A DUAL-RECEIVER METHOD FOR SIMULTANEOUS MEASUREMENTS OF RADOME TRANSMISSION EFFICIENCY AND BEAM DEFLECTION

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Abstract

Characterization of radome performance involves measuring the radome-induced microwave signal attenuation and change in propagation direction. Transmission efficiency (TE) is a measurement of the percentage of microwave energy passing through the radome. Beam deflection (BD) is a measurement of the change in the direction of propagation of the energy as it passes through the radome.

Typical instrumentation configurations include one or two receivers interfaced with a monopulse antenna through a tracking loop. Tracking is mechanized at either the transmit or receive location.

The difficulty with these configurations is the complexity required to implement, coordinate, monitor, and measure tracking with sufficient speed and accuracy [1]. MI Technologies has developed and tested a relatively inexpensive and simple dual-receiver method that provides high accuracy and fast test time. A radome measurement system of this configuration is installed and has been successfully tested for The Boeing Company.

Keywords: Instrumentation, Data Acquisition, Measurement Systems, Radome Measurements, Scanners

1. Definitions

Transmission efficiency and beam deflection are standard measurements of antenna radomes [1, 2].

Transmission Efficiency: TE is the percentage of microwave energy that passes through a radome under test. It is typically measured over various radome look angle regions by comparing power levels received by a test antenna, with the radome installed on a test positioner, to a reference power level that is measured without the radome. Ignoring multipath effects between the radome, test positioner, and test antenna, losses through the radome are due to a combination of reflection, diffraction, absorption, refraction, and depolarization.

Beam Deflection: BD is the change in the direction of propagation of the microwave energy as it passes through the radome. Non-symmetric phase delay of the energy causes it to change propagation direction twice, as it enters and as it leaves the radome. For test antennas with a tracking null, boresight shift is commonly used interchangeably with BD. BD rate (BDR) is the angular rate of change of beam deflection.

2. Disadvantages of Sequential Measurements

Measuring TE and BD sequentially with a single receiver is simple but has several disadvantages. Two significant problems are antenna pattern coupling and increased test time.

To test BD, the test antenna must actively track the boresight shifts. A basic single-receiver test system includes a control computer, transmit signal source, source positioner, radome positioner, positioner control equipment, test antenna, radio frequency (RF) signal multiplexer, and receiver. The receiver must be dual-use, that is, configurable to track (for BD testing) or extract amplitude data (for TE testing).

During BD testing, as illustrated in Figure 1, the receiver processes multiplexed RF amplitude and phase data and generates tracking errors. These errors are used as feedback signals to the positioner control equipment. As the radome positioner is scanned, the source positioner or test antenna positioner is controlled to track out the errors generated by the receiver. Synchro or encoder position data from the tracking mechanism is transferred to the control computer for analysis.

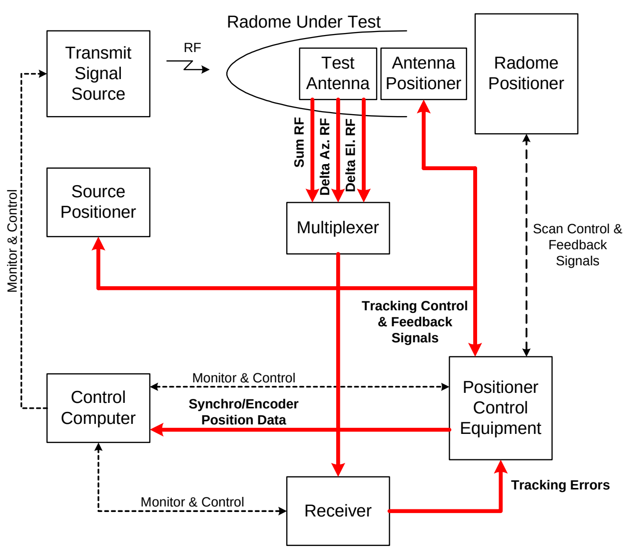

Figure 1. Single-Receiver BD Test Configuration

The test antenna positioner is typically a two-axis gimbal assembly. The test antenna must be a tracking antenna that operates using a technique such as monopulse, conical scanning, or sequential lobing.

During TE testing, as illustrated in Figure 2, the receiver extracts and collects amplitude information from the complex sum channel signal. The amplitude data is transferred to the control computer for analysis. Delta channel signals are not used.

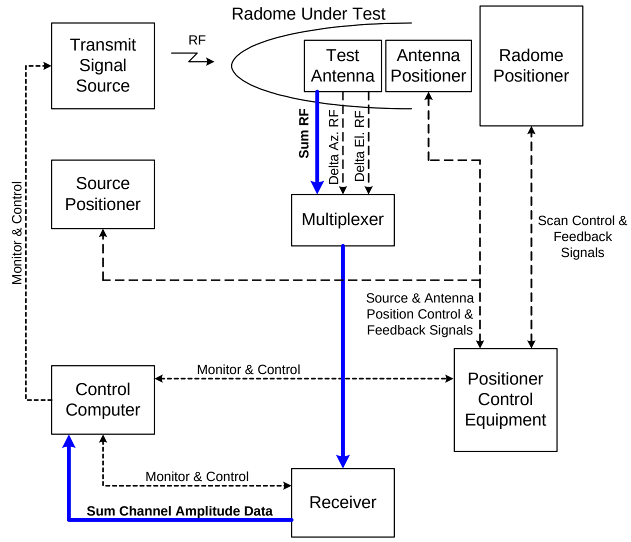

Figure 2. Single-Receiver TE Test Configuration

For TE measurement, if the test antenna is mounted to the test positioner so that it moves with the radome scan axis, coordinated motion is required to counter-steer the antenna as the radome is scanned [1]. This coordination maintains the pointing direction of the test antenna relative to the transmit antenna.

However, the radome induces changes in the signal propagation direction. These changes result in electrical boresight shifts between the test antenna and the transmit antenna during a scan. If not compensated for, amplitude errors are present in the measurements due to the signal level variation that is caused by the changes in the test antenna gain. During TE testing, the variation can be compensated for by offsetting the test antenna by the deflection angles that are measured during BD testing.

When simultaneously testing TE and BD, tracking serves two purposes. First, test antenna pattern characteristics are isolated from the measurements. Second, tracking position is directly proportional to propagation direction. These effects result in simple linear analysis relationships.

Dual receivers, one for BD tracking and one for processing TE amplitude data, provide the simultaneous capability that isolates the test antenna gain from the measurements. Since the test antenna tracks out the errors induced by the radome, it remains electrically boresighted to the transmit antenna throughout a scan.

The tracking position of the test antenna can be used to measure BD because any deviation in the position of the tracking antenna (with the radome) from the reference position (the tracking point without the radome) is in response to the boresight shift. Changes in the tracking position are directly proportional to changes in the propagation direction. The tracking position can be subtracted from the reference position to obtain the amount of BD.

Sequential testing has another significant disadvantage - it requires additional test time. Two separate scans must be executed to measure a radome's TE and BD performance; so total radome test time may be doubled. Often, this disadvantage requires a simultaneous TE/BD measurement capability, even if the test antenna gain variation can be tolerated.

3. Common Dual-Receiver Configurations and Test Methods

Dual-receiver systems come in a variety of configurations and use different test methods. Commonly, one or more of the following features, capabilities, and characteristics are required:

- High-Accuracy Antenna Gimbal
- Independent Angle Measurement Subsystem
- Custom Interfaces
- Additional and Frequent Maintenance and Calibration
- Complex Test and Analysis Software

The motion required to accurately track an antenna beam can be very demanding of the gimbal to which the tracking antenna is mounted [3]. Structural stiffness and backlash requirements can drive the cost of such a gimbal very high. In addition, requirements for measuring the gimbal angular positions for BD are extremely difficult to meet - often, an independent angle measurement subsystem must be used instead.

One independent angle measurement subsystem is based on deflection of a laser beam. One or more autocollimators are used to sense small gimbal angular movements during tracking. One or more mirrors are rigidly mounted to the rear of the test antenna or gimbal assembly. This type of BD measurement technique requires custom interfaces (hardware and software), additional maintenance, and frequent calibration.

Test and analysis software that are required to operate dual-receiver measurement systems are often very complex. Often, the two receivers are different, requiring different interfaces operating simultaneously. An independent angle measurement subsystem requires a separate software interface. Analysis software must be customized based on particular radome pass/fail criteria. On the other hand, standard software packages, such as those offered by MI Technologies, can be readily modified and/or interfaced via executable scripts to create automatic user interface, control, and analysis functions of a customized radome measurement system.

4. MI Technologies' Dual-Receiver Configuration and Test Method

MI Technologies developed, tested, and installed a dual-receiver radome measurement system that has many advantages over common types of systems. Figure 3 includes a block diagram of such a system. Receiver #1 processes TE data while receiver #2 processes BD data. Receiver #2 (the tracking receiver) requires three signal inputs from the tracking antenna: sum, delta azimuth, and delta elevation.

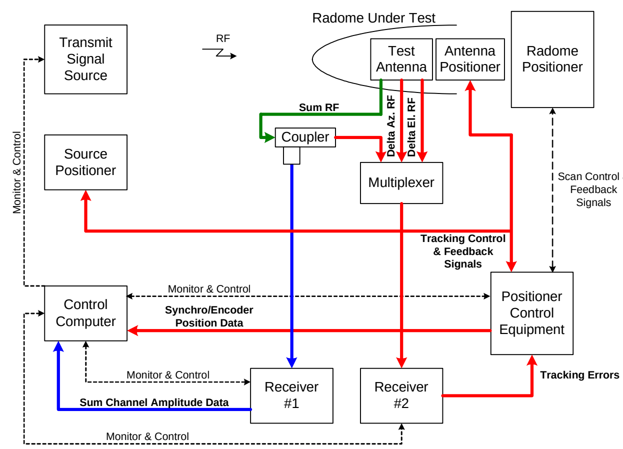

Figure 3. MI Technologies' Dual-Receiver Test System Configuration

The sum channel RF signal is coupled to receiver #1 directly and passed to receiver #2 via the multiplexer. Receiver #1 processes the sum channel signal, extracting the amplitude data required for TE measurements. Receiver #2 processes the sum channel, delta azimuth channel, and delta elevation channel signals, generating the tracking errors required for BD measurements. Receivers #1 and #2 operate simultaneously and independently.

It is important not to change the relative characteristics of the three signals into the multiplexer with the addition of the coupler - any such change will effectively change the test antenna's antenna patterns and hence, tracking characteristics. Therefore, the insertion loss of the coupler in the sum channel signal path must be replicated in the delta channel signal paths.

To optimize tracking, programmable gains are computed and entered based on the tracking antenna's cross-over beamwidths and the required tracking repeatability. Independent azimuth and elevation channel gains are used. These gains can be used to help compensate the tracking loop if the hardware channels cannot be adequately matched.

Furthermore, one side of the delta channel pattern must be nominally in phase with the sum channel pattern [4]. The tracking firmware of the receiver returns the real parts of the complex delta-over-sum ratios:

$$\text{Az Error} = \text{Re}\{\Delta_{Az}/\Sigma\}$$

$$\text{El Error} = \text{Re}\{\Delta_{El}/\Sigma\}$$

Therefore, the quality of the tracking is a function of the phase differences near the sum-delta crossover points. Typically, phase matching within 10 degrees is adequate for stable tracking. This tracking implementation operates for both amplitude-comparison and phase-comparison monopulse tracking techniques.

For amplitude-comparison monopulse, the antenna outputs are real (vs. complex) signed values. The amplitude differences due to off-boresight energy produce outputs whose amplitude ratios are proportional to the tracking errors. The tracking receiver generates azimuth and elevation error signals by computing the delta-to-sum ratios (Az Error = Δ_{AZ}/Σ and El Error = Δ_{EL}/Σ where Σ, Δ_{AZ}, and Δ_{EL} are real values).

For phase-comparison monopulse, the phase differences due to off-boresight energy produce outputs whose real amplitude ratios are proportional to the tracking errors. The tracking receiver generates azimuth and elevation error signals by computing the real parts of the delta-to-sum ratios (Az Error = $\text{Re}(\Delta_{AZ}/\Sigma)$ and El Error = $\text{Re}(\Delta_{EL}/\Sigma)$ where Σ, Δ_{AZ}, and Δ_{EL} are complex values)).

Calibration of the tracking receiver is not required because any nonlinearity present in the measured signals is symmetric about the test antenna's boresight null. Although the tracking slope, and hence speed, are affected, the tracking point is not. As a result, only a second mixer assembly and an IF unit are required for the second receiver. The cost of the second receiver is minimized while the inherent receiver accuracy and speed are maintained.

The system can be configured to track with either an X-Y scanner or the antenna gimbal. A null seeker positioner (typically, a precision servo-controlled X-Y scanner as the source positioner) is normally employed to continuously orient the transmit antenna along the apparent electrical boresight of the test antenna [2].

The relative low cost and simplicity of such a system result from the utilization of MI Technologies' standard products. A standard MI-2097 automatic measurement system is the backbone of the system. Included are an MI-3000 Data Acquisition and Analysis Workstation with software, MI-1797 microwave receiver, MI-4190 series position control equipment (controller and power amplifier unit (PAU)), and interconnecting hardware and cabling. Key software packages are the MI-3041 acquisition and analysis software, MI-3042 antenna analysis software, and MI-3047 radome analysis software.

Control and analysis in custom system configurations are accomplished with the addition of software scripting. The flexibility of scripting allows a system to meet the needs of customized system configurations without the expense of modifying standard product software.

The following table summarizes the advantages of an MI Technologies dual-receiver system.

Common Dual-Receiver System	**MI Technologies Dual-Receiver System**
High-Accuracy Antenna Gimbal	Gimbal with Standard Dual-Speed Synchro Package
Independent Angle Measurement Subsystem	X-Y Scanner (Null Seeker)
Custom Interfaces	Primarily Standard Product Interfaces
Additional and Frequent Maintenance and Calibration	Standard Product Maintenance and Calibration
Complex Test and Analysis Software	Straightforward and Customizable Test Scripts and Standard Product Analysis Software

A dual-receiver radome measurement system of this configuration is currently operational at Boeing's Avionic Laboratory Antenna Range located in St. Charles, MO.

5. Boeing, St. Charles Dual-Receiver Radome Measurement System

MI Technologies' dual-receiver system installed at Boeing, St. Charles, MO, is being used to test and characterize F-18 aircraft radomes in conjunction with state-of-the-art antennas. The system includes a MI-3000 Data Acquisition and Analysis Workstation with software, MI-4193 position controllers and PAUs, MI-1797 microwave receiver equipment, MI-3630 5x5 ft. X-Y scanner, customer-furnished radome positioner, and custom software scripting.

The MI-3630 5x5 ft. X-Y scanner operates as the null seeker positioner. It provides motion in three axes: horizontal, vertical, and roll. The horizontal and vertical axes are used for tracking (in the tracking antenna's azimuth and elevation planes) while the roll axis is used to maintain copolarization of the transmit signal with the tracking antenna's polarization. The roll axis position can be automatically coordinated, based on user-defined relationships, with the positions of the radome positioner axes. All three axes use highly accurate photoelectric incremental encoder position measurement and feedback. Figure 4 includes a picture of the installed scanner, viewed in the direction of the receive radome positioner (in the building in the background).

Figure 4. MI-3630 5x5 Ft. X-Y Scanner

The radome positioner provides F-18 radome motion in yaw, pitch, and roll. The tracking antenna can be mounted to the positioner roll axis so that it moves with the radome, or it can be mounted independently and stationary relative to any positioner motion. The yaw and roll axes are controlled using dual-speed (1:1 and 36:1) synchro packages while the pitch axis is controlled using a high-accuracy photoelectric incremental encoder. Figure 5 includes a picture of the installed radome positioner with an independently mounted test antenna and the radome not mounted - the azimuth axis positioner is not visible.

Figure 5. Radome Positioner

The MI-3000 acquisition and analysis workstation includes a state-of-the-art computer with peripherals and software. MI-3041 acquisition and analysis software, MI-3042 antenna analysis software, and MI-3047 radome analysis software are installed. These software packages allow fast, multiple-frequency, multiple-step acquisitions of antenna pattern data as well as simultaneous, single-frequency, multiple-step acquisitions to measure radome TE and BD performance. Figure 6 includes a picture of the control room with the installed MI-3000 workstation and other equipment.

Figure 6. Control Room Equipment

Two pairs of MI-4193 positioner controllers and PAUs are used in the system. The first controller interfaces with the X-Y scanner's horizontal and vertical axes. These two axes can be controlled manually or automatically. Automatic control is switched appropriately during a radome test acquisition so that the tracking errors generated by the receiver, instead of the encoder signals provided from the scanner, are used as position feedback. The second controller interfaces with the X-Y scanner's roll axis and the radome positioner's yaw, pitch, and roll axes. This controller provides the capability of coordinating the scanner roll axis position with radome axis positions.

Receiver equipment includes a complete MI-1797 receiver and a second partial receiver. The complete receiver processes TE data while the second partial receiver simultaneously processes data for BD testing. Separate digital intermediate frequency (IF) units are utilized for each type of processing in order to maintain the speed and accuracy specifications required to characterize the radome.

Signal couplers, isolators, and filters are used to achieve high isolation between the BD channels and the coupled TE channels. Each of the three antenna outputs (sum, delta azimuth, and delta elevation) are coupled, filtered, isolated, and asynchronously multiplexed. The outputs of two multiplexers are input to separate mixers for downconversion to the receiver IF. Isolation on the order of 40 dB is required to eliminate the effects of multiplexer switching transients, component leakage, and out-of-band frequency signals.

The following table lists key performance specifications of the Boeing, St. Charles system.

Parameter	Specification
Frequency Range	7-12 GHz (reconfigurable for 2-18 GHz antenna measurements)
Tracker Position Accuracy	0.015 milliradian (max.)
Tracker Static Position Repeatability	0.005 milliradian (max.)
RF Signal Stability	0.1 dBm (max.)
Power Dynamic Range	75 dB (nominal)

6. Conclusions

MI Technologies' dual-receiver method for simultaneous measurements of radome TE and BD offers a convenient, accurate, and fast measurement capability. This capability is accomplished with the utilization of MI Technologies' standard products and their inherent flexibility and performance capabilities. The flexibility of the hardware and software allow easy customization for many applications.

7. References

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