A COMPACT ANTENNA TEST RANGE BUILT TO MEET THE UNIQUE TESTING REQUIREMENTS FOR ACTIVE PHASED ARRAY ANTENNAS

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ABSTRACT

Microwave Instrumentation Technologies (MI Technologies) in cooperation with Hollandse Signaalapparaten B.V. (Signaal) and the Royal Netherlands Navy has designed and produced a compact antenna test range to specifically address the unique testing requirements imposed in the testing of active phased array antennas. The compact range was built specifically to test Signaal's new Active Phased Array Radar (APAR) prior to introduction into various naval fleets throughout the world. This reversible Compact Antenna Test Range (CATR) allows antenna testing in both transmit and receive modes. The measurement hardware is capable of testing both CW and pulsed waveforms with high dynamic range. In addition to conventional antenna pattern measurements the system is capable of measuring EIRP, G/T and G/NF, as well as providing analysis software to provide aperture reconstruction. A special Antenna Interface Unit (AIU) was designed and built to communicate with the Beam Steering Computer which controls the thousands of T/R modules which make up the APAR antenna system. A special high power absorber fence and other safeguards were installed to handle the transmit energy capable of being delivered from the APAR antenna system.

Keywords: Compact range, facility descriptions, measurement systems

1. Introduction

Modern active phased array antennas use thousands of transmit/receive modules (T/R modules) to form a transmit or receive beam. In the case of the APAR antenna 3500 active T/R modules are used for each antenna face. For this class of antenna the transmitter and receiver cannot be separated from the antenna itself. Therefore the antenna, transmitter, and receiver must be tested as a system. Since reciprocity does not exist with the active phased array antenna, both transmit and receive patterns must be measured.

A beam steering computer communicates with each of the T/R modules to set the phase states of each module forming the desired beam. The beam width and beam position relative to the face of the antenna can be derived by correctly controlling each of the antennas T/R modules.

Many new problems are introduced to the measurement system when testing this class of antenna. Although a CW measurement may be made of the receive configuration in most cases the transmit beam must be measured in a pulsed configuration. Transmitting high power in an indoor range requires the use of special high power absorber. This absorber requires airflow through the absorber, which introduces new problems in the facility design. The ability for the beam steering computer to change the direction of the beam relative to the antenna surface brings about safety concerns. Special thermocouples must be used to insure that the beam is truly pointed towards the measurement equipment and high power absorber. If the beam were to be directed to an area of the chamber where standard absorber is used a fire could result.

2. Facility

For testing of Signaal's APAR antenna an indoor compact range was selected. A MI Technologies Model 5712M compact range was chosen for the chamber. The Model 5712M encompasses a slightly larger quiet zone of 4 meters diameter compared the standard Model 5712, 12 foot quiet zone.

To facilitate loading and unloading of the APAR antenna a motorized slide was installed to move the test positioner and APAR antenna in and out of the chamber. A bridge crane located outside of the chamber is used for loading and unloading of the antenna. Two large RF shielded doors are located at the rear of the chamber to allow this large test positioner and test article to enter and exit the chamber. Outside of the chamber boresight alignment mirrors are located at positions unique to Signaal's antennas which are to be tested in the facility. A laser interferometer is mounted in the antenna to perform the boresight alignment.

A special high power fence is located at the compact range feed large enough to contain the RF energy transmitted during the power transmit tests of the APAR antenna. Twin 5 horsepower electric fans are used to achieve the necessary airflow to protect the high power absorber located in the fence.

A diagram of the Signaal facility is included in Figure 1.

3. Positioning System

The testing of the APAR antenna brought many challenges to the design of the antenna positioning system. The APAR antenna with coolant weighs approximately 2500 kgs when fully populated. Signaal determined that a .02 degree global positioning accuracy would be required to test the APAR antenna. This is required though the entire 75 degree elevation positioning and 180 degrees of azimuth travel used during test.

The antenna positioning system is a roll over upper azimuth over elevation over lower azimuth over slide configuration. In addition, a larger offset arm is used to scan the APAR antenna on its phase center. A liquid rotary joint was installed through the roll positioner to pass the coolant required to cool the T/R modules during transmit tests. A diagram of the antenna positioning system is included in Figure 2.

4. Measurement System

The requirement that both transmit and receive measurements would be performed in the range dictated that the range be reversible, i.e. the signal source and microwave receiver needed to be able to be cabled to either the compact range feed or antenna under test. As this was to be a production facility it was important that this recabling be done with little manual intervention. An automated switching system was developed to accomplish this range reversal. RF switches, attenuators, amplifiers and high power loads were designed into the system and configured by the system computer dependent of the type of test that was to be performed.

The measurement system consists of the Model 2095P Pulsed Microwave Measurement System with custom software configured to the special requirements of this facility. RF energy is provided by a Model 2180/2186 Microwave Signal Source. The microwave receiver is a Model 1795P Pulsed Microwave Receiver. Positioning of the antenna and feed positioners is handled with a Model 2012/ 4180 Positioning subsystem.
To provide a versatile interface between the 2095P system, the Signaal APAR system and a safety interlock unit, MI Technologies provided an Antenna Interface Unit (AIU). This unit allows the downloading of operational instructions from the 2095P for the APAR antenna, which provides control information to the APAR Beam Steering Computer and Timing Unit, and handles signals to/from the safety interlock system.

The AIU is a stand-alone unit mounted in the 2095P console. It contains high speed microprocessors for timing, control, and data transfers between the APAR antenna and the 2095P system. The interface between the 2095P and the APAR antenna is through a fiber optic interface provided by Signaal.

Special test capability was added to the 2095P measurement system to aid in the testing of this unique system. To be able to measure the antenna patterns it is necessary to calibrate the APAR antenna. This calibration procedure is employed by the APAR antenna.

Transmit patterns are measured at two power levels. For +/- 90 degree patterns the tests are conducted at low duty cycle to avoid damage to the absorber in the compact range. High power transmit patterns are limited to +/- 10 degrees to keep the transmit beam within the confines of the high power fence and high power absorber.

The capability to measure G/T and G/NF was added to the measurement facility. The procedure for measuring G/T and G/NF is as follows:

1. Measure received power P_{on} at AUT with RF on.
2. Measure received power P_{off} at AUT with RF off.
3. Substitute a Standard Gain Horn (SGH) for the AUT and measure the received power P_r with RF on.

For this test the measured receive power is with the APAR receiving. The fiber optic digital interface of the Sum, Delta Azimuth and Delta Elevation channels are downloaded through the AIU and stored in a data file on the 2095P system computer. A power meter is used in conjunction with the SGH to perform the P_r measurement. The 2095P software then performs data analysis on these files to calculate G/T and G/NF using the following equations.

$$\frac{G}{T} = \left(\frac{Pon}{Poff} - 1 \right) \frac{kBG_{STD}}{P_r}$$

$$\frac{G}{NF} = \frac{G}{T} T_o$$

Where P_{on} and P_{off} are calculated from the P_{on} and P_{off} sample measurements. *B* and *k* are constants. *B* is the value of the receiver equivalent bandwidth input by the user during the creation of the collect file for the measurement. *k* is Boltzmann's constant and is equal to 1.381 Watt seconds per degree Kelvin.

G_{STD} is the gain of the standard gain horn and is available in a lookup table as a function of frequency. T_o is the ambient temperature of the compact range in degrees Kelvin which is input by the user during the creation of the collect file for the measurement. All variables are known so G/T and G/NF is calculated.

The system is also capable of measuring Effective Isotropic Radiated Power (EIRP). This is accomplished by measuring the received power P_{rsgh} at the compact range feed with Power, P_{in} on the input of a SGH mounted directly in front of the APAR antenna. Then the Power, P_{in}, is input into the APAR antenna and the receive power P_{raut} is measured at the compact range feed. This test is performed in pulsed and CW modes as a function of frequency.

The 2095P software then calculates EIRP based on the following formula.

$$EIRP = P_{raut} * \frac{G_{sgh} P_{in}}{P_{rsgh}}$$

5. Safety

The requirement to transmit inside of the chamber brought about many concerns for the safety of the range personnel. A safety interlock unit was design and built to monitor various safety features in the chamber. The interlock unit controls a RF switch which allows RF energy to be sent to the input of the APAR antenna during transmit tests. It also communicates with the AIU to report any system failures.
Around the high power fence, sixteen thermocouples were installed to monitor that the transmit beam is within the confines of the high power fence. If any of these monitors rise above a preset limit the error is sent to the safety interlock unit to shutdown the RF energy. Thorough tested was conducted to insure that these thermocouples would still remain accurate even when being bombarded by the high power of the APAR antenna. In addition the Safety Interlock monitors the following sensors:

Doors - Each of the chamber doors has redundant switches used to monitor that the chamber doors are closed during high power testing.

Fire Protection – The fire protection system includes a signal that indicates that the fire protection system is operational and functioning.

HVAC – The heating and air conditioning system is monitored to assure that it is operating.

Air Flow – Air flow sensors are installed in the high power fence to insure that each of the 5 horsepower fans are on and producing the necessary airflow.

APAR Shutdown – The APAR system itself can disable the RF in the event that it has detected and error.

In addition the Safety Interlock Unit has a large shutdown switch the allow the range personnel to shut down the RF and disable positioner movement.

6. Conclusion

The testing of active phased array antennas provide new challenges in the design of the test facility. The test positioner is required to accurately position large loads over a wide degree of positioning angles. The range needs to be reversible to allow testing to be conducted for both the transmit at receive modes of operation. An interface needs to exist between the measurement computer and the computer(s) of the antenna to synchronize the two systems in testing over a wide frequency range. Finally, when transmit testing needs to be conducted indoors special safety equipment needs to be installed to protect the facility and range personnel.

FACILITY

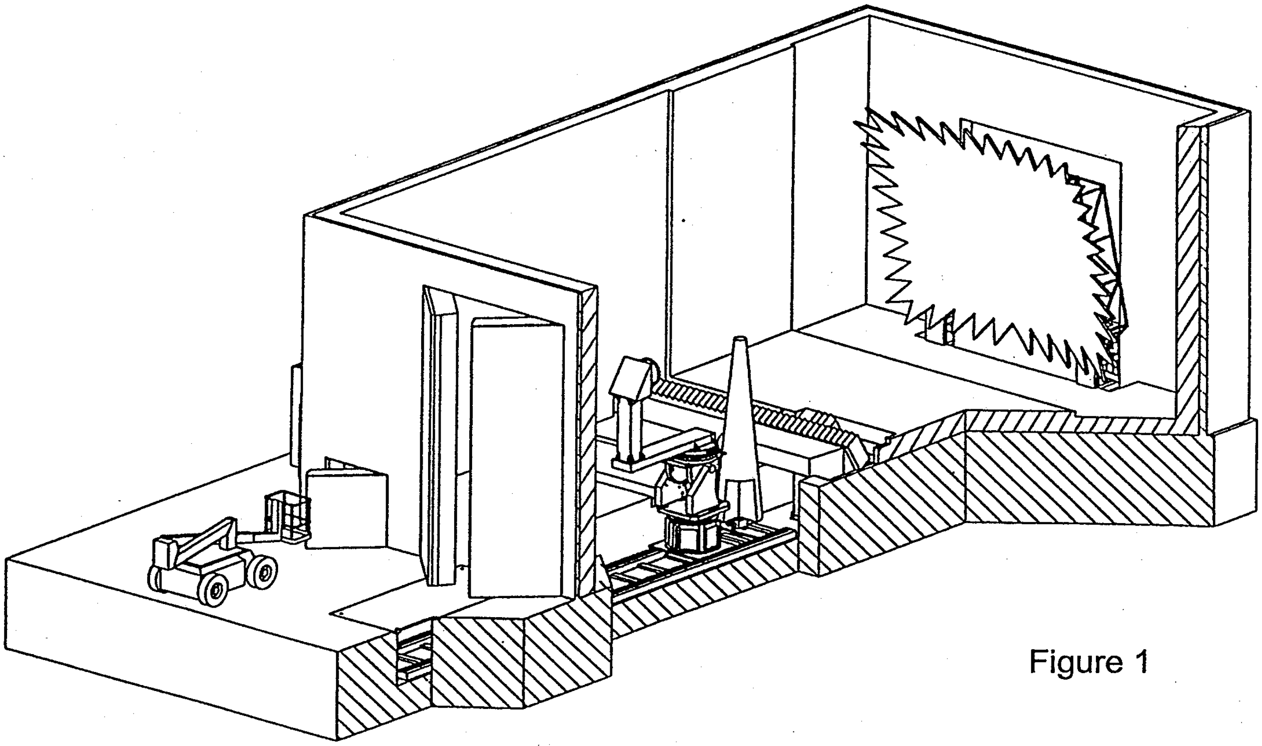

Figure 1

AUT POSITIONER

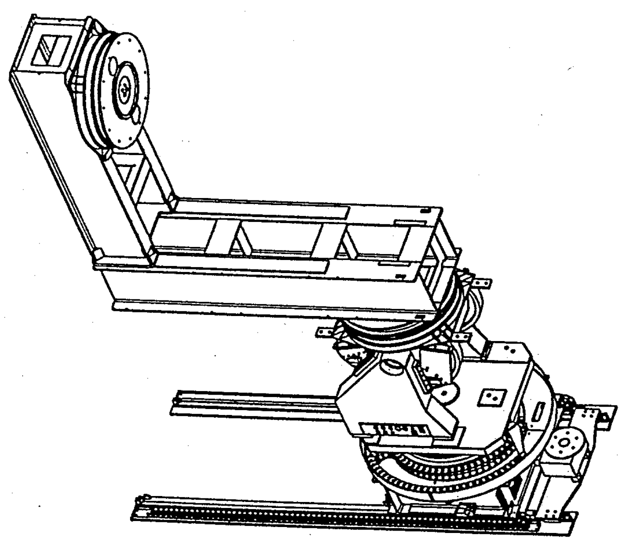

Figure 2