PORTABLE RF TARGET SIMULATOR

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ABSTRACT

RF guided missile developers require flight simulation of their target engagements to develop their RF seeker. This usually involves the seeker mounted on a Flight Motion Simulator (FMS) as well as an RF target simulator that simulates the signature and motion of the target. Missile intercept engagements are unique in that they involve highly dynamic relative motion in a short period of time. This puts demanding requirements on the RF target simulator to adequately present the desired phase slope, amplitude, and polarization to the seeker antenna and electronics under test.

This paper describes a newly installed RF Target Simulator that addresses these requirements in a unique fashion. The design utilizes a compact range reflector, dynamically rotated in two axes as commanded by the flight simulation computer, to produce the desired changing phase slope and an RF feed network dynamically controlled to produce the desired changing polarization and amplitude. Physical optics analysis establishes an accurate correlation between reflector physical rotation and resulting angle-of-arrival of the wave front in the quiet zone. The RF Target Simulator is self contained in a two-man portable anechoic chamber that can be disengaged from the FMS and rolled to and from the FMS as needed. Measurements are presented showing the performance of the RF Target Simulator.

Keywords : Compact Range, Precision Dynamic Positioning, Facility Description, Quiet Zone, RF Target Simulation

1. Introduction

MI Technologies, in conjunction with Dynetics, has developed and installed a new RF Target Simulator for use in an existing Hardware-in-The-Loop (HWIL) simulation test facility for AMRDEC in Huntsville, Alabama. The RF Target Simulator provides a controlled RF environment for characterizing RF seekers being developed for ground to air intercept engagements. The RF Target Simulator simulates the motion of the desired target and produces an appropriate RF return based on the relative geometry between it and the missile seeker under test. It is used in conjunction with the seeker mounted on a flight motion simulator. It supports the development and validation of the seeker's acquisition and tracking algorithms with both the seeker and the target under dynamic motion. Technical challenges included predicting and compensating for the effects on the quality of the plane wave due to the rotation of the reflector, dynamically producing the desired polarization in response to real time digital commands and achieving the required dynamic positioning accuracies.

2. System Description

The RF Target Simulator consists of the following main subsystems;

- Compact Range Reflector
- Reflector Positioning System
- RF Feed and Network
- Portable Anechoic Chamber With Mounting Structure

Figure 1 is a block diagram of the system showing the main subsystems and interfaces to the flight simulation computer and associated equipment.

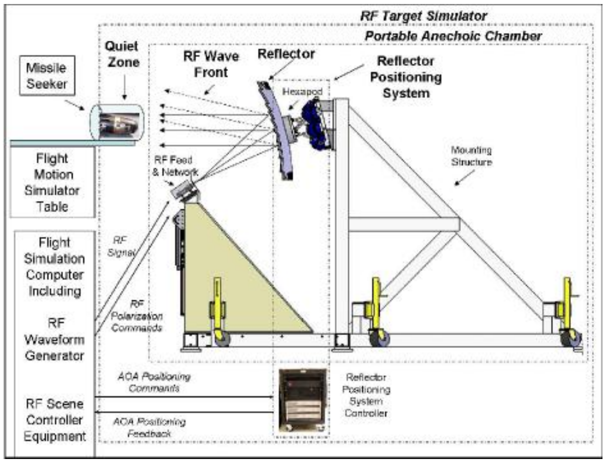

Figure 1 RF Target Simulator Block Diagram

The "RF Wave Front" simulates the RF return of a target by presenting an RF Plane Wave of the desired frequency, polarization and line-of-site angle (angle-of-arrival) to the Missile Seeker under test. The Quiet Zone generated by the RF Target Simulator is a cylindrical region 6 inches in length along the direction of propagation of the wave and sufficient in diameter about the direction of propagation to enclose the Seeker aperture that is up to 6 inches in diameter.

The process begins with commands from the Flight Simulation Computer's RF Scene Controller and the RF Signal from the RF Waveform Generator. The RF Feed Network receives polarization commands from the RF Scene Controller at an update rate of up to 1.5 kHz. It also receives the RF signal of the desired frequency and amplitude from the RF Waveform Generator. The RF Feed Network adjusts the polarization of the RF signal, based on the commands, and transmits the signal via the Feed to the Reflector surface.

Similarly the Reflector Positioning System's Controller receives angle-of-arrival position, rate and acceleration commands from the Flight Simulation Computer's RF Scene Controller at an update rate of up to 1.5 kHz. It processes the signals to determine the correct movement of the Reflector Positioning System to dynamically move & position the Reflector. The Reflector positioning System utilizes a Hexapod that is capable of dynamically rotating the Reflector about two axes of rotation to produce the desired angle-of arrival of the RF Plane Wave to the Missile Seeker under test. Achieved position and rate are fed back to the Reflector Positioning System Controller to close the servo loop. The Reflector Positioning System Controller applies the necessary compensation to achieve desired servo loop performance.

The Reflector has a parabolic surface contour to create the RF Plane Wave from the signal transmitted from the Feed. The perimeter of the Reflector is serrated to reduce the effects of edge diffraction. The Reflector is made of carbon composite achieving a high degree of structural stiffness at a low weight. The natural frequency of the Reflector structure is over 250 Hz. The reflector is able to maintain its parabolic shape as it is dynamically rotated.

The Portable Anechoic Chamber (Figures 2 & 3) provides a quiet RF environment within which to test. It is designed to be small enough to fit through the laboratory doors but large enough to encompass the Reflector, Feed and Missile Quiet Zone when in place. The Chamber is lined with appropriate absorber to diminish any stray signals. The Reflector, Hexapod, RF Feed Network, and Mounting Structure are all contained within the Portable Anechoic Chamber and move with it. When the Anechoic Chamber is moved into the lab it is secured to the foundation at a predetermined position. The Mounting Structure is secured through the bottom of the Anechoic Chamber to the foundation. Access to the interior of the Chamber, when in the installed position, is provided by a side door in the Chamber.

Figure 2 Portable Anechoic Chamber/Compact Range

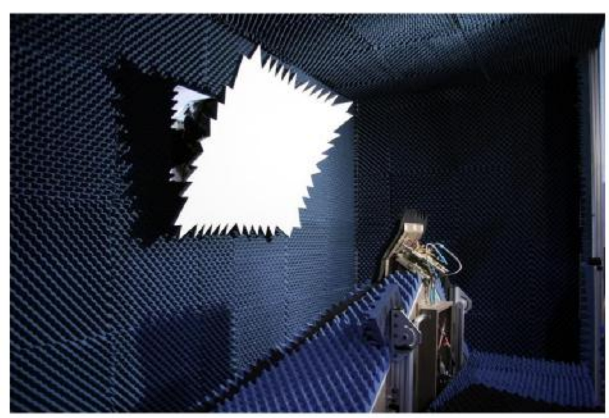

Figure 3 Compact Range inside Portable Chamber

3. Design Considerations

RF Target Simulators for HWIL applications are often implemented by making the room containing the flight motion simulator into an anechoic chamber and by switching either a bank of antennas to simulate target motion or by dynamically moving antennas on a set of curved rails. In either approach the room becomes dedicated to the effort with the antennas located in the far field at the end of the chamber opposite the flight motion simulator. The requirement for the AMRDEC installation was to create a portable chamber, and equipment that could be removed to allow other uses for the flight motion simulator. This drove the decision to use a compact range to reduce the size of the chamber needed and allow portability. Having made this decision, the next decision was how to steer the plane wave to produce the desired angle-of-arrival. Choices considered included moving the reflector, moving the feed or moving both in concert. Rotating both in concert to steer the plane wave was desirable because it maintains focus between the feed and reflector minimizing distortion. However, this became impractical due to dynamic positioning requirements.

The flight simulation required extremely accurate positioning and resolution of movement under high dynamic conditions. It involved achieving angle-of-arrival accuracies on the order of 50 micro radians statically and 400 micro radians dynamically. Dynamic motion involved accelerations on the order of 2,000 deg/sec^2, velocities of 11deg/sec and a servo loop bandwidth of nearly 30 Hz.

Movement of the feed was also discarded because of dynamic motion concerns. The RF feed and its control circuits and connections would be subjected to forces that would impact RF performance. Rotating the reflector about a pivot point was determined to be the most agile approach to achieve dynamic movement. However, rotating the reflector while keeping the feed stationary causes defocusing of the plane wave. Predicting and compensating for this effect was one of the technical challenges.

4. Predicting & Compensating to produce a Quality Plane Wave

In a typical feed/reflector compact range, the elements are aligned and focused to statically place the quiet zone surrounding the unit under test. Physical optics based programs such as GRASP8 [1] easily predict the quality of the plane wave in this situation, specifically its phase slope, amplitude and phase taper and ripple. However, in the RF Target Simulator case the reflector is rotated with the feed fixed causing a defocusing of the plane wave since the feed is no longer at the focal point. In addition the center ray and peak energy of the plane wave move off the aperture of the seeker. As illustrated in Figure 4, a rotated reflector carries its quiet zone away from its original location. Thus the quiet zone must be large enough to ensure that the seeker aperture remains within it as the plane wave is rotated. For this reason the reflector was designed to produce an oversized cylindrical quiet zone of 18 inch diameter to accommodate the desired range of angle-of arrival motion which was 10 x 10 degrees.

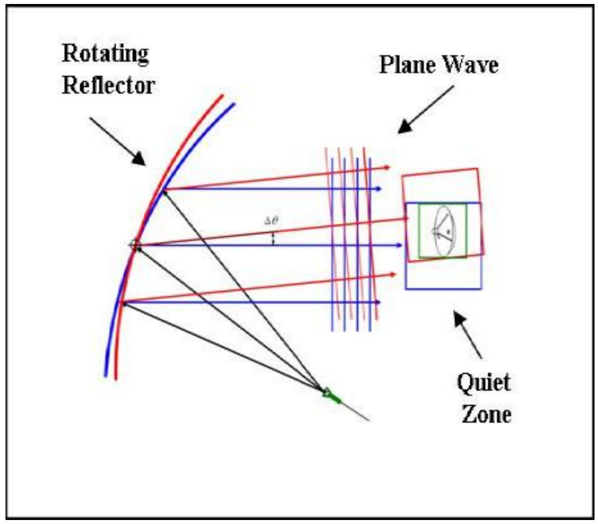

Figure 4 Rotated Reflector And Its Quiet Zone

It was necessary then to predict what wave front the seeker actually sees as the focus changes and center ray moves around with reflector rotation. The goal was to predict this response to a very high degree of accuracy so that the reflector can be positioned to present the desired wave front to the seeker as commanded by the simulation computer's RF scene generator. The key wave front parameter is phase slope. The seeker will process the target return it sees, looking for the centroid of the signal and determining its AOA primarily from the phase slope of the wave front. The amplitude/phase ripple and taper must be good enough not to corrupt this processing. The design goal was to predict the AOA as seen by the seeker as a function of reflector rotation, within 10 micro radians.

The reflector & feed were modeled in GRASP8. Simulations were performed to develop a matrix of reflector rotation data in azimuth and elevation that correlates to AOA as determined by the linear approximation of the plane wave in the quiet zone as seen by the seeker aperture. A matrix of discrete rotations every 0.17 degrees, was correlated to a warped matrix of resulting AOA covering the operating range of 10 by 10 degrees. A vector matrix method was developed to transfer the warp from the AOA matrix to the reflector rotation matrix. This resulted in two sets of matrix data; (1) Grid Reflector Rotation Matrix-to-Warped AOA Matrix and (2) Grid AOA Matrix-to-Warped Reflector Rotation Matrix. Bilinear interpolation was used to establish the correlation for any data between values on the grid. The matrices were programmed into the reflector positioning system Controller. As the positioning controller receives an AOA command from the flight simulation computer's RF scene generator it uses the grid AOA matrix to determine the proper rotation of the reflector. Data from the position feedback sensors are applied to the grid reflector rotation matrix to determine the achieved AOA to report back to the flight simulation computer. Phase probe testing proved this approach to be successful in compensating for defocusing due to rotation of the reflector to produce the desired AOA with the proper phase slope and good quality plane wave characteristics. Phase probe testing was performed with the reflector rotated at various combinations of AOA commands across an operating range of 10 by 10 degrees. Table 1 and Figures 5 through 7 show some achieved test results.

Measured Data	Average Value across AOA Operating Range of 10 by 10 degree commands
Amplitude Taper	0.3dB
Amplitude Ripple	+/-0.23dB
Phase Variation	+/-2.4 deg
AOA Error	283 micro radians

Table 1 Summary of Test Zone quality and achieved AOA response to commands across operating range

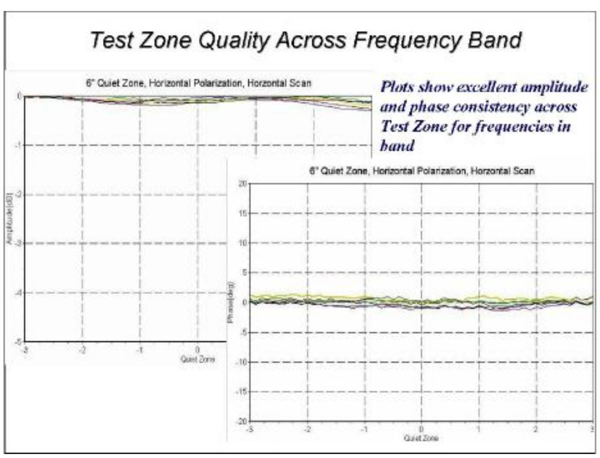

Figure 5 Test Zone Quality Across Frequency Band

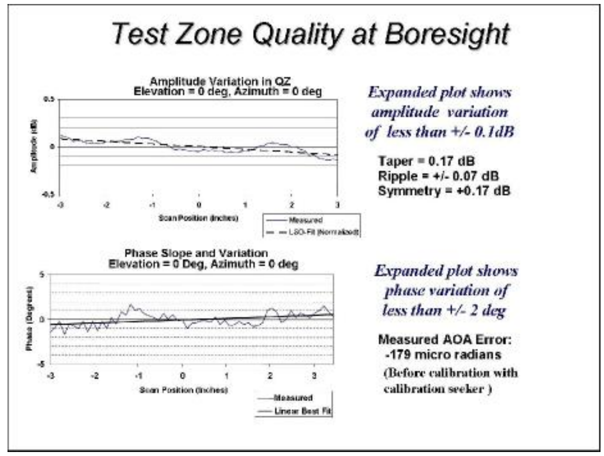

Figure 6 Test Zone Quality at Boresight

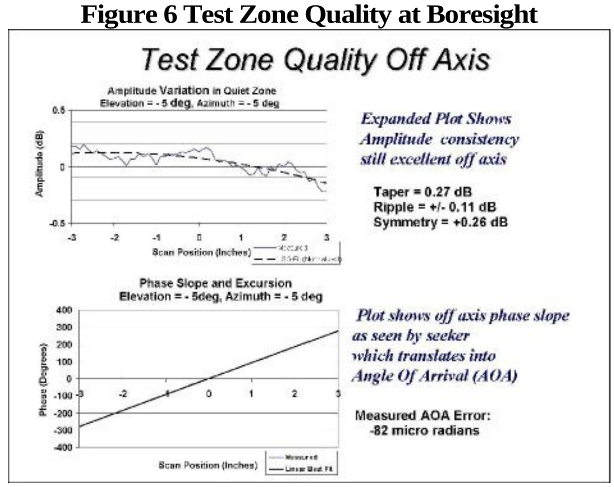

Figure 7 Test Zone Quality Off Axis

Note: A calibration seeker was developed for AMRDEC by Dynetics to allow very accurate calibration of the RF Target Simulator in its installed state. The calibration seeker uses an automatic routine to command the RF Target Simulator to AOA positions across the 10 by 10 degree operating range and measure its responses. Based on this data the Grid AOA Matrix-to-Warped Reflector Rotation Matrix can be quickly adjusted to calibrate out small error such as misalignment. The fidelity of the calibration seeker allows calibration of the RF Target Simulator to achieve AOA static positioning on the order of 50 micro radians accuracy.

5. Dynamically Controlling Polarization

To accommodate active RF seekers that roll, the polarization changes continually through the flight simulation. To correctly simulate the RF return of the target, it is necessary for the compact range feed to dynamically match the seeker polarization. However, it is undesirable to do this by physical rotation of the feed due to vibration of the high frequency components and their connections. A technique was developed to electronically change the polarization of the compact range feed allowing it to stay physically stable. Figure 8 shows a simplified diagram of the RF feed network concept.

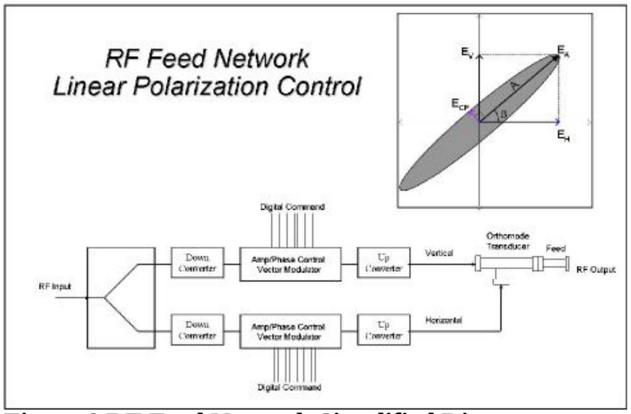

Figure 8 RF Feed Network Simplified Diagram

The design strategy is to split the RF signal into two nearly identical polarization paths, vertical and horizontal, each capable of varying amplitude and phase. The ratio of their amplitude is adjusted to create the desired polarization while keeping them in phase. Each signal is applied to one of two orthogonally polarized ports of an orthomode transducer connected to the compact range feed. This produces the desired linearly polarized signal.

Selecting a method to vary amplitude was complicated by the lack of suitable components in the frequency band of interest. Attenuators were not chosen to dynamically adjust the amplitude ratio because they have too much phase variation as attenuation is varied. Digitally controlled vector modulators that allow amplitude and phase control seemed ideal for creating the desired signals in each path. However commercially available vector modulators at the frequency band of interest did not have the necessary performance or were not economical. To solve this problem the signal is first down converted to a frequency where appropriate components are available, then passed through the vector modulators where the ratio of their amplitudes are set while maintaining the same phase, then up converted to the desired frequency before entering the orthomode transducer.

Test results in Figures 9 & 10 show excellent polarization linearity and accuracy while maintaining cross-polarization less than -24 db.

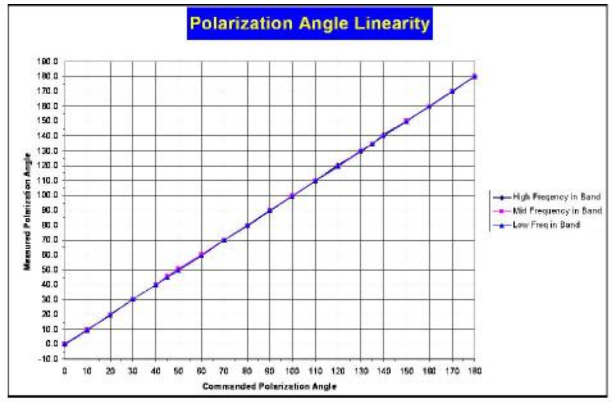

Figure 9 Polarization Angle Accuracy

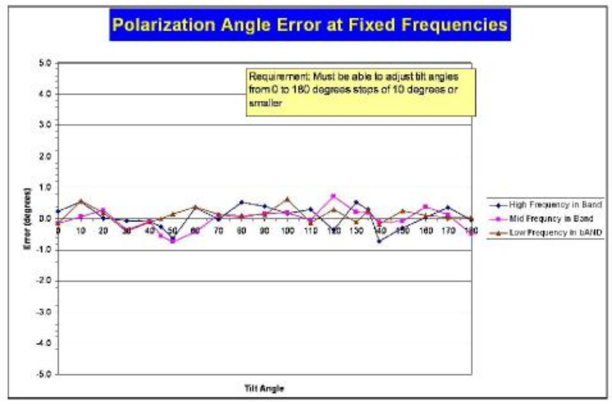

Figure 10 Polarization Error

Note that the vector modulators can be set to adjust the phase of the two signals to be orthogonal to each other rather than keeping them in phase. If these are then fed to the transducer the result will be a circular polarized signal rather than linear. The RF feed network is capable of supporting dynamically controlled circular polarization as well as linear for future seeker development if needed.

6. Achieving Dynamic Positioning Accuracy

The requirement was to produce the angle of arrival for two simultaneous degrees of freedom, i.e. rotation in elevation and in azimuth. However, the desired dynamic accuracy of the produced AOA necessitated extremely good alignment of the reflector with the FMS, and high agility in its positioner. A hexapod was chosen because of its performance and flexibility. A Hexapod, or Stewart Platform, shown in Figure 11, is a parallel kinematics system composed of six struts to provide motion and accuracy for positioning with six degrees of freedom (x, y, z, pitch, roll and yaw).

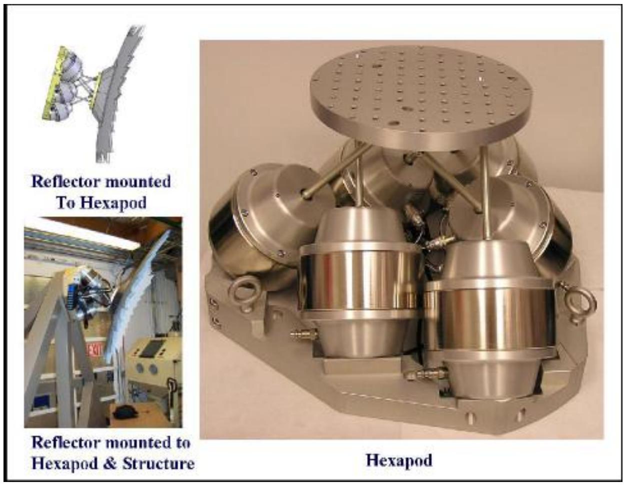

Figure 11 Hexapod

The hexapod chosen uses voice coils to linearly actuate the struts and provide high dynamic performance. The struts move in concert together, though sometimes with some in compression and others in extension, to produce the commanded motion. The available six degrees of freedom provided flexibility in alignment and placement of the center of rotation of the reflector. The user coordinate system is defined by simple operator inputs that offset it from the hexapod coordinate system. The center of rotation can be anywhere within the travel range of the hexapod. This provided enormous flexibility during integration as compared to a fixed mechanical design.

During the flight simulation, the flight simulation computer's RF scene generator calculates the necessary Angle-Of-Arrival (AOA) to represent the appropriate RF return of the target based on the relative geometry between the target and the interceptor at that interval in time. It sends the desired state of the AOA to the reflector positioning system controller. That is, it sends the desired AOA and its rate of change and its acceleration. The positioning controller converts these to reflector rotation commands in elevation and azimuth using the Grid AOA Matrix-to-Warped Reflector Rotation Matrix discussed earlier, and closes the servo loop to achieve the AOA. The positioning controller loop operates at a faster update rate than the commands coming to it from the RF scene generator. The positioning controller employs a propagation equation that uses the last commanded AOA position, velocity and acceleration it received to smooth its response during the interval between commands. In summary, the flight simulation computer's RF scene generator presents the positioning controller with a dynamically changing flight profile which the reflector positioning system must follow to within the order of 400 micro radians. For testing, representative pre-calculated target flight profiles were sent from the RF scene generator to test the reflector positioning system. Figure 12 shows the tracking performance of the Reflector positioning system to one of these flight profiles.

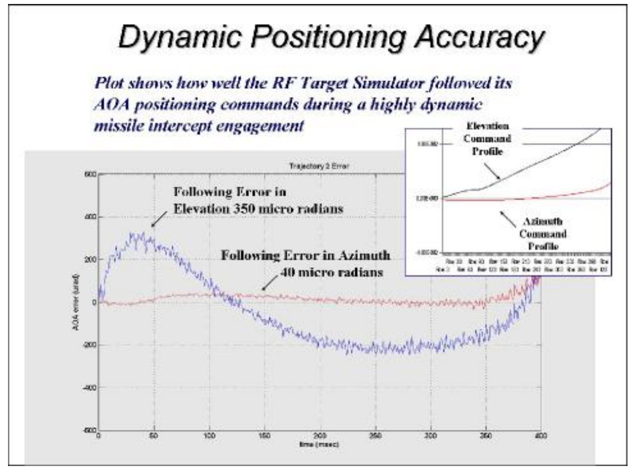

Figure 12 Dynamic Positioning Accuracy

7. Summary

An existing Optical Hardware-in-The-Loop (HWIL) simulation test facility for AMRDEC in Huntsville Alabama has been upgraded with an RF target simulation capability using compact range technology. It allows RF seeker development in support of highly dynamic intercept engagements. Its portability allows the facility to be used for other sensor testing without being dedicated to RF. The system engineering design used novel approaches to achieve the dynamic RF target simulation. Key technical challenges were met by (1) Using GRASP8 to create a Grid AOA Matrix-to-Warped Reflector Rotation Matrix to produce a quality plane wave with the right characteristics, (2) Down converting the signal to allow use of digitally controlled vector modulators then up converting to the orthomode transducer to produce the correct polarization (3) Using hexapod technology to achieve the desired agility and flexibility in producing the RF target return.

8. References

[1] Knud Pontoppidan editor "GRASP8 Technical Description", TICRA Engineering Consultants, Laederstraede 34 DK-1201 Copenhagen K Denmark