PHASE CENTER MEASUREMENTS FOR A WRAP-AROUND GPS ANTENNA

Steven J. Meyer
Naval Air Warfare Center Weapons Division
Code 543400D
China Lake, CA

Scott R. Kujiraoka
Naval Air Warfare Center Weapons Division
Code 543E00E
Point Mugu, CA

ABSTRACT

Global Positioning System (GPS) technology is being used as a sensor in telemetry systems to provide time, space and position information (TSPI) as well as end game or vector scoring. The accuracy of these measurements depends on precisely locating the phase center of the GPS antenna. A procedure has not currently been addressed by anyone to measure the phase center of a conformal wrap-around GPS antenna. This paper will discuss some techniques on determining the antenna phase center.

KEY WORDS

Phase Center, Global Positioning System (GPS), Wrap-around Antenna

BACKGROUND

The Joint Advance Missile Instrumentation program (JAMI) has been exploring the use of GPS as a sensor for telemetry systems. One of the items required to implement GPS in a telemetry system is a GPS antenna. The conformal wrap-around antenna used on missile systems maintains the aerodynamics and a good radiation pattern coverage when the missile rolls. A wrap-around telemetry (S-Band) antenna is also needed to transmit the telemetry data.

For the JAMI investigations, single frequency C/A code is used, where the errors are removed from the GPS signal by using Double-Difference corrections (DDGPS). This frequency is referred to as L1 (1575.4 MHz). Several dual band (L1/S) antennas have been designed, two made for a 5-inch diameter

missile and two for a 2.75-inch diameter missile. When we started testing these antennas, several problems appeared, and a Central Test and Evaluation Investment Program (CTEIP) called Multiple Band Antennas for Telemetry (MuBAT) was formed to resolve the problems.

Some of the problems we found include; (a) the need for a filter between the pre-amp and the L1 antenna to prevent unwanted telemetry signals from leaking through, (b) low noise figures for the GPS antenna system, (c) the need for software design tools to handle multiple antennas in a single band, and (d) locating the phase center of the L1 antenna. The tracking ability of a GPS receiver in a high dynamic environment is dependent on the signal-to-noise ratio. Even though there is about 600 to 700 MHz of separation between the L1 and S-band signals, the S-band transmitter would saturate the pre-amp so that very few of the GPS signals could be received. Approximately eight Satellite Vehicles (SV's) were tracked prior to powering the S-band transmitter. When the transmitter was turned on, the number of SVs would drop to one or two. Eugene Law documented these and other problems with L1 and L-band antennas in his current paper for ITC 2000 [1]. A low noise figure pre-amp located as close to the antenna as possible is needed. MuBAT is looking into building wrap-around antennas with built-in filter/limiter/preamplifier. A software tool is being upgraded to design multiple band antennas. This paper describes what we have done to date to address the problem of finding the phase center of the antenna, but there is still more work that needs to be done in this area.

INTRODUCTION

What is the phase center of an antenna and why is it important? The phase center is defined as a reference point from which all radiation emanates, and radiated fields measured on the surface of a sphere whose center coincides with the phase center have the same phase [2]. The phase center of most antennas is not one single point, but rather a surface. It may not even be contained within the antenna structure. The phase center will appear to move depending on the angle of the signal to the antenna. When a phase center is identified, it is usually the average of all the different phase centers from all the SVs being received.

Knowing the phase center of the GPS antenna is important to be able to make accurate measurements. For the 5-inch wrap-around antennas, not knowing the location of the phase center will cause errors in the measurements on the order of ± 2.5 inches. For the JAMI program, this is a good portion of the error budget for producing an end-game-scoring accuracy of 12 inches. Therefore, being able to accurately define the phase center of the antenna becomes very important to meet the end-game-scoring requirements.

METHODS OF MEASUREMENTS

There are two methods of measurements that are outlined in literature. One method is to use a reference antenna that has been surveyed with the antenna under test located at a known fixed distance from the reference antenna [3]. GPS measurements are then taken to find the position vector from the reference antenna to the antenna under test. By knowing the phase center of the reference antenna, the average phase center of the antenna under test can be calculated. This would be a simple and easy method for a highly directional antenna that has a good ground plane and looks up at the sky. The problem with using

this method on a wrap-around antenna is that it is omnidirectional and looks down at the ground as well as at the sky. This causes multipath problems that would skew the data. Another problem is the phase center will change as the antenna is rotated and several measurements would have to be done to get a good idea on how the phase center moves as the antenna is rotated.

The other method is to put the antenna under test in an anechoic chamber and place it in the field of a transmitting horn on a positioner that is capable of precise placement of an antenna relative to the rotation axes. This method is outlined in the Antenna Handbook [2]. Since NAWCWD has an anechoic chamber, this method was chosen to measure the phase center of a wrap-around GPS antenna. This chamber has a rotating circular table to achieve all 360° azimuth angles, as well as a rotary joint pedestal to measure all 360° roll angles (thereby achieving all 4π steradian angles).

TEST SET-UP

The test set-up for phase center measurements is shown-on Figure 1. The nose of the missile was defined as the zero degree azimuth angle (Az = 0°). The missile mockup model with attached wrap-around antenna was mounted onto the anechoic chamber pedestal. A reference measurement was taken with the GPS antenna array's RF connector located at the center of rotation of the chamber table. Each measurement involved the rotation of the table from the Az = +90° to Az = -90°, while measuring the phase in two degree increments. The pedestal was moved forward and backward, with respect to the transmitting antenna, and phase measurements were conducted until a symmetric phase pattern was achieved. Several antennas were tested but the only results for the Haigh-Farr (model 2410) GPS/S-band 5-inch wrap-around antenna will be presented.
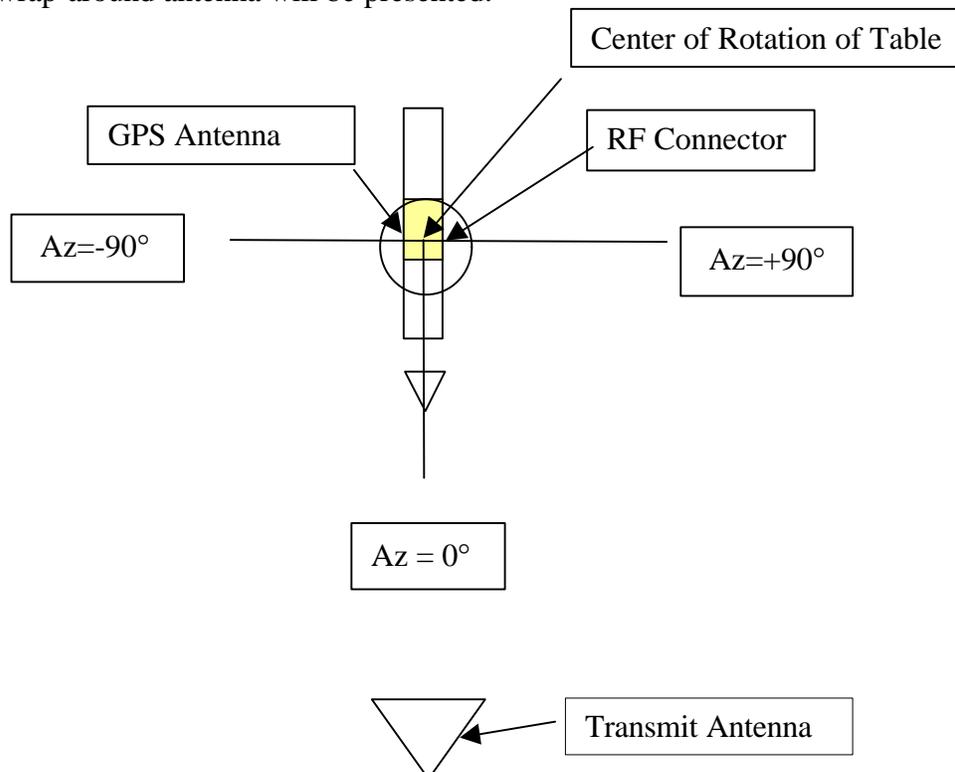
Figure 1. Test Set-up

RESULTS

Figure 2 shows the initial reference phase plot. If the phase center were directly along the horizontal center axis of the missile and along the vertical line through the RF connector, the phase plot would be a straight line. Obviously Figure 2 does not represent the phase center. After several iterations, the RF connector was moved closer to the transmitting antenna by 4.675 inches. The phase measurement plot on Figure 3 is not a flat line, but the phase plot is symmetrical. The symmetrical plot shows that the phase center is in line with the vertical center of rotation. When the tests were conducted, the pedestal did not allow the missile body to be translated so that it could be offset from the horizontal missile axis. Due to this limitation, the phase center could not be resolved any further.
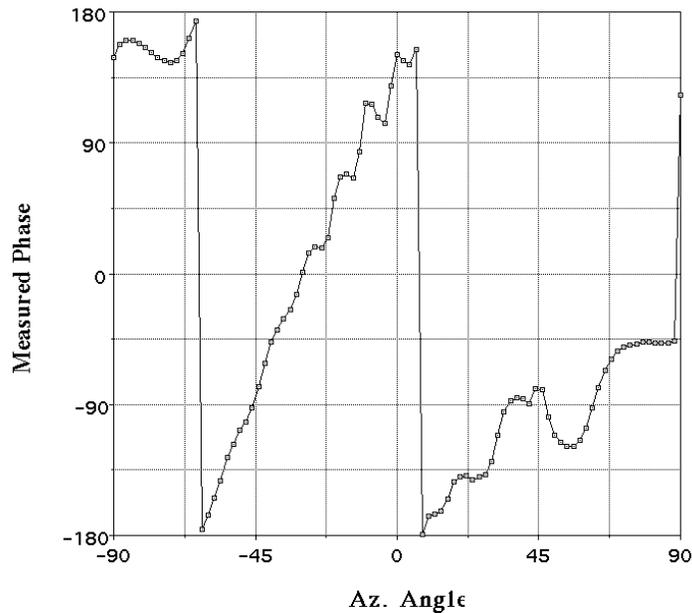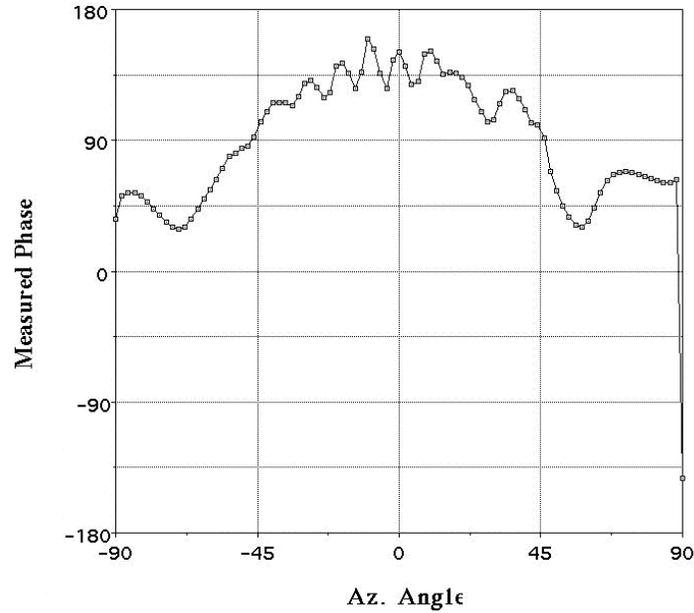

Figure 2. Reference Phase Plot

Figure 3. Final Phase Plot

The following equation from the Antenna Handbook [2] is used to calculate the radius of the phase center from the center of rotation:

$$r = \frac{\lambda_o}{2\pi} \frac{\psi}{(1 - \cos\theta)} \qquad (1\text{-}1)$$

Where,   r= radius from center of rotation,
              λ_o= wavelength of the frequency at which the antenna is tested,
              ψ = phase measurement,
and θ = azimuth angle (Az).

The geometry of the equation is shown on Figure 4.

a. Physical Set-up   b. Typical Phase Plot
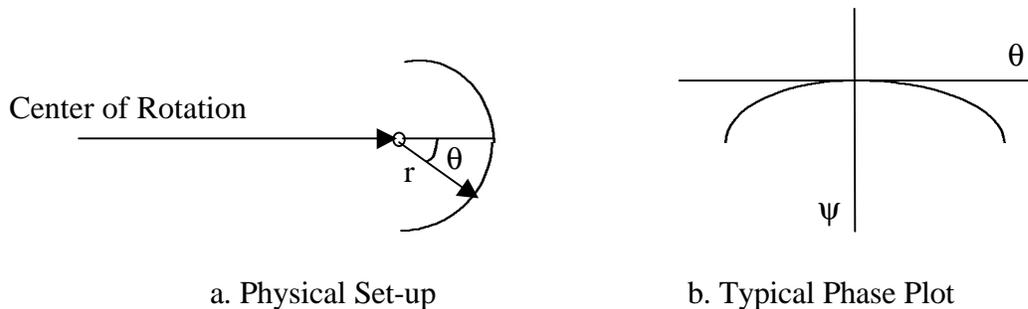
Figure 4. Definition of equation

Using the measured phase verses azimuth data and taking the average, 'r' was calculated to be 6.1 centimeters or 2.4 inches. The phase data for several points around Az = 0° was not averaged in since the data was not reasonable. There are two reasons for this. First, when Az=0° the denominator will equal to zero in equation 1-1 which causes the result to blow up. The second reason might be the fact that there is a large null on the magnitude plot of the wrap-around antenna (see Figure 5) near Az=0° therefore little or no signal is being received. Since the radius of the missile is 2.5 inches, this indicates that the phase center is located at or near the surface of the missile antenna.
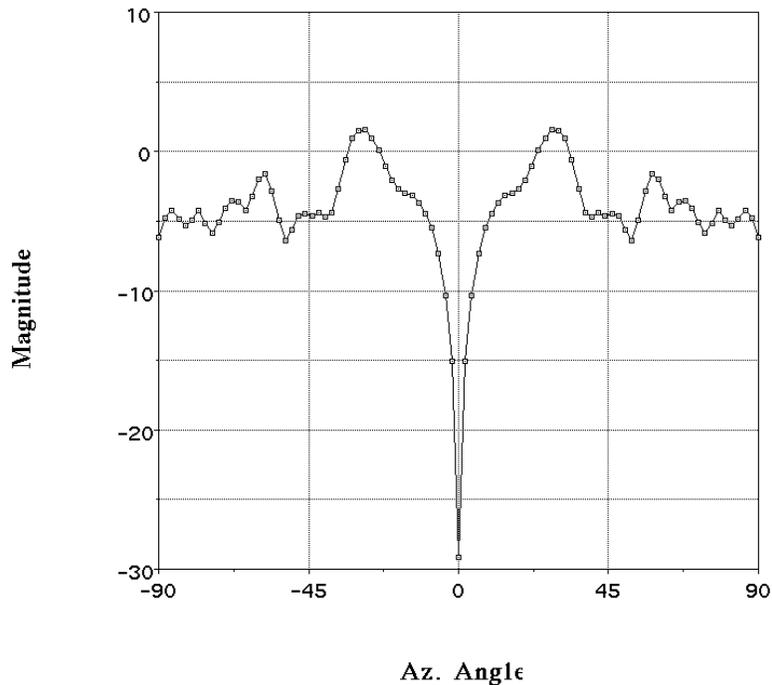

Figure 5. Magnitude Plot of 5-inch Wrap-around Antenna

Assuming the phase center is located on the surface of the missile and using equation 1-1 to find the theoretical phase center, Figure 6 shows the theoretical verses the measured phase. This verifies our initial assumptions. As can be seen, the measured phase center does move around with a change of azimuth angle.

Another assumption we might be able to make from the phase data being erratic near Az = 0° is that the phase center switched from one side of the missile body to the other as it rotated through Az = 0°. This would make the phase center of the antenna a circle around the missile body located about 4.675 inches aft of the GPS RF connector. A roll cut of the antenna would verify this, but this measurement has not yet been done. Another way to verify this is to look at the first phase plot on Figure 2. If the phase center is a circle around the missile body, then as the measurement is being taken through Az = 0°, the phase center should shift to the other side, and would produce a symmetric plot. Since the plot is not symmetric, our assumption is incorrect.
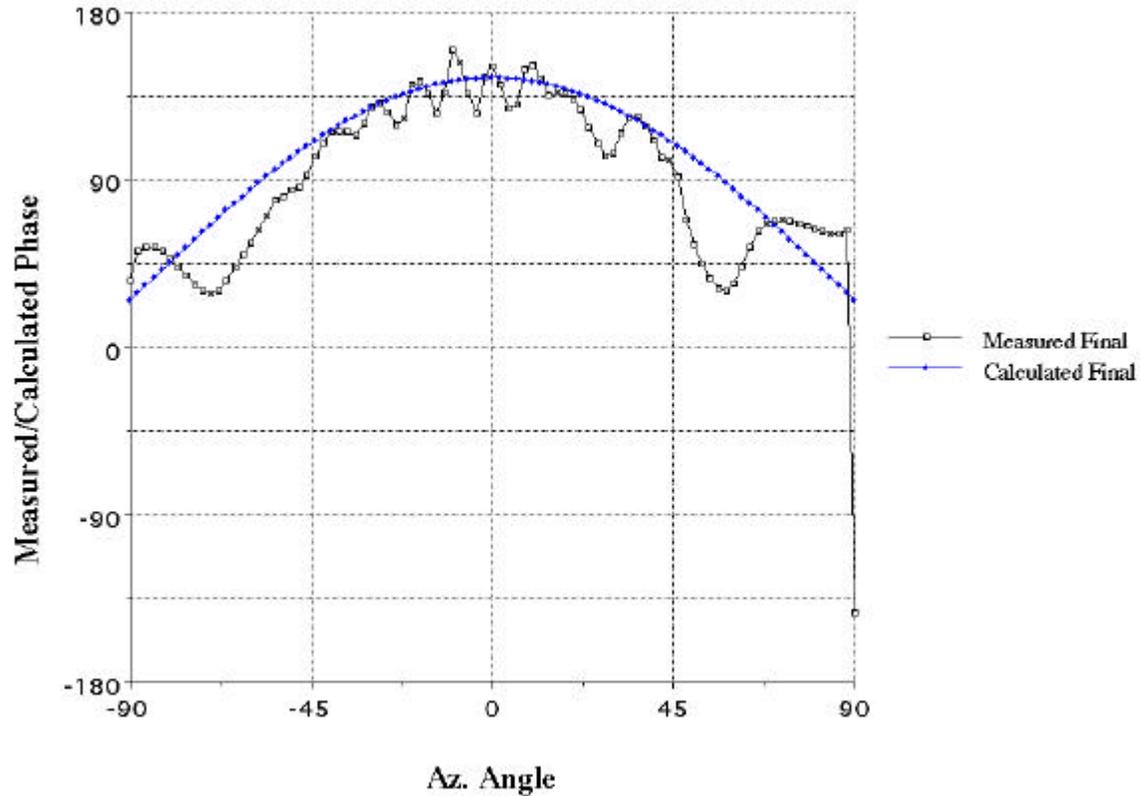
Figure 6. Theoretical Phase Plot vs. Measured

Another assumption is that the phase center is an area on the surface of the missile in line with the RF feed as shown on Figure 7. The phase center would be 4.675 inches aft of the GPS RF connector and 2.5 inches from the centerline of the missile. This would give a radius, 'r' of 5.3 inches from the center of rotation. There would also be a 28° offset angle, 'ϕ'. Figure 8 is created by using the data from Figure 2, and overlaying data created from equation 1-1 where 'r' is 5.3 inches and theta has a 28° offset and solving for phase.
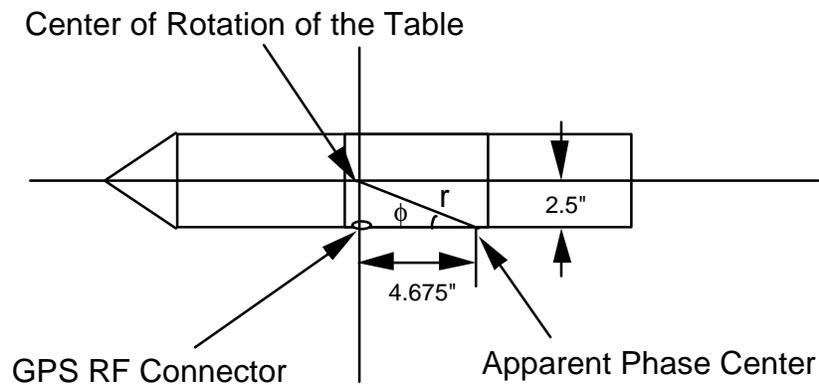

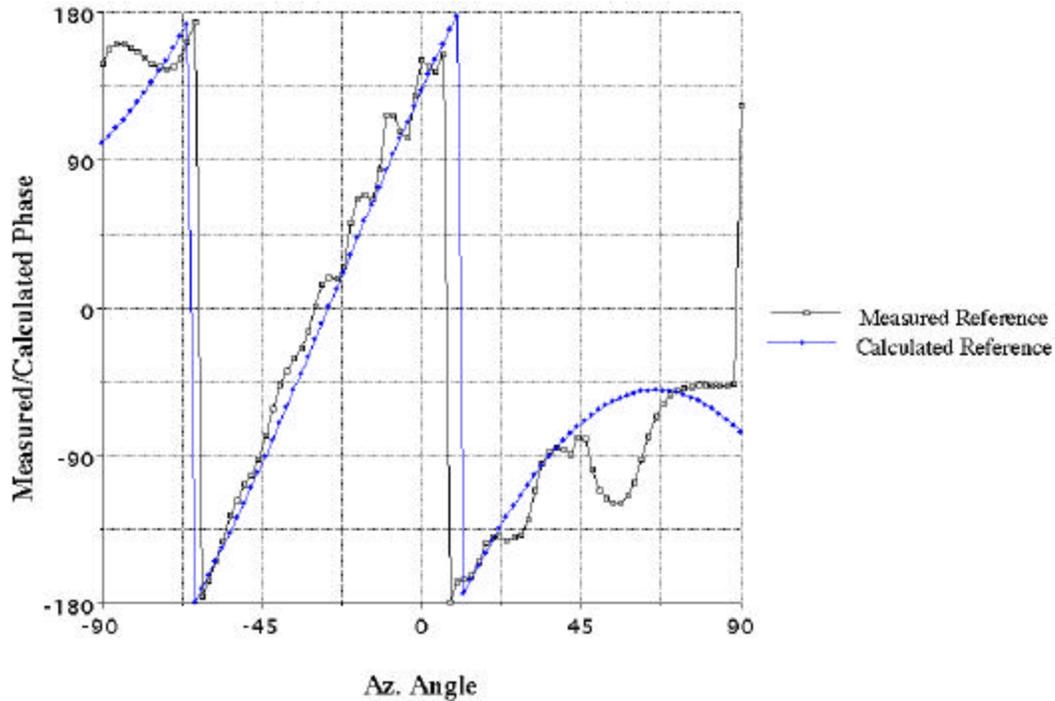Figure 7. Geometry for Reference Phase Plot on Figure 2.

Figure 8. Measured Phase Plot vs. Theoretical Phase plot with 4.675 inch offset

The radius is not quite right since the slopes do not match. The measured radius is greater than the calculated radius but the general shape is there. Again, a roll cut needs to be made to verify this assumption. Therefore, the apparent phase center is located about 4.675 inches behind the GPS RF feed connector and on the surface of the missile.

REMOVING THE ERROR

Knowing where the phase center is did not help in reducing the GPS location error due to the phase center. There is still ± 2.5 inches of error if the roll position of the missile is not known. One way to remove this error is to keep track of the missile's roll position and do post processing on the GPS data. The most accurate method is to add or subtract the phase information of the different SV's phase measurements to translate the apparent phase center to the centerline of the missile axis. This corrected phase data could be used to compute the missile position, but this method might need Pitch and Yaw information as well as Roll.

ADDITIONAL WORK

The most obvious piece of information that is missing from fully describing the phase center is a phase plot in the roll plane around the area that is 4.675 inches aft of the GPS connector. The assumptions made about the phase center need to be further verified.

Some additional work that needs to be accomplished is to have the software development tools used to design antennas, upgraded so they can predict the antenna phase center. This may not be possible if there is not a close-formed solution to solve for the phase center.

There might also be a problem with missiles that have high roll rates. Since the phase centers will most likely not be along the center axis of the missile, there is some concern that the spin will modulate the phase data so greatly that the GPS receiver will not be able to maintain lock on the SVs. It would be helpful to be able to design an antenna where the phase center can be used as a design parameter. Is it possible to design wrap-around antennas so the phase center is located in the center of the missile?

Algorithms need to be developed to remove the measurement errors due to the phase center not being located along the center axis of the missile. These algorithms might be used in either the air (real time) or on the ground (post processing).

CONCLUSIONS

GPS sensors are being developed to work in missile environments. In order to use these sensors, GPS antennas need to be packaged in a conformal wrap-around fashion. The GPS antenna not only needs a broad radiation pattern to give good coverage as the missile rolls, but also needs to have its phase center defined. Knowing the phase center as accurately as possible would increase the missile location accuracy, especially for end-game-scoring applications.

This paper presented an approach to find the phase center of a wrap-around antenna. Actual measurements were made on the Haigh-Farr model 2410 L1/S-band antenna. The phase center was found to be an area 4.675 inches aft of the GPS RF connector, and on the surface of the antenna. The data measurements were not complete and a roll cut of phase data needs to be taken to verify the location.

Some follow-on work needs to be accomplished. After the phase center is located, there needs to be a way to correct for the fact that the phase center may not lie along the centerline of the missile. It would also be advantageous to have antenna design software packages predict the location of the phase center or be able to design an antenna to place the phase center along the centerline of the missile.

REFERENCES

[1] Law, Eugene, Kingery, R., Cramer, D., "Investigation of Telemetry and GPS Compatibility," Proceedings of the International Telemeter Conference, Vol. 36,San Diego, CA, OCT 2000.

[2] Lo, Y.T., Lee, S.W., <u>Antenna Handbook - Theory, Applications, and Design</u>, Van Nostrand Reinhold Company, New York, 1988, pg. 8-73 to 8-84

[3] Mader, Gerald L., "GPS Antenna Calibration at the National Geodetic Survey," http://www.grdl.noaa.gov/GRD/GPS/Projects/ANTCAL/Files/summary_old.html