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Use of a Remotely Controlled Dihedral for Calibrating a Polarimetric Radar

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Collecting high resolution radar imagery of ground vehicles is of interest to many Army and DOD agencies. Systems used to acquire this data rely on high-quality calibration data to produce meaningful radar images. A system to collect high resolution radar data has been built at the U.S. Army Research Laboratory. A method to quickly and accurately collect the calibration data needed by this system, an inverse synthetic aperture radar (ISAR), is presented in this report.

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Thanks also goes to Suzanne R. Stratton of the Sensors Directorate for writing the software to control the positioner and providing helpful suggestions to the author as he completed this report.

It should also be noted that the procedure described by this report was developed by Donald G. Bauerle, H. Bruce Wallace, and the author over the course of many measurement programs.

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1. INTRODUCTION

Radar imagery is a useful tool in evaluating the features of an object that contribute to that object's radar cross section (RCS). The U.S. Army Research Laboratory (ARL) has designed and built a millimeter wave (MMW) inverse synthetic aperture radar (ISAR) system for acquiring radar imagery. This system operates with 1.5 GHz of instantaneous bandwidth at either X, Ku, Ka, or W band, providing image resolution of approximately 10 cm. The data collected with this system is used by several Army and DOD agencies to analyze the radar reflection characteristics of U.S. and foreign vehicles.

To ensure the quality of the data, the ISAR system is calibrated several times daily during a measurement program. A traditional method to collect the calibration data requires a trihedral corner reflector and three dihedral corner reflectors that are aligned by hand and then measured. The method described in this report replaces the three dihedrals with only one dihedral corner reflector that is precisely aligned by a three-axis positioner. By using the three-axis positioner, the alignment of the dihedral for each of the desired measurements is improved increasing the quality of the calibration measurements while also reducing the amount of time needed to collect the calibration data.

2. BACKGROUND

The calibration used by the ARL is based on two sources. To provide a full polarimetric capability, an implementation of a method described by Barnes (1986) is used. To account for gain and phase errors inherent in the ISAR hardware, Wallace and Pizzillo's (to be published) expansion on a technique described by Churchill, Ogar, and Thompson (1981) is employed.

The ARL implementation of these calibration measurements requires measuring the phase and amplitude returns from the following calibration sources: a trihedral corner reflector, a dihedral corner reflector with the crease 0° off the vertical, a dihedral corner reflector with the crease 22.5° off the vertical, and a dihedral corner reflector with the crease 45° off the vertical. In addition, a measurement of the sky is needed to compensate for any DC offset in the receiver. Care should be taken to ensure all calibration measurements are made at the same range. The target measurement should be made at this same range, if possible, to avoid additional signal processing needed to correct for range offset.

With a pulsed radar system such as the ARL ISAR system, there is an additional reason to collect both the calibration data and test data at the same range. In a pulsed radar system, the DC noise level of the system could be a function of time. This is caused by the trailing edge of the main bang leaking into the receiver, raising the DC level of the receiver. This influence on the receiver by the main bang decays to zero with time as a function of the receiver hardware. A typical decay rate would be on the order of hundreds of nanoseconds, influencing the return from targets within a couple of hundred feet. Therefore, to eliminate the effect of the main bang decay in the receiver, it would be recommended to make all calibration and target measurements at the same range.

Measurements of the trihedral and sky are straightforward with few, if any, potential complications. The trihedral is mounted on a pole at a set height above the ground such that any return from the ground is negligible. The distance from the radar to the trihedral should be the same as the distance from the radar to the target to be measured. Once the trihedral is in place, it should be aimed such that the plane of the face of the trihedral is normal to the transmit path of the radar. After the trihedral has been positioned in this manner, it can be used for calibration measurements. Once the trihedral is positioned, it can be used throughout a test program.

The sky measurement is the easiest of all the calibration measurements. The radar is pointed toward the sky such that there is nothing in the radar's field of view that could contribute to any return. Once pointed at the sky, a measurement can be taken at the same range as the other calibration measurements. Should the surroundings make a measurement of the sky impractical, then placing a piece of radar absorber in front of the antenna and then making the measurement will produce the needed result. Regardless of which method is used to measure the sky, it is important that the range gate of the radar is set to the same range as when measuring the calibration reflectors.

Making the dihedral measurements requires precision alignment of the dihedral with respect to the ISAR system. The ARL method of making the three dihedral measurements involves using one dihedral mounted on a three-axis positioner. The positioner is used to align the dihedral with the radar and then rotate the dihedral to each desired orientation. Once the dihedral is aligned, the 0°, 22.5°, and 45° positions must be determined. This is accomplished by determining the 0° and 90° positions and then dividing the interval between 0° and 90° to determine the 22.5° and 45° positions.

The positioner used is capable of sweeping the dihedral in both azimuth and elevation. A stepper motor that is also a part of the positioner allows the dihedral to be precisely rotated about its center with an angular resolution of 0.0144°. The positioner is small enough to fit in the radar shadow behind the dihedral when the dihedral is aligned with the radar, eliminating the possibility of the positioner interfering with the calibration measurements. The dihedral and positioner are shown in Figure 1.

A polar plot of the return from a dihedral that has been rotated 360° about its axis results in a cloverleaf pattern, as shown in Figure 2. With the radar linearly polarized, a copolarized return produces the plot shown in Figure 2. A linear cross-polarized return produces the plot shown in Figure 3.

Based on these plots, some observations can be made about the return from a dihedral. At 0°, 90°, 180°, and 270°, there is a maximum return with the linear copolarized case and a maximum return with the cross-polarized case. Conversely, at 45°, 135°, 225°, and 315°, there is a minimum return with the linear copolarized case and a maximum return with the cross-polarized case. It can also be seen that the maximum regions of the plots are broader than the minimum regions of the plots.

These observations lead one to conclude that the area where a minimum return or null occurs is more apparent than where a maximum return occurs. Therefore, it is more efficient to find the 0°, 90°, 180°, and 270° positions utilizing the linear cross-polarized return; while it would be more desirable to use the linear copolarized return to find the 45°, 135°, 225°, and 315° positions.

The method described here depends on finding the 0° and 90° positions of the dihedral. The 0° position is chosen because it is necessary for the calibration of the ISAR and it can easily be determined by monitoring the cross-polarized return of the radar. The 90° position is chosen because it can easily be determined by monitoring the same cross-polarized combination that is used to determine the 0° position. By using the same polarization combination, only the change in position of the dihedral will contribute to any difference in the received signal. Any effect the radar has on the polarization of the received signal will remain constant and not be a factor.

Once the 0° and 90° positions are known, the 22.5° and 45° positions are determined by the computer used to control the stepper motor that provides the rotational stage of the positioner. To determine the 22.5° and 45° positions, the computer first determines the number of steps it takes the stepper motor to

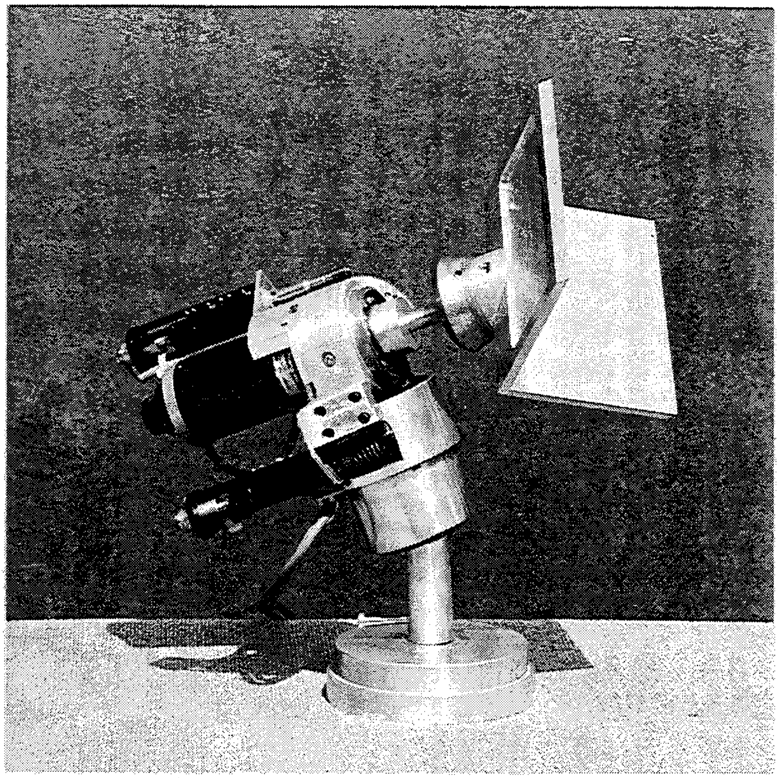

Figure 1. Diehedral and positioner.

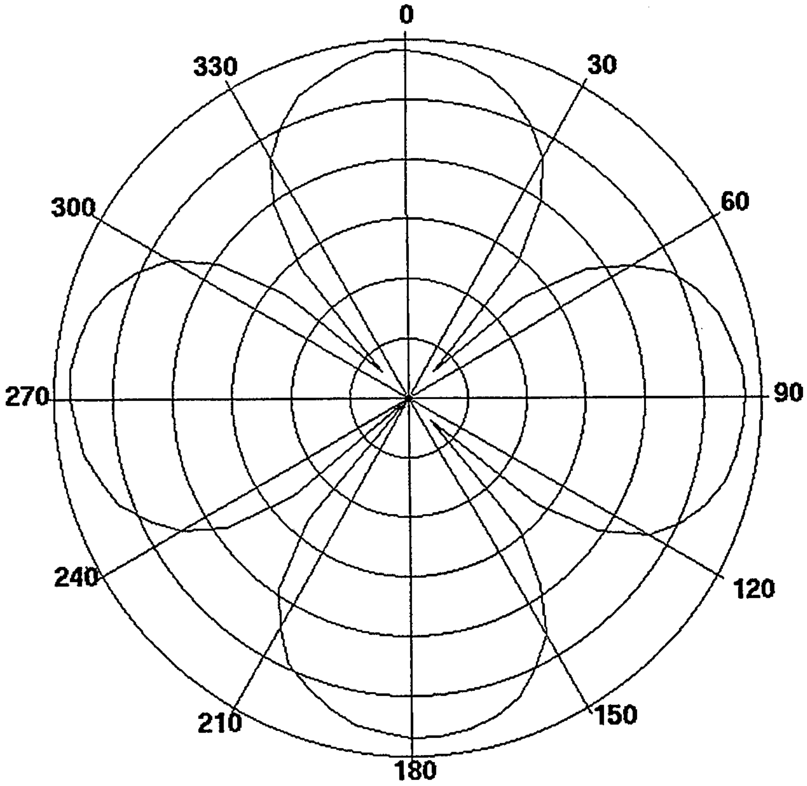

Figure 2. Linear copolarized return from a dihedral corner reflector rotated through 360° (uncalibrated log scale −10 dB/div.).

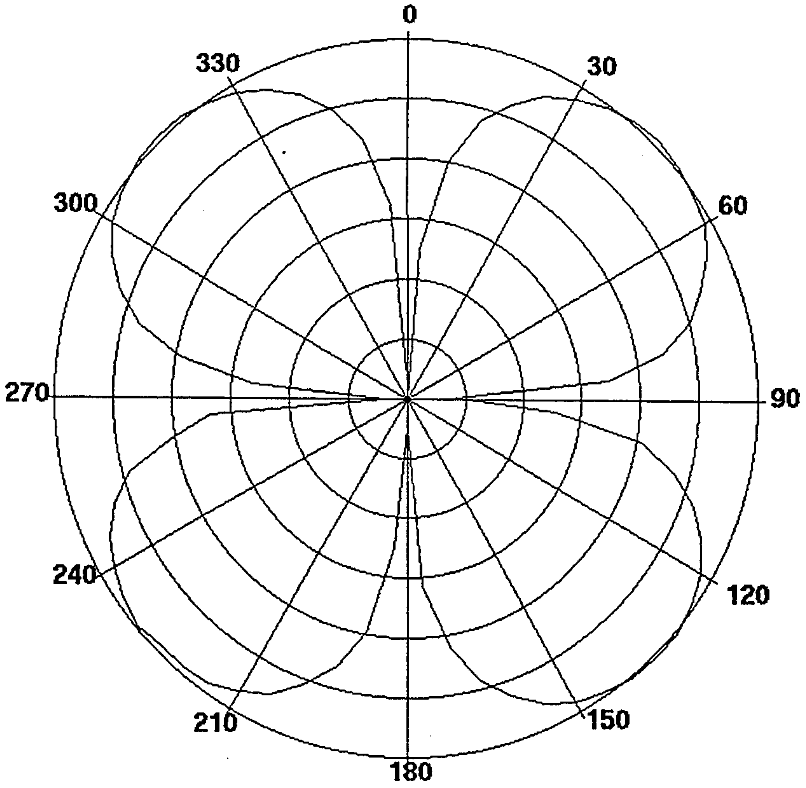

Figure 3. Linear cross-polarized return from a dihedral corner reflector rotated through 360° (uncalibrated log scale −10 dB/div.).

rotate from 0° to 90°. The number of steps between 0° and 90° is then divided by four for 22.5° and by two for 45°. The resulting quotients are then added to the 0° position, resulting in the positions for 22.5° and 45°, respectively.

3. DIHEDRAL ALIGNMENT PROCEDURE

To determine the position of the desired dihedral orientations, the 0° and 90° positions of the dihedral must be determined. This requires aligning the dihedral with the radar and then searching for the minimum return from the cross-polarized return. This section will describe a method to obtain the 0° and 90° positions.

3.1 Select Copolarization. Aligning the dihedral with the radar ensures that the dihedral is pointing at the radar, resulting in a maximum return from the dihedral. The copolarized return is monitored as the dihedral is positioned at approximately 0° and 90° to determine the maximum return as the azimuth and elevation axis of the dihedral are scanned. So to begin the azimuth and elevation alignment process, the copolarized return should be selected for monitoring.

3.2 Set Dihedral to 0°. The order in which the azimuth and elevation axes are aligned is not important. The method described in this report will begin with aligning the elevation axis. For elevation alignment, the dihedral needs to be set to about 0° (vertical crease). Since the broad maximum return is being used for this alignment, it is not necessary to be at exactly 0°; a close approximation is all that is needed.

3.3 Adjust Elevation of Dihedral for Maximum Return. With the dihedral at approximately 0°, the dihedral should be swept in elevation. As the dihedral is being swept in elevation, the copolarized return needs to be monitored to find the maximum return from the dihedral during the sweep. Once the position of the maximum return is known, the dihedral should be set in elevation to that position.

3.4 Set Dihedral to 90° (Horizontal Crease). After the elevation position has been found, the azimuth position needs to be determined. To accomplish this, the dihedral needs to be rotated 90° from the position used in the elevation alignment process. Again, it is not critical that the dihedral be in exactly the 90° position, but it is desirable for the dihedral to be as close as possible to 90° off of the previous position. This will ensure that the maximum return observed while adjusting the azimuth axis will be the same as the maximum return that was observed while adjusting the elevation axis.

3.5 Adjust Azimuth of Dihedral for Maximum Return. With the dihedral rotated 90°, the dihedral should be swept in azimuth. As before with the elevation alignment, the return from the dihedral needs to be monitored while the dihedral is being swept. After the position that corresponds to the maximum return has been found, the dihedral should be set in azimuth to that position.

After the azimuth has been set, the elevation position needs to be checked to see if it is still in alignment. If it is no longer in alignment, the elevation axis needs to be realigned and then the azimuth axis needs to be rechecked. The procedure continues until both axes are set for maximum return. A good indication that both axes are set at the proper position is when the maximum observed at the 0° position is the same as the maximum observed at the 90° position.

3.6 Rotate Dihedral 360° Measuring Every 5°. The cloverleaf pattern that results from a measurement of a full rotation of the dihedral is a good way to check for proper alignment in both azimuth and elevation. If the azimuth and elevation axes are both properly aligned, then the "leaves" of the cloverleaf pattern should be approximately the same size, as in Figures 2 and 3. However, if either axis is not in alignment, then an unbalanced pattern or an indistinguishable pattern will result. Some examples of incorrect alignment are shown in Figures 4–6. To make this check, the dihedral should be measured as it is rotated a full 360°. The return from the dihedral should be recorded at least every 5° to obtain a meaningful plot.

3.7 Plot Measurement and Check for Balanced Pattern. After the data for a full rotation of the dihedral is collected, it should be plotted in polar format. It should be obvious from the plot whether or not the cloverleaf pattern is balanced around the full 360°. A balanced polar plot would have the maxima of each "leaf" within 1 dB of the others. If the plot is unbalanced, it is necessary to repeat the steps for aligning the elevation and azimuth axes of the dihedral. If the plot is balanced, then the 0° and 90° positions can be precisely located.

3.8 Select Cross-Polarized Return. To determine the 0° and 90° positions, the cross-polarized return needs to be monitored to find the minimums associated with these angles. The order in which the 0° and 90° positions are located is not important. The procedure in this report first locates the 0° position. The procedure for finding the 0° and 90° positions is similar, with the 90° position being somewhat easier to locate. This is because once the 0° position has been located, the 90° position should be approximately 90° off of the 0° position.

3.9 Locate and Set 0° Point of Reflector. A coarse and a fine adjustment procedure is used to find the 0° point. The coarse adjustment rotates the reflector from −10° to +10° in 0.5° steps with the position used to align the reflector in elevation at the 0° point. At each step of the rotation, the cross-polarized return is recorded and plotted. A null should be apparent in the resulting plot. The 0° position should then be set for the position of the null in the plot. If no null is apparent, it may be necessary for a larger angle to be scanned.

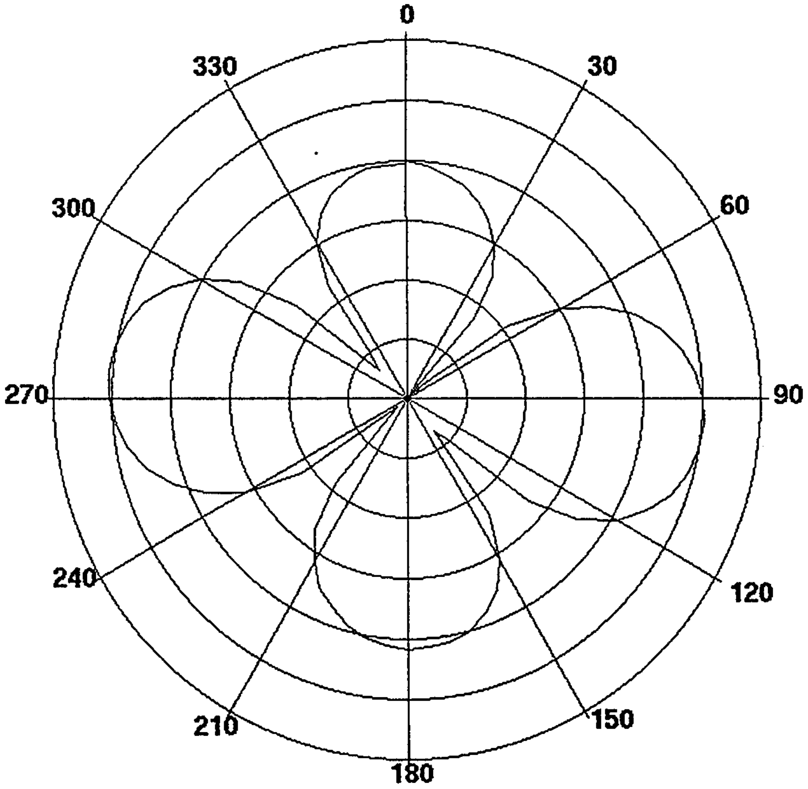

Figure 4. Linear copolarized return from a dihedral corner reflector rotated through 360°—elevation axis not properly aligned (uncalibrated log scale −10 dB/div.).

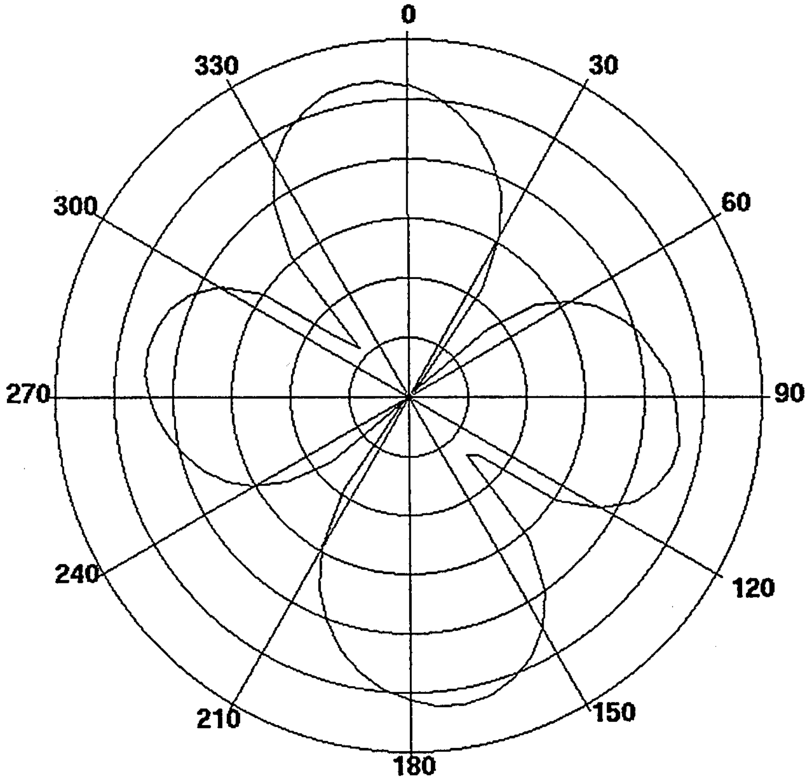

Figure 5. Linear copolarized return from a dihedral corner reflector rotated through 360°—azimuth axis not properly aligned (uncalibrated log scale −10 dB/div.).

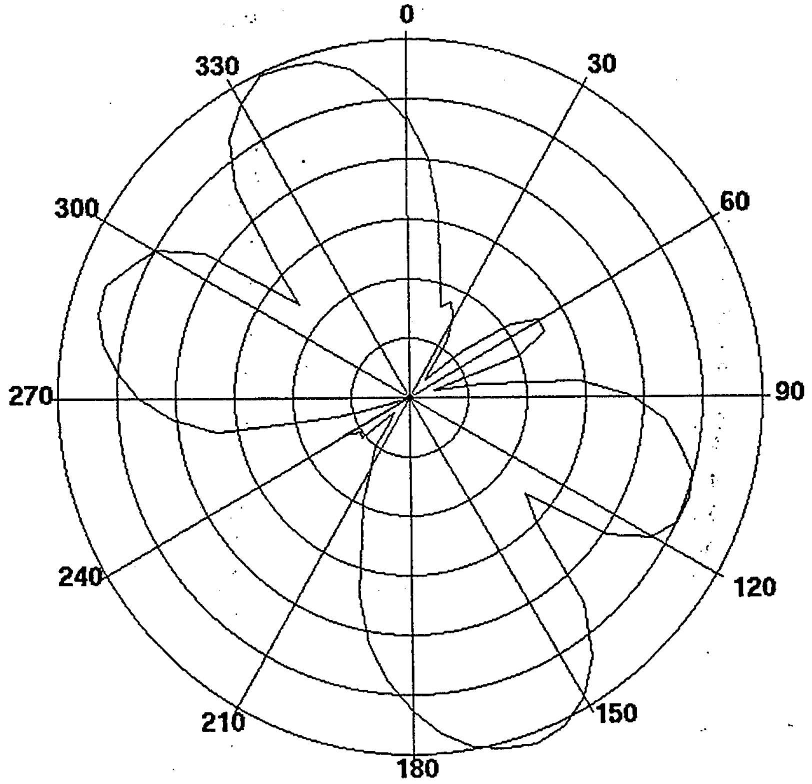

Figure 6. Linear copolarized return from a dihedral corner reflector rotated through 360°—elevation and azimuth axis not properly aligned (uncalibrated log scale −10 dB/div.).

With the new 0° setting, the operator can now make the fine adjustment to the 0° position. The fine adjustment rotates the reflector from −4° to +4° in 0.1° steps. Again, at each step of the rotation, the cross-polarized return is recorded and plotted. The 0° position should then be reset to correspond to the null from the resulting plot. This procedure should be repeated to ensure that the 0° position is correctly determined.

3.10 Locate and Set 90° Point of Reflector. Locating the 90° position of the reflector once the 0° position is known is an easier task than initially finding the 0° position. With a precision stepper motor, the 90° position can be computed based on the number of steps it takes for the motor to rotate 90°. But to ensure the accuracy of the 0° position, the 90° position should be determined and set in a manner similar to the fine adjustment for the 0° position.

With the 0° position as a reference point, the reflector should be rotated from 86° to 94° in 0.1° steps. At each step of the rotation, the cross-polarized return from the radar receiver should be recorded and plotted. The position of the null associated with this plot shows the true 90° point of the reflector. Setting the position of the null as the 90° point of the reflector completes the reflector setup procedure.

4. CONCLUSION

The time needed to make the calibration measurements takes away from time that could be spent measuring targets. However, because of the importance of obtaining high-quality calibration data, any effort to increase the speed of the measurement cannot impact on the quality. The method for dihedral alignment described in this report takes only 20 minutes to complete. This is a significant reduction in the time over our previous method, without any impact on the quality of the calibration data. The potential exists to decrease this time even further by upgrading the instrumentation used to align the dihedral.

In the past, a computer-controlled motor pot was used to provide the rotational stage of the positioner. With the motor pot providing the rotation capability, the calibration measurement would take at least 1 hour to complete. Once the motor pot was replaced with the stepper motor, this time decreased to 20 minutes. The decrease in time is attributed to the ability of the stepper motor to more precisely rotate the dihedral in small increments and to the increased speed of the stepper motor.

To further improve on the time needed to align the dihedral, computer control of the azimuth and elevation axis could also be implemented. Currently, a motor pot provides the movement for each axis. Each motor pot is controlled by the operator who can control the direction and speed of the motor pot. By introducing computer control of the motor pots or replacing the motor pots with motors that can be computer controlled, the alignment procedure could be speeded up, or at the least, the operator would be free to execute other tasks.

5. REFERENCES

Barnes, R. M. "Polarimetric Calibration Using In-Scene Reflectors." MIT Lincoln Laboratory Report TT-65, 10 September 1986.

Churchill, F. E., G. W. Ogar, and B. J. Thompson. "The Correction of I and Q Errors in a Coherent Processor." IEEE Transactions on Aerospace and Electronic Systems, AES-17, 1, pp. 131–137, January 1981.

Wallace, H. B., and T. Pizzillo. "A Technique for the I and Q Calibration of Wide Band Radars Using External Targets." To be published in IEEE.

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