AD-P006 393

COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: Target and Clutter Scattering and Their Effects on Military Radar Performance (Diffraction par les Cibles et le Fouillis et ses Effets sur les Performances des Radars Militaires).

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-A244 893.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: P006 373 thru AD#: P006 396
AD#: AD#:
AD#: AD#:

DTIC
ELECTE
APR 15 1992
S C D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Accession For
NTIS GRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist Avail and/or Special
A-1

DTIC FORM 463 MAR 85

OPI: DTIC-TID

①

POLARIMETRIC MONOPULSE RADAR SCATTERING MEASUREMENTS OF TARGETS AT 95 GHz

by

R. J. Wellman, I. Nemarich, H. Dropkin
D. R. Hutchins, J. L. Silvious, and D. A. Wikner
Harry Diamond Laboratories
US Army Laboratory Command
Adelphi, MD 20783-1197, USA

Summary

This paper describes a 95-GHz polarimetric monopulse instrumentation radar and selected scattering measurement results for an armored vehicle. The radar is all-solid-state, coherent, frequency steppable over a 640-MHz bandwidth, and completely polarimetric for linearly or circularly polarized radiation. Details of the methods used to perform the amplitude and phase calibrations and the effectiveness of polarization distortion matrix corrections are included in the paper. Measurements made with the radar of various vehicles on a turntable have allowed quasi-three-dimensional polarimetric ISAR images of the targets to be generated. Sample images for an infantry combat vehicle are presented together with high-resolution range profiles of the target for all monopulse channels.

1. Introduction

Sensor systems operating at about 95 GHz are being investigated for use in smart munitions designed to defeat armored vehicles. Specific radar scattering properties of these targets frequently are required for evaluating the performance of a sensor system. In this paper a 95-GHz polarimetric monopulse instrumentation radar is described that is capable of acquiring the required target signature data.

Measurements have been made for several vehicles with the radar located on the US Army Missile Command (MICOM) 100-m tower at Redstone Arsenal, AL, and the target mounted on a tiltable turntable. Data were collected for various radar depression angles and target azimuth angles to allow computation of radar cross section (RCS) polar plots, high-resolution range (HRR) profiles for the two-angle monopulse sum and difference channels, and inverse synthetic aperture (ISAR) images for the monopulse channels.

Section 2 of this report describes the basic characteristics of the radar and Section 3 contains a discussion of the procedures used for calibration of the radar. Some sample target signatures obtained for an infantry combat vehicle are given in Section 4 to demonstrate the radar's capabilities. Conclusions reached regarding the radar system, the calibration procedures, and the scattering measurements are contained in Section 5.

2. Description of the Radar System

The radar described in this paper was designed for obtaining 95-GHz target signature data of ground-based targets with the radar located on a tower and with computer-controlled operation from a remote ground station. Fig. 1 shows the radar head and pedestal. A video camera that is boresighted with the radar and a metallic cover for the system are not shown in the photograph to allow a view of the radar hardware. The radar head is covered during operation, if needed, to allow it to be air-conditioned for temperature control. Data recording and control of the tower-mounted radar are performed at a ground station located in an 11-m-long semi-trailer. Data from the target platform also are recorded at that location.

The basic characteristics of the radar are summarized in Table 1. The radar is a completely polarimetric two-coordinate amplitude-comparison monopulse system. It is a coherent, pulsed radar that operates in a frequency-stepped mode between 95.00 and 95.64 GHz. The frequency-step size can be selected to be 1, 2, 5, 10, or 20 MHz, and the radar pulse repetition frequency (PRF) is also selectable to be 1, 2, 5, or 10 kHz. The system was operated with 64 10-MHz steps and a transmit PRF of 10 kHz for the measurements reported here. The peak power of the all-solid-state transmitter is 45 W, the pulse width is 100 ns, and there is one adjustable range gate.

Either circularly or linearly polarized radiation can be transmitted by the radar according to which mode of operation is selected. For example, one pulse with either right-hand circular polarization (RHCP) or left-hand circular polarization (LHCP) may be transmitted and both senses of polarization can be received. The polarization of succeeding pulses may be right- or left-circular depending on the transmit format selected. A similar mode of operation is possible with horizontal (H) and vertical (V) polarization.

The radar has a lens antenna that can be easily removed and replaced with another having a different diameter. For a specific measurement scenario a lens with a diameter between 3.8 and 15.2 cm may be selected from six available lenses. The one-way 3-dB beamwidths of these lenses range between about 1.5 and 5.2 deg.

A simplified schematic diagram of the radar circuit is shown in Fig. 2. It is seen in the figure that the transmitter output is routed via the switchable circulator into either the H-channel or the V-channel monopulse comparator and then to the lens via a multi-mode feed horn. A wire-grid diplexer is placed between the feed horns and the lens for proper routing of the radiation. The quarter-wave-plate (QWP) between the diplexer and the lens may be aligned to maintain the original incident linear polarization, or it may be rotated to convert the radiation of one channel to RHCP and the other to LHCP. If the QWP is oriented for the linear polarization mode, the vertical and horizontal components of reflected radiation are diplexed into the V- and H- channel comparators, respectively, and the resulting sum, elevation difference, and azimuth difference signal may be detected for each polarization. If the QWP is oriented for the circular polarization mode, the sum and difference signals for the RHCP and LHCP components of the reflected radiation are similarly detected

The oscillator source for the six sum and difference channel mixers is frequency stepped synchronously with the transmitter source and maintains a constant offset of 3 GHz.

The radar Data Acquisition System (DAS) has six I/Q detectors for the monopulse sum and difference signals. The relative phase of the two sum channels and their log amplitudes also are processed in the DAS. For each transmitted pulse the signals received in each of the 16 channels are sampled, multiplexed, and digitized by two 12-bit A/D's. The multiplexed data are transmitted from the radar via a fiber-optic data link to the remote computer control/recording system. The latter is a PC that includes an 80386 20-MHz processor, 4 Mbytes of memory, and two 300-Mbyte disc drives. Data are archived on 150-Mbyte, streaming 112.5-Kbyte/s cassette tapes. Although the custom interface to the radar DAS has a 240-Kbyte/s capability, the limit on the recording rate reduces the maximum data rate to 120 Kbytes/s.

The radar is mounted on a pedestal that can be computer controlled locally or from a remote station to scan the radar or to orient it to a fixed position. The pedestal is an elevation-over-azimuth type with 0.01-deg pointing accuracy. It has scanning rates that can be selected to be between 0.1 and 10 deg/s.

As indicated above, a video camera is mounted on the radar head, and it can be boresighted with the radar to video record the target whose signature is being measured.

3. Radar Calibration Procedures

The radar calibration procedure is very complicated due to the number and types of data channels. The procedure can be broken up into three distinct sections: the amplitude calibration for the log receiver in the sum-channels, the sum-channel relative polarimetric phase calibration, and coherent sum and difference channels calibration. Some preliminary calibrations were done in the laboratory before the radar was taken to the field measurement site at Redstone Arsenal, and a series of pre-measurement checks and calibrations were done at the field test site. Only the basic features of these checks and calibrations are given here since many are well-known procedures.[2] These include taking proper account of gain imbalances in I/Q detectors and nonlinear responses in detectors and amplifiers.

The radar calibrations at the field measurement site were performed using the reflectors listed in the calibration target array of Table 2. The range of each reflector to the radar and its RCS were chosen so that the signal levels from reflectors 1, 2, and 4 were approximately equal and in the linear range of the receivers (about 6 dB below A/D saturation). The log receivers were calibrated using reflectors 2 and 4. Reflector 3 was used for calibrating the relative polarimetric phase channel and for determining a sign in the polarization distortion matrix (PDM) calibration described below.

The dynamic range of the system was more than adequate to insure that the maximum signal levels from the target were below the saturation level of the detectors and the amplifiers were well above the noise level of the system. The dynamic range was about 66 dB for the linear channels and about 72 dB for the log channels. Stability checks were made periodically, and corrections were made for the minimal drifts that were observed.

Transfer curves for the log receiver in each sum channel were generated in the laboratory using a 3-GHz source to simulate the IF signal from the sum channel mixer and with a precision attenuator to vary the signal level. The amplitude calibrations at the field site were performed by boresighting the radar on the appropriate corner reflector and varying the precision attenuator to simulate the expected range of signal levels for the target. These measurements were used to verify the transfer curves measured in the lab. Absolute calibration of the amplitude for each polarization channel was determined using the signal level corresponding to the known RCS of the reflector, the transfer curve for that channel, and the ratio of the radar range to that reflector and the range to the target to be measured.

The relative polarimetric phase channel initially was calibrated in the laboratory and a reference look-up table was generated. This table related the phase angle of the signal into the I/Q detector to that at its output. A gridded trihedral was used at the field site as the reference reflector, and the phase difference between the coherent sum channels was measured. These values then were used to determine their relationship to the phase angle values in the reference table for each of the coherent sum channels . A correction table was generated from this measurement as a function of frequency so that the actual polarimetric phases could be computed directly from the measured values for each frequency. The polarimetric phase calibration was checked using the gridded trihedral by comparing the phase differences between RHCP and LHCP signals for both senses of transmitted polarizations. These values agree to within ±3 deg overall.

The effects of imperfect cross-polarization isolation in the radar can be mitigated by use of the PDM calibration technique.[3] This calibration method is intended to remove the radar system parameters from the data so that the target polarization scattering matrix can be determined without degradation due to the system. It can be used for both linear and circular polarization by making measurements of the four reflectors listed in Table 2. For this report, the PDM calibration technique was carried out for circular polarization. The calibration method for the coherent receivers is shown in block form in Fig. 3.

For calibration purposes, 200 ramps of data are taken for each of the four reflectors, where a ramp consists of 64 frequency-stepped pulses transmitted with RHCP and 64 pulses transmitted with LHCP. The sum channel I/Q corrections were generated by characterizing each I/Q detector at four signal levels for every 22.5 deg change in input phase from 0 to 360 deg. This I/Q correction reduced the amplitude variation due to I/Q errors to 40 dB below the average signal level and the maximum phase correction was 3 deg. The PDM calibration is applied to the coherent sum channels only. The PDM correction parameters are calculated for each frequency and for each polarization, and then they are applied to the data to obtain the calibrated amplitudes and phases.

The difference (or delta) channels are calibrated by taking the ratio of the delta channel and sum channel signal levels and then adjusting the delta channel phase to compensate for phase variations in the sum channel due to the PDM correction and phase variations between sum and difference channels versus frequency.

The PDM calibration technique described above improved the cross-polarization isolation of the system to about 35 dB. Table 3 shows a comparison of the frequency-averaged RCS amplitudes for two reference reflectors after performing the other calibrations and applying the PDM calibration to the linear sum channels. The RCS's in dBsm were used to compute the averages. The RCS amplitudes representing the various transmitted/received polarization combinations are σ_{RR}, σ_{RL}, σ_{LR}, and σ_{LL}, where the first subscript is the polarization of the transmitted radiation and the second is the polarization of the received radiation. The data for the log channels indicates the cross-polarization isolation levels without compensation. The improvement in the cross-polarization isolation using the PDM calibration technique is between 5 and 10 dB, but this was limited by the influence of scatterers in the antenna sidelobes. The agreement between the log channel and the PDM-corrected linear channel amplitudes for these reflectors is good. The small root-mean-square deviations (RMS's) for the copolarized returns indicate the degree of amplitude stability of the system.

Ideally there should have been no cross-polarized reflection from the dihedral for circular polarization. The small values of σ_{RL} and σ_{LR} shown in Table 3 are believed to result from a combination of incomplete cross-polarization cancellation by the PDM calibration, slight imperfections in the calibration targets, spurious returns from the reflector poles, and sidelobe clutter. The total for all of these possible effects is seen to be at least 35 dB below the copolarized reflection for all polarizations after the PDM calibration.

The results of the phase measurements on the various reflectors after the PDM and other calibrations are indicated in Table 4. The table gives the corrected phases and their RMS's at 95.3 GHz. As shown, the measured phases have an RMS deviation of about ±3 deg. Another measure of the phase performance of the calibrated system is shown in Table 5. This table gives the average difference in phase between adjacent frequency steps and the phase difference for one particular mid-band frequency pair. The RMS deviations also are listed. Any measurement phase errors will influence the quality of HRR profiles and ISAR images, but as indicated the phase errors are small. In fact, the capability of the system is such that an HRR profile of a single reflector using a single ramp of data and a 64-point FFT approaches the processing sidelobe levels.

A method was devised for removing the effects of small motions of the radar platform while measurements of a target were being performed. The motion compensation is done by tracking the phase of a fixed corner reflector set up away from the target and with its return peaked in one difference channel. An FFT of a single ramp of data is performed and the phase of the peak signal from the reference reflector is determined. Each ramp of target data is then adjusted for the phase variation in the reference reflector from ramp to ramp.

Antenna radiation patterns were obtained at the test site using the various reflectors. The approximate two-way sum channel beamwidth for the 5-cm lens used for the target measurements reported here was 3 deg. Sidelobe levels were difficult to determine due to the trees in the area, but in pretest measurements one-way antenna pattern sidelobes averaged well below 20 dB from the peak. Laboratory measurements of the cross-polarization isolation of the antennas showed that on average the isolation was more than 25 dB, one way. The responses of the monopulse difference channels were calibrated by scanning the radar across the appropriate reflector. The relative phase of the difference channel with respect to that of the sum channel was calibrated by scanning to one side of the reflector and establishing a look-up table for setting the relative phase to be 0 deg at each of the system frequencies. Laboratory measurements of the monopulse null depths showed that they averaged at least 25 dB below the sum peak. The radar monopulse boresight angle was determined for each polarization channel using the appropriate reflector. The boresights were found to vary slightly, with most of the variations being in the azimuth delta channels. The overall boresight angle difference for the RR and RL channels, for example, was about 0.3 deg, with most of the difference being in azimuth. The optical boresight on the video camera was set to coincide with the LR radar boresight for field measurements.

4. Target Signature Measurements

Target signatures were measured at the US Army MICOM Target and Seeker Measurement Facility which includes a stable tower and a self-propelled mobile turntable. The tower has a 9x5 m laboratory at a height of 61 m and a 3x2 m laboratory elevator that can be stopped at various heights. The measurements reported here were made with the radar in the tower elevator about 61 m above ground level. The radar was positioned in front of an opened elevator window to allow an unobstructed view of the target.

The target was mounted on the mobile turntable that was positioned about 115 m from the base of the tower. The turntable platform can tilt up to 45 deg and rotate continuously from 0 to 360 deg about an axis normal to the platform. The rotation rate is variable from 0.5 to 2.5 deg/s. Quasi-continuous data on the turntable tilt and azimuth angles were transmitted to the radar ground station for recording.

Efforts were made to shield the turntable as much as possible to prevent spurious reflections. Standard US Army Diamond/Hexagon Camouflage netting (for frequencies up to about 100 GHz) and radar-absorbing material were used. Some measurements were made to determine the magnitude of any spurious reflections from the turntable or ground that affect the target signatures. The total returns from the screening nets and from sidelobes were typically −5 dBsm or less. Reflections from the turntable generally were −10 to −15 dBsm. The turntable was located as far as possible from trees in the area, and no significant problem was encountered during the course of the measurements due to radar scattering from trees.

A meteorological station was not available at the site, but a station was located at the Redstone Arsenal base. Weather data were obtained on a daily basis throughout the period during which measurements were made.

The measurements of the target signatures were made at various radar depression angles. For each radar depression angle the radar was boresighted on the center of rotation of the target. The turntable then was rotated at its slowest rate (0.5 deg/s) while data were collected with the radar fitted with the 5-cm lens. The radar was operated in the pulse-to-pulse polarization switching mode with 64 frequency steps of 10 MHz each. Each data buffer includes the signal returns for 128 transmitted pulses where the transmit polarization was switched every pulse and the frequency was stepped every other pulse. The basic data were taken at a 10-KHz PRF but only every other data buffer was recorded due to recording system limitations. The target rotates 0.006 deg during one data buffer. The target data are accumulated for 370 deg of rotation of the turntable so that there is some overlap in the data. The turntable position is recorded along with the data and is inserted into the co-boresighted video camera data stream. A typical 12-min data file contains 85 Mbytes of data before calibration. After calibration the data can be processed further and used for various purposes.

Measurements were made on various armored vehicles, including the Soviet BMP infantry combat vehicle shown in Fig. 4. Polar plots of the polarimetric RCS's for the BMP and with the radar at a 45-deg depression angle are presented in Fig. 5. The data were sampled every 0.5 deg and averaged over 64 frequencies to generate the plot. The RCS's in dBsm were used to compute the averages. It is apparent that the RL and LR polar plots are almost identical, as they should be theoretically. The RR and LL pair are very similar, but there are some small differences. Table 6 shows some comparison RCS statistics for the BMP vehicle at 30-, 45- and 60-deg radar depression anglos. The RCS data for target azimuth angles between 0 and 360 deg were averaged for each frequency. All data points were used to obtain the average; that is, the average sample interval was 0.013 deg. The resulting single-frequency averages then were averaged across the frequency band. Included with the bandwidth averages for comparison is the azimuth-angle-averaged RCS at one particular frequency (95.3 GHz).

It is seen in Table 6 that the RMS deviation for the single frequency average is much larger than that for the bandwidth average of the mean for each of the frequencies. An explanation of this result may be the following. The target can be viewed as a complex array of scatterers that appears to be different to the radar after the target has rotated through a small angle. When viewed at a single frequency the various independent sets of scatterers interfere differently, and there is a relatively large standard deviation from the mean RCS value. As the frequency is changed each member of the independent set of scatterers also interferes differently, but there is a degree of correlation when the whole (0 to 360 deg) set of scatterers is viewed at the different frequencies. Apparently the 64 10-MHz frequency steps are sufficient for the data to exhibit this correlation, and the result is the smaller RMS deviation in the average of the mean for each of the frequencies.

The calibrated monopulse sum and difference channel data can be used to generate HRR profiles that display both the RCS amplitude and the elevation- and azimuth-angle errors for each range subcell. These HRR profiles for the BMP at a 90-deg azimuth angle (left broadside) and a radar depression angle of 45 deg are shown in Fig. 6. The profiles were generated by doing a 64-point FFT on the calibrated sum and difference channel data. The difference channel angle errors were generated using the calibrated ratios in the look-up tables derived from the monopulse response patterns. The plots are for an average of 64 ramps of data and the range resolution is 0.23 m. HRR profiles shown in Fig. 6 are for the RR and LR polarizations. The LL and RL profiles are similar to the RR and LR plots, respectively, and are not presented here.

Fig. 6 shows that the RCS profiles for the RR and LR polarizations have a similar extent in range, but otherwise they are quite different. The plots for the azimuth and elevation-angle differences show the angular location for the effective single scatterer in each range subcell, and these values also are different for the copolarized and cross-polarized radar returns. This type of data may be quite useful for classification, identification, and tracking of a target in a MMW polarimetric monopulse seeker application.

The measurements also allowed the generation of ISAR images of the target, and typical ISAR images of the BMP for RR and LR polarization are shown in Fig. 7. The target azimuth angle was 90 deg (left broadside) and the radar depression angle was 45 deg. The left side of the target is to the left in the images, and the front of the target is at the top. The ISAR images were created by computing a two-dimensional FFT of 64 sets of frequency-stepped data for the sum- and elevation-angle channels. The total rotation of the target during the data-taking time for the ISAR images was 0.812 deg. The downrange resolution for the images was 0.23 m and the cross-range resolution was 0.15 m. The sum channel ISAR image shows the RCS amplitude associated with each of the radar resolution cells of 0.23 × 0.15 m, and the elevation-angle-difference ISAR image shows the angular location above and below the plane of the sum channel ISAR of the effective single scatterer associated with each resolution cell. It is evident that the monopulse elevation angle data provides the third-coordinate information needed for construction of a point-scatterer model of the target without recourse to a geometric model of the target.

The images shown in Fig. 7 use the same set of data that were used to generate the HRR profiles of Fig. 6. It can be seen that these HRR profiles and ISAR images are quite consistent with one another.

5. Conclusions

A detailed description has been given of the characteristics of a 95-GHz fully polarimetric monopulse instrumentation radar and the procedures used for calibration of the radar. In particular, it was shown that the use of the PDM calibration technique improved the radar's cross-polarization isolation to 35 dB and the phase accuracy to ±4 deg across a 630-MHz frequency band.

Polarimetric monopulse radar target signature data for a Soviet BMP infantry combat vehicle were presented to show the capabilities of the radar. The fully polarimetric RCS polar plots for the BMP showed that the LR and RL RCS's are virtually the same (as they should be) and those for RR and LL are very similar.

The RCS amplitude and the azimuth- and elevation-angle-difference HRR profiles of the target also were presented for RR and LR polarizations. It was indicated that distinctive features and differences in these profiles may be useful for classification, identification, and tracking of a target in a MMW seeker application.

Standard ISAR imaging techniques were used to generate two-dimensional polarimetric images of the BMP target. These images were presented along with the corresponding polarimetric ISAR images of the elevation angle differences. It was pointed out that the elevation-angle information in the monopulse channels provides a third dimension to the images which can be very useful for the generation of point-scatterer models of a target.

In conclusion, the instrumentation radar described in this report has been shown to be capable of providing target signature data of various types that may prove useful for the evaluation of target detection, classification, and identification algorithms and for the generation of target models.

Acknowledgements

The work reported on here would not have been possible without the encouragement and managerial support of Peter B. Johnson and Z. G. Sztankay. Their efforts are gratefully acknowledged. Thanks also are extended to H. Haralamos and a number of US Army MICOM staff members for their contributions to obtaining the results presented here.

References

1. N. C. Currie and C. E. Brown (Editors), "Principles and Applications of Millimeter-Wave Radar," Artech House, Norwood, MA, 1987.

2. N. C. Currie (Editor), "Radar Reflectivity Measurement: Techniques and Applications," Artech House, Norwood, MA, 1989.

3. R. M. Barnes, MIT Lincoln Laboratory, "Polarimetric Calibration Using In-Scene Reflectors," 1986, MIT Lincoln Laboratory Project Report TT-65 on Contract F19628-85-C-0002.

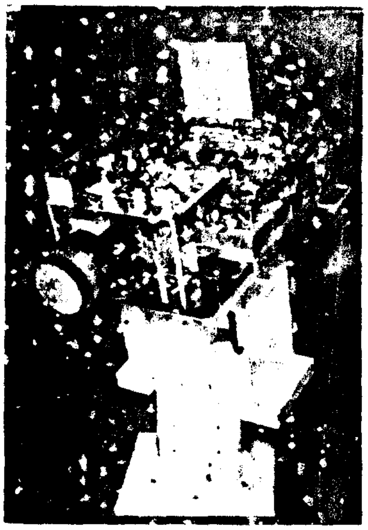

Figure 1. 95-GHz polarimetric monopulse radar.

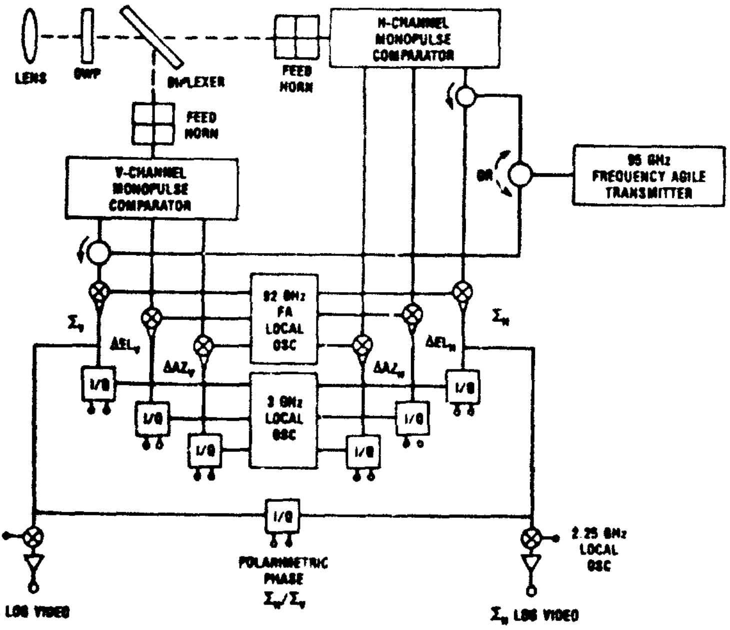

Figure 2. A simplified schematic of the 95 GHz polarimetric monopulse radar.

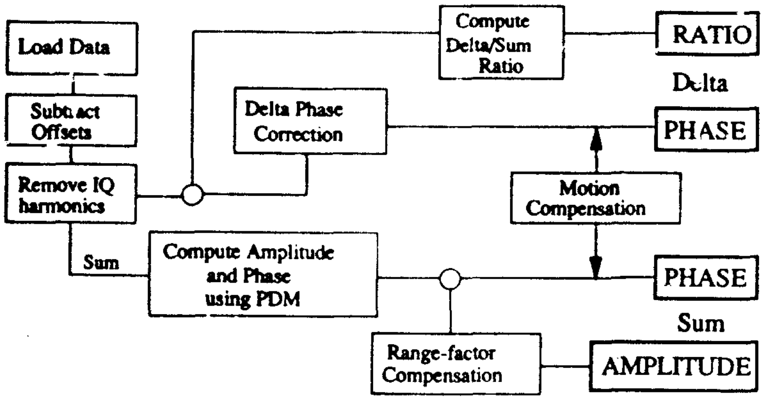

Figure 3. Block diagram of the coherent receiver calibration procedure.

Figure 4. Soviet BMP infantry combat vehicle.

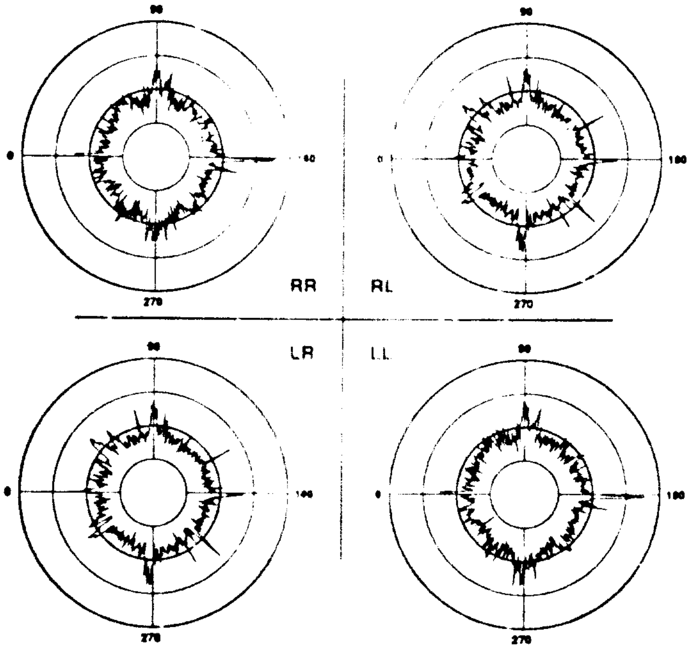

Figure 5. Polar plots of frequency-averaged RCS's for a Soviet BMP. The RCS range on the plots is 0 to 30 dBsm, and the radar depression angle was 45 deg.

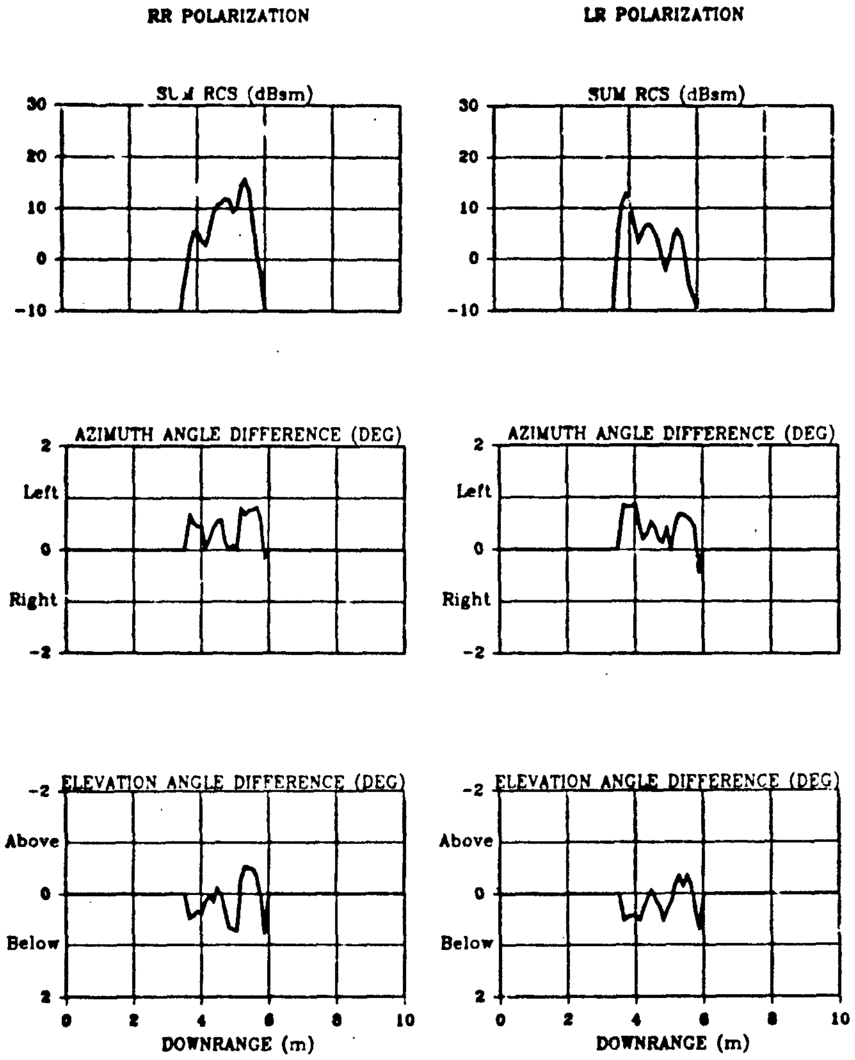

Figure 6. Monopulse sum and difference channel high-resolution range profiles for a Soviet BMP. The radar depression angle was 45 deg., and the target azimuth angle was 90 deg. (left broadside).

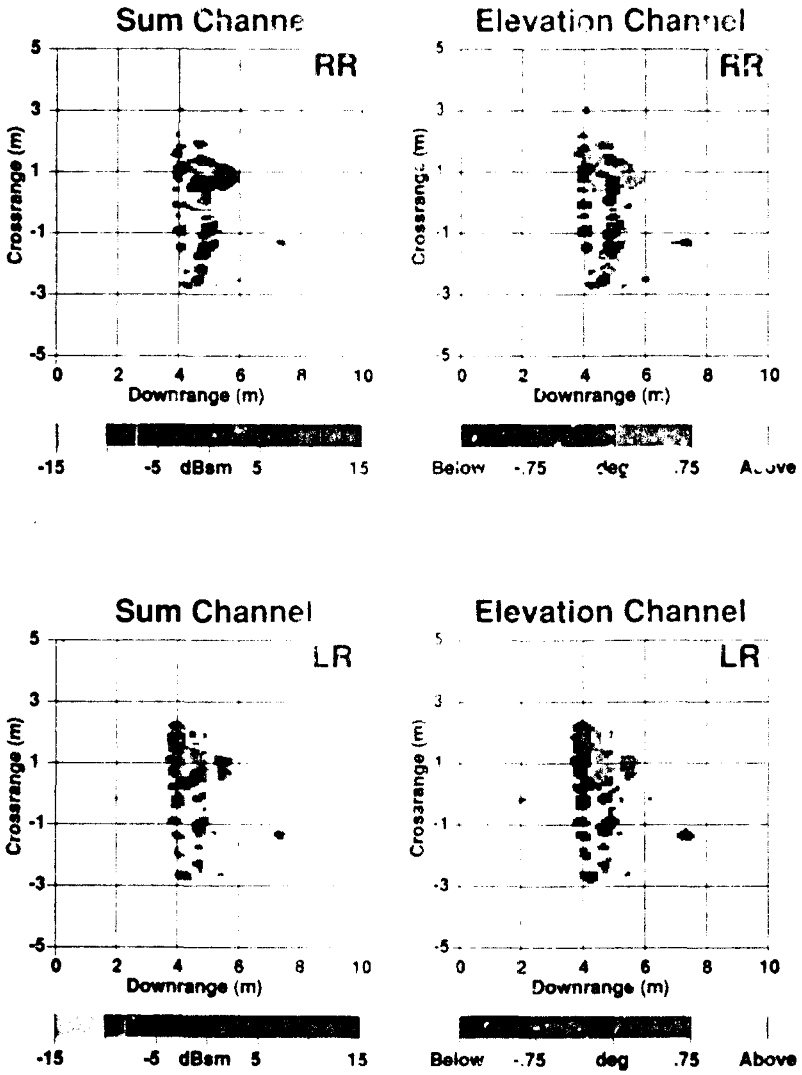

Figure 7. Monopulse sum and elevation-angle-difference channel ISAR images for a Soviet BMP. The radar depression angle was 45 deg, and the target azimuth angle was 90 deg (left broadside).

TABLE 1. BASIC FEATURES OF THE RADAR SYSTEM

- Frequency: 95.0 GHz
- Two-coordinate amplitude-comparison monopulse
- Polarization agile: RHCP/LHCP or V/H (selectable)
- Coherent and wide bandwidth
- Frequency steppable: 64 10-MHz steps
- Peak power: 45 W
- Pulse width: 100 ns
- Pulse repetition frequency: 10 kHz
- Antenna beamwidth (one way): 1.5 to 5.2 deg (selectable)
- Receiver IF bandwidth: 30 MHz
- Receiver noise figure: 8 dB
- Dynamic range (amplitude): ≥ 66 dB
- Data recording: 16 channels for each pulse

TABLE 2. REFLECTORS IN TARGET ARRAY USED FOR CALIBRATIONS

Reflector No.	Reflector Type	RCS(dBsm)	Range to Radar (m)
1	Dihedral (45°)	20	99
2	Dihedral	23	119
3	Gridded trihedral	14	139
4	Trihedral	30	158

TABLE 3. FREQUENCY-AVERAGED RCS (dBsm) FOR CALIBRATION REFLECTORS

Reflector Type	Receiver	σ_{RR}	σ_{RL}	σ_{LR}	σ_{LL}
Dihedral	Linear	23.0 ± 0.1	−15 ± 2	−15 ± 2	23.1 ± 0.1
	Log	23.0 ± 0.1	−7 ± 3	−7 ± 4	23.1 ± 0.1
Trihedral	Linear	−5 ± 4	30.0 ± 0.3	30.0 ± 0.3	−4 ± 4
	Log	−4 ± 6	30.0 ± 0.1	29.9 ± 0.1	0 ± 4

TABLE 4. SINGLE-FREQUENCY PHASE (deg) FOR CALIBRATION REFLECTORS

Reflector Type	ϕ_{RR}	ϕ_{RL}	ϕ_{LR}	ϕ_{LL}
Trihedral		290 ± 3	290 ± 3	
Dihedral	350 ± 3			347 ± 3
Gridded trihedral	115 ± 4	112 ± 4	113 ± 4	107 ± 4

TABLE 5. AVERAGE PHASE DIFFERENCE (deg) PER FREQUENCY STEP FOR CALIBRATION REFLECTORS

Reflector Type	$\Delta\phi_{RR}$	$\Delta\phi_{RL}$	$\Delta\phi_{LR}$	$\Delta\phi_{LL}$
Dihedral (all pairs)	12 ± 1			12 ± 1
Dihedral (one pair)	14 ± 4			14 ± 3
Trihedral (all pairs)		223 ± 2	223 ± 2	
Trihedral (one pair)		223 ± 4	223 ± 4	
Gridded trihedral (all pairs)	130 ± 2	130 ± 3	130 ± 3	130 ± 2
Gridded trihedral (one pair)	129 ± 5	130 ± 6	130 ± 5	132 ± 6

TABLE 6. AVERAGE RCS (dBsm) FOR A SOVIET BMP OVER 0 TO 360 DEG AZIMUTH ANGLES AND FOR VARIOUS RADAR DEPRESSION ANGLES

Type Average	Dep. Angle	σ_{RR}	σ_{RL}	σ_{LR}	σ_{LL}
Bandwidth	30	8.0 ± 0.2	7.2 ± 0.8	7.2 ± 0.8	8.1 ± 0.2
	45	7.9 ± 0.2	7.4 ±0.8	7.5 ±0.8	7.9 ±0.1
	60	7.8 ± 0.1	7.6 ± 0.6	7.7 ± 0.6	7.8 ± 0.2
Single Freq.	45	8.0 ± 5.9	6.9 ± 5.9	7.0 ± 6.0	8.1 ± 5.9

DISCUSSION

G. Neininger, GE

Illuminating a target like a tank at approximately 200 meters there will exist probably more than one scatterer within the detection area. Does this not confuse the monopulse comparator?

Author's Reply

If one does a high range resolution image, with range resolution of 23 meters, the monopulse channels can give angle information versus range, thereby separating some of the scatterers. If there are two scatterers at one range the monopulse channel will give the composite scattering center. However, by doing the ISAR processing, this ambiguity can be resolved.

E. Schweicher, BE

You mentioned a 45 W peak power. What kind of solid-state transmitter did you use at 95 GHz?

Author's Reply

The transmitter uses injection locked impact oscillators. The final stage has a 40-diode power combiner to get the 45 watts and the 640 MHz bandwidth.

U. Lammers, US

What kinds of phase excursions did you get due to tower sway, and at what rate did you have to compensate for them?

Author's Reply

For moderate wind conditions less that 10 mph, phase variations due to tower motion were about ± 15- 20°. This consisted of a slow variation < 1 Hz and a 5 Hz resonance. I have not looked at this in detail, but we have compensated for this when calibrating the data. The compensation is done ramp by ramp where a ramp of 64 pulses at each polarization stepping frequency 10 MHz per pulse sequences 12.8 ms. The total sample rate is 40 Hz.