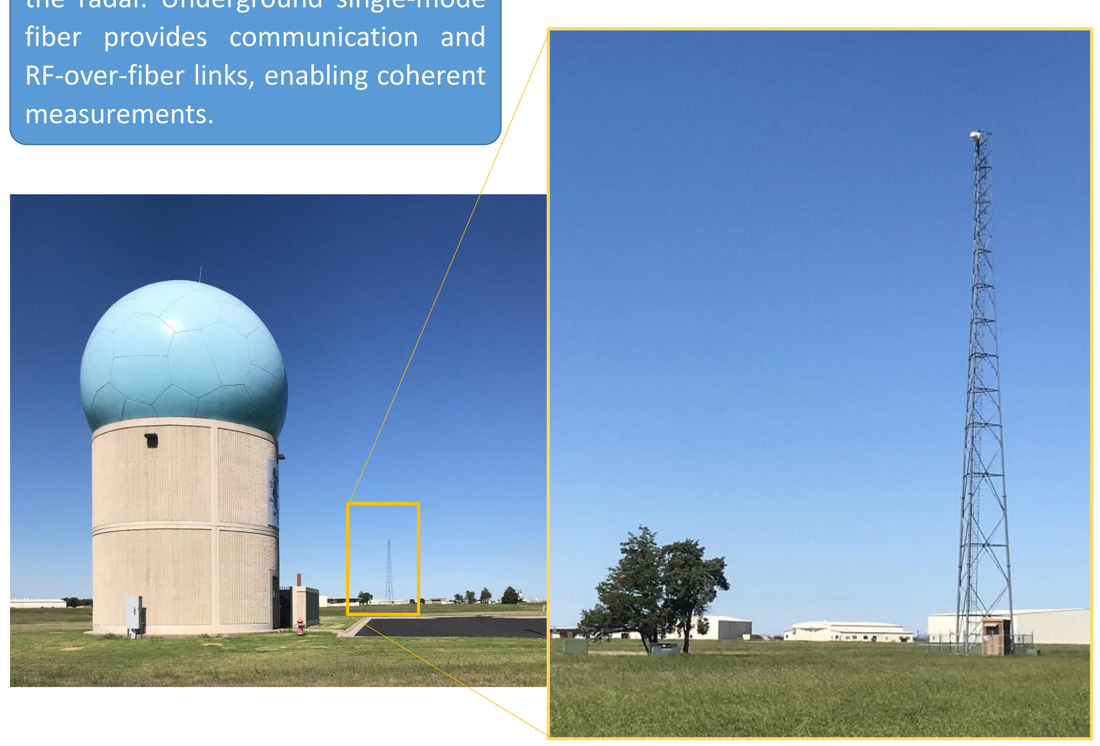
Advanced Technology Demonstrator

The ATD radar (right) is a dual-polarization phased array weather radar installed in Norman, Oklahoma in 2018.



Calibration Tower

The Calibration Tower (below-right) is a subsystem of the ATD radar for characterization of the far-field antenna patterns and calibration of the radar. Underground single-mode fiber provides communication and RF-over-fiber links, enabling coherent measurements.



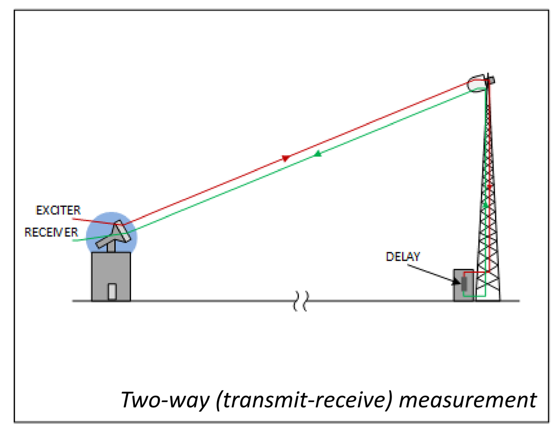
Above: Aerial view of calibration tower measurement range. Calibration tower location is noted; imagery has not been updated since tower was installed in 2019 (imagery: Google Earth).

Mode Examples

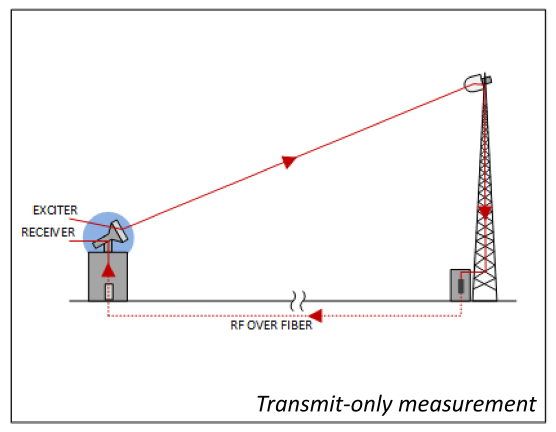
Right: A pulse from the ATD is received by the calibration tower horn, delayed 100 µs, and re-transmitted back at the ATD.

Below: A pulse from the ATD is received by the calibration tower horn and routed to the receiver via the RF-over-fiber link.

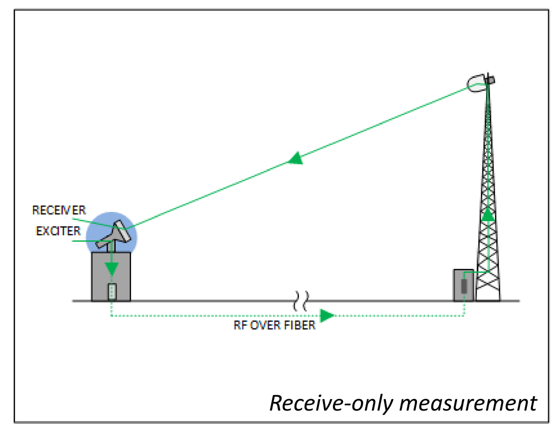
Below right: A pulse generated by the ATD exciter is routed via RF-over-fiber link and transmitted by the calibration tower horn.



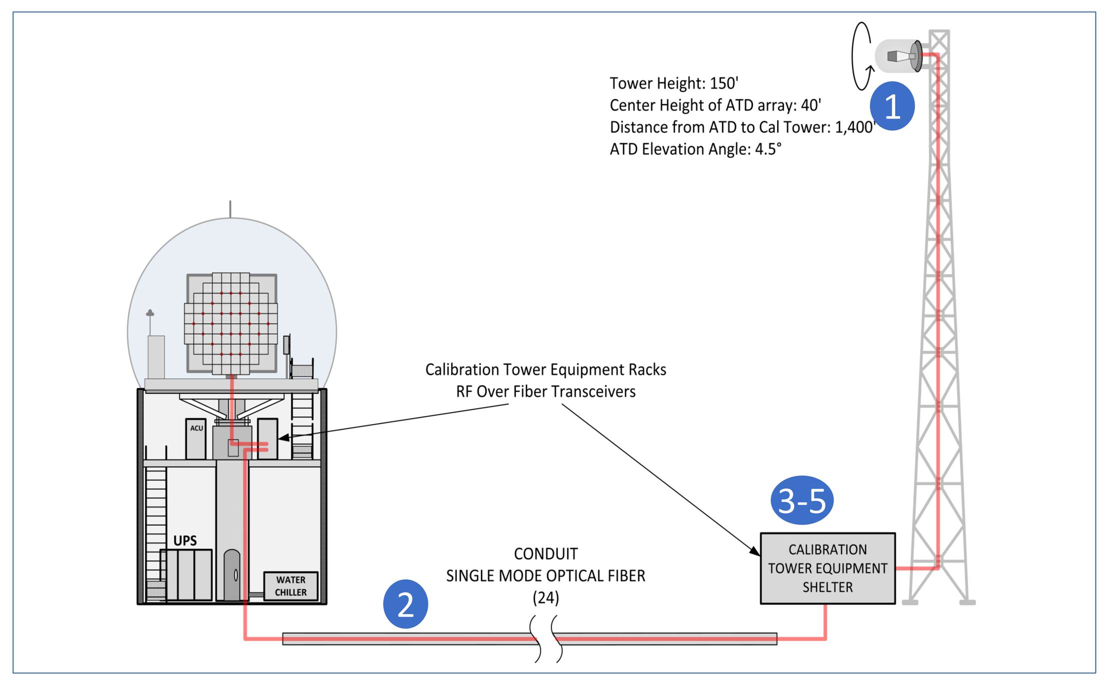
Two-way (transmit-receive) measurement



Transmit-only measurement

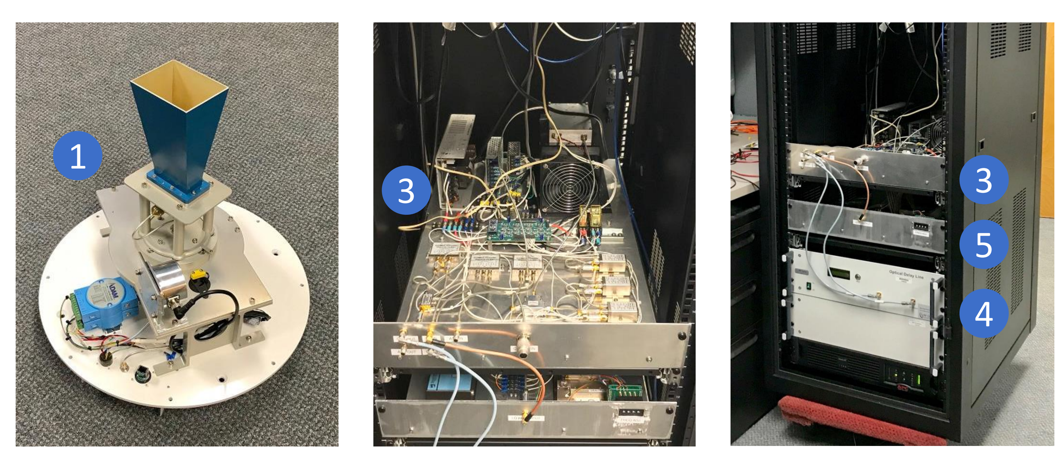


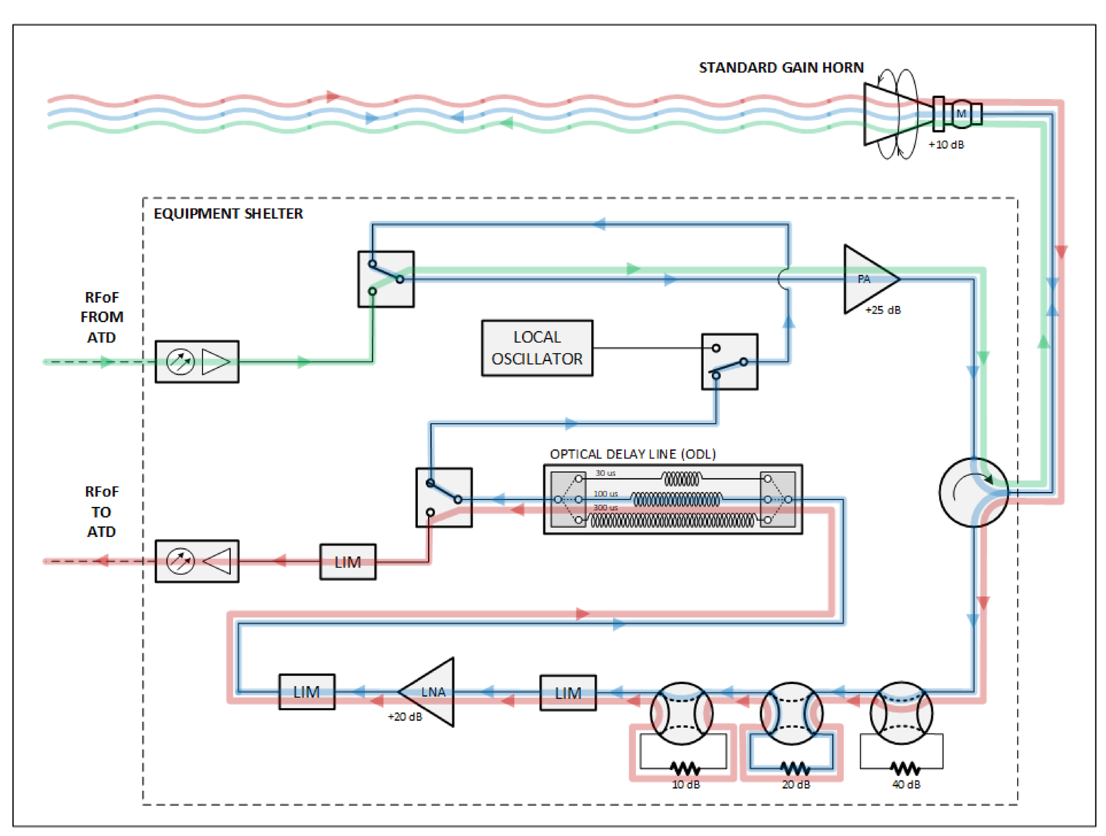
Receive-only measurement



Equipment Overview

The Calibration Tower comprises a rotating horn (1) on a 45 m tower connected to the ATD radar via single-mode fiber (2). At the calibration tower shelter, a network of switches (3), an optical delay line (4), and a continuous-wave RF source (5) enable multiple measurement modes (see below). Control of all remote equipment is automated by the main system.

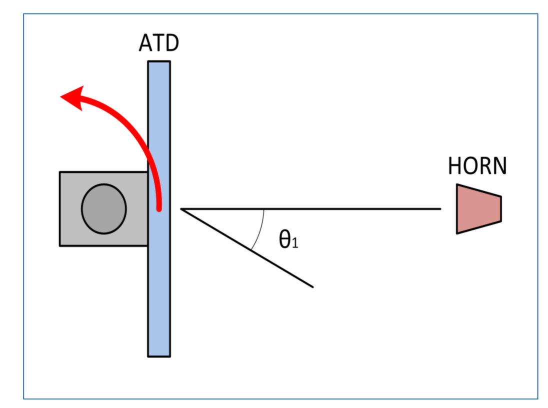




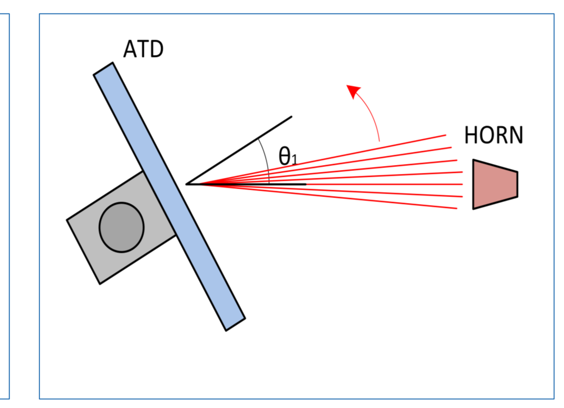
Above: Schematic diagram of calibration tower shelter equipment showing signal paths for two-way antenna measurements (blue), transmit-only antenna measurements (red), and receive-only antenna measurements (green)

Steered Beam Characterization Using the Far-Field Tower

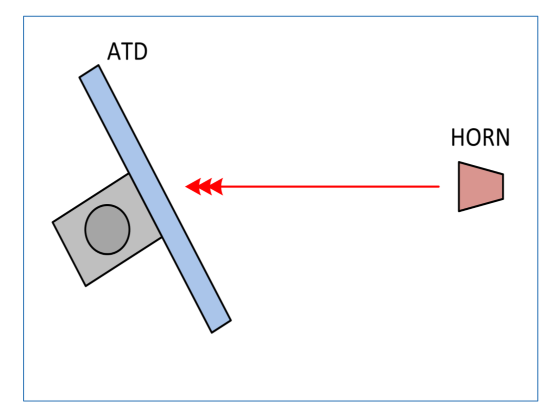
Due to the existence of cross-polar patterns and steering-angle-dependent gains in both polarizations, it is necessary to characterize the beams at a large number of steering angles. Although operationally the ATD radar will scan only electronically, the antenna can also be mechanically positioned in both azimuth and elevation. To measure these steering-dependent beam biases, the antenna is mechanically moved in steps. At each step, the beam is electronically steered toward the tower, and both transmit and receive measurements for both polarizations are captured for the associated steering angle. This data can be used to calibrate out the steering angle dependence of power returned as well as any mismatches between the horizontal and vertical beam peaks. The process illustrated below is entirely automated.



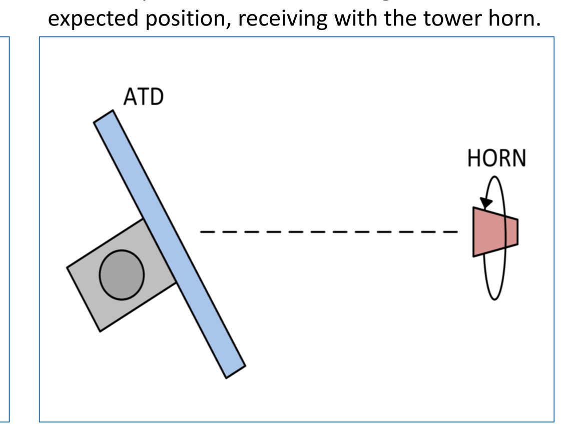
1. Mechanically move ATD antenna such that first desired steering angle is toward the tower.



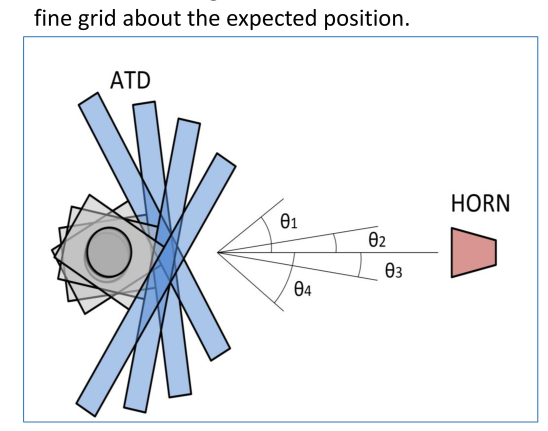
2. Electronically steer toward the tower and transmit pulses in a small, fine grid around the expected position, receiving with the tower horn.



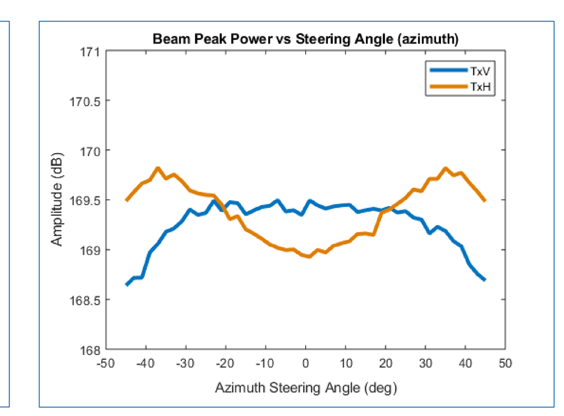
3. Transmit from the tower horn and receive with the ATD, scanning the receive beam in a small, fine grid about the expected position.



4. Rotate the horn 90° and repeat steps 2-3 for the other polarization.



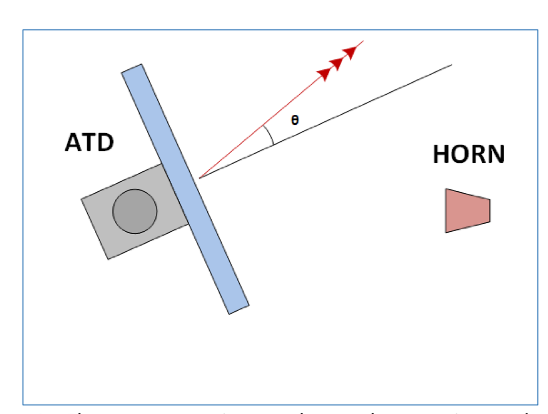
5. Mechanically move the ATD antenna and repeat steps 1-4 for every desired steering angle.



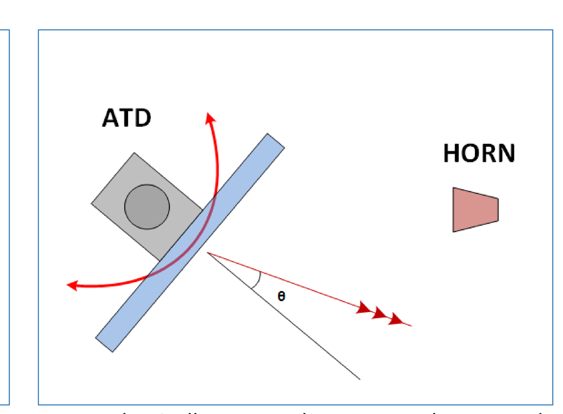
6. After data collection, separately plot TxH, TxV, RxH, and RxV vs. steering angle. For each coarse steering angle, use the peak from its fine steering grid to ensure the best beam-horn alignment. (credit: D. Schvartzman, CIMMS)

Pattern Measurement Using the Far-Field Tower

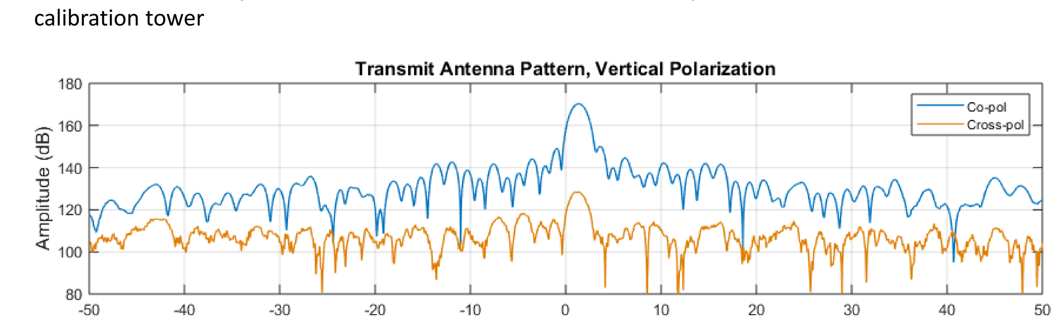
It is also possible to derive far-field antenna patterns from measurements using the calibration tower. The ATD is configured to transmit (or receive) continually at a single electronic steering angle while the antenna is mechanically rotated to sweep the beam across the calibration tower horn. This can be repeated for any steering angle and for transmit, receive, or two-way patterns.



1. Choose a steering angle to characterize and transmit continually from the ATD or the calibration tower



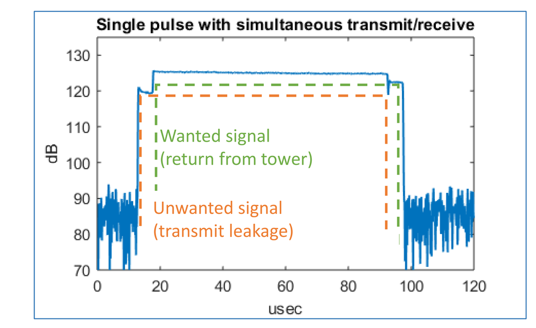
2. Mechanically rotate the ATD so the steered beam sweeps across the calibration tower horn.

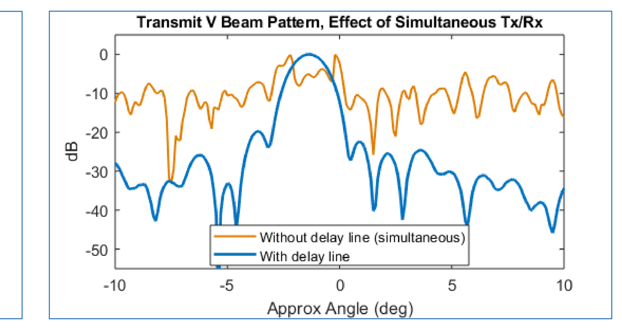


Above: Transmit antenna patterns (ATD transmitting in vertical polarization, calibration tower horn receiving in vertical for co-pol and horizontal for cross-pol)

Challenge: Simultaneous Transmit and Receive

The ATD supports pulse widths up to 150 µs, far longer than the ~5 µs round-trip time for pulse to reach the calibration tower and return. To receive the beginning of the pulse, the receiver must be listening even while the end of pulse is still being transmitted. This is acceptable when the ATD antenna is transmitting from a single element or receiving. However, when transmitting from all elements, RF leakage corrupts the desired return signal. A delay line was added to temporally separate the return from the transmission.





Left: When transmitting with the full array, the receiver sees a combination of the desired return from the calibration tower and the transmit pulse in the form of RF leakage from the high-power amplifiers. *Right:* The transmit leakage corrupts the transmit pattern measurements (orange trace). When the desired signal is separated in time from the transmit, the pattern is recoverable (blue trace).

Challenge: Multipath Mitigation

One challenge associated with using a tower on an uncontrolled range is that unwanted reflections from the ground and nearby structures may interfere with the desired signal from the direct path. Permanent mitigating structures (e.g. RF absorber or diffraction fences) will need to be installed to reduce the impact of secondary reflections on the measurements.

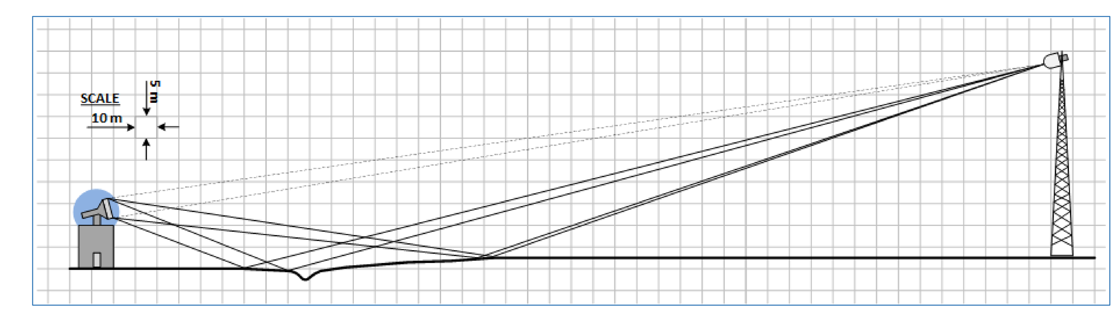
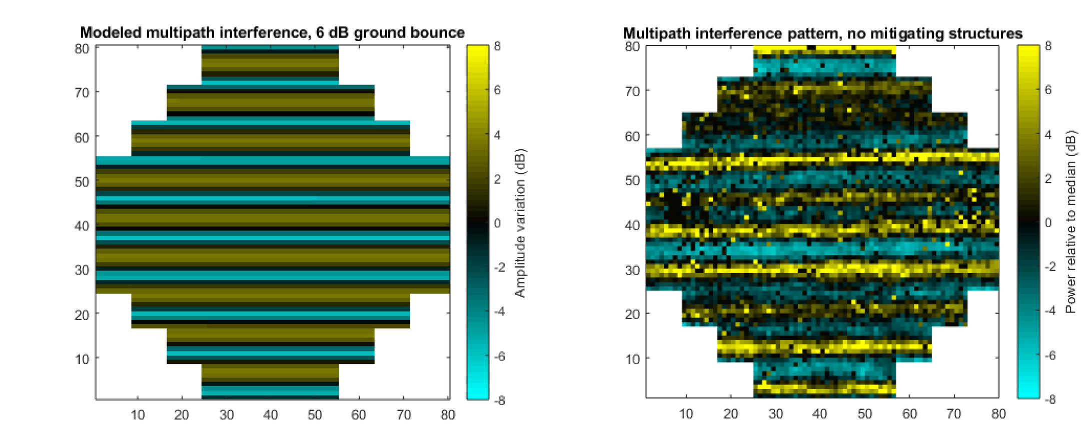
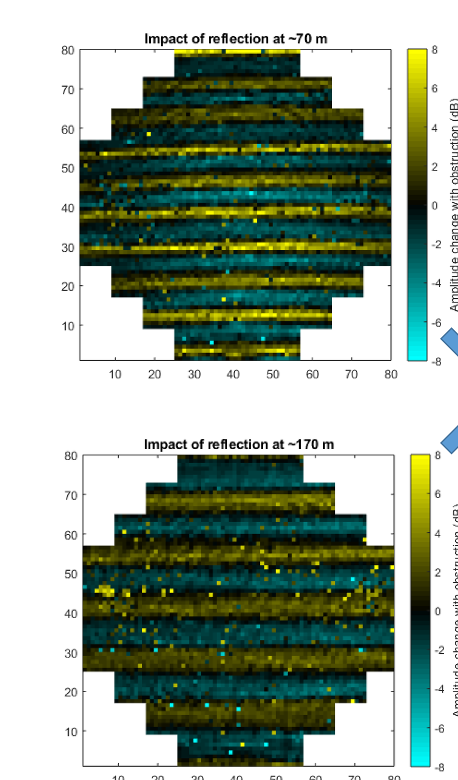


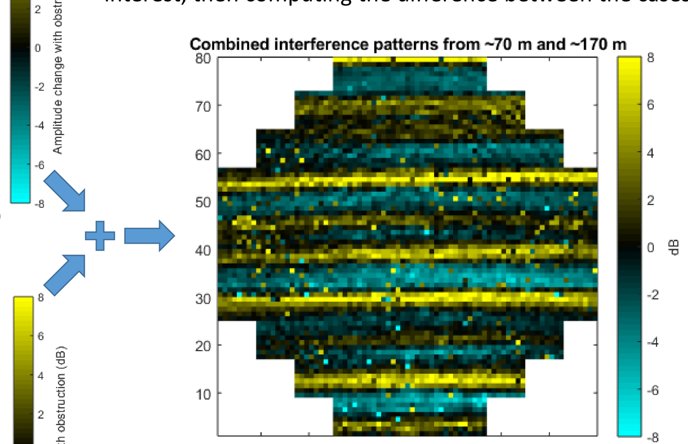
Illustration of measurement range showing two likely areas of ground reflections. The signal received by any given element will be the sum of the RF from direct path and all bounce paths. These paths may interfere constructively or destructively at different points on the array depending on the phase lengths.



Left: Model of multipath interference assuming flat, level terrain. This simple geometry predicts alternating fringes of constructive and destructive interference. (credit: A. Morris, MIT Lincoln Laboratory) *Right:* Power received at the calibration tower horn when transmitting from each element individually, normalized to the median power. Interference fringes are visibly present but not as uniform as predicted, suggesting that there may be multiple sources of reflections present from the real terrain.



Left: Impact of reflections from the two ground locations identified in the illustration above. These figures are generated by measuring the signal transmitted from each element with and without an obstruction in the area of interest, then computing the difference between the cases.



Above: When the two figures to the left are summed, we find that the combined impact of these two reflection locations compares favorably to the total interference pattern shown at the top right. This suggests that planned diffraction fences in these two areas will eliminate the major contributors to multipath interference.

Acknowledgments

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The Advanced Technology Demonstrator is part of the Multifunction Phased Array Radar (MPAR) initiative, a multi-US-agency program. It was designed and built in collaboration with MIT Lincoln Laboratory and General Dynamics Mission Systems.