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DESIGN GROUND BASED RADAR BY USING MATLAB SIMULINK

Ahmed Sabri Kadhim*
*Department of Electronic Technologies, Basra Technical Institute, Basra, Iraq

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ABSTRACT

The Purpose of this paper is to study the radar and its basic principles, the characteristic that effect on its parameters and explain its types and its application and study the change of parameters of ground based radar parameters for design ground radar for both target (missile and aircraft). By using (MATLAB Program), a program designed to show the effect of change of same parameter for ground based radar. The change include cross- sectional area of the antenna peak, power transmitted by the radar. Study the effect of radar cross –section on detection range and on peak power when doubling it or halving it.

INTRODUCTION

Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. Radar transmits radio waves or microwaves that reflect from any object in their path. A receive radar, which is typically the same system as the transmit radar, receives and processes these reflected waves to determine properties of the object(s) [1].

Radar was secretly developed by several nations in the period before and during World War II. The term RADAR was coined in 1940 by the United States Navy as an acronym for RAdio Detection And Ranging. The term radar has since entered English and other languages as a common noun, losing all capitalization [2].

The modern uses of radar are highly diverse, including air and terrestrial traffic control, radar astronomy, air-defense systems, antimissile systems; marine radars to locate landmarks and other ships; aircraft anti collision systems; ocean surveillance systems, outer space surveillance and rendezvous systems; meteorological precipitation monitoring; altimetry and flight control systems; guided missile target locating systems; ground-penetrating radar for geological observations; and range-controlled radar for public health surveillance. High tech radar systems are associated with digital signal processing, machine learning and are capable of extracting useful information from very high noise levels [3].

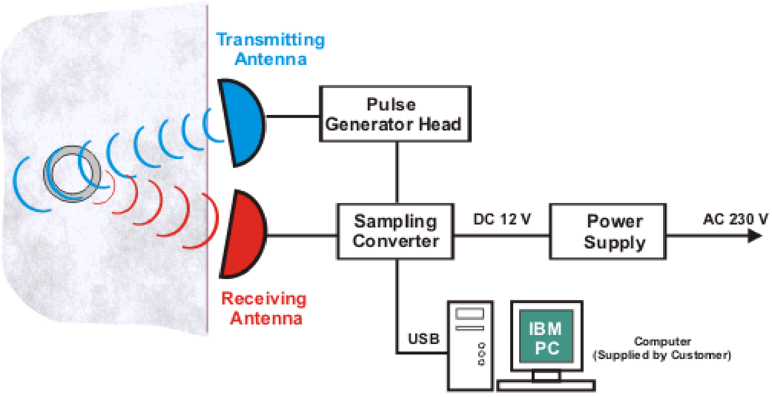

Fig 1: Radar operation [1]

RADAR CLASSIFCAION

The word radar is an abbreviation for Radio Detection and Ranging. In general, radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search for targets. Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position, and other target identifying characteristics [4].

Radars can be classified as ground based, airborne, space borne, or ship based radar systems. They can also be classified into numerous categories based on the specific radar characteristics, such as the frequency band, antenna type, and waveforms utilized. Another classification is concerned with the mission and/or the functionality of the radar. This includes: weather, acquisition and search, tracking, track-while-scan, fire control, early warning, over the horizon, terrain following, and terrain avoidance radars. Phased array radars utilize phased array antennas, and are often called multifunction (multimode) radars. A phased array is a composite antenna formed from two or more basic radiators. Array antennas synthesize narrow directive beams that may be steered mechanically or electronically. Electronic steering is achieved by controlling the phase of the electric current feeding the array elements, and thus the name phased array is adopted [5].

Radars are most often classified by the types of waveforms they use, or by their operating frequency. Considering the waveforms first, radars can be Continuous Wave (CW) or Pulsed Radars (PR). CW radars are those that continuously emit electromagnetic energy, and use separate transmit and receive antennas. Un modulated CW radars can accurately measure target radial velocity (Doppler shift) and angular position. Target range information cannot be extracted without utilizing some form of modulation. The primary use of unmodulated CW radars is in target velocity search and track, and in missile guidance. Pulsed radars use a train of pulsed waveforms (mainly with modulation) [1].

In this category, radar systems can be classified on the basis of the Pulse Repetition Frequency (PRF) as low PRF, medium PRF, and high PRF radars. Low PRF radars are primarily used for ranging where target velocity (Doppler shift) is not of interest. High PRF radars are mainly used to measure target velocity. Continuous wave as well as pulsed radars can measure both target range and radial velocity by utilizing different modulation schemes.

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 - 1.0**	**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 - 40.0**	**K**
MMW	**Normally >34.0**	**L<60.0; M>60.0**

High Frequency (HF) radars utilize the electromagnetic waves. Reflection off the ionosphere to detect targets beyond the horizon. Very High Frequency (VHF) and Ultra High Frequency (UHF) bands are used for very long range Early Warning Radars (EWR). Because of the very large wavelength and the sensitivity requirements for very long range measurements, large apertures are needed in such radar systems [6].

Radars in the L-band are primarily ground based and ship based systems that are used in long range military and air traffic control search operations. Most ground and ship based medium range radars operate in the S-band. Most weather detection radar systems are C-band radars. Medium range search and fire control military radars and metric instrumentation radars are also C-band [7].

The X-band is used for radar systems where the size of the antenna constitutes a physical limitation; this includes most military multimode airborne radars. Radar systems that require fine target detection capabilities and yet cannot tolerate the atmospheric attenuation of higher frequency bands may also be X-band. The higher frequency bands (Ku, K, and Ka) suffer severe weather and atmospheric attenuation. Therefore, radars utilizing these frequency bands are limited to short range applications, such as police traffic radar, short range terrain avoidance, and terrain follows radar. Milli-Meter Wave (MMW) radars are mainly limited to very short range Radio Frequency (RF) seekers and experimental radar systems [1].

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RADAR EQUATIONS

Consider radar with an Omni directional antenna (one that radiates energy equally in all directions). Since these kinds of antennas have a spherical radiation pattern, we can define the peak power density (power per unit area) at any point in space as

$$P_D = \frac{Peak\ transmitted\ \ power}{area\ of\ a\,sphere} \quad (\frac{watt}{m^2}) \qquad (1)$$

The power density at range **R** away from the radar (assuming a lossless propagation medium) is**:**

$$P_D = \frac{P_t}{4\pi R^2} \quad (\frac{watt}{m^2}) \qquad (2)$$

Where P_t is the peak transmitted power and $4\pi R^2$ is the surface area of a sphere of radius R. Radar systems utilize directional antennas in order to increase the power density in a certain direction. Directional antennas are usually characterized by the antenna gain G and the antenna effective apertureA_e. They are related by:

$$A_e = \frac{\lambda^2 G}{4\pi} \qquad (3)$$

Where λ is the wave length. The relationship between the antenna's effective aperture A_e and the physical aperture A is:

$$A_e = \rho A \qquad (4)$$

Where $0 \leq \rho \leq 1$, ρ is referred to as the aperture efficiency, and good antennas require $\rho \to 1$. In this book we will assume, unless otherwise noted, that A and A_e are the same. We will also assume that antennas have the same gain in the transmitting and receiving modes. In practice, ρ =0.7 is widely accepted.
The power density at a distance $\boldsymbol{R}$ away from radar using a directive antenna of gain $\boldsymbol{G}$ is then given by:

$$P_D = \frac{P_t G}{4\pi R^2} \qquad (5)$$

When the radar radiated energy impinges on a target, the induced surface currents on that target radiate electromagnetic energy in all directions. The amount of the radiated energy is proportional to the target size, orientation, physical shape, and material, which are all lumped together in one target-specific parameter called the Radar Cross Section (RCS) and is denoted by $\boldsymbol{\sigma}$.
The radar cross section is defined as the ratio of the power reflected back to the radar to the power density incident on the target,

$$\sigma = \frac{P_r}{P_D} \ (m^2) \qquad (6)$$

Where P_r is the power reflected from the target. Thus, the total power delivered to the radar signal processor by the antenna is:

$$P_{Dr} = \frac{P_t G \sigma}{(4\pi R^2)^2} A_e \qquad (7)$$

Substituting the value of $\boldsymbol{A_e}$ from Eq. (3) into Eq. (6) yields:

$$P_{Dr} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad (8)$$

Let S_{min} denote the minimum detectable signal power. It follows that the maximum radar range R_{max} is:

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right)^{1/4} \qquad (9)$$

Eq. (8) suggests that in order to double the radar maximum range, one must increase the peak transmitted power P_t sixteen times; or equivalently, one must increase the effective aperture four times.

In practical situations the returned signals received by the radar will be corrupted with noise, which introduces unwanted voltages at all radar frequencies. Noise is random in nature and can be described by its Power Spectral Density (PSD) function. The noise power N is a function of the radar operating bandwidth, B. More precisely

$$N = Noise\ PSD \times B \qquad (10)$$

The input noise power to a lossless antenna is

$$N_i = kT_eB \qquad (11)$$

Where $\boldsymbol{k} = \mathbf{1.38} \times 10^{-23}$ (joule/degree keliven) is Boltzman's constant, and $\boldsymbol{T_e}$ is the effective noise temperature in degree Kelvin. It is always desirable that the minimum detectable signal ($\boldsymbol{S_{min}}$) be greater than the noise power. The fidelity of a radar receiver is normally described by a figure of merit called the noise figure **F** (see Appendix A for details). The noise figure is defined as**:**

$$F = \frac{(SNR)_i}{(SNR)_o} = \frac{S_i/N_i}{S_o/N_0} \qquad (12)$$

$(SNR)_i$ and $(SNR)_o$are, respectively, the Signal to Noise Ratios (SNR) at the input and output of the receiver. S_i is the input signal power, N_i is the input noise power, $S_o$and N_o are, respectively, the output signal and noise power.
Substituting Eq. (10) into Eq. (11) and rearranging terms yield:

$$S_i = kT_eBF(SNR)_o \qquad (13)$$

Thus, the minimum detectable signal power can be written as:

$$S_{min} = kT_eBF(SNR)_{omin} \qquad (14)$$

The radar detection threshold is set equal to the minimum output SNR, $(SNR)_{omin}$
Substituting Eq. (13) in Eq. (8) gives:

$$\mathrm{R_{max}} = \left(\frac{P_tG^2\lambda^2\sigma}{(4\pi)^3kT_eBF(SNR)_{omin}}\right)^{1/4} \qquad (15)$$

Or equivalently,

$$\mathrm{SNR_o} = \frac{P_tG^2\lambda^2\sigma}{(4\pi)^3kT_eBFR^4} \qquad (16)$$

Radar losses denoted as L reduce the overall SNR, and hence

$$\mathrm{SNR_o} = \frac{P_tG^2\lambda^2\sigma}{(4\pi)^3kT_eBFLR^4} \qquad (17)$$

If some of the inputs are not available in the proper format, the functions *"dB_to_base10.m"* and / or *"base10_to_dB.m"* can be used first. Plots of SNR versus range (or range versus SNR) for several choices of RCS and peak power are also generated by the function *"radar_eq.m"*. Typical plots utilizing Example 1.4 parameters are shown in Fig. 2 In this case, the default values are those listed in the example. Observation of these plots shows how doubling the peak power (3 dB) has little effect on improving the SNR. One should consider varying other radar parameters such as antenna gain to improve SNR, or detection range.

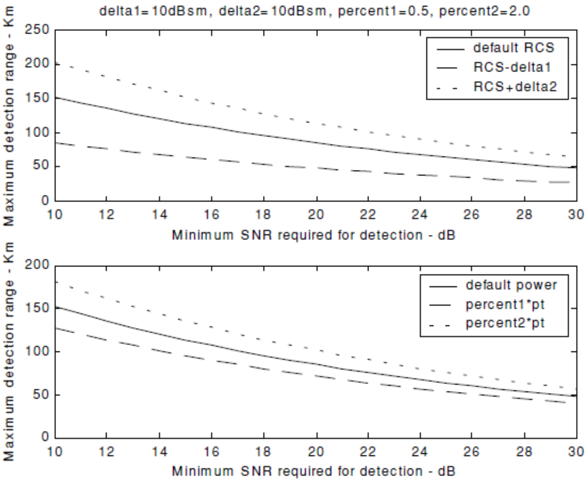

Fig 2: Maximum detection range against Minimum SNR

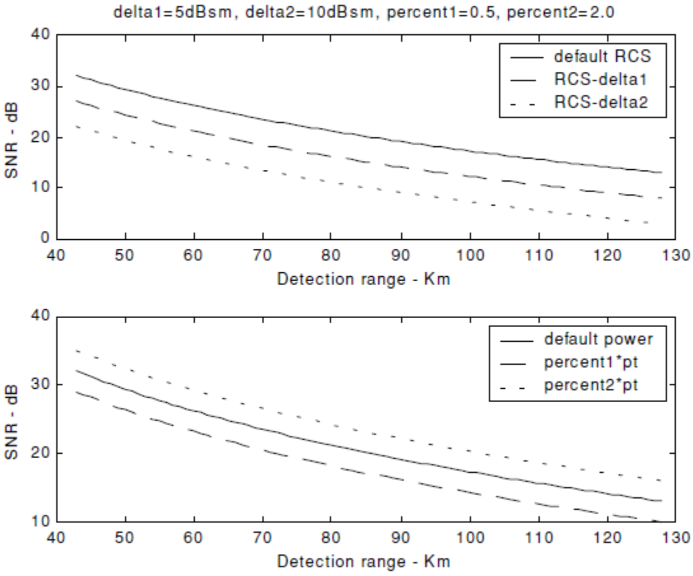

Fig 3: Typical outputs generated by the function “radar_eq.m”.

DESIGN

A ground based radar to be design to fulfill the following mission: Search and Detection. The threat consists of aircraft with an average RCS of 6 dBsm ($\sigma a=4m2$), and missiles with an average RCS of -3 dBsm ($\sigma m=0.5m2$). The missile altitude is 3Km, and the aircraft altitude is about 8 Km. We Assume a scanning radar with 360 degrees azimuth coverage. The scan rate is less than or equal to 1 revolution every 2 seconds. We Assume L to X band. We need range resolution of 150 m. No angular resolution is specified at this time. Also we assume that only one missile and one aircraft constitute the whole threat. We Assume a noise figure F = 6 dB, and total receiver loss L = 8 dB. For now use a fan beam with azimuth beam width of less than 3 degrees. We Assume that 13 dB SNR is a reasonable Detection threshold. Finally, assume flat earth. The desired range resolution is $\Delta R=150\ m$. Thus, using Eq. (5) one calculates the required pulse width as $\tau=1\ \mu\ sec$, or equivalently the required bandwidth $B=1\ MHz$. At this point a few preliminary decisions must be made. This includes the selection of the radar operating frequency, the aperture size, and the single pulse peak power.

The choice of an operating frequency that can fulfill the design requirements is driven by many factors, such as aperture size, antenna gain, clutter, atmospheric attenuation, and the maximum peak power, to name a few. In this design, an operating frequency f=3 GHz is selected. This choice is somewhat arbitrary at this point; however, as we proceed with the design process this choice will be better clarified.

Second, the transportability (mobility) of the radar drives the designer in the direction of a smaller aperture type. A good choice would be less than 5 meters squared. For now choose Ae=2.25 $m2$. The last issue that one must consider is the energy required per pulse. Note that this design approach assumes that the minimum detection SNR (13 dB) requirement is based on pulse integration. This condition is true because the target is illuminated with several pulses during a single scan, provided that the antenna azimuth beam width and the PRF choice satisfy Eq. (9).

The single pulse energy is E=$Pt\tau$. Typically, a given radar must be designed such that it has a handful of pulse widths (waveforms) to choose from. Different waveforms (pulse widths) are used for definite modes of operations (search, track, etc.). However, for now only a single pulse which satisfies the range resolution requirement is considered. To calculate the minimum single pulse energy required for proper detection, use Eq. (8). More precisely,

$$\mathrm{E} = P_t\lambda = (4\pi)^3 kT_e FLR^4 SNR_1 G^2\lambda^2\sigma \qquad (18)$$

All parameters in Eq. (18) are known, except for the antenna gain, the detection range, and the single pulse SNR. The antenna gain is calculated from
G=4$\pi A_e\lambda^2$= 4π×2.250.12=2827.4G=34.5 dB
Where the relation ($\lambda = \frac{c}{f}$) was used.

In order to estimate the detection range, consider the following argument. Since an aircraft has a larger RCS than a missile, one would expect an aircraft to be detected

at a much longer range than that of a missile. This is depicted in Figure.2, where Rarefers to the aircraft detection range and Rmdenotes the missile detection range. As illustrated in this figure, the minimum search elevation angle $\theta_1$is driven by the missile detection range, assuming that the missiles are detected, with the proper SNR, as soon as they enter the radar beam. Alternatively, the maximum search elevation angle θ_2 is driven the aircrafts .position along with the range that corresponds to the defense's last chance to intercept the threat (both aircraft and missile). This range is often called “keep out minimum range” and is denoted by R_{min} . In this design approach,

R_{min} =30 Km is selected. In practice, the keep-out minimum range is normally specified by the user as a design requirement.

The determination of $\boldsymbol{R_a}$ and $\boldsymbol{R_{mis}}$dictated by how fast can a defense interceptor reach the keep-out Minimum range and kill the threat. For example, assume that the threatening aircraft velocity is 400 $ms⁄$and The threatening missile velocity is 150 $ms⁄$. Alternatively, assume that an interceptor average velocity is 250 $ms⁄$. It follows that, the interceptor time of flight, based on $Rmin$=30, is

$$T_{interceptor} = 30 \times 103250 = 120sec \qquad (19)$$

Therefore, an aircraft and a missile must be detected by the radar at

$$R_a = 30Km + (120 \times 400) = 78Km \qquad (20)$$
$$R_m = 30Km + (120 \times 150) = 48Km \qquad (21)$$

Note that these values should be used only as a guide. The actual detection range must also include a few more kilometers, in order to allow the defense better reaction time. In this design, choose Rm=60, Km=95 Km. Therefore, the maximum PRF that guarantees an unambiguous range of at least 90Km is calculated from Eq. (18). More precisely,

$$\mathrm{f_r} \le \mathrm{c}^2 \times \mathrm{R_u} = 3 \times 1082 \times 95 \times 103 = 1.579\mathrm{KHz} \qquad (22)$$

Since there are no angular resolution requirements imposed on the design at this point, the only criterion that will be used to determine the radar operating PRF. Select,

f_r=1000 Hz (23)

The minimum and maximum elevation angles are, respectively, calculated as

$\theta_1 = tan^{-1}(360) = 2.86^o$ (24)
$\theta_2 = tan^{-1}(895) = 4.81^o$ (25)

These angles are then used to compute the elevation search extent (remember that the azimuth search extent is equal to360^o). More precisely, the search volume Ω (in steradians) is given by

Ω=θ_2−θ_1 (57.296)2×360 (26)

Consequently, the search volume is

Ω=360×θ_2−θ_1 (57.296)2=360×4.81−2.86 (57.296)2=0.213 $steradians$ (27)

The desired antenna must have a fan beam; thus using a parabolic rectangular antenna will meet the design requirements. Select Ae=2.25 $m2$; the corresponding antenna 3-dB elevation and azimuth beam widths are denoted as θe,, respectively. Select

θ_e=θ_2−θ_1=4.81−2.86=1.95^o (28)

The azimuth 3-dB antenna beam width is calculated using Eq. (8) as

θ_a=4$\pi G\theta_e$=4×π×18022827.4×π^2 ×1.95=7.486° (29)

It follows that the number of pulses that strikes a target during a single scan is calculated using Eq. (1.81) as $np\leq\theta afr\theta scan$=7.486×1000180=41.58$np$=42 (30)
The design approach presented in this book will only assume non-coherent integration (the reader is advised to re-calculate all results by assuming coherent integration, instead). The design requirement a 13 dB SNR for detection. By using Eq. (10), one calculates the required single pulse SNR

(SNR_1) =101.32×42+(101.3)24×422+101.342 =0.937(SNR_1) =−0.282 (31)

Furthermore, the non-coherent integration loss associated with this case is computed
LNC_1=1+0.9370.937=2.06 LNC_1=3.13dB (32)
E_m= (4π) 3k Te FLR_m^4 (SNR_1) G^2 $\lambda^2\sigma_m$ (33)

RESULTS

It’s clearly had been shown from figure below that the target range to minimum SNR required for detection-db) =10 for figure (3)

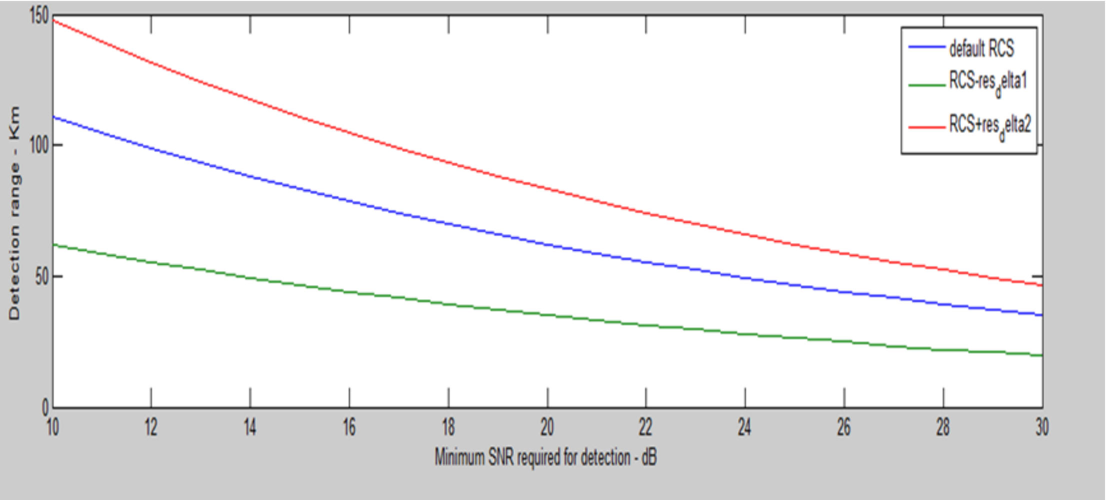

Fig 4: Detection range against SNR

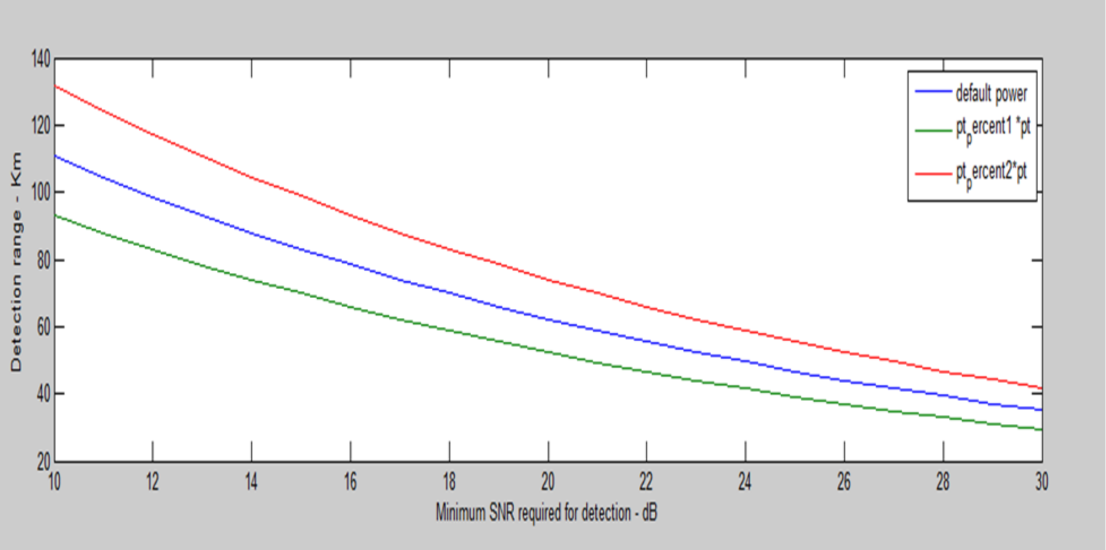

Fig 5: both target types (missile and aircraft)

This figure found the relationship between the radar cross section (RCS) and the range detection The radar cross section (RCS) on default which equal to (0.1square meter) the detection range would be 110 Km or more but when the (RCS) multiple with (res) which equal to (5) in program the detection range would be for150Km .The detection range would be for 60 Km when (RCS) divided by (res) which equal to 10.

So when the radar crosses section increase the range of detection for radar are increase by certified the value of (minimum SNR required for detection).

CONCLUSION

This paper study the radar characteristics specially the radar cross section (RCS) and the range detection, also we used the radar equation to make relation between detection range in kilometers and minimum signal to noise (SNR) ration in dB. This done by simulation by using Matlab program.

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