Low Cost, Automated, RTCA/DO-213 Compliant - Radome Test System

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Abstract

The commercial aviation industry faces several issues in regard to servicing and maintaining the radomes that abound in the aircraft fleet flying today. The first issue is the historically high cost of radome test systems. As a result of this, there are limited numbers of test systems in operation today and some geographic regions have insufficient radome test capacity. Advances in weather radar and increased reliance on them for turbulence avoidance and more efficient route planning around storm systems will increase the importance of ensuring that weather radar systems are performing well and consequently that weather radar radomes are in good condition and have been adequately tested. Because of the potential consequence of flying with a bad radome and the demands of new radar systems, its more important than ever to ensure test systems in use adhere to requirements and to spread awareness of these challenges within the aviation community.

Recently, a design effort was conducted specifically geared towards developing a system concept for radome testing that would both provide a robust test capability that fully meets the RTCA-DO-213 after repair test requirements and one that is much lower in cost than traditional systems that are fielded today. This paper describes the issues cited above and provides a description of the low cost - compliant solution

Keywords: Low Cost Radome Measurement System, Radome Measurements, RTCA/DO-213

1. Introduction

The term ***radome*** originated as a contraction of the term radar dome – the covering over a radar antenna to protect it from environmental elements. Presumably, the presence of the radome does not prevent the radar from operating satisfactorily. The radome as part of the radar system is an electromagnetic window, tuned to the operating frequencies of the radar equipment within the radome. When the radar is mounted on an aircraft the radome surface typically serves additionally as an aerodynamic surface, integrated into the design of the airframe. Now that radar deployment has become commonplace, the performance characteristics of radomes have often been taken for granted by all but the experts specialized in antenna design. [1]

Today, all commercial aircraft and many general aviation aircraft carry weather avoidance radar systems. The major parts of the aircraft weather radar system consist of the radar antenna, transmitter/receiver, display, antenna positioning system and critical to the operation of the aircraft and weather system, the radome.

2. Commercial Weather Radome Testing

Testing of commercial weather radomes is controlled by the Federal Aviation Administration (FAA) and is documented in:

- RTCA/DO-213, Minimum Operational Performance Standards for Nose-Mounted Radomes (commonly referred to as DO-213)

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 new and repaired radomes. Testing for repaired radomes is normally limited to Transmission Efficiency (TE) only. New production radomes are additionally tested for side lobe level and qualification testing further adds requirements for incident reflection, beam width and beam deflection.

Certain radar systems may require higher performance from the radome to achieve the desired system performance. Therefore, DO-213 defines several radome classes as a function of TE to accommodate system requirements in aircraft installations. The classes of radomes are shown in Table 1.

	Transmission Efficiency	
	Average	Minimum
Class A	90%	85%
Class B	87%	82%
Class C	84%	78%
Class D	80%	75%
Class E	70%	55%

Table 1 DO-213 radome class by TE level

Design and manufacturing of radomes is done by a specialized segment of the aviation industry and there is a good understanding and test practice within that segment. Repair of radomes is often performed by organizations with less understanding of the function and importance of the radome and with less skill to repair and test it properly. Often these organizations are aircraft composite and structural repair organizations and their expertise is in repairing aircraft. Thus they have a lot of mechanical and aircraft expertise, but often do not have the requisite RF or electromagnetic expertise.

The causes of degradation of a radome's electrical performance that will result in a need to repair the radome are rain erosion, impact damage (hail, bird strikes, and ground equipment), lightning strike damage and static burns. Especially during the thunderstorm season, damage and the need for repair is frequent and common. [2]

3. The importance of radome testing

3.1. Lack of test capacity can ground an aircraft

MI Technologies receives many requests per year from companies that serve the aviation industry, most of them in some sort of parts fabrication or repair activity. A lot of them are composite repair houses that repair any component of the aircraft made from composite materials. Commonly, there is one notable exception to their capability and that is the ability to repair the composite radome for the weather radar which is a high dollar value item for which there are limited spares. Due to the historically high cost to establish radome test capability, many facilities cannot afford the investment.

As a result of this, a common scenario is that an aircraft can be grounded somewhere while the radome has to be shipped to a more distant repair facility because the local facilities do not have radome test capability. Alternatively, increasing spare radomes in stock can be done, but this is expensive. If there is no spare radome available, then the aircraft remains grounded until the radome is repaired. If the distance to a facility that can do the repair is significant, then the amount of time the aircraft is grounded increases. As air travel has become routine and has permeated all areas of the world, the demand for after repair radome test has outgrown current capacity and there is a need for a low cost yet accurate and compliant test solution.

3.2. An improperly repaired radome degrades the radar performance

A damaged or improperly repaired radome can cause signal attenuation, refraction or distortion of the main beam. As a result, the radar can have reduced range from signal loss, underestimate the severity of weather, paint false or inaccurate returns of weather (i.e. a line of thunderstorms directly ahead may appear to be off to the left or right), or have improper windshear avoidance performance. Proper maintenance and repair of the radome is critical to achieve maximum signal strength from the radar transmitter. It is very important to avoid putting more coatings on than are necessary. A large buildup of coatings will cause a loss of radar signal strength through the radome itself.

One reputable FAA repair station reports, that they see a lot of improper repairs that have been made on radomes. These can include: using incorrect materials, applying the materials incorrectly, not controlling the thickness correctly or allowing moisture to remain in the radome. [3]

3.3. Modern radars transmit less power and rely more on good radome TE

Weather radar performance has improved dramatically in the last decade with multiple suppliers developing and producing new generation devices. State-of-the-art electronic and processing technologies provide operational convenience and features to the General Aviation community that was previously available only to large air transport aircraft. Now these new radars are both being installed on new airframes and also being retrofitted onto older aircraft.

However, as the components and processing have improved, another trend has been reduced transmit power. While this is very beneficial for the airframe and reduces the amount of power it has to supply to the radar, it also means that the radar is more susceptible to performance degradation due to attenuation and the radome is a key source of attenuation. Thus the radome TE test is more critical with these newer systems. A recent incident as reported in Aviation International News (AIN) highlights the potential issue: a poor radome can create. It was found that about 150 aircraft were fitted with modern radar, but the radome performance was not upgraded and its design dated to a time of higher power weather radars. As a result, there were multiple cases where experienced flight crews flew into dangerous weather because it did not show up on the radar screen. After investigation it was determined that the radome TE was inadequate for the newer, lower power radars. [4]

3.4. Turbulence avoidance and route planning are increasing the importance of accurate weather radar performance

Sudden and unexpected severe turbulence is not that uncommon and has injured countless passengers and flight crew including some fatalities. It is estimated that airlines are facing greater that $100 million in turbulence-related costs annually, according to the U.S. Department of Transportation and the Federal Aviation Administration (FAA). One key technology to aid the situation is called the Enhanced Turbulence (E-Turb) Mode Radar. This technology is a software signal-processing upgrade to existing predictive Doppler wind shear systems that are already on airplanes. With it the aircraft's radar can provide flight crews advance warning of turbulence, so that they can avoid it altogether and keep themselves and their passengers out of harm's way. [5]

Regions of adverse weather such as convective activity, clear air turbulence, or mountain wave activity, can effectively close off regions of airspace to traffic. Without direct knowledge of the location and severity of the turbulence, the restricted region may be larger than necessary, placing an undue cost and disruptive burden on controllers, operators, and the traveling public. With forecasts of significant increases in the demand for air travel over the next 20 years, these capacity constraints appear likely only to worsen with time. In such an environment, blocking airspace in accordance with current practices on bad weather days will not be a viable strategy. To keep the system going, it is only natural that air traffic decision makers will need to route more aircraft in closer proximity to areas of weather currently deemed as hazardous. Better tools to identify and pinpoint areas of actual hazard will therefore be needed to safely negotiate these weather systems. E-Turb will be a contributor. [6]

As the industry relies more on the weather radar both to avoid turbulence and to fly in closer to storms and through gaps in storms, the importance of the weather radar operating properly and thus having a good radome is increased.

4. Key Requirements of RTCA/DO-213

The key requirements of RTCA/DO-213 are summarized below:

- Transmission efficiency is measured one way through the radome. It is the amount of power being passed completely through the radome in the direction the radar main beam is pointed compared to the amount of power traveling the same path with the radome removed.
- The radome/antenna positioner must locate the test antenna within the radome at the same location as used in the aircraft installation.
- Gimbal sequence shall consider the order of the actual antenna system in the aircraft installation.
- For indoor ranges, the minimum range distance R, between the signal source and receiving antenna shall be determined by $D^2/2\lambda$ where D is the diameter of the largest antenna and λ is the free space wavelength at the test frequency.
- The test antenna must have the same size and polarization with beamwidth and sidelobes equal to or better than the antenna for which the radome has been certified to operate.
- Good RF stability is required. This is established by measuring the RF repeatability. DO-213 requires system level repeatability of +/-2% power or less than +/-0.08 dB throughout the span of a radome test.
- Data is taken at the following antenna gimbal angle orientations:
    - For El Angles: 0, +/-10, and +/-20 or +/-25 degrees
    - For Az Angles 0, +/-20, +/-40, +/-60, and +/-80 degrees
- ¼ wave tuning is utilized and measurements are taken at max power and min power. These are then averaged together to minimize the affects of standing waves between the test and system antennas. [2]

Based on the current state of the radome test environment in the commercial aircraft industry today coupled with the increasing need for good radomes and accurate test, as described above, MI Technologies undertook an effort to develop a low cost, high quality and accurate radome test system that fully meets the requirements for DO-213 after repair testing. The resulting solution is robust and sets a new threshold in affordability.

5. Design Aspects

There are three fundamental approaches that could be considered for the system, compact range, near field and far field. The compact range can provide excellent results and can be set up without requiring as much facility space; however, you have the added cost of the reflector to consider which is not required for the far field system. The near field approach can also provide excellent results, but because significantly more data has to be taken to make the necessary measurements, test time on a per radome basis will be significantly longer than either compact range or far field and this is not suitable for a large aircraft repair facility that is handling significant quantities or radomes. The far field range is very affordable, provides excellent results and lends itself to automation and ease of use. For this reason, a far field approach was chosen.

5.1. Radome Test Range Design

The radome test range design is shown in Figure 1. The size of the test room was determined by considering the range length as well as providing adequate room for the positioner and radome handling space. The example shown below will test radome up to and including the Boeing 747 radome. The room dimensions are nominally 5.5 M height x 5.5 M width x 14.5M Length (18' H x 18'W x 48' L). The range antenna and the system antenna are precisely and permanently aligned with each other and do not move during the measurements.

The range antenna is transmitting and all testing is performed at the single frequency of operation of the weather radar which is typically within 9.3 to 9.5 GHz. A narrow band filter is used on the input of the measurement device to filter out any out of band signals.

Because the two directive antennas stay precisely aligned to each other throughout the test and because the filtering rejects any out of band signals, the measurement is largely impervious to off axis or out of band stray signals. As a result of this, the requirements for the test room are significantly reduced. Provided that there is not a significant source of in band stray radiation near by, a full fledged shielded anechoic chamber is not required. Eight (8) inch absorber is only needed on the end walls to knock down potential mutual coupling.

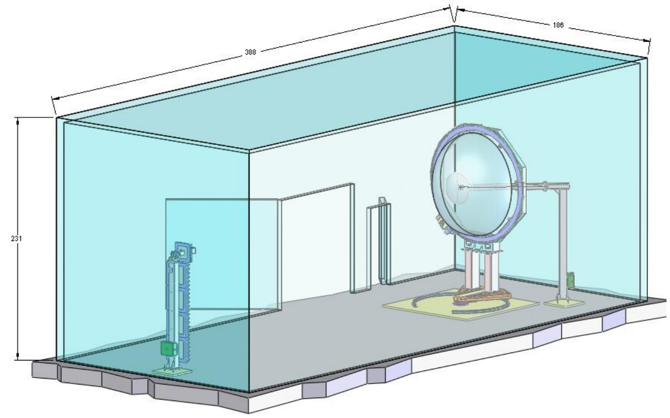

Figure 1 Radome Test Range Design

5.2. Positioning System

The overall positioning system is comprised of three positioner subsystems; the radome test positioner, the system antenna positioner and the range antenna positioner. A transmit source antenna (range antenna which illuminates the radome and system antenna) is mounted to the range antenna positioner located at the far end of the range. The radome test positioner supports and rotates the radome about a “fixed” antenna (system antenna) located inside the radome. The system antenna receives the transmitted signal and is supported by the system antenna positioner. The individual positioner subsystems, and their orientation to each other, are illustrated in Figure 1.

The range antenna is mounted on a fixed post that does not move after it is precisely aligned with the range axis. The range antenna positioner incorporates a linear slide that allows the range length to be varied between two predefined locations typically one quarter wavelength apart. The system antenna is mounted on a fixed boom over post and does not move after it is precisely aligned with the range axis.

The radome positioner and system antenna positioner are shown in Figure 2. The radome positioner is a roll over azimuth configuration. This configuration can simulate either the az over el or el over az gimbal configuration of the radar system in a single positioner. The antenna boom enters radome aperture at an angle. This coupled with the roll over azimuth configuration provides maximum azimuth travel to all areas of the radome without interference with the antenna boom. The antenna boom contains pressure sensitive collision avoidance features that automatically disconnect power to the motor is a collision is imminent.

Both radome roll and az axes utilize tape encoders and achieve the following specifications:

- Position accuracy ±0.5°
- Repeatability ±0.1°
- Velocity 0.75 RPM
- Radome capacity 300 pounds

The overall layout is simple, inexpensive and yet very rigid and accurate. There are no moving RF cables which significantly reduces errors caused by flexing cables. The large radome roll ring when coupled with radome mounting adapters allows both very small and very large radomes to be tested on the same positioner. The large azimuth rail provides much better stiffness and stability than a smaller azimuth stage couple with an offset arm. Additionally, the vertical load is transferred directly into the rail. Both radome roll and lower az axes are implemented without the use of large bearings significantly reducing cost. The az axis is very low profile providing better range RF performance and increased volume for radome handling during load and unload operations. The axis alignment and stability is such that the roll/azimuth intersection is "stable" to within a sphere of 0.64 cm (0.25") diameter

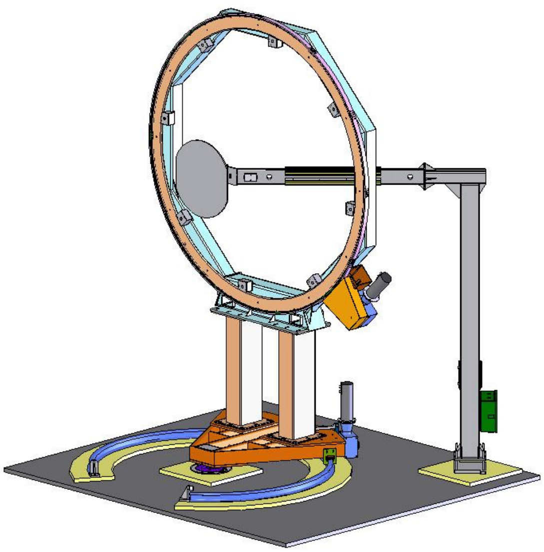

Figure 2 Radome and System Antenna Positioner

5.3. Control and Instrumentation

The control and instrumentation approach are shown in Figure 3. Control and instrumentation includes position control, RF instrumentation and control and processing software. The heart of the system is the the MI-3003 Data Acquisition and Analysis Workstation. The MI-3003 provides state of the art control of antenna, microwave component, radome and RCS measurement equipment. When coupled with the MI-3000 Family of software packages it supports highly efficient range operations, data management, data presentation and analysis. The specific software modules include the MI-3047 Radome software coupled with the basic acquisition and analysis software which provides capabilities to perform radome acquisition and analysis. The analysis functions available far exceed the TE requirements of DO-213 and also include beam deflection, boresight error and sidelobe levels. DO-213 specifications and parameters can be easily applied as thresholds to the measurement results. Custom thresholds are also supported. Additionally, measured radome results can be plotted over the radome surface, see example in Figure 4, to help repair personnel quickly isolate the damaged portion of the radome.

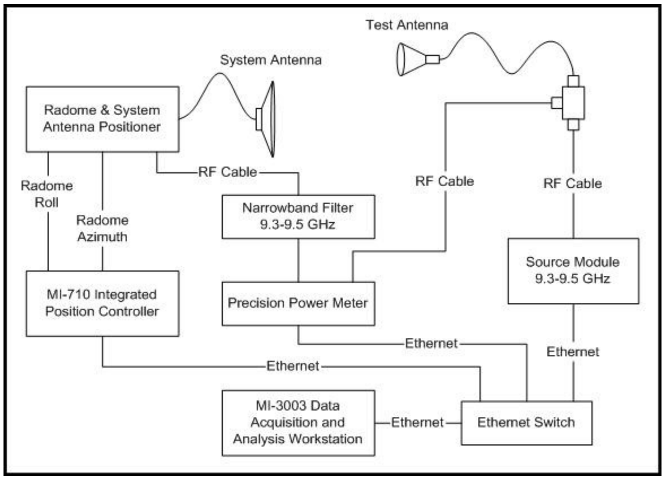

Figure 3 Control and Instrumentation Diagram

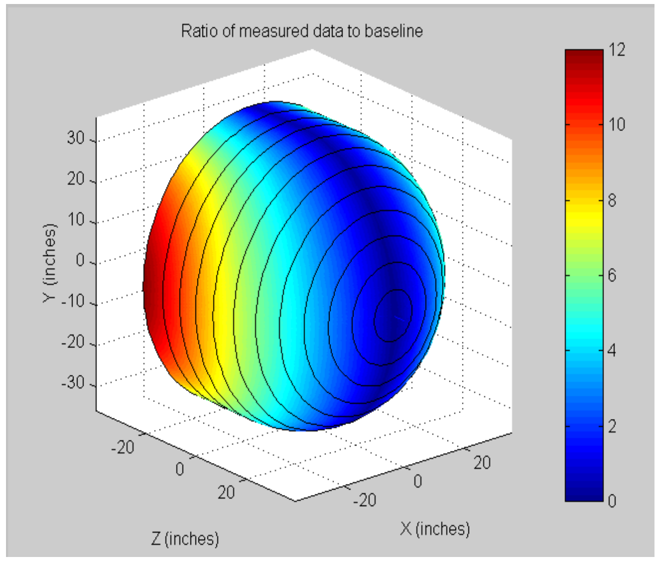

Figure 4 Radome Test Results Plotted over Radome Surface

The RF system is based around a commercially available precision dual channel power meter. Modern power meters have excellent linearity and stability. To this a narrow - band pass filter tuned to the weather radar single frequency is added eliminating out of band noise sources. One channel is used for the radiated signal, the second channel is used as a reference channel and is cabled directly to the source so that drift can be eliminated by ratioing the radiatied channel with the reference channel in post processing. Use of the power meter is considerably less expensive than a tradition VNA or Receiver approach. The RF source is a single frequency synthesized source module. To keep the cost low, there is no control panel or display and control over the module is provided through the MI-3003 Data Acquisition and Analysis Workstation. The control interface is limited to RF on and RF off commands.

Position Control functions are handled with the MI-710 Position Controller. This state of the art positioner controller integrates all control functions and the power amplifiers for the motors into a single package that is significantly less expensive than the prior generation of controllers that involved separate control and power amplifier boxes and the associated cabling between the units. Traditional data collection strategy for measurements is to perform a step and scan operation. This method moves a particular axis while holding all other axes in a fixed location. The MI-710 allows coordinated motion where in the radome roll and lower azimuth axes are moved together in a synchronized arrangement during the measurement so that a desired relationship among the axes' position is maintained while the axes are in motion. This relationship is defined so that the radome passes through the measurement points and the data is taken during a continuous scan. This significantly reduces test time and test expense. Further, if polarization sensitive radomes are to be tested, the coordinated motion feature allows an easy upgrade with range and system antenna roll positioners to maintain radome/antenna polarization orientation during scans.

The control and measurement system is greatly simplified and designed specifically to do the TE measurement. It has minimal components and the cabling and all control is over robust and straight forward Ethernet interfaces. The system has a built in scripting function and testing can be fully automated.

With upgrade kits the system can easily be upgraded to also do production and qualification testing.

6. Summary

Limited radome test capacity as a result of the historically high cost of test systems can result in the grounding of aircraft while a radome is shipped to a remote site for repair and test. Additionally, the importance of radome test is growing because modern weather radars often transmit lower power, and good radar performance is becoming more important as it is used increasingly for avoiding turbulence and for more efficient route planning that may take aircraft closer in to potentially severe weather.

MI Technologies has developed a simple, cost effective Radome test system that is fully compliant with the after repair test requirements of RTCA/DO-213 to address this need.

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