Military Radome Performance and Verification Testing

Thomas B. Darling
Vice President, Customer Support
MI Technologies

Incredible efforts are made by system designers to produce state-of-the-art radar and other RF based capabilities for our military. Modern radar systems are used for various purposes including, but not limited to: weather assessment; navigation; terrain following/terrain avoidance; weapons fire control; electronic warfare; enemy tracking, listening and identification, etc.

Dependant upon extremely high measurement precision, repeatability and accuracy, these radar systems all require protection from the elements. While many think about the exotic hardware and sexy looking screen shots produced by these sophisticated radar systems, most do not think about one extremely critical component of these systems: the radar dome or radome. When one considers the critical need for proper operation of these systems for our military, as well as the harsh conditions during conflicts, this component protects vital systems which can make the difference between survival and disaster.

The most well recognized radome is the one positioned on the nose of an aircraft or missile. However, many military applications, and new commercial applications, are positioning microwave based systems in other locations on the aircraft. These often require odd shapes in order to protect the RF system and to be sufficiently aerodynamic. Military radome testing is, not surprisingly, considerably more involved than for commercial applications.

Typical Measurement Parameters

Some of the typical parameters measured to characterize the performance of a radome include:

Transmission Efficiency (TE)

Transmission Efficiency is the percentage of microwave energy that passes through a radome, typically measured over various angular regions (which usually represent the area of the radome actually used by the radar system). It is measured by comparing power levels received by a test antenna in two different conditions. A reference measurement is made with the radome off, then again after installation of the radome over the radar antenna. The resulting data is plotted over the surface of the radome. While ideally "transparent", all radomes will have losses as the RF signal passes through it due to a combination of reflections, diffraction, absorption, refraction and depolarization.

Beam Deflection (BD)/ Boresight Shift (BS)

Beam Deflection is the change in the direction of propagation of the microwave signal as it passes through the radome. If one considers the geometry associated with the tracking of a fast moving enemy target or terrain avoidance for a low flying, fast moving aircraft, even very small angular errors introduced by the radome can have significant effects. (For test antennas with a tracking null, the term boresight shift is often used interchangeably with Beam Deflection. Beam Deflection can then be a term reserved for the case of a sum beam.)

Reflectivity

Reflectivity is the change in the magnitude of the reflection coefficient at the port of the radar antenna which is caused by the presence of the radome. This is measured using a reflectometer with a remote head. The reflection coefficient is measured before and after the radome is installed with the antenna pointing out into a reflection-less environment (such as an anechoic chamber or an outdoor range). Ideally, this measurement is independent of pointing direction of the radar antenna.

Antenna Pattern Distortion

Pattern distortion is the change to the radar antenna radiation pattern caused by the presence of the protective radome. Patterns are taken with and without the radome present. Various analyses can be made to assess the changes to the pattern shape including: beam width, side lobe levels, peak/null location, lobe imbalance, null fill, etc. This requires that the radar antenna rotate with the radome to maintain a particular antenna to radome aspect as the antenna pattern is measured.

Measurement Approaches

There are several approaches typically employed to measure radome performance. The three most common are described below. While the details of the mechanical positioning system can be very different for each approach, a basic test system includes a control computer, transmit signal source, source positioner, radome positioner, position control equipment, test antenna, RF signal multiplexer and the receiver.

Far Field Testing

Traditional radome testing has often employed an outdoor far field test range. While outdoor testing has its own inherent disadvantages, the relatively long length of the range allows for slightly less precision in the mechanical positioning systems (as compared to the use of a Compact Range).

TE and BD may be measured with a single receiver by sequentially switching between ports of the tracking antenna. To measure BD, the radar antenna positioner actively tracks the boresight of the illuminating wave front, first with the radome installed and then without it. Serving dual use, the receiver provides a tracking signal for BD or to extract amplitude data for TE measurements. The test antenna positioner is typically an XY scanner. The test antenna must be a tracking antenna that operates using one of the typical techniques such as monopulse differences, conical scanning or sequential lobing. TE data can be acquired from the sum channel vs. radome position data.

An enhanced architecture for BD and TE which employs two receivers is shown in **Figure 1**. Receiver #1 processes the TE data and receiver #2 processes the BD data. Receiver #2 (the tracking receiver) requires three signal inputs from the tracking antenna (sum, delta azimuth, delta elevation). The sum RF channel is coupled directly to receiver #1 and passed to receiver #2 via the multiplexer. Receiver #1 process the sum channel, extracting the amplitude data required for the TE measurement. Receiver #2 processes the sum channel, delta azimuth channel and the delta elevation channel signals, generating the tracking errors required to make the BD measurement. Both receivers operate simultaneously and independently. The system can be configured to track either with a XY scanner (**see Figure 2**) or the antenna gimbal (**see Figure 3**). A null seeker positioner is normally used to translate continuously the transmit antenna to the apparent electrical boresight direction of the antenna radome combination.

Compact Range (CR) Testing

Many systems employ a compact range reflector in an indoor range to create plane wave illumination of the test article. A CR range, a device for producing a localized plane wave within a confined space, operates by collimating an RF point source with a paraboloidal reflector. Avoiding problems associated with weather and other outdoor anomalies, the CR provides the security required by military test programs and utilizes a stable indoor test environment.
See Figures 4 & 5.

Near Field (NF) Testing

A continuing trend for antenna measurement technology has been the migration to near field scanning techniques. The ever increasing speed of digital computers and the reduced size of a near field range compared to other test methods is driving this change. Near field scanning is recognized for the excellent radiation pattern accuracy. Since radome measurements entail ascertaining the difference between two radiation patterns, it is understandable that near field measurements yield an accurate measure of radome performance. However, closed loop BD tracking functions are unavailable. **See Figures 6 & 7**.

Required Accuracy

TE accuracy or repeatability is typically specified as +/-2% of full power. This corresponds to +/-0.08 dB, and can be extremely difficult to achieve. The difficulty increases if there are moving RF cables, if the radar antenna must counter-steer the radome positioner to maintain alignment with the range antenna, or if a significant amount of time elapses between measurements with the radome off.

Boresight shift (BS) is typically specified to about +/-0.1 mrad, or +/-0.0057 degrees. This can also be difficult to achieve. This deflection is normally measured by aligning the radar antenna to the incident field (or vice versa) with and without the radome mounted, and reporting the angular difference between the two measurements. Two common geometries for measuring boresight shift use either a two axis gimbal inside the radome or a down range XY translation stage. The down range scanner becomes easier to get in spec as the distance increases. The gimbal approach is always difficult, since the accuracy of a typical high-precision gimbal rarely exceeds the accuracy required at the system level.

Both TE and BS are measured with the radar antenna and range antenna always pointing directly at each other. The simplest and most accurate positioning geometry for these parameters generally has the radar antenna mounted on a stationary post secured to the floor. The combination of radome shape, system antenna insertion depth, and required angular coverage sometimes precludes the use of this simple geometry.

Pattern distortion measurements, are made by rotating the radome and radar antenna together to obtain the antenna pattern with and without the radome. When pattern distortion measurements are required along with TE and/or BS measurements, a positioning system with two different modes of operation is needed. Sometimes the antenna and radome rotate together, but sometimes the radome rotates while the antenna remains stationary.

Radome Construction & Repair

Normal flight operation of aircraft will subject the radome to significant thermal stresses, as well as other deleterious effects such as bird strikes, hail and rain exposure. Rain can cause moisture to migrate into the potentially porous radome materials. Even small amounts of water, which may “wick” into the fibrous materials, will freeze at altitude causing delamination of layers. This can create a progressive failure of the radome materials.

Typically manufactured from a variety of composite materials and a metallic mounting ring, radomes are often comprised of multiple layers of different materials. The radome will be coated with various specialized paints targeting various properties (to minimize rain erosion, static build up, etc). While materials and conditions are readily controlled during the initial manufacture, most radomes are expected to have a long life which will include multiple repair cycles. Control of repair materials and repair procedures is critical to the proper performance of the repaired radome in the field. Once repaired, the radome performance must be verified to the applicable standards or established test requirements. Many measurement systems will yield test data expressed as test positioner aspect angles, based upon the coordinate system employed by the measurement system. This can create a problem for those folks attempting to repair the radome, who need to know where the problem exists on the radome surface. Advanced systems employ three dimensional models of the radome surface to translate test results from the test positioner coordinate system onto a 3D isometric view of the radome. Adding aircraft coordinates to the test results (such as fuselage station, waterline and buttline) and displaying failing results in a graphical manner provides more meaningful data in useful terms for the composite repair personnel. With such data, they can more easily identify and minimize the area to be repaired. **See Figure 8**.

Conclusion

Proper radar system operation on aircraft requires known radome performance. Normal use of aircraft will subject radomes to conditions which will likely affect its performance over time. Commercial aircraft operated in the US are subject to requirements specified by the Federal Aviation Administration. In the interest of safety and reliability of radomes following damage, the FAA issued Advisory Circular 43.12 stating that "all repairs to a radome, no matter how minor, should return the radome to its original or properly altered condition, both electrically and structurally." If a repair adds or replaces skin plies, electrical testing must be performed using the techniques and procedures of the Aircraft Technical Committee report ARTC-4, "Electrical Test Procedure for Radomes and Radome Material." Additional radome test requirements are called out by DO-213, "Minimal Operational Performance Standards for Nose-Mounted Radomes." This specification was originally developed by the Radio Technical Commission for Aeronautics (RTCA) in response to the development of predictive windshear weather radar systems. This document specifies the tests to perform on both a new and repaired commercial radomes. Testing for repaired commercial radomes is normally limited to transmission efficiency only and most radome repair shops test to this standard. New radomes are additionally tested for boresight error, antenna sidelobe degradation and incident reflection.

Military requirements, however, are very stringent and usually require more sophisticated measurement approaches (than for commercial requirements). The test requirements for military radome applications are usually specified by the original supplier of the radar system for the aircraft. The radome is, after all, an integral part of the complete radar system. Generating unique performance requirements for each airframe, the test system supplier must then help determine the optimal approach based upon the test requirements, available test facilities and test throughput requirements.

MI Technologies has produced numerous radome testing systems for both commercial and military applications. Delivering test systems and routine test services for missile radomes, wing tip radomes and other shapes (in addition to nose radomes), MI has employed all of the techniques discussed here. Working with military contractors, MI has delivered test systems and/or radome testing services for: F1, F15, F16, F18 and Gripen fighters; MC-130E military transports; B-737 and MD-80 commercial aircraft; PAC-3 missiles, and numerous other military, as well as commercial, radomes.

Thomas B. Darling
Vice President, Customer Support
MI Technologies
1.678.475.8300
tdarling@mi-technologies.com
www.mi-technologies.com

References:

1. D.W. Hess, R. Luna, J. McKenna, "Electromagnetic Radome Measurements: A Review of Automated Systems," *Loughborough Antennas and Propagation Conference Proceedings* 2000

2. R. Luna, T. Thomas, D. Darsey, J. Vortmeier, "A Dual Receiver Method for Simultaneous Measurements of Radome Transmission Efficiency and Beam Deflection," *AMTA Proceedings* 2003

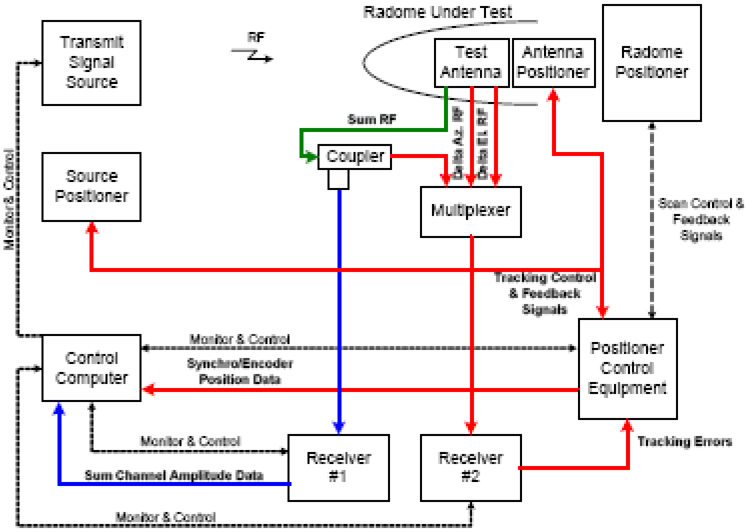


Fig.1, A Dual-Receiver Test System Configuration

Fig.2, 5 ft x 5 ft XY Scanner

Fig.3, A Yaw/Pitch Gimbal

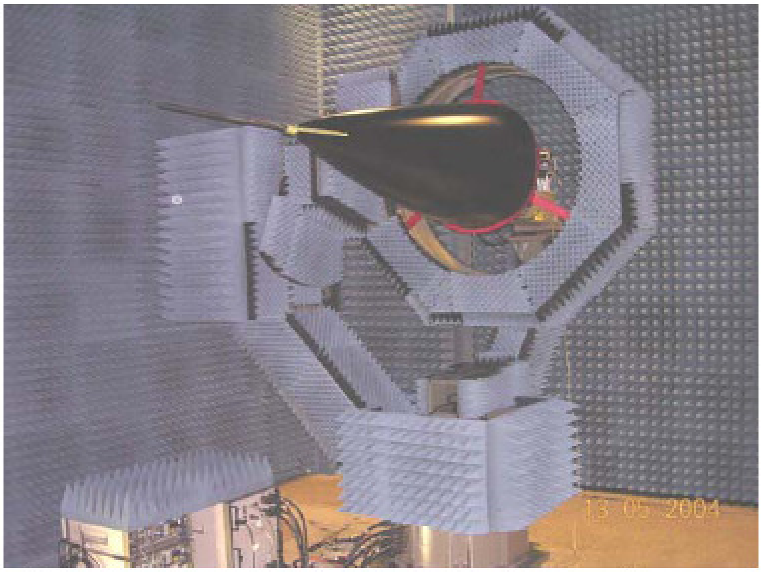
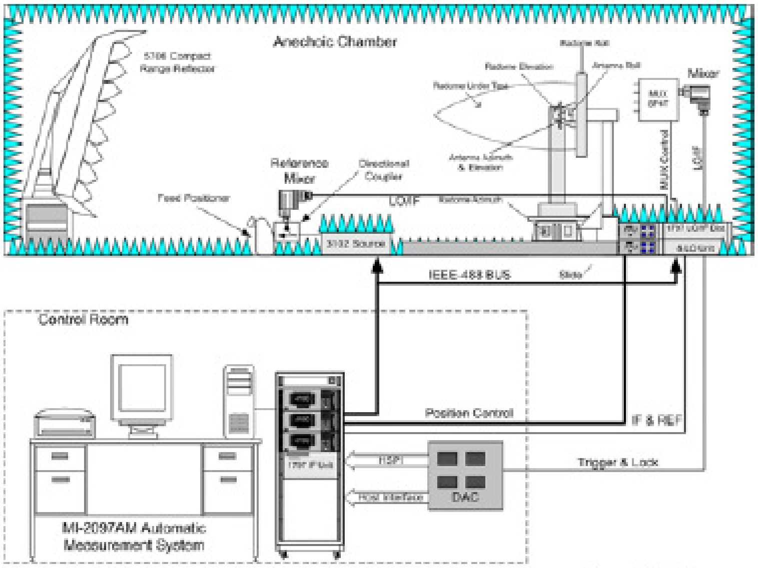


Fig.4, Radome Test Positioner for Compact Range Test System with Radome



Fg.5 Block Diagram of Compact Range for Radome Testing

Fig.6, A Spherical NF Arch with Utility Radar From BAE Systems, Isle of Wight, UK

Fig.7, Spherical NF Arch with Sampson Radome From BAE Systems, Isle of Wight, UK

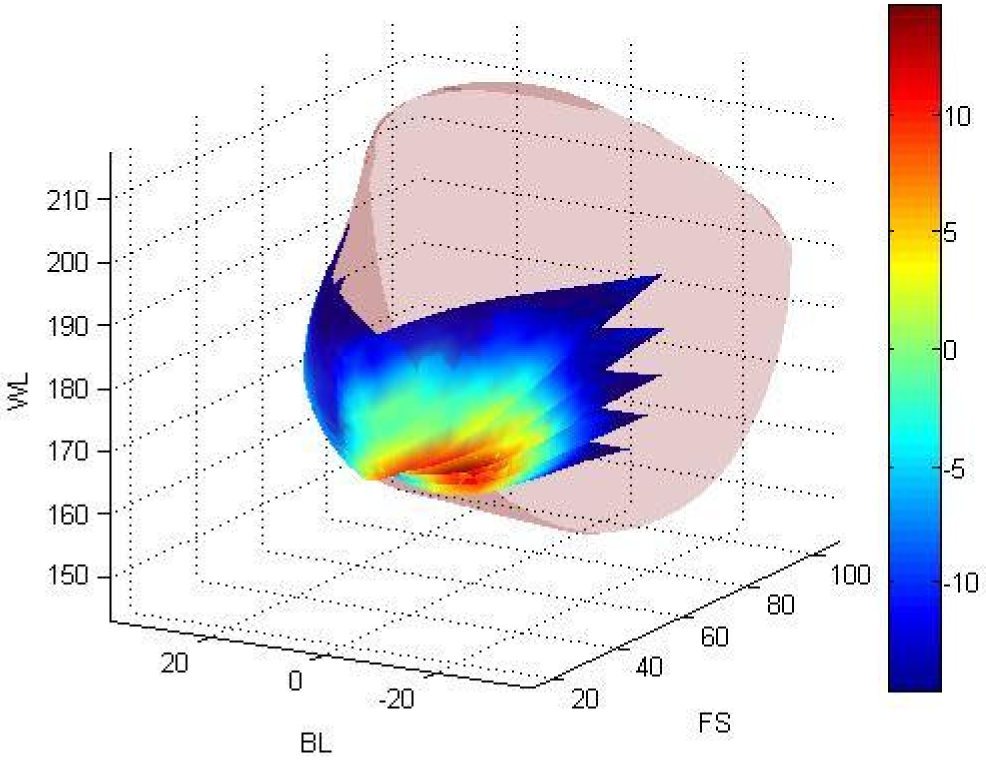


Figure 8: 3D Plot of TE Results on MC-130E Radome