Characterization of monostatic radar system for accuracy improvement through parameter estimation

Abstract: This paper presents the characteristics of monostatic radar for improving accuracy of detection through determination of the factors that were responsible for power losses in radar signal transmission and interception by targets. These factors were improved upon by looking at some parameter like the antennae gain or transmitter gain, and evaluating the result through Matlab testing of some measured distance values. This was achieved by simulating mathematical radar equations by liu, 2014, of signals transmitted over selected distances say, from 5km to 100km and evaluated the result. The table of results was found to have increased in accuracy with increasing transmitter gain over long distances though it was a function of the distance of the receiver from the target object to transmitter.

Key words: Transmitter, Receiver, Transmitter gain, Signal, Target.

I. INTRODUCTION

RADAR (Radio Detection and Ranging) is a system that uses electromagnetic waves to detect the presence of objects in the outer space. Radars can also be used to measure the range, direction and velocity of the target. In monostatic radar systems, the transmitter and receiver are collocated [1] at the same site. It implies that the echo signal travel the same path as the transmitted signal. Thus, the Direction-Of-Departure (DOD) of the transmitted signal and the Direction-Of-Arrival (DOA) of the echo from the target are the same ($\theta DOD = \theta DOA$) as well as the target distances to the transmitter (Tx) and receiver (Rx) ($\rho_{Tx} = \rho_{Rx}$). Different properties of electromagnetic radiations such as reflection, scattering, constant speed and the possibility for beam-forming are exploited in radar implementation. For instance when the electromagnetic wave propagating through a medium encounters another medium with a different refractive index, the wave undergoes reflection or scattering. The underlying principle of radar systems is to collect the reflected electromagnetic waves from objects and process them appropriately to obtain as much information of the objects as possible. The information includes the target's presence, direction of arrival, distance, velocity etc. The basic concept of radar arises from the classical experiment by Heinrich Hertz at the end of 19th century for verifying the predictions of `James Clerk Maxwell's theory of the electromagnetic field [2]. This reflected energy indicates the presence of a target. Similarly, the constant speed of the electromagnetic waves in a homogeneous medium offers the possibility to calculate the distance from the target.

Wireless positioning systems have received a great deal of attention in recent years. Various types of wireless sensor networks have been investigated for different types of sensors (radio-frequency, infrared, optical, inertial, etc.) and estimation algorithms [3]. For radio-frequency-based systems, several signal metrics, such as time of flight measurements

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(TOA, TDOA) and direction of arrival measurements (AoA), were detailed [4], to have the same parameters which were characterized in this work.

II. METHODOLOGY

To characterize the monostatic radar system, radar equations from [5] as in equation 3.1 below were simulated in Matlab in order to determine the parameters that can affect the accuracy of position of a target in radar system. The simulated results were plotted to show their relationship to the subject matter. A radio wave is transmitted to the atmosphere. If there is any object in the environment, it will absorb a portion of the signal energy; another portion will be refracted or passed through the object body. The remaining portion will be reflected by the object towards the transmitter (source). The receiver can be located along with the transmitter or separated from the transmitter. The receiver receives the reflected signal and after further processing, the necessary parameters of the object are determined. Some important points, which are useful for understanding of radar detection, are given below:

(a) The reflected signal can never have the same intensity as the original.

(b) The scope of determination of reflecting signals depends on the signal strength and pulse duration of the original signal.

(c) If the target is close to the transmitter, short pulse duration will be useful.

(d) A sufficiently long interval between each pulse is required for distant targets.

To characterize the monostatic radar system, a study of the radar equation [5] was carried out by considering an isotropic antenna, transmitting an electromagnetic signal having power P_t. The range of the radar antenna is denoted by R. So, the power density at the distance R will be; [5];

$$power\ density = P_t \frac{1}{4\pi R^2} \qquad (3.1)$$

Where;

$P_{t = 40}$ Signal power according to(Skolink,2018)

R = Distance in km

Characterizing the power density of the radar antenna over selected distance, say from 5km to 100km range, a Matlab code for equation 3.1 was generated and simulated to get the result as presented in Table1.

In all practical cases, the radiating element cannot be isotropic i.e. the antenna will be directive. Now, having the directive gain, G, the power density of the signal at distance R will be [5];

$$power\ density = P_t \frac{G}{4\pi R^2} \qquad (3.2)$$

To characterize the effect of transmitter gain on the power density of the radar antenna over selected distance, a Matlab code for equation 3.2 was developed and simulated to get the result as presented in Table 2.

Low power received as the distance increases can lead to position estimate error of the radar target due to fading. Though there was an improvement in the power density when compared to the result from equation 3.1. This shows that in characterizing radar system, transmitter gain is a major factor to be considered in order to maintain accuracy in position estimate of target.

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The target's scattering properties are characterized by its Radar Cross Section (RCS), denoted by the symbol σ. It is not necessary for the RCS to be the same as the physical cross section. Therefore, the power intercepted by the target is [5];

$$power\ intercerpted\ by\ the\ target = P_t \frac{G\sigma}{4\pi R^2} \quad (3.3)$$

So, the echo signal power that reaches the receiver is

$$power\ density\ at\ the\ receiver = P_t \frac{G\sigma}{4\pi R^2}\frac{1}{4\pi R^2} \quad (3.4)$$

To characterize the power density at the receiver antenna while considering target's scattering properties which are characterized by its Radar Cross Section (RCS), a Matlab code for equation 3.4 was developed and simulated to get the result as presented in Table 3.

The effective aperture of the receiving antenna is A_e. The received signal power will be (Skolink, 2008);

$$P_r = P_t \frac{G\sigma}{4\pi R^2}\frac{1}{4\pi R^2}\, Ae \quad (3.5)$$

But the effective aperture of an antenna is dependent on the gain, *G*. The relationship between effective aperture and gain is, $G = \frac{4\pi A_e}{\lambda^2}$. So, the expression for the received power will be (Skolink, 2008); $P_r = P_t \frac{G\sigma}{4\pi R^2}\frac{1}{4\pi R^2} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$ (3.6)

To characterize the received power at the receiver antenna while considering target's scattering properties which are characterized by its Radar Cross Section (RCS) and the transmitting gain, a Matlab code for equation 3.6 was developed and simulated to get the result as presented in Table below.

Parameters used for the simulation is as follows (Skolink, 2008):

Pt = 40

G = 20

λ = 50

σ = 1.327

R = from 5km to 100km

From equation (3.6), the range of a radar system can be determined. The range of radar is the maximum distance from where it can detect a target. In the maximum distance, the signal power will be the minimum that can be intercepted. So, from equation (3.6), the range will be (Skolink, 2008);

$$R^4{}_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{4(4\pi)^2 R^2 P_{r,min}}\right) \quad (3.7)$$

If the target is located in the far field, the considerations of parameters will be slightly different. Suppose there is a flat two-dimensional target located in the far field, it will cause refraction through the target and a mirrored reflection [6]. This reflection is in relation to the 'virtual' source from the

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same distance *R* behind the target. The whole situation is pictured in Image1

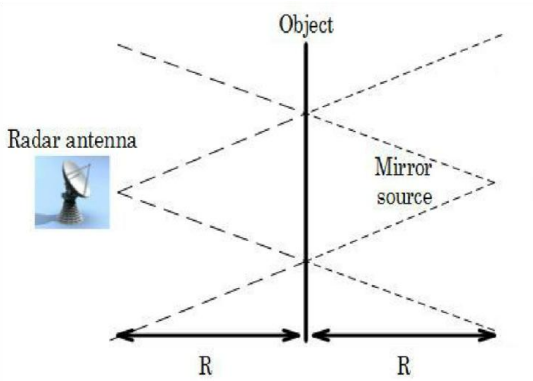

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Image. 1 Reflection on a flat far field target.

So, for a flat shaped - 2D target, the power density at the receiver will be (Skolink, 2008);

$$power\ density\ at\ the\ receiver = \frac{P_t G_t}{4\pi(2R)^2} \qquad (3.8)$$

Here, G_t is the transmitter antenna gain. The signal power intercepted by the receiver is

$$P_r \frac{P_t G_t G_r \lambda^2}{4(4\pi)^2 R^2} \qquad (3.9)$$

In (3.9), G_r is the receiver antenna gain. The resulting expression for range is [6];

$$R_{max} = \sqrt{\frac{P_t G_t G_r \lambda^2}{P_{r,min} 4(4\pi)^2}} \qquad (3.10)$$

In the above characterization, it is considered that both the transmitter and receiver are located at the same place i.e. the radar system is monostatic.

III. RESULT AND DISCUSSION

Table1, 2, and 3 shows an abridged sample network characterization output from power density with varied parameters respectively.

To characterize the power density of the radar antenna over selected distance, a Matlab code for equation 3.1 was developed and simulated to get the result as presented in table 1.

Table 1: Power Density as a Function of the Range of the Radar Antenna Distance

Distance (km)	**Power Density (watts) x 10^{-3}**
5	0.0032
10	0.0008
15	0.0004
20	0.0002
25	0.0001
30	0.0001
35	0.0001
40	0.0000
45	0.0000
50	0.0000
55	0.0000
60	0.0000
65	0.0000
70	0.0000
75	0.0000
80	0.0000
85	0.0000

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90	0.0000
95	0.0000
100	0.0000

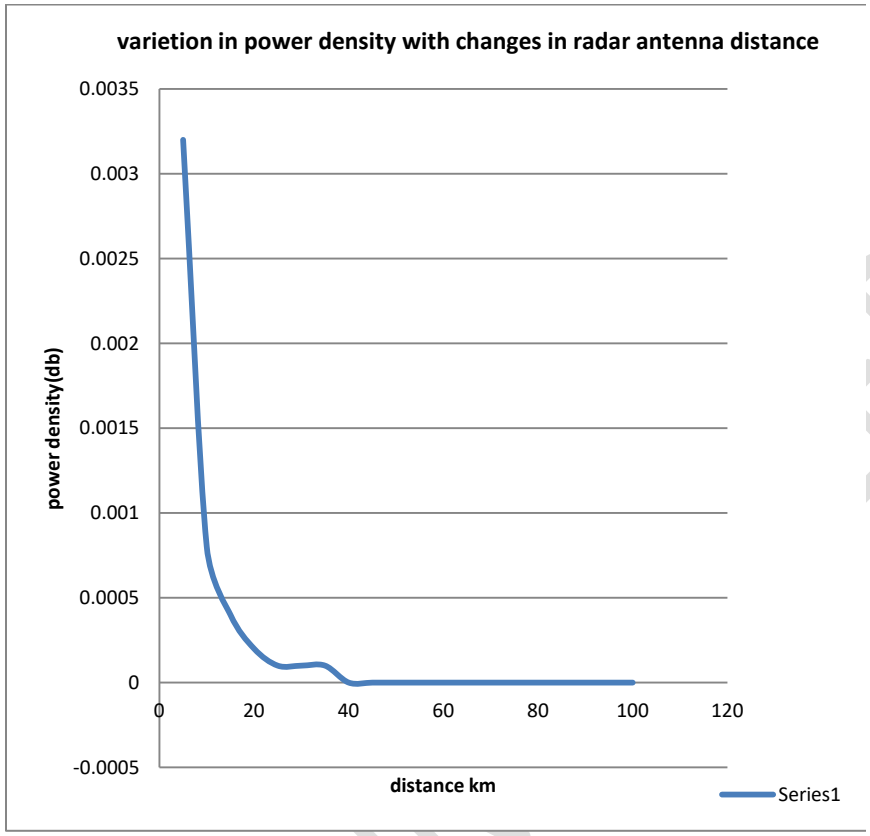

Fig. 1: Variation of Power Density with Change in Rader Distance

From figure 1, it can be observed that the longer the distance of the radar antenna from the transmitter, the lower the power received and this can lead to error in position estimate of the radar target.

Effect of Transmitter Gain on the Power Density

To characterize the effect of transmitter gain on the power density of the radar antenna over selected distance, a Matlab code for equation 3.2 was developed and simulated to get the result as presented in table 2. Table 2: Effect of Transmitter Gain on the Power Density

Distance (km)	**Power Density (watts)**
5	0.0637
10	0.0159
15	0.0071
20	0.0040
25	0.0025
30	0.0018
35	0.0013
40	0.0010
45	0.0008
50	0.0006

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55	0.0005
60	0.0004
65	0.0004
70	0.0003
75	0.0003
80	0.0002
85	0.0002
90	0.0002
95	0.0002
100	0.0002

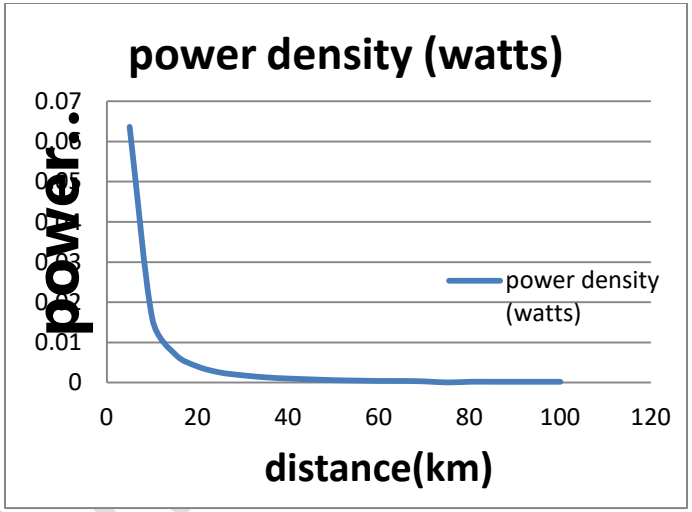

Fig. 2: Effect of Transmitter Gain on Power Density

From figure 2, it can be observed that the transmitter gain improved the received power density in the radar signal though; it is still a function of distance of the radar antenna from the target object to the transmitter. The lower the power received as the distance increases can lead to error in position estimate of the radar target. Though there was an improvement in the power density when compared to the result from equation 3.1. This shows that in characterizing radar system, transmitter gain is a major factor to be considered in order to maintain accuracy in position estimate of target.

Effect of Target's Scattering Properties on the Power Density

To characterize the power density at the receiver antenna while considering target's scattering properties which are characterized by its Radar Cross Section (RCS), a Matlab code for equation 3.4 was developed and simulated to get the result as presented in table 3.

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Table 3: Power Density at the Receiver with variation in Target's Scattering Properties

Distance (km)	Power Density (watts) x 10^{-4}
5	0.2689
10	0.0168
15	0.0033
20	0.0011
25	0.0004
30	0.0002
35	0.0001
40	0.0001
45	0.0000
50	0.0000
55	0.0000
60	0.0000
65	0.0000
70	0.0000
75	0.0000
80	0.0000
85	0.0000
90	0.0000
95	0.0000
100	0.0000

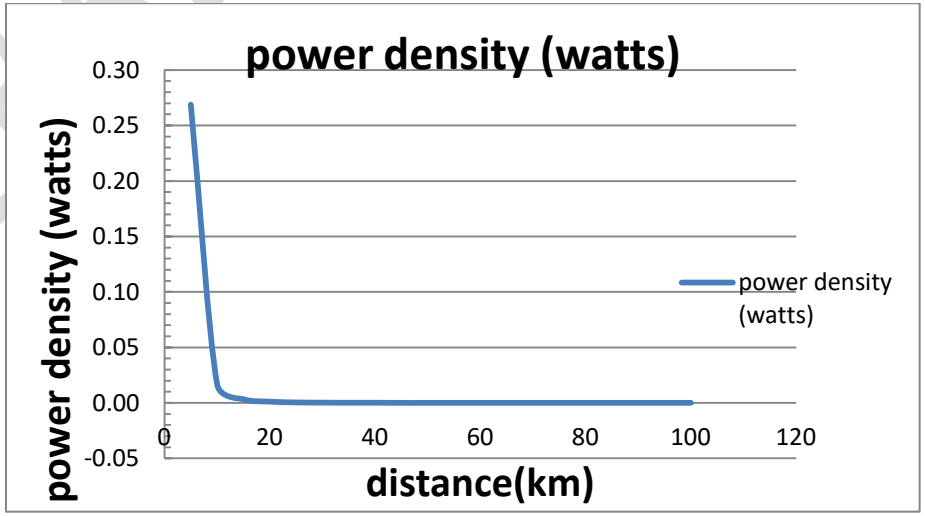

Fig. 3: Power Density at the Receiver with variation in Target's Scattering Properties

The result from Matlab simulation for the characterization of the power density at the receiver antenna while considering target's scattering properties which are characterized by its Radar Cross Section (RCS) show a

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high level of drop in the power density at the receiver antenna due to the scattering loss in the signal. This also will greatly affect the position estimate accuracy of a target in radar system.

REFRENCES

1. Willis, N. J. (2010) Bistatic Radar. Sci.Tech. Publishing Inc. W. Raleigh NC.

2. Skolnik, M. I.(2002) *Introduction to Radar Systems.* McGraw-Hill, New York.

3. Fink, A., & Beikirch, H. (2011, September). *Analysis of rss-based location estimation techniques in fading environments.* Paper presented at the International Conference on Indoor Positioning and Indoor Navigation, Guimaraes, Portugal. pp. 1-6

4. Liu, H., Darabi, H., Banerjee, P., & Liu, J. (2007). Survey of Wireless Indoor Positioning Techniques and Systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 37*(6), pp. 1067-1080.

5. Liu, Y., & Liang, J. (2014). Optimization for distributed Radar Sensor Network (RSN) and MIMO-RSN in flat fading channels. *Elsevier Journal*, *13*(C), pp. 253-259.

6. W. **Wiesbeck** at Karlsruhe Institute of Technology. W. **Wiesbeck** ... Adv. Radio Sci., 5, 379–384, **2007** www.adv-radio-sci.net/5/379/**2007**/.

7. Skolnik, M. I.(2008) IEEE Aerospace and electronic system magazine 23(5) 41-41

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