Performance Evaluation of Radar Signal to Noise Ratio (SNR)

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Abstract **- Radar is an object-detection system that uses electromagnetic waves for detecting distant of both moving and fixed objects. There are several factors that affect the performance of the radar receiver such as signal reception, signal to noise ratio (SNR), receiver bandwidth and receiver sensitivity. This project concentrated on performance of Signal to Noise ratio against target detection range for different radar cross section (RCS) and peak power (Pt). All the analysis has been done by using the MATLAB programming in order to design the program and simulate the radar equation of SNR. The data collection has been done by doing the research on the radar. Theoretical and simulation results show that SNR will be affected by the strength of transmits power (peak power) and radar cross section.**

Keywords: radar, signal to noise ratio, radar cross section

I. INTRODUCTION

A. Radar

The word "RADAR" is an acronym for Radio Detection and Ranging [1]. Radar is an electromagnetic system that uses radio waves for detecting, locating, tracking, and recognizing objects [2]. It operates by transmitting particular kind of radio frequency waveform toward objects and observing the reflected signal back to them. As radio waves strike an object, some portion of signal will be reflected and returned back to the radar set (monostatic radar). This reflected energy is used to determine location and other information of reflective objects. Radar systems are active devices used in civilian and military application [3]. The aim of surveillance radar is to detect targets by illuminating an area of interest with electromagnetic radiation. In maritime environment, the term target usually refers to any radar backscatter that is not due to the scattering from an ocean surfaces [4]. However, no matter what application it is used for, the basic principle of radar remain unchanged. Mostly radar has been classified based on their types of waveforms which are Continuous Wave (CW) or Pulsed Radar (PR) [5]. This research focused on monostatic radar which has single antenna or known as pulse radar.

Figure 1 shows a simplified pulsed radar block diagram. Synchronization timing signals that required during the system is generated by the time control. The modulator or transmitter block will modulate the signal and sent directly to the radar antenna. The duplexer controls the switching between transmitting and receiving antenna. One antenna can be used for both transmit and receive. During transmission it directs the radar electromagnetic energy towards the antenna [2]. Alternatively, on reception, it directs the received radar echoes to the receiver [1]. The receiver amplifies the reflected signal and the target information will be processed by the signal processor.

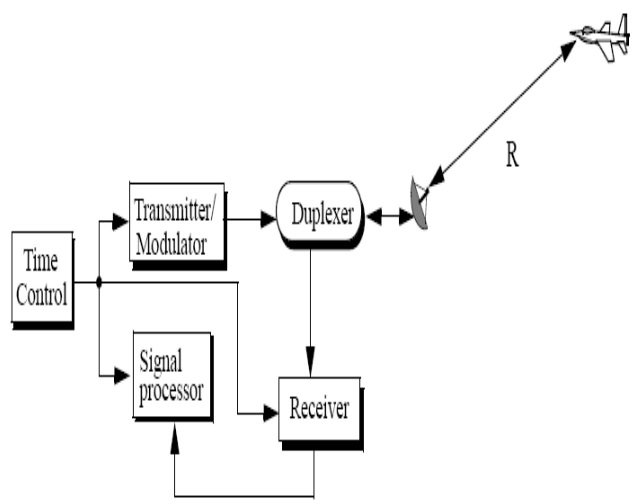

Figure 1: A Simplified pulsed radar block diagram

Table 1 below shows the radar classification based on their operating frequency. Basically C-band radars used for most weather detection radar systems [6]. Medium range search and fire control military radars also operate in C-band frequency. This research used frequency of 5.6 MHz which considered as C-band frequency to evaluate the SNR equation.

Table 1: Radar frequency bands

Letter designation	Frequency (GHz)	New band designation (GHz)
HF	0.003-0.03	A
VHF	0.03-0.3	A<0.25; B>0.25
UHF	0.3-0.1	B<0.5; C>0.5
L-band	1.0-2.0	D
S-band	2.0-4.0	E<3.0; F>3.0
C-band	4.0-8.0	G<6.0; H>6.0
X-band	8.0-12.5	I<10.0: J>10.0
Ku-band	12.5-18.0	J
K-band	18.0-26.5	J<20.0; K>20.0
Ka-band	26.5-40	K
MMW	Normally >34.0	L<60.0; M>60.0

B. Signal to Noise Ratio (SNR)

Signal to noise ratio (SNR) is defined as the signal power to noise power corrupting the signal [7]. In practical situation, the reflected signal that received by the radar antenna will be corrupted with noise [8]. SNR is one of the factors that affect the performance of the radar receiver system. It is always measured in decibel (dB) unit. Table 2 below shows description of the all parameters involves for radar range equation [9].

$$SNR = \frac{Pt\,G^2\,\lambda^2\sigma}{(4\pi)^3\,kT_eBFLR^4}$$

Table 2: Description of the signal to noise ratio (SNR) radar equation.

Symbol	Description	Units	Status
pt	*Peak power*	*Watts*	*input*
f	*radar center frequency*	*Hz*	*input*
g	*antenna gain*	*dB*	*input*
sigma	*target cross section*	m^2	*input*
te	*effective noise temperature*	*Kelvin*	*input*
b	*bandwidth*	*Hz*	*input*
nf	*noise figure*	*dB*	*input*
loss	*radar losses*	*dB*	*input*
range	*target range*	*meters*	*input*
snr	*SNR*	*dB*	*output*

The details of parameters summarize as in Table 3 below.

Table 3: Details Descriptions of parameters

Symbol	Details descriptions of parameter
Pt	radar peak transmitted power
Gt	is the transmit antenna gain and used to characterize the focusing ability of antenna.
Gr	used to characterize the ability of the receive antenna to "capture power". If the radar uses the same antenna (monostatic antenna) for transmit and receive then *Gr = Gt* **.**
σ	Effective area that reflects enough energy to produce a target return at receiver; determined entirely by target; factors - size, shape, skin material, aspect angle - not target speed.
R	is the range from the radar to the target
K	is Boltzman's constant and is equal to 1.38 x 10^{-23} w/(Hz ˚ K)
T_o	is a standard temperature of 290° K. It is the standard temperature used to compute the noise figure
nf	noise performance of a receiver

II. METHODOLOGY

This research aims to obtain the theoretical measure of radar performance based on signal to noise ratio. Figure 2 shows flowchart for MATLAB programming to simulate the Signal to Noise ratio for radar system (monostatic radar).

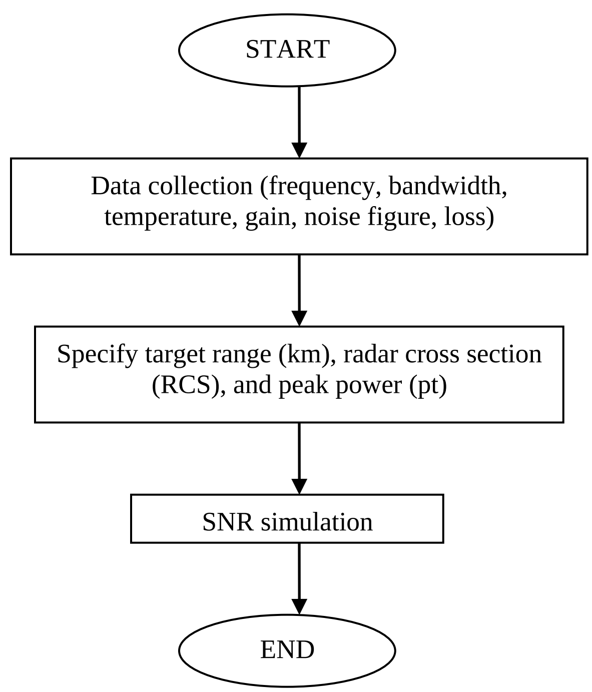

Figure 2: Flow chart for SNR simulation using MATLAB

In this project, the performance evaluation of radar SNR had been simulated via MATLAB programming. The function “radar_eq.m” is designed so that it can accept the single value for the input “range”. User can varies their required parameters excluded constant parameters. After the user specified the desired target range, radar cross section, and peak power, the simulation of SNR had been done to analyze the performance of the signal to noise ratio against target detection range for different values of target radar cross section or in term of peak power.

III. SIMULATION RESULTS AND DISCUSSIONS

Figure 3 shows the results of simulation for various RCS. There are six different target cross section values as shown in that graph which are 30dB, 20dB, 10dB, 0dB, -10 dB, and -20 dB. From the graph, it can be concluded that the SNR values was proportional to the RCS values. Higher RCS values would result of higher SNR.

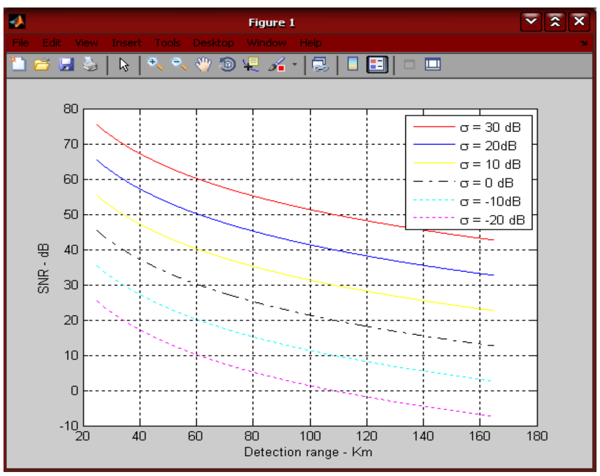

Figure 3: SNR versus detection range for different values of RCS

Figure 4 describes the relationship between the SNR and peak power. In theory, the high values of peak power would result in high values of SNR. Therefore to maximize the values of SNR, the values of peak power should be high. This peak value basically depends on the characteristic of the radar antenna. The value for the peak power of 3MW shows the best performance but it still goes down as the target range increased due to SNR is inversely proportional to the target detection range.

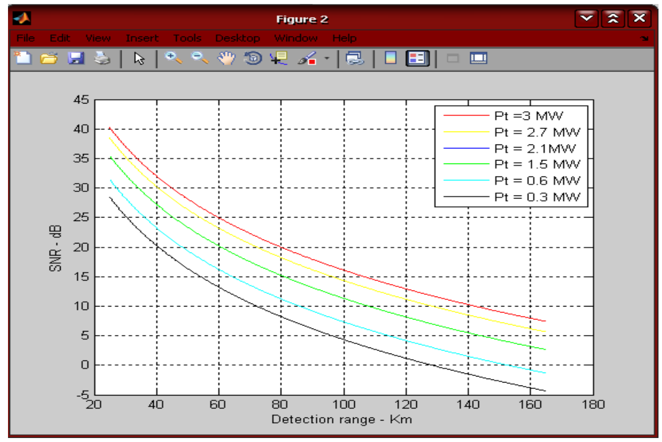

Figure 4: SNR versus detection range for different values of peak power.

Table 4 below shows the values of SNR in decibel for different target detection range that obtained from the simulation. For the performance evaluation, the target has been set from 25km to the maximum range of 165km. From the results obtained in table below, it can be conclude that as the target range increased, the performance of SNR was decreased. This table represents all the values of SNR that has been obtained from the three figures below which are Figure 5, Figure 6, and Figure 7.

Table 4: Data of SNR for different radar cross section and peak power

		PEAK POWER (MW)		
		2.16	**1.5**	**0.6**
RCS (m^2)	**RANGE (KM)**	**SNR (dB)**	**SNR (dB)**	**SNR (dB)**
	25	47.0168	45.4332	41.4538
	45	36.8059	35.2223	31.2429
	65	30.4179	28.8343	24.8549
1	**85**	25.7577	24.1741	20.1947
	105	22.0869	20.5032	16.5238
	125	19.058	17.4744	13.495
	145	16.4797	14.8961	10.9167
	165	14.2351	12.6515	8.6721
	25	37.0168	35.4332	31.4538
	45	26.8059	25.2223	21.2429
	65	20.4179	18.8343	14.8549
	85	15.7577	14.1741	10.1947
0.1	**105**	12.0869	10.5032	6.5238
	125	9.058	7.4744	3.495
	145	6.4797	4.8961	0.9167
	165	4.2351	2.6515	-1.3279
	25	27.0168	25.4332	21.4538
	45	16.8059	15.2223	11.2429
	65	10.4179	8.8343	4.8549
0.01	**85**	5.7577	4.1741	0.1947
	105	2.0869	0.5032	-3.4762
	125	-0.942	-2.5256	-6.505
	145	-3.5203	-5.1039	-9.0833
	165	-5.7649	-7.3485	-11.3279

RCS is used to present the ability of the target to capture and reradiate in the direction of the receive antenna. It is related to several factors such as target size, the material, and coating on the target that will contribute to the values of SNR. By referring to the three figures below, it shows that the curve of radar SNR performance decreasing as the values of RCS decreased. Each RCS was analyzing with different peak power which are 2.16MW, 1.5MW, and 0.6MW. From the radar equation as stated previously, we can see that SNR is proportional with the RCS. Some targets with large values of RCS will reflect a large portion of the incident power. This situation denoted high values of SNR owing to amount of reflected signal from the targets. The simulation of RCS for $1m^2$ shows the best performance compared to the other two simulations which are $0.1m^2$ and 0.01m2. The highest peak power shows the ability to improve SNR performance due to antenna transmitted power which influenced the signal strength.

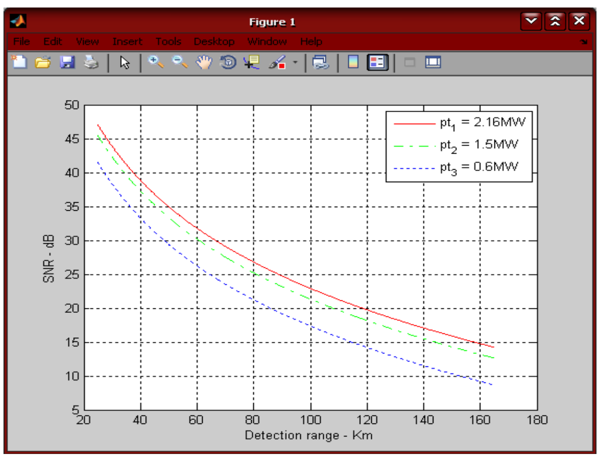

Figure 5: SNR versus target detection range for RCS= $1m^2$

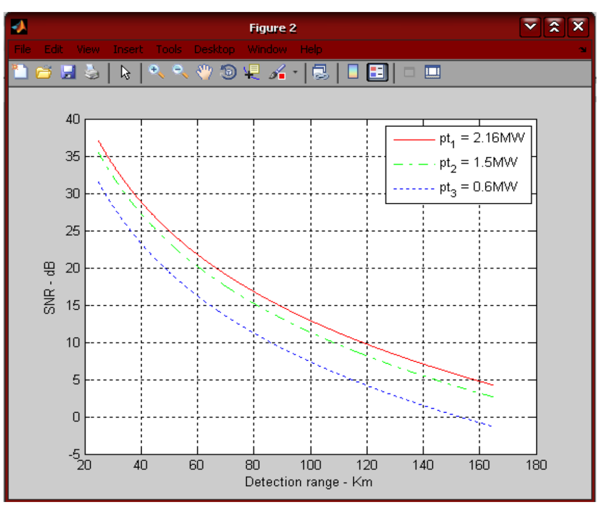

Figure 6: SNR versus target detection range for RCS = $0.1m^2$

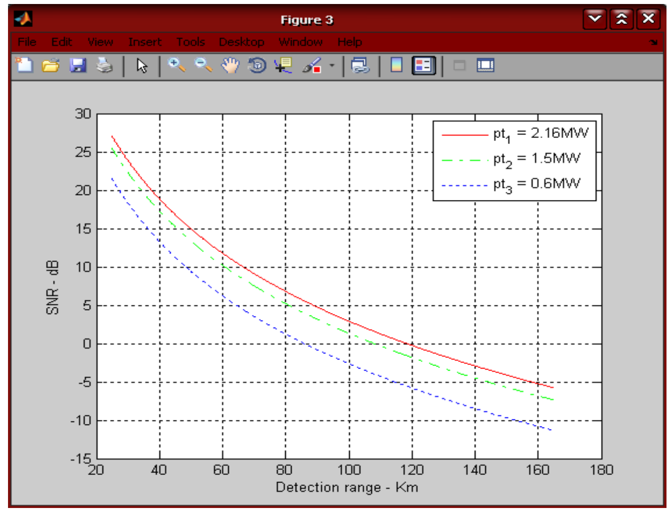

Figure 7: SNR for different target detection range for RCS= $0.01m^2$

IV. CONCLUSIONS

Many properties and phenomena of radio waves are crucial to the operation of radar system. In analyzing the radar performance, this project concentrated on SNR which is one of the major factors that affect radar performance. All the receivers require the signal to exceed the noise by some amount. Basically if the signal power is less than or equals the noise power it is not detectable. Noise is generated by electronic components of radar system. If there is too much noise in a circuit, SNR will be low and if the circuits in good quality, SNR will be high.

Objective of this project is to analyze the performance of SNR for different values of peak power and radar cross section. Simulation result shows that high values of peak power would result in high values of SNR. The more output power of the transmitter (P_{peak} increased), the longer the maximum detection range. However, from the simulation result, the performance of SNR decreased as the target range increased. As mentioned before, this project has presented an analysis of SNR performance for different radar cross section and peak power. The values of SNR will be low if these both factors are in small values. The aim to analyze the radar performance of SNR to relate with theoretical performance has been achieved.

ACKNOWLEDGEMENT

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PROGRAMMING

```
function [snr] = radar_eq(pt, f, g, sigma, te, b, nf, loss, range)

c = 3.0e+8; % speed of light
lambda = c / f; % wavelength
p_peak = 10*log10(pt); % convert peak power to dB
lambda_sqdb = 10*log10(lambda^2); % compute wavelength square in dB
sigmadb = 10*log10(sigma); % convert sigma to dB
four_pi_cub = 10*log10((4.0 * pi)^3); % (4pi)^3 in dB


k_db = 10*log10(1.38e-23); % Boltzman’s constant in dB
te_db = 10*log10(te); % noise temperature in dB
b_db = 10*log10(b); % bandwidth in dB
range_pwr4_db = 10*log10(range.^4); % vector of target range^4 in dB

s = p_peak + g + g + lambda_sqdb + sigmadb;
n = four_pi_cub + k_db + te_db + b_db + nf + loss + range_pwr4_db;
snr = s - n;
return
```

```
close all

clear all

pt = 1.5e6; % peak power in Watts
freq = 5.6e9; % radar operating frequency in Hz
g = 45.0; % antenna gain in dB
sigma = 0.1; % radar cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 5.0e6; % radar operating bandwidth in Hz
nf = 3.0; %noise figure in dB
loss = 6.0; % radar losses in dB


range = linspace(25e3,165e3,1000); % traget range 25 -165 Km, 1000
points
snr1 = radar_eq(pt, freq, g, sigma*10000, te, b, nf, loss, range);
snr2 = radar_eq(pt, freq, g, sigma*1000, te, b, nf, loss, range);
snr3 = radar_eq(pt, freq, g, sigma*100, te, b, nf, loss, range);
snr4 = radar_eq(pt, freq, g, sigma*10, te, b, nf, loss, range);
snr5 = radar_eq(pt, freq, g, sigma, te, b, nf, loss, range);
snr6 = radar_eq(pt, freq, g, sigma/10, te, b, nf, loss, range);


 % plot SNR versus range

figure(1)
rangekm = range ./ 1000;
plot(rangekm,snr1,'r',rangekm,snr2,'b',rangekm,snr3,'y',rangekm,snr4,'k
-.',rangekm,snr5,'c:',rangekm,snr6,'m:')
grid
legend('\sigma = 30 dB','\sigma = 20dB','\sigma = 10 dB','\sigma = 0
dB','\sigma = -10dB','\sigma = -20 dB')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');

snr1 = radar_eq(pt*2.0, freq, g, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt*1.8, freq, g, sigma, te, b, nf, loss, range);
snr3 = radar_eq(pt*1.44, freq, g, sigma, te, b, nf, loss, range);
snr4 = radar_eq(pt, freq, g, sigma, te, b, nf, loss, range);
snr5 = radar_eq(pt*.4, freq, g, sigma, te, b, nf, loss, range);
snr6 = radar_eq(pt*.2, freq, g, sigma, te, b, nf, loss, range);

figure (2)
plot(rangekm,snr1,'r',rangekm,snr2,'y',rangekm,snr3,'b',rangekm,snr4,'g'
,rangekm,snr5,'c',rangekm,snr6,'k')
grid
legend('Pt =3 MW','Pt = 2.7 MW','Pt = 2.16MW','Pt = 1.5 MW','Pt = 0.6
MW','Pt = 0.3 MW')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');
```

```
close all

clear all

pt = 1.5e6; % peak power in Watts
f = 5.6e9; % radar operating frequency in Hz
g = 45.0; % antenna gain in dB
sigma = 0.1; % radar cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 5.0e6; % radar operating bandwidth in Hz
nf = 3.0; %noise figure in dB
loss = 6.0; % radar losses in dB

range = linspace(25e3,165e3,1000); % traget range 25 -165 Km, 1000
points
snr1 = radar_eq(pt*1.44, f, g, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt, f, g, sigma, te, b, nf, loss, range);
snr3 = radar_eq(pt*.4, f, g, sigma, te, b, nf, loss, range);


% plot SNR versus range

figure(2)
rangekm = range ./ 1000;
plot(rangekm,snr1,'r',rangekm,snr2,'g -.',rangekm,snr3,'b:')
grid
legend('pt_1 = 2.16MW','pt_2 = 1.5MW','pt_3 = 0.6MW')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');


snr1 = radar_eq(pt*1.44, f, g, sigma*10, te, b, nf, loss, range);
snr2 = radar_eq(pt, f, g, sigma*10, te, b, nf, loss, range);
snr3 = radar_eq(pt*0.4, f, g, sigma*10, te, b, nf, loss, range);

figure(1)
rangekm = range ./ 1000;
plot(rangekm,snr1,'r',rangekm,snr2,'g -.',rangekm,snr3,'b:')
grid
legend('pt_1 = 2.16MW','pt_2 = 1.5MW','pt_3 = 0.6MW')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');

snr1 = radar_eq(pt*1.44, f, g, sigma/10, te, b, nf, loss, range);
snr2 = radar_eq(pt, f, g, sigma/10, te, b, nf, loss, range);
snr3 = radar_eq(pt*0.4, f, g, sigma/10, te, b, nf, loss, range);

figure(3)
rangekm = range ./ 1000;
plot(rangekm,snr1,'r',rangekm,snr2,'g -.',rangekm,snr3,'b:')
grid
legend('pt_1 = 2.16MW','pt_2 = 1.5MW','pt_3 = 0.6MW')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');
```