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Linear polarization of radar cross section measurement on tank miniature

Muhammad Panji Kusuma Praja[1,*], Wahyu Pamungkas[2]
[1,2]Faculty of Telecommunication and Electrical Engineering, Institut Teknologi Telkom Purwokerto
[1,2]D. I. Panjaitan, No. 128, Purwokerto 53147, Indonesia
[*]Corresponding email: panji@ittelkom-pwt.ac.id

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Abstract — The use of radar technology, especially for the interests of state defense and security, has become the focus of development launched by the government of Indonesia. Equipment and vehicles in the defense and security sector are the top priority to be detected using radar technology. When a radar transmitter transmits its signal toward a target, some part of the signal will bounce in all directions, including to the receiver and some will be absorbed by the radar target. The radar target is assumed to have a small size, to focus more on the beamwidth of the radar transmitting antenna to the target. This research has focused on measuring radar targets in the form of defense equipment in the form of tanks made in miniature, which are smaller than their original forms. The selected antenna polarization uses linear polarization with vertical and horizontal types. This research compared each polarization with the value of the Radar Cross Section (RCS) in the combination of the same polarization and different polarization. The measurement results show that the largest RCS value is obtained at an angle of 200° by 13 with a combination of Horizontal-Horizontal polarization and the smallest RCS value is obtained at an angle of 50° by -4 with a combination of Horizontal-Vertical polarization. With the results of these measurements, it can be concluded that the measurement of RCS for defense and security equipment can be carried out by measuring the miniature of the defense and security equipment.

Keywords – Linear polarization, radar cross-section, scattering, tank miniature

I. INTRODUCTION

Radar is an electromagnetic wave system for detecting, ranging, and mapping an object. The Electromagnetic wave has several polarization techniques, which could be reflected or scattered in all directions if it hits the object with a certain reflection coefficient. The intensity of the reflected wave received in the radar antenna is called Radar Cross Section (RCS). RCS parameters on radar can be measured by considering the object from a research aspect and operational. Some parameters that must be considered in RCS measurement are far-field, polarization, instrument sensitivity, and range facility requirements are essential to program planning [1].

RCS area is a measure of a target's capacity to reflect radar signals in the direction of the receiving antenna, not the same as the physical area. RCS is defined as a region intercepting the amount of power that, when scattered isotropically, generates a density at the receiver equal to that of the actual target. The RCS of a target is a function of the incident wave's polarization, the angle of incidence, the angle of observation, the target's shape, the target's electrical characteristics, and the frequency of operation in general. The characteristics and mechanism of the polarization rotation and RCS reduction are investigated in [2]. As a result, two targets of similar physical size and shape may have vastly different radar cross-sections [3].

The objectives of both the experiments and the operational applications must be carefully considered in RCS measurement projects. Far-field, polarization, instrumentation sensitivity, and range facility requirements are all critical concerns in program development. The response of an isolated target was previously measured in a facility that attempted to provide a free-space backdrop. Some measurement projects have expanded to include radar detection for a target embedded in a surrounding clutter environment with the relative target and radar motion dynamics, as interest in target detection in an operating setting has grown. In such instances, the target, clutter background, and operational dynamics must all be simulated; this is known as ”dynamic” measurement, as opposed to the ”static” measurement of an isolated target. Recent advances in radar technology and processing techniques have also raised the bar for instrumentation and processing above what was previously acceptable. To evaluate the prominent aspects of the radar waveform and its processing, specialized instrumentation, signal processing techniques, and test facilities are required. As a result, determining the scope of the measurement is critical to the development of a measurement program [1].

RCS diagrams are usually difficult to identify because of the dimensions of the detected radar object. The radar object represents a 2-dimensional shape while the original shape of the radar object is 3-dimensional [4]. To avoid the phenomenon of an object being easily detected by radar, the RCS parameter can be set to be minimized. This applies to the military world that has radar objects such as ships, planes [5], drones [6], or other combat equipment [7]. RCS models and measurements can not only be simulated but can also be further implemented using FPGAs such as research conducted by [8].

The shapes of radar objects such as triangular, spherical, cylindrical, and elliptical plates associated with RCS parameters have been studied previously by [9]. Each of these forms has produced different formulas with different RCS variation functions. In a more tangible form, RCS measurements on radar objects have been widely carried out in the military [10]–[14] through equipment such as jet engines, aircraft bodies, and military troop bodies. The design of the radar object’s constituent materials can also determine the quality of the RCS quality measurement, as was done by [15], who investigated the effect of plasma materials on the RCS value reduction.

In this study, we present a contribution in the form of making miniature defense equipment which is then measured in its RCS value to represent the original form of military tank vehicles. We model and validate the position of radar objects from radar transmitters and receivers and design a miniature tank with precise dimensions to be used as radar objects.

This paper was organized as follows. In section II, we try to explain the method we used in this research and we illustrate the experimental setup. There will be some explanation about frequency design, the scenario of placing radar objects and the explanation of the size of the radar object. In section 4, we described the results of the measurement, and we discussed each resulting graphic of RCS. Finally, in section 5, the conclusion will be given.

II. RESEARCH METHOD

This section discusses radar, radar cross section, polarization, scattering parameter, and modeling.

A. Radar

Radar is a technology for ranging, locating, and detecting an object by the electromagnetic system. In general, a radar system consists of a transmitter and a receiver. It transmits electromagnetic waves as a signal incident that hits an object and detects an echo signal or reflected signal, which could be captured by a receiver for analysis later. The distance of the target is determined by measuring the different times between the signal transmitted to the target and back to the receiver [16].

$$t = \frac{2R}{c} \tag{1}$$

where t is the time delay (s), R is the distance between antenna and object (m), and c is the light velocity for $(3 \times 10^{8} {}^{m}\!/_{s})$.

Radar system used to configure in monostatic or bistatic. The Monostatic system uses a single antenna for transmitting and receiving electromagnetic waves. In contrast, bistatic system radar emits electromagnetic waves by the transmitter antenna and captures echo signals by the receiver antenna.

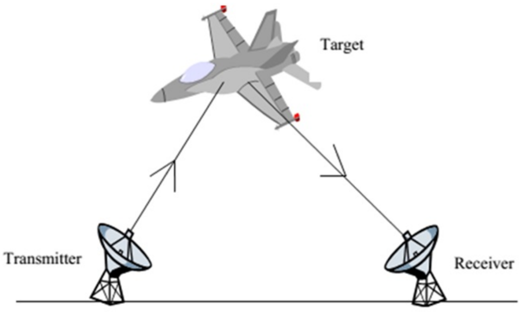

Fig. 1. Bistatic radar system [3].

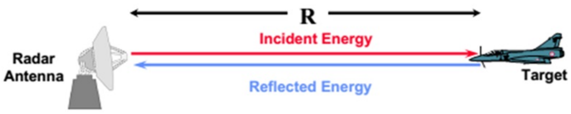

Fig. 2. Monostatic radar system.

B. Radar Cross Section

The RCS is the amount of energy that intercepts the target or object and is scattered back to the antenna receiver. RCS is denoted by σ, used for identifying the scattering properties of a radar target. It represents a target's size as seen by the radar and has a dimension of square meters. RCS can measure the target by [17].

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2 \tag{2}$$

$$\sigma = \frac{\text{power reflected toward source/unit solid angle}}{\text{incident power density}/4\pi} \tag{3}$$

where E_r is the reflected field strength at radar, E_i is the incident field strength at radar, and R is the distance between radar and target.

The radiation pattern that is transmitted and received is relative to the target orientation of the RCS or is the effective cross-sectional area of the target visible to the radar. RCS can measure targets by bouncing signals toward the receiving antenna of the radar. RCS is the ratio of backscatter density towards the radar to the power density received by the target.

C. Polarization

Electromagnetic waves are waves generated from changes in the magnetic field and electric field in sequence, where the direction of the electric field and magnetic field vector vibrations are perpendicular to each other and both are perpendicular to the direction of wave propagation.

Polarization can be categorized into three types, namely linear, elliptical and circular. In its application, vertically and horizontally mounted antennas are designed to receive both vertically and horizontally polarized waves.

D. Scattering Parameter

In many radar systems used, the target radar is assumed to have a small size, to focus the beamwidth of the radar transmitting antenna on the target. When a radar transmitter transmits its signal toward a target, some part of the signal will bounce in all directions, including the receiver and some will be absorbed by the radar target. Reflection and absorption will certainly reduce the total power of the radar transmitter. If the total reflected power is denoted by T and the absorbed power is denoted by a then the total power transmitted from the transmitter will be c which is:

$$\sigma_c = \sigma_T + \sigma_a \tag{4}$$

The reflection generated by the radar target will bounce in all directions. If the direction of reflection is opposite to the direction of the incident wave, it is called a backscattering cross-section, and if the reflection is in all directions except for the backscattering Cross Section, it is called a bistatic scattering cross-section. The total cross-section is found by adding up the bistatic and backscattering cross-sections.

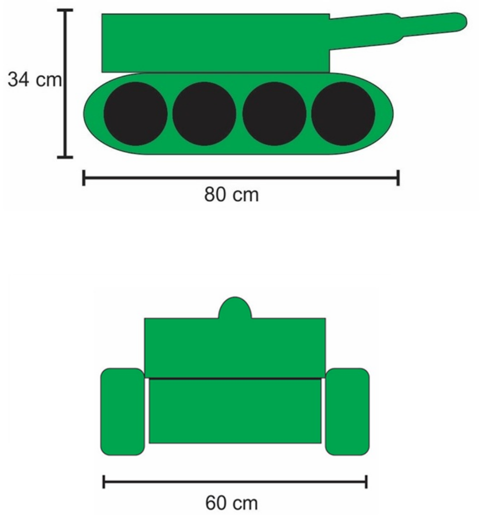

Fig. 3. Tank miniature by side view and rear view.

E. Modelling

RCS measurement of miniature tank use frequency that has been determined before. A miniature tank based on the size of the tank, in a real condition that has been minimized ten times. In this case, RCS measurement used frequency at 4 GHz. It means in real conditions, RCS is measured at a frequency of 400 MHz.

RCS measurement needs a minimum distance between the radar antenna and the object that will be detected. A range measurement based on the far-field area concept in electromagnetic waves. A far-field area is an area of an antenna in which the distribution of electromagnetic field is not dependent on the range from the antenna. In this area, the component of transversal waves and angular distribution is not dependent on the radial. A radiation pattern of the antenna can be found in this area. A minimum distance of far-field area can be calculated by the following formula:

$$R = \frac{2D^2}{\lambda} \tag{5}$$

with R is the minimum distance (m), D is the longest dimension, and λ is the wavelength (m).

$$R = \frac{2(0.14)^2}{0.075} \tag{6}$$

$$= 0.529m \tag{7}$$

III. RESULT

This section discusses the measurement method and experiment results.

A. Measurement Method

In this study, we used the indoor measurement method as has been done in [18] to measure RCS simply, the bistatic antenna has been applied, and the target is set by the distance with the antenna. Measurements are carried out on a ground-based target or in this case, a miniature tank arranged as in Fig. 4 in the measurement scenario. The antenna used as a transmitting and receiving antenna is a microstrip antenna with a working frequency of 4 GHz and a gain of 3.9811. The sending antenna is connected to a signal generator with a power of 0.003 Watt, and the receiving antenna is connected to a spectrum analyzer to read the power level received by the antenna after hitting the target object.

The positioning of the receiving antenna and the radar antenna are arranged as shown in Fig. 5 with a distance of 40cm. The use of transmitting and receiving antennas, respectively, is intended for the model of a bistatic radar system. A bistatic radar system transmits electromagnetic waves to the target through the sending antenna, and then the receiving antenna receives an echo signal from the electromagnetic waves reflected by the target [5].

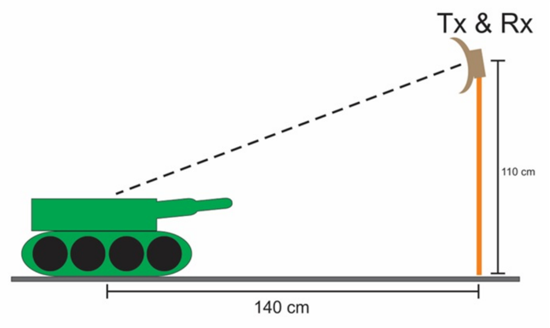

Fig. 4. Configuration of distance between antenna and tank.

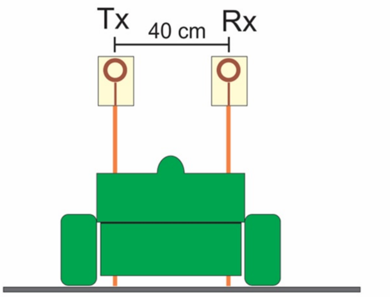

Fig. 5. Configuration of distance between antenna receiver and antenna receiver.

The RCS measurement in this experiment uses several measurement scenarios that depend on the orientation of the transmitting and receiving antennas. The placement of the different antenna orientations is intended to compare the size of the RCS, which is represented by the power level received after electromagnetic waves hit an object.

Fig. 6. Experimental measurement of antenna and tank miniature configuration.

Ground-based target or miniature tank in this experiment was placed 140 cm in front of the antenna transmitter and receiver. Next, the object is rotated 360° with a rotation angle interval of every 10°, which is centered on the center of the object, which is used as the axis of rotation.

B. Experimental Result

The results of the RCS measurement are obtained using four scenarios of the transmitting antenna and receiving antenna, namely Vertical-Vertical (VV), Horizontal-Horizontal (HH), Vertical-Horizontal (VH), and Horizontal-Vertical (HV), as shown in Fig. 7 - Fig. 10. The use of variations in the linear polarization model affects the received power level even though it uses the same power on the sending side for all scenarios. This will also affect the RCS value obtained from the echo signal of the object being measured.

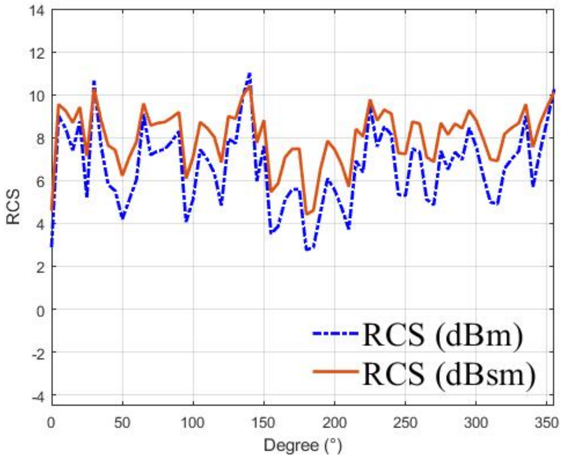

Fig. 7. Radar cross section on VV polarization.

In Fig. 7, which uses the VV linear polarization model, the most significant RCS result is produced at an angle of 140° , which is 11 dBm. The smallest RCS represented by the power level can be read at 2.76 dBm at an angle of 180°. This showed that by adjusting the orientation direction, the back of the object is detected as a cross-section with the smallest area compared to the cross-section on the other side, resulting in the slightest echo signal compared to echo signals from other angles.

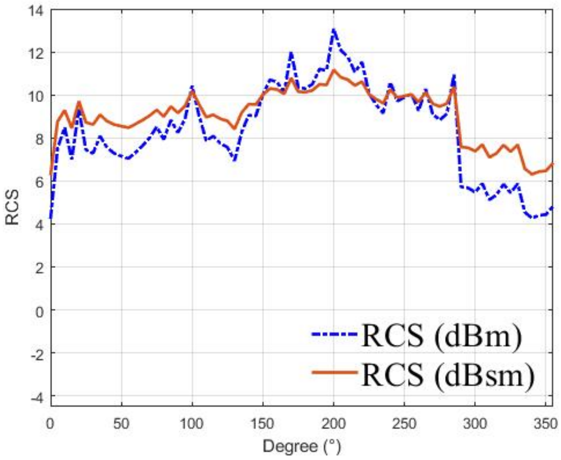

Fig. 8. Radar cross section on HH polarization.

If we use linear polarization with the Horizontal-Horizontal (HH) model, then the transmitter and receiver antenna produces the largest RCS value at an angle of 200° of 13.07 dBm and the smallest RCS value at 0° of 4.23 dBm as seen on Fig. 8.

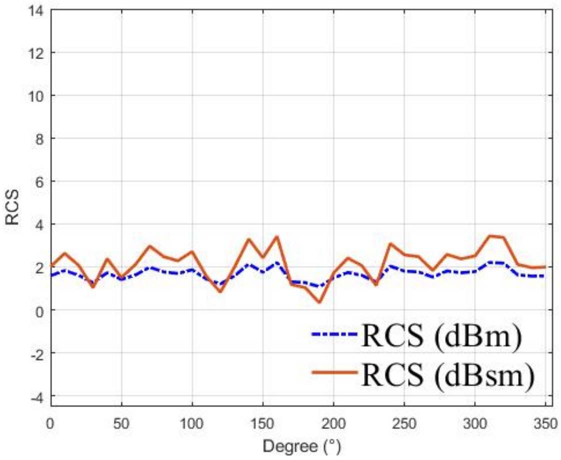

Fig. 9. Radar cross section on VH polarization.

The results of the research on the VH linear polarization model for the transmitting antenna and receiving antenna produced the largest RCS value at an angle of 310° of 2.2 dBm and the smallest RCS value at an angle of 190° of 1.07 dBm. The RCS value shown in Fig. 9 showed that the RCS value in the different orientation directions of the receiving and sending antennas, namely VH is smaller than the antennas that have the same orientation direction, namely VV or HH.

The linear polarization of the HV model for the transmitting antenna and receiving antenna produces the most considerable RCS value at an angle of 320° of 11.22 dBm and the smallest RCS value at an angle of 100° of 1.27 dBm. Because the arrangement of the orientation of the transmitting and receiving antennas significantly affects the received power level, the same orientation direction will produce a more significant RCS value compared to using a different antenna orientation.

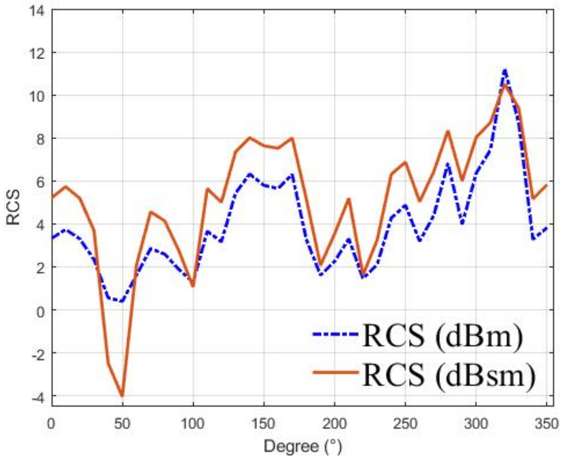

Fig. 10. Radar cross section on HV polarization.

IV. DISCUSSION

Positioning of antenna orientation by vertical or horizontal aims to produce vertical polarization or horizontal polarization, which is called linear polarization. In this research, while antenna orientation is set Horizontal-Horizontal (HH), the incident wave emitted to the object with the direction of an electric field in a horizontal orientation and scattered signals that are received are matched with the antenna receiver that has a horizontal direction of an electric field. The condition allows the antenna receiver has a maximum received power level. As shown in Fig. 8 the positioning of the antenna transmitter and antenna receiver by HH produced the largest RCS value at an angle of 200° of 13.07 dBm. In the other direction of an electric field, namely VV polarization, the maximum power level received at 11 dBm at an angle of 140°.

RCS measurement depends on the received power level received by the antenna receiver as a result of scattered signals that are reflected by the object. While the antenna transmitter and antenna receiver have different orientations, they will modify the direction of an electric field and the direction of a magnetic field, which affect the received power level at the minimum result. The scenario of antenna positioning by VH shows the most considerable RCS level at 2.2 dBm of an angle 310°.

V. CONCLUSION

We measured the backscattered RCS from a tank miniature in great detail. The experimental data show that the RCS from a tank miniature intake is highly sensitive to the inlet's orientation In relation to the radar, as well as being radar frequency dependent. These findings suggest that the modeling of tank miniature RCS has some intriguing issues. Researchers working on tank miniature RCS modeling will benefit from the measured data offered here since it gives them a better understanding of the problem's complexity and a broader perspective to assist them in developing a more complete and realistic tank RCS model. This is a vital area in the effort to produce realistic synthetic target signatures for target identification/recognition applications. Hence a strong, dependable model is in great demand.

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