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SYSTEM ENGINEERING FOR A RADOME TEST SYSTEM

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ABSTRACT

This paper will discuss the system level design of a radome test system implemented in a compact range. The system includes a tracking pedestal controlled by an autotrack controller, a measurement receiver, a unique five-feed arrangement for the compact range which accommodates both tracking and measurement functions, and a laser autocollimator for coordinate system referencing. Key elements of system design include the required coordinate system transformations, the mechanical design of the positioning system and its contribution to the system error budget, the dynamics of the tracking system, and the synchronization of the autotrack controller, the measurement receiver, and the system controller. These aspects of system design will be discussed and measurement and analysis results will be presented.

Keywords: Compact Ranges, Facility Descriptions, Instrumentation

1. INTRODUCTION

When a radome is used to protect an antenna from the elements, from observation, or from the stresses of flight on an aircraft, the properties of the radome affect the performance of the antenna. Specialized measurement systems are required to characterize the performance of the antenna/radome combination. Measurements typically made on radomes include boresight shift, transmission loss, and the effects of the radome on the pattern and/or polarization of the antenna mounted beneath it.

The system described in this paper for performing these measurements on a radome is implemented in a compact range. The system includes an autotrack controller for detecting the radome-induced boresight shift, as well as an antenna measurement receiving system for the measurement of antenna patterns, polarization, and transmission loss. These subsystems are integrated by specialized hardware and software to perform high-accuracy automated radome measurements.

This paper describes several unique aspects of the radome measurement system. These include the tracking subsystem, which is built upon the Scientific-Atlanta Model 3842 Autotrack Controller and a specialized tracking pedestal, and the interface between the 3842 and the Scientific-Atlanta Model 1795 microwave measurement receiver. Also described are the laser autocollimator used for coordinate system correction, the rotating linear compact range feed scheme used for automated polarization measurements, and the pattern averaging technique used for comparison of the antenna patterns with and without the radome.

2. TRACKING SUBSYSTEM

In the measurement system described in this paper, a tracking system continuously steers the antenna mounted under the radome to the direction of arrival of the primary plane wave generated by the compact range. The tracking is accomplished by sequential lobing of the feeds of the prime-focus fed compact range, producing plane waves whose directions of arrival are sequentially switched in two planes to provide a tracking modulation.

The feed arrays that perform this operation are specialized for tracking by sequential-lobing. The arrays consist of five-feeds each. A typical feed array is shown in Figure 1. The top and bottom feeds produce plane waves squinted from the nominal range axis in the elevation plane. The left and right feeds produce plane waves squinted in the azimuth plane. The switching networks included in the feed arrays switch the excitation to the appropriate feed under the control of the 3842 Autotrack Controller.

The autotrack controller is an instrument most often used in systems where an antenna must track a satellite or some other airborne vehicle for communications from the ground. The hardware and firmware of the autotrack controller are capable of producing control signals that synchronize the sequential lobing operation of a tracking feed. When the tracking signal arrives at the antenna from a direction other than the boresight direction, the sequential lobing results in the imposition of an amplitude modulation on the received signal from the antenna. The autotrack controller autonomously controls the tracking pedestal to point the antenna in a direction where this amplitude modulation is minimized. This is the antenna boresight direction.

Figure 2 illustrates the generation of plane waves with offset directions of arrival in the compact range and the effect of a pointing error in the antenna. As the figure indicates, when the antenna is pointed so that the offset plane waves are received at different amplitude levels on the receiving antenna pattern, an amplitude modulation on the received signal results. The autotrack controller generates rate commands to the tracking pedestal which tend to drive this amplitude modulation to zero, bringing the antenna back to the boresight direction.

Figure 3 shows a typical tracking pedestal. The pedestal is an azimuth-over-roll configuration with the roll axis pointed perpendicular to the range axis (the direction of arrival of the primary plane wave generated by the compact range) when the radome azimuth positioner is at 0°. In this position, roll axis motion corrects for elevation boresight error and azimuth axis motion for azimuth boresight error. As the radome azimuth positioner approaches 90°, the tracking pedestal azimuth axis must counter-rotate to keep the antenna main beam pointed in the direction of the range axis. When this happens, the roll axis error signal gain is multiplied by the secant of the tracking pedestal azimuth angle to keep the dynamic performance of the tracking subsystem constant. The autotrack controller performs this gain multiplication automatically.

The autotrack controller keeps the antenna pointed in the direction of the compact range field direction of arrival whether a radome is present or not. Therefore, the difference between the angular readouts of the tracking pedestal when the radome is mounted and when it is not represents the boresight shift induced by the radome.

If only the boresight shift measurements were of interest, the amplitude of the voltage at the terminals of the antenna would not be required. However, since the transmission loss through the radome is also an important performance parameter, a measurement receiver must be used to derive the amplitude of the antenna terminal voltage. The terminal voltage required for transmission loss measurements is that corresponding to a plane wave incident in the boresight direction when the antenna is pointed in the boresight direction. The offset tracking feeds generate plane waves offset from the antenna boresight direction when the tracking subsystem is active, so the tracking signal cannot be used for transmission loss measurements. Instead, the fifth feed in the array, the central measurement feed, is used for this measurement. Synchronization of the autotrack controller, the central measurement feed, and the measurement receiver is the subject of the next section.

3. 1795/3842 INTERFACE

The Model 3842 Autotrack Controller is capable of controlling the excitation switching of a four-feed array for tracking by sequential lobing. The addition of the fifth feed for transmission loss measurements requires additional logic hardware for synchronization. The logic hardware must insure that the demodulation of the tracking signal in the 3842 is really synchronized with the operation of the tracking feeds. That is, the elevation tracking error signal must be derived from sequential IF signals in response to plane wave excitation from the top and bottom feeds, and the azimuth tracking error signal must be derived from sequential IF signals related in the same way to the excitation of the left and right feeds. In addition, the logic hardware must insure that the measurement receiver makes its amplitude measurement when the central measurement feed is excited. A specialized interface unit serves this function in the radome measurement system.

Figure 4 illustrates the interconnection of the 3842, the 1795 receiver, and the feed arrays. As the figure indicates, the feed control output of the 3842, which normally controls the tracking feed assembly directly, is routed through the interface unit where it is modified and synchronized with the high-speed parallel interface of the receiver. This I/O port of the receiver is normally connected directly to the Data Acquisition Coprocessor (DAC) resident in the system controller. The DAC detects record increments from the positioning subsystem, triggers the receiver, and receives the data via the high-speed parallel interface. In the radome measurement system, this I/O interface is also intercepted by the interface unit for synchronization with the operation of the 3842.

Figure 5 shows a timing diagram of the key control signals in the interface unit. As the diagram indicates, the 1795 receiver is always operated in a triggered mode in this system. In computer-controlled operation, the DAC detects a record increment from the positioning subsystem and issues a trigger over the high-speed parallel interface. The 1795/3842 interface unit detects that the DAC has control of the receiver trigger by monitoring the external trigger enable on the high-speed parallel interface. When the interface unit detects that the DAC has issued a trigger to the receiver, it intercepts the trigger and holds it off until the beginning of the next tracking sequence issued by the 3842 feed control subsystem.

At the beginning of the next tracking sequence from the 3842, the interface unit activates the central measurement feed and deactivates the tracking feeds. At the same time, it drives the tracking output modulation to the 3842 to zero, causing the 3842 to issue zero rate commands to the tracking pedestal axes. After a settling period, the interface unit issues a trigger to the receiver and begins to monitor the measurement busy line on the high-speed parallel interface. This line will remain asserted until the measurement is complete, *i.e.* until the receiver has acquired and coherently averaged as many measurement samples as it was set up to acquire. When the measurement busy line is de-asserted, the interface unit waits for the beginning of the next feed lobing sequence, then begins once again to drive the tracking feeds and to pass the tracking modulation to the 3842. As far as the 3842 is concerned, it is tracking as it normally does throughout the entire operation. Similarly, as far as the receiver is concerned, it measures the amplitude of the received signal just as it normally does under computer control. This eliminates the necessity of modifying either the 1795 or the 3842.

When the 1795 is operating in the manual mode (not under computer control), the tracking subsystem may still be engaged. In order to insure that the same measurement is produced in the manual mode, the interface unit asserts the external trigger line to the 1795 even when the DAC does not assert it. The interface unit synchronizes the feed operation with the measurement cycle just as it does under computer control, and since the receiver is not in remote mode when the high-speed parallel interface is active, but only in external trigger mode, the front panel operation of the receiver is indistinguishable from that when it is truly free-running.

The interface unit also performs some of the functions of the tracking receiver usually used with the 3842. It recovers the tracking amplitude modulation from the IF signal and adjusts the IF gain to provide a tracking signal of the proper amplitude. It samples the measurement IF from the receiver, which is present whether the receiver is sampling it or not, and performs its processing on this sample. The remainder of the IF signal is routed to the 1795 IF unit which performs the final downconversion and digital sampling of the signal.

4. COORDINATE SYSTEMS

Since the measurement of boresight direction is a critical function of this system, it is necessary to measure the positioner and tracking pedestal pointing angles with the utmost accuracy. The angular readout devices on the positioners measure angles to their specified accuracy in the positioner coordinate system, but in order to know directions in space it is necessary to know the relative orientations of the positioner coordinate system and a coordinate system fixed in space. To accomplish this, a laser autocollimator system is included in the radome measurement system. The purpose of this autocollimator system is to monitor the relative orientations of the positioner and world coordinate systems instantaneously as the radome is scanned through the test volume.

Figure 6 illustrates the idea of the autocollimator correction. The figure shows two coordinate systems rotated with respect to each other. The rotations required to bring the coordinate systems into coincidence are designated α, β, and γ in the figure, and are known as Euler angles. If the Euler angles required to bring two coordinate systems into coincidence are known, then directions measured in one coordinate system (positioner readout angles) can be transformed to the other coordinate system (the fixed world coordinate system).

The autocollimator subsystem includes mirrors mounted to the azimuth turntable of the radome positioner. The autocollimator measures the angle between the reflected and incident laser beams on the mirrors and, by extension, the direction of the normal to the mirror illuminated by the laser. If the positioner tilts with respect to the world coordinate system in such a way that the mirror normal tilts as well, then the autocollimator will detect this tilt. However, if the mirror tilts in the plane of the mirror surface (the plane perpendicular to the mirror normal), the autocollimator will not detect this tilt. Therefore, a measurement on a single mirror is not sufficient to determine the Euler angles required to rotate the positioner coordinate system into coincidence with the world coordinate system.

The radome measurement system uses autocollimator data from two mirrors at adjacent azimuth angle locations on the turntable to derive the Euler angle information. In outline, the algorithm works this way:

(1) Determine the angles θ and ϕ in the world coordinate system corresponding to the laser direction of incidence.

(2) Determine the angles θ and ϕ in the world coordinate system corresponding to the mirror normal directions with no radome in place.

(3) Compute the angles θ and ϕ in the positioner coordinate system corresponding to the mirror normal directions with no radome in place.

(4) Measure the angles θ and ϕ in the world coordinate system corresponding to the mirror normal directions with the radome in place.

(5) Using the measured directions of the mirror normals in the world coordinate system and the computed directions of the mirror normals in the positioner coordinate system for two positioner azimuth angles, compute the Euler angles describing the rotation between the positioner and world coordinate systems.

(6) Correct the measured data in the positioner coordinate system (the positioner angle readouts) to the world coordinate system using the computed Euler angles.

Computation of the required Euler angles from the autocollimator measurements is quite involved algebraically, and may be the subject of a future paper. The algorithms developed follow the concept of the outline above.

5. POLARIZATION AND PATTERN MEASUREMENTS

The radome measurement system may also be used to characterize the effects of the radome on the polarization and pattern of the antenna. To perform polarization measurements, a single feed with a rotary joint is used to illuminate the compact range reflector. The single feed is rotated with respect to the reflector at a high speed and a set of measurements is triggered by the software at each record increment separated in time. The set of measurements is processed to determine the polarization-related peaks and nulls at each record increment, which provides a measurement of the axial ratio at the given point on the antenna pattern. Data for measurements with and without the radome installed are compared to determine the effect of the radome on the antenna polarization.

For both polarization and pattern effects, a sliding window average is computed. This sliding window average yields a measurement of the average effect of the radome for a closely spaced set of directions of arrival. This technique permits meaningful evaluation of the polarization and pattern data in the presence of beam shift and beam broadening induced by the radome.

6. CONCLUSIONS

A new radome measurement system is described in this paper. The radome measurement system incorporates novel concepts in tracking, coordinate system correction, and data reduction. Some of these features have been described in this paper. The radome measurement system provides high-accuracy measurements of the effects of the radome on the antennas mounted beneath it. The precise measurements of the radome effects thus afforded will permit the designers of radomes to insure that the influence of the radome on the system operational characteristics is within the required limits for system operation.

7. REFERENCES

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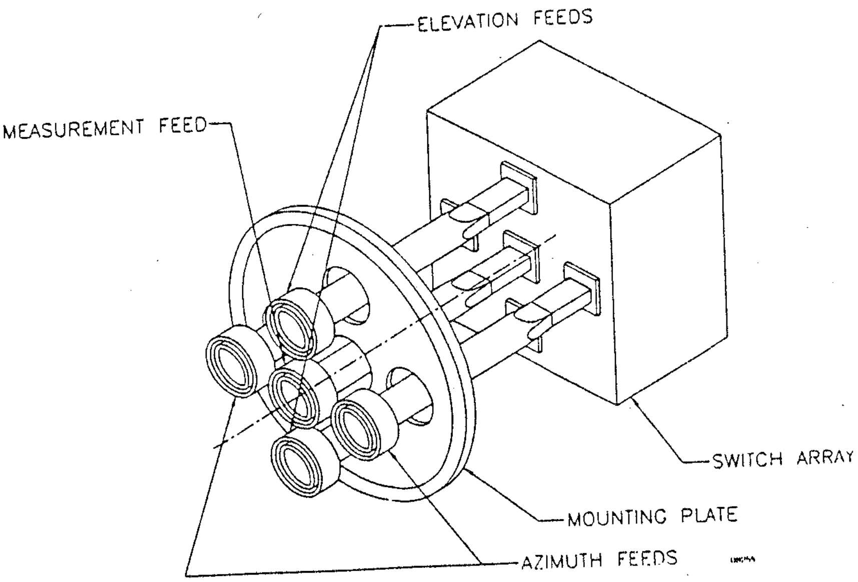

Figure 1. Radome measurement feed array assembly

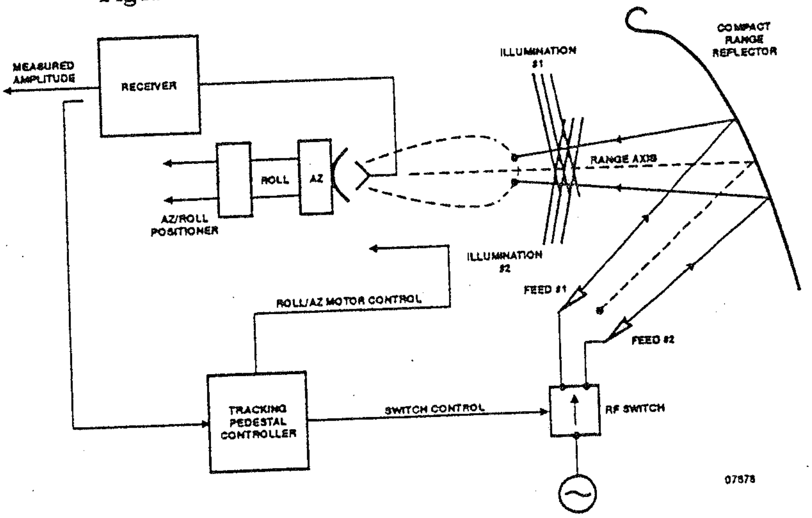

Figure 2. Generation of offset tracking beams in the compact range

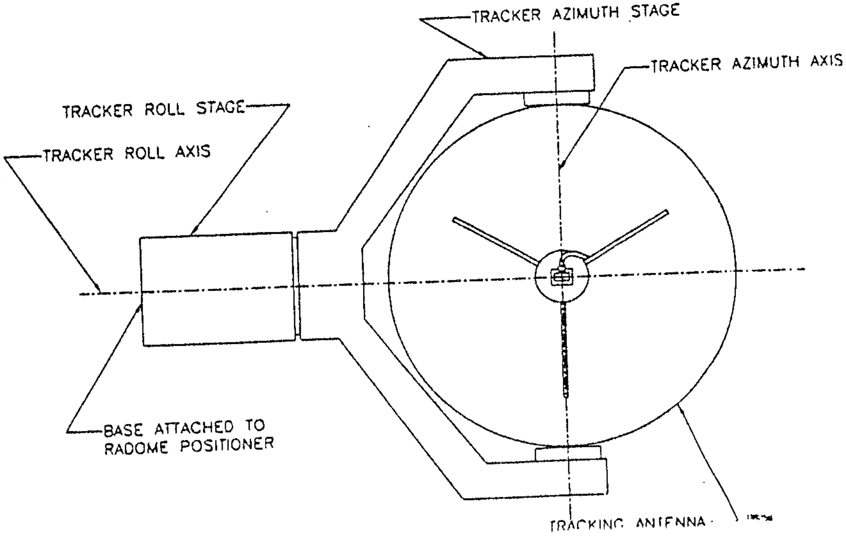

Figure 3. Tracking pedestal and antenna

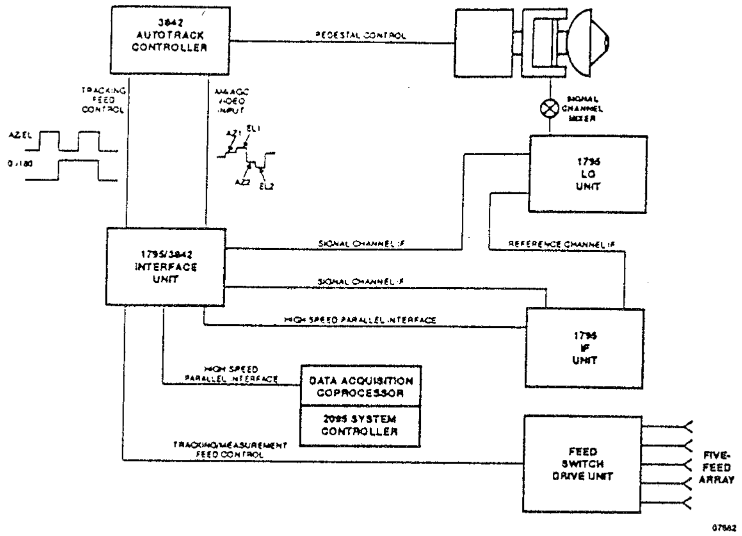

Figure 4. 1795/3842 Interface Unit connection

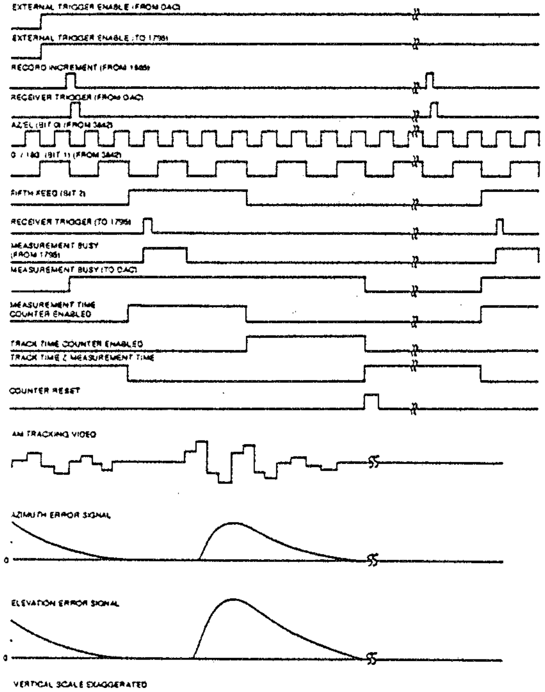

Figure 5. Interface unit timing diagram

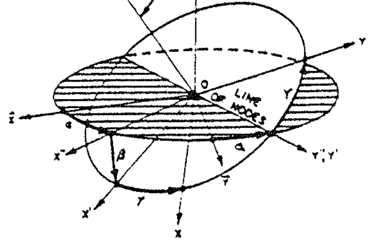

Figure 6. Rotation of coordinate systems (from Hollis, Lyon, and Clayton [1])