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Study and analysis of radar system

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الآية

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(أَمَّنْ هُوَ قَانِتٌ آنَاء اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُوْلُوا الْأَلْبَابِ).

صدق الله العظيم

سورة الزمر الآية (9)

Dedication

To our parents who are always supporting us, our family, our friends, our colleagues and every person who help us in this thesis.

Acknowledgement

We would like to acknowledge the following for help, encouragement, and support during the preparation of this thesis. First, we thank God for giving us the endurance to complete this work. We could not have completed this thesis without the continuous support of our families and friends. Finally we would like to thank electronic engineering department and Dr. **Ibrahim khidir** for reviewing and correcting different parts of the thesis.

Abstract

Radar is an electromagnetic system that detects and locates objects by transmitting electromagnetic signals to free space, receives echoes from objects and extracts information from the echo signal. Radar is used to enhance the capability of human senses for observing the environment, especially the sense of vision. It help human to improve the sight in unpleasant condition such as fog, rain, dark or too far away. The objective of the thesis is to study radar system simulation that capable of determine the range, range resolution and Doppler frequency of an object. The radar system simulation is analysis using MATLAB software by implementing the radar equation.

المستخلص

الرادار هو نظام كهرومغناطيسي الذي يكشف ويحدد الكائنات عن طريق نقل الإشارات الكهرومغناطيسية إلى الفضاء الحر، وتلقي أصداء من الكائنات، واستخراج المعلومات من إشارة صدى .يستخدم الرادار لتعزيز قدرة الحواس البشرية لمراقبة البيئة، وخاصة الشعور بالرؤية .وهو يساعد الإنسان لتحسين البصر في حالة صعوبة الرؤية مثل الضباب، المطر، الظلام أوالمسافات البعيدا جدا .والهدف من هذه المشروع هو دراسة لنظام رادار يكون قادر على تحديد المدى، ودقة المدى وحساب تردد دوبلر .تم تحليل نظام الرادار باستخدام برنامج ماتلاب من خلال تنفيذ مجموعة من معادلات الرادار.

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Abbreviations

RADAR	Radio Detection And Ranging
ACC	adaptive cruise control
BSD	blind spot dectection
PRI	pulsed repeation interval
PPI	plain position indicator
ABM	anti-ballistic missile
SNR	signal to noise ratio
ARM	anti- radiation missile
PRF	pulsed repeation frequency
CW	continuous wave
RF	radio frequency
IF	intermediate frequency
MTI	moving target indicator
FMCW	frequency modulated continuous wave

List of symbols

C	-	Speed of light (m/sec)
T	-	Time (sec)
R	-	Range (meter)
R_{max}	-	Maximum range (meter)
pav	-	Average power (watt)
P_t	-	Transmitting power (watt)
B	-	Bandwidth (Hz)
Δt	-	Time between the pulsed leading edge striking the target and the trailing edge striking the target.(sec)
V	-	Velocity (m/sec).
G	-	Gain of the antenna (unitless)
A_{et}	-	Effective area of antenna (m)
σ	-	Radar cross section (m^2)
λ	-	Wavelength (m)
λ_o	-	Free space wavelength (m)
F	-	Frequency (Hz)
NF	-	Noise figure in ratio (unitless)
K	-	Boltzmann constant ($1.38\ x\ 10^{-23}$) (J=watt/sec)
θ	-	Target aspect angle in degree.

F_d	-	Doppler frequency (Hz)
τ	-	Pulsed width (sec)
dt	-	duty cycle
L	-	Radar loss

Chapter one

Introduction

1.1 Preface:-

Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detects the nature of the echo signal. Radar is used to extend the capability of one's senses for observing the environment, especially the sense of vision. The value of radar lies not in being a substitute for the eye, but in doing what the eye cannot do-Radar cannot resolve detail as well as the eye, nor is it capable of recognizing the "color" of objects to the degree of sophistication which the eye is capable. However, radar can be designed to see through those conditions impervious to normal human vision, such as darkness, haze, fog, rain, and snow. In addition, radar has the advantage of being able to measure the distance or range to the object. This is probably its most important attribute.

An elementary form of radar consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator of some sort, a receiving antenna, and an energy-detecting device or receiver .A portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. It’s the energy reradiated in the back direction that is of prime interest to the radar. The receiving antenna collects the returned energy and delivers it to a receiver, where it is processed to detect the presence of the target and to extract its location and relative velocity. The distance to the target is determined by measuring the time taken for the radar signal to travel to the target and back. The direction, or angular position, of the target may be determined from the direction of arrival of the reflected wave front.

The usual method of measuring the direction of arrival is with narrow antenna beams. If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave (Doppler Effect) is a measure of the target's relative (radial) velocity and may be used to distinguish moving targets from stationary objects. In radars which continuously track the movement of a target, a continuous indication of the rate of change of target position is also available.

The name radar reflects the emphasis placed by the early experimenters on a device to detect the presence of a target and measure its range. Radar is a contraction of the words radio detection and ranging. It was first developed as a detection device to warn of the approach of hostile aircraft and for directing antiaircraft weapons. Although well-designed modern radar can usually extract more information from the target signal than merely range, the measurement of range is still one of radar's most important functions. There seem to be no other competitive techniques which can measure range as well or as rapidly as can radar [1].

At the beginning of the 20th century, radar technology was developed in earnest the first time for a military purpose during World War II. Today, more than half a century later, there are much wider radar application areas beyond the military one. Radar is needed for weather forecast, airport traffic control and automotive applications such as adaptive cruise control (ACC), blind spot detection (BSD) and active pedestrian safety.

Radars can be classified as ground based, airborne, space borne, or ship based radar systems.

The first use of radar was for military purposes: to locate air, ground and sea targets. This evolved in the civilian field into applications for aircraft, ships, and roads. In aviation, aircraft are equipped with radar devices that warn of aircraft or other obstacles in or approaching their path, display weather information, and give accurate altitude readings.

It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain.

Radar system has three chief attribute:-

- To Detected target at great distance.
- To Located position with high accuracy.
- Speed of the target.

Classification of radar based on specific function:-

A Primary Radar transmits high-frequency signals toward the targets. The transmitted pulses are reflected by the target and then received by the same radar. The reflected energy or the echoes are further processed to extract target information.

Secondary radar units work with active answer signals. In addition to primary radar, this type of radar uses a transponder on the airborne target/object [2].

1.2 Problem statement:-

This thesis is about to study and analysis radar system parameter.

1.3 Objective of thesis:-

The objectives of thesis are:-

-To study RADAR system parameter.

-To modeling and design RADAR systems.

-To simulate RADAR system.

-To evaluate RADAR system.

1.4 Methodology:-

We use the mathematical equation, descriptive Block diagram, computer models and then using MATLAB as software.

1.5 Thesis outline:-

Chapter one presents the introduction of RADAR system.

Chapter two explains the background of RADAR system.

Chapter three describes the radar system module by explaining the block diagram and mathematical equation.

Chapter four present Simulation and Result.

Chapter five describes the Conclusion and Recommendation.

Chapter Two

Background and Literation Review

2.1 Background:-

The history of radar starts with experiments by Heinrich Hertz in the late 19th century that showed that radio waves were reflected by metallic objects. This possibility was suggested in James Clerk Maxwell's seminal work on electromagnetism. However, it was not until the early 20th century that systems able to use these principles were becoming widely available, and it was German inventor Christian Hülsmeyer who first used them to build a simple ship detection device intended to help avoid collisions in fog. Numerous similar systems, which provided directional information to objects over short ranges, were developed over the next two decades.

In 1886-1888 the German physicist Heinrich Hertz conducted his series of experiments that proved the existence of electromagnetic waves (including radio waves), predicted in equations developed in 1862–1864 by the Scottish physicist James Clerk Maxwell. In 1887 Hertz's experiment he found that these waves would transmit through different types of materials and also would reflect off metal surfaces in his lab as well as conductors and dielectrics. The nature of these waves being similar to visible light in their ability to be reflected, refracted, and polarized would be shown by Hertz and subsequent experiments by other physicists.

In 1904, Christian Hülsmeyer gave public demonstrations in Germany and the Netherlands of the use of radio echoes to detect ships so that collisions could be avoided. His device consisted of a simple spark gap used to generate a signal that was aimed using a dipole antenna with a cylindrical parabolic reflector. When a signal reflected from a ship was picked up by a similar antenna attached to the separate coherer receiver, a bell sounded. During bad weather or fog, the device would be periodically spun to check for nearby ships. The apparatus detected the presence of ships up to 3 kilometers (1.6 mi), and Hülsmeyer planned to extend its capability to 10 kilometers (5.4 mi). It did not provide range (distance) information, only warning of a nearby object. He patented the device, called the telemobiloscope, but due to lack of interest by the naval authorities the invention was not put into production.

Hülsmeyer also received a patent amendment for estimating the range to the ship. Using a vertical scan of the horizon with the telemobiloscope mounted on a tower, the operator would find the angle at which the return was the most intense and deduce, by simple triangulation, the approximate distance. This is in contrast to the later development of pulsed radar, which determines distance via two-way travel time.

The development of systems able to produce short pulses of radio energy was the key advance that allowed modern radar systems to come into existence. By timing the pulses on an oscilloscope, the range could be determined and the direction of the antenna revealed the angular location of the targets. The two combine produced a "fix", locating the target relative to the antenna.

In the 1934–1939 period, eight nations developed independently, and in great secrecy, systems of this type: the United Kingdom, Germany, the United States, the USSR, Japan, the Netherlands, France, and Italy. In addition, Britain shared their information with the united states and four commonwealth countries: Australia, Canada, New Zealand, and South Africa, and these countries also developed their own radar systems. During the war, Hungary was added to this list. The term RADAR was coined in 1939 by the United States Signal Corps as it worked on these systems for the Navy.

During war II the Battle of Britain (1939 -1941), significant success was attributed to the Chain Home network which detected incoming air-raids and provided information to guide interceptors to home in on the bombers. Detection reports were sent via landline to 'filter rooms' which coordinated the efforts of the short supply of interceptors and thus made up a formidable force multiplier. The CH was never really understood by the Germans, and no serious attempts to jam destroy the whole system.

Stealth Technology was invented in the 1940s, when German submarines suffered severe losses because they were detected by airborne radars once they were on The surface technicians found that a mixture of graphite and rubber could substantially weaken the radar echoes if was applied as 'schornsteinfeger ' ('chimney sweep') coating on the submarine's hull .However ,this only worked while the subs were in the dry dock once the anti-reflective coating was wet from sea water ,it was water and salt layer which reflected the radar signals.

During the war, higher and higher frequencies of electromagnetic spectrum were put to use. Researchers started with the first experiments at some 10MHz ,and the chain home operated around 20MHz (with later extension up to 70MHz),and the bulk of the of the air surveillance and tracking radars worked between 200MHz and 800MHz The refinement of 1921's cavity magnetron transmitter device by Randall and H. Boot in 1940 was a significant breakthrough. The magnetron was the heart of the American HSS bombing radar which operated at 3 GHz was far its plan position Indicator (PPI) screen showed a map of the underlying terrain with a resolution that was hitherto unheard of. This type of magnetron Wasn't known in Germany and 3GHz was far beyond the frequency range of their interceptor and warning devices .In the fact ,a conference between Hitler's top military ranks and some researches had come to the conclusion that 800GHz was enough and that it atmosphere at all. Rated top secret, the H2S radar was not be used over Germany, for fears that its carrier might be shot down, letting the magnetron fall into hostile hands.

At end of the war, most of today technologies had already been put to use although they relied on contemporary technical means. there was chirp radar in production, the monopulse principle was invented and even a synthetic Aperture Radar already existed .The chain home was used to detect the V2 rockets after they left their launch sites, hence it can also be called the world's first anti-ballistic Missile (ABM) radar system .Among the few ideas which were born later than 1945 are the phased array antenna technology and the concept of multistate radar.

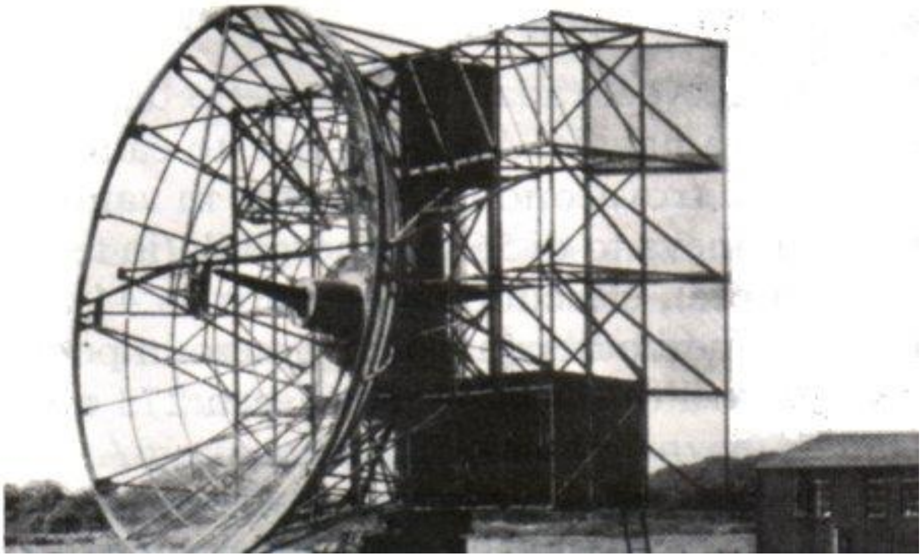

Figure2.1: Radar during word II

After war II Germany was ejected from the radar business. Until 1950 any research into the field of radar was forbidden. radar use was widened to numerous fields including: civil aviation, marine navigation, radar guns for police, meteorology and even medicine. Key developments in the post-war period include the travelling wave tube as a way to produce large quantities of coherent microwaves, the development of signal delay systems that led to phased array radars, and ever-increasing frequencies that allow higher resolutions. An increase in signal processing capability due to the introduction of solid state computers has also had a large impact on radar use.

Radar was kept highly secret throughout war II and only in 1946 was in published that an American device had successfully measured the distance to the moon.

This is a round trip of some 770,000km Even later. it became known that a Hungarian device had already done the same thing in 1944 It is very hard to find any remaining WW Il radar equipment in muscums today Even though radars aren't as impressive as 50 ton battle tanks, every single radar had influence comparable to a whole battleship, so some sense of the impact and significance of radar has been lost. The Online Air Defense Radar Museum features a selection of American radars. The Historical Electronics Museum Linthicum Maryland (close to Baltimore Washington International Airport) has inter alia an SCR tracker like the ones used to down the majority of VI flying bombs. It also has a scR-270 like the one that detected the Japanese assault force on Pearl Harbor

The Vietnam War(1961 975) saw the first of Anti-Radiation Missiles use(ARM) which was carried by the F-105 Thunderchief, also affectionately known as ’thud’ or wild weasel. Once a radar warning receiver inside the aircraft detected signal from ground–based acquisition or missile guidance radar

At modern days the layperson may know radar only as an invisible threat when speeding on a motorway, because police radars are employed as a means to enforce law. However radar is also on its way to be used to their advantage as automotive radars are now entering the market. They are used to automatically keep a set distance from the car in front and to warm the driver when obstacles are encountered in his lane. These days no major airport can be operated without radar. Flight controllers in the tower use radar to keep track of dozens of aircraft which are circling in the waiting loop and to schedule them for landing. The public is only made aware of this when radar is defective and hundreds of flights are cancelled or redirected to other airports and local hotels are unable to accommodate any more guests as a result[2].

Figure2.1: modern Radar

Many of the first devices that with were set up at two researchers played Lastly is when the transmitter and receiver do not share the same location but are different place These bistatic radars are getting new attention. The extension of the principle, using a transmitter plus several interconnected receiving sites is called Multistate Radar and is also subject of ongoing research. Like Passive Radar, imaging radar and Multi-coloured radars are the latest buzzwords that are circling around developers laboratories. Passive radar relies on background illumination by whatever source happens to be there. Imaging radar is what the name implies the results are displayed as if they had been gathered by a camera and with comparable resolution. Multi-coloured radar is another word for ultra-wideband radar which is able to extract much more information out of the scene it [3].

2.1.1 RADAR CLASSIFICATIONS

Primary Radar:

A Primary Radar transmits high-frequency signals toward the targets. The transmitted pulses are reflected by the target and then received by the same radar. The reflected energy or the echoes are further processed to extract target information.

Secondary Radar:

Secondary radar units work with active answer signals. In addition to primary radar, this type of radar uses a transponder on the airborne target/object.

Pulsed Radar:

Pulsed radar transmits high power, high-frequency pulses toward the target. Then it waits for the echo of the transmitted signal for some time before it transmits a new pulse. Choice of pulse repetition frequency decides the range and resolution of the radar.

Target Range and bearings can be determined from the measured antenna position and time-of-arrival of the reflected signal.

Pulse radars can be used to measure target velocities. Two broad categories of pulsed radar employing Doppler shifts are

- **MTI (Moving Target Indicator) Radar**

The MTI radar uses low pulse repetition frequency (PRF) to avoid range ambiguities, but these radars can have Doppler ambiguities.

- **Pulse Doppler Radar**

Contrary to MTI radar, pulse Doppler radar uses high PRF to avoid Doppler ambiguities, but it can have numerous range ambiguities.

Doppler Radars make it possible to distinguish moving target in the presence of echoes from the stationary objects. These radars compare the received echoes with those received in previous sweep. The echoes from stationary objects will have same phase and hence will be cancelled, while moving targets will have some phase change.

If the Doppler shifted echo coincides with any of the frequency components in the frequency domain of the received signal, the radar will not be able to measure target velocity.

Continuous Wave Radar:

CW radars continuously transmit a high-frequency signal and the reflected energy is also received and processed continuously. These radars have to ensure that the transmitted energy doesn’t leak into the receiver (feedback connection). CW radars may be bistatic or monostatic; measures radial velocity of the target using Doppler Effect.

CW radars are of two types

1. Unmodulated

An example of unmodulated CW radar is speed gauges used by the police. The transmitted signal of these equipments is constant in amplitude and frequency. CW radar transmitting unmodulated power can measure the speed only by using the Doppler-effect. It cannot measure a range and it cannot differ between two reflecting objects.

2. Modulated

Unmodulated CW radars have the disadvantage that they cannot measure range, because run time measurements is not possible (and necessary) in unmodulated CW-radars. This is achieved in modulated CW radars using the frequency shifting method. In this method, a signal that constantly changes in frequency around a fixed reference is used to detect stationary objects. Frequency is swept repeatedly between f1 and f2. On examining the received reflected frequencies (and with the knowledge of the transmitted frequency), range calculation can be done.

2.2.1 RADAR Application:

Military Applications:

- In air defense it is used for target detection, target recognition and weapon control (directing the weapon to the tracked targets).
- In missile system to guide the weapon.
- Identifying enemy locations in map.

Air Traffic Control:

- To control air traffic near airports. The Air Surveillance RADAR is used to detect and display the aircraft's position in the airport terminals.
- To guide the aircraft to land in bad weather using Precision Approach RADAR.
- To scan the airport surface for aircraft and ground vehicle positions.

Remote Sensing:

RADAR can be used for observing weather or observing planetary positions and monitoring sea ice to ensure smooth route for ships.

Ground Traffic Control:

RADAR can also be used by traffic police to determine speed of the vehicle, controlling the movement of vehicles by giving warnings about presence of other vehicles or any other obstacles behind them.

Space:

- To guide the space vehicle for safe landing on moon.
- To observe the planetary systems.
- To detect and track satellites.
- To monitor the meteors [4].

2.2 Literature Review:-

Pulse-Doppler radar is a radar system that determines the range to a target using pulse-timing techniques, and uses the Doppler effect of the returned signal to determine the target object's velocity. It combines the features of pulse radars and continuous-wave radars, which were formerly separate due to the complexity of the electronics.

Pulse-Doppler systems were first widely used on fighter aircraft starting in the 1960s. Earlier radars had used pulse-timing in order to determine range and the angle of the antenna (or similar means) to determine the bearing. However, this only worked when the radar antenna was not pointed down in that case the reflection off the ground overwhelmed any returns from other objects. As the ground moves at the same speed but opposite direction of the aircraft, Doppler techniques allow the ground return to be filtered out, revealing aircraft and vehicles. This gives pulse-Doppler radars "look-down/shoot-down" capability. A secondary advantage in military radar is to reduce the transmitted power while achieving acceptable performance for improved safety of stealthy radar.

Pulse-Doppler techniques also find widespread use in meteorological radars, allowing the radar to determine wind speed from the velocity of any precipitation in the air. Pulse-Doppler radar is also the basis of synthetic aperture radar used in radar astronomy, remote sensing and mapping. In air traffic control, they are used for discriminating aircraft from clutter. Besides the above conventional surveillance applications, pulse-Doppler radar has been successfully applied in healthcare, such as fall risk assessment and fall detection, for nursing or clinical purposes.

The earliest radar systems failed to operate as expected. The reason was traced to Doppler effects that degrade performance of systems not designed to account for moving objects. Fast-moving objects cause a phase-shift on the transmit pulse that can produce signal cancellation. Doppler has maximum detrimental effect on moving target indicator systems, which must use reverse phase shift for Doppler compensation in the detector.

Doppler weather effects (precipitation) were also found to degrade conventional radar and moving target indicator radar, which can mask aircraft reflections. This phenomenon was adapted for use with weather radar in the 1950s after declassification of some World War II systems.

Pulse-Doppler radar was developed during World War II to overcome limitations by increasing pulse repetition frequency. This required the development of the klystron, the traveling wave tube, and solid state devices. Pulse-Doppler is incompatible with other high power microwave amplification devices that are not coherent.

Early examples of military systems include the AN/SPG-51B developed during the 1950s specifically for the purpose of operating in hurricane conditions with no performance degradation.

The Hughes AN/ASG-18 Fire Control System was a prototype airborne radar/combination system for the planned North American XF-108 Rapier interceptor aircraft for the United States Air Force, and later for the Lockheed YF-12. The US's first pulse-Doppler radar, the system had look-down/shoot-down capability and could track one target at a time [5].

Weather, chaff, terrain, flying techniques, and stealth are common tactics used to hide aircraft from radar. Pulse-Doppler radar eliminates these weaknesses.

It became possible to use pulse-Doppler radar on aircraft after digital computers were incorporated in the design. Pulse-Doppler provided look-down/shoot-down capability to support air-to-air missile systems in most modern military aircraft by the mid-1970s.

Rejection speed is selectable on pulse-Doppler aircraft-detection systems so nothing below that speed will be detected. A one degree antenna beam illuminates millions of square feet of terrain at 10 miles (16 km) range, and this produces thousands of detections at or below the horizon if Doppler is not used.

Pulse-Doppler radar uses the following signal processing criteria to exclude unwanted signals from slow-moving objects. This is also known as clutter rejection. Rejection velocity is usually set just above the prevailing wind speed (10 to 100 mile/hour or 15 to 150 km/hour). The velocity threshold is much lower for weather radar.

Surface reflections appear in almost all radar. Ground clutter generally appears in a circular region within a radius of about 25 miles near ground-based radar. This distance extends much further in airborne and space radar. Clutter results from radio energy being reflected from the earth's surface, buildings, and vegetation. Clutter includes weather in radar intended to detect and report aircraft and spacecraft [6].

Clutter creates a vulnerability region in pulse-amplitude time-domain radar. Non-Doppler radar systems cannot be pointed directly at the ground due to excessive false alarms, which overwhelm computers and operators. Sensitivity must be reduced near clutter to avoid overload.

This vulnerability begins in the low-elevation region several beam widths above the horizon, and extends downward. This also exists throughout the volume of moving air associated with weather phenomenon.

Pulse-Doppler radar corrects this as follows:

- Allows the radar antenna to be pointed directly at the ground without overwhelming the computer and without reducing sensitivity.
- Fills in the vulnerability region associated with pulse-amplitude time-domain radar for small object detection near terrain and weather.
- Increases detection range by 300% or more in comparison to moving target indication (MTI) by improving sub-clutter visibility.

Clutter rejection capability of about 60 dB is needed for look-down/shoot-down capability, and pulse-Doppler is the only strategy that can satisfy this requirement. This eliminates vulnerabilities associated with the low-elevation and below-horizon environment.

Pulse compression, and moving target indicator (MTI) provide up to 25 dB sub-clutter visibility. MTI antenna beam is aimed above horizon to avoid excessive false alarm rate, which renders systems vulnerable. Aircraft and some missiles exploit this weakness using a technique called flying below the radar to avoid detection (Nap-of-the-earth). This flying technique is ineffective against pulse-Doppler radar.

Pulse-Doppler provides an advantage when attempting to detect missiles and low observed ability aircraft flying near terrain, sea surface, and weather.

Audible Doppler and target size support passive vehicle type classification when identification friend or foe is not available from a transponder signal. Medium pulse repetition frequency (PRF) reflected microwave signals fall between 1,500 and 15,000 cycles per second, which is audible. This means a helicopter sounds like a helicopter, a jet sounds like a jet, and propeller aircraft sound like propellers. Aircraft with no moving parts produce a tone. The actual size of the target can be calculated using the audible signal.

The signal processing enhancement of pulse-Doppler allows small high-speed objects to be detected in close proximity to large slow moving reflectors. To achieve this, the transmitter must be coherent and should produce low phase noise during the detection interval, and the receiver must have large instantaneous dynamic range.

- Pulse-Doppler signal processing detailed explanation. Pulse-Doppler signal processing also includes ambiguity resolution to identify true range and velocity.
- Ambiguity resolution detailed explanation. The received signals from multiple PRF are compared to determine true range using the range ambiguity resolution process.
- Range ambiguity resolution detailed explanation. The received signals are also compared using the frequency ambiguity resolution process.
- Frequency ambiguity resolution detailed explanation. Pulse-Doppler radar requires a coherent oscillator with very little noise. Phase noise reduces sub-clutter visibility performance by producing apparent motion on stationary objects.

Cavity magnetron and crossed-field amplifier are not appropriate because noise introduced by these devices interfere with detection performance. The only amplification devices suitable for pulse-Doppler are klystron, traveling wave tube, and solid state devices [7].

Chapter three

Radar System Model

3.1 Block diagram of pulsed radar system:-

The basic parts of Radar system are illustrated in the simple block diagram .The radar signal, usually a repetitive train of short pulses, is generated by the transmitter and radiated into space by the antenna. The duplexer permits a single antenna to be time-shared for both transmission and reception. Reflecting objects (targets) intercept and reradiate a portion of the radar signal, a small amount of which is returned in the direction of the radar.

The returned echo signal is collected by the radar antenna and amplified by the receiver. If the output of the radar receiver is sufficiently large, detection of a target is said to occur. Radar generally determines the location of a target in range and angle, but the echo signal also can provide information about the nature of the target.

The output of the receiver may be presented on a display to an operator who makes the decision as to whether or not a target is present, or the receiver output can be processed by electronic means to automatically recognize the presence of a target and to establish a track of the target from detections made over a period of time. With automatic detection and track (ADT) the operator usually is presented with the processed target track rather than the raw radar detections. In some applications, the processed radar output might be used to directly control a system (such as a guided missile) without any operator intervention [8].

3.2 Component of pulsed radar block diagram:

3.2.1 Transmitter:

The transmitter power amplifier, such as a klystron traveling-wave tube, crossed-field amplifier, or solid-state device. A power oscillator such as a magnetron also can be used as the transmitter; but the magnetron usually is of limited average power compared with power amplifiers, especially the klystron, which can produce much larger average power than can a magnetron and is more stable. It is the average power, rather than the peak power, which is the measure of the capability of radar.

Since the basic waveform is generated at low power before being delivered to the power amplifier, it is far easier to achieve the special waveforms needed for pulse compression and for coherent systems such as moving-target indication (MTI) radar and pulse Doppler radar. Although the magnetron oscillator can be used for pulse compression and for MTI, better performance can be obtained with a power amplifier configuration. The magnetron oscillator might be found in systems where simplicity and mobility are important and where high average power, good MTI performance, or pulse compression is not required.

The transmitter of typical ground-based air surveillance radar might have an average power of several kilowatts. Short-range radars might have powers measured in milliwatts. Radars for the detection of space objects and HF over-the-horizon radars might have average powers of the order of a megawatt.

The radar equation shows that the range of Radar is proportional to the fourth root of the transmitter power. Thus, to double the range requires that the power be increased by 16. This means that there often is a practical, economical limit to the amount of power that should be employed to increase the range of Radar.

Transmitters not only must be able to generate high power with stable waveforms, but they must often operate over a wide bandwidth, with high efficiency and with long, trouble-free life [9].

3.2.2 Duplexer:

The duplexer acts as a rapid switch to protect the receiver from damage when the high-power transmitter is on. On reception, with the transmitter off, the duplexer directs the weak received signal to the receiver rather than to the transmitter. Duplexer can use to Switching the antenna between the transmitting and receiving modes. The duplexer allows one antenna to be used to both transmit and receive A solid-state circulator is sometimes used to provide further isolation between the transmitter and the receiver.

3.2.3 Antenna:

The transmitter power is radiated into space by a directive antenna which concentrates the energy into a narrow beam. The narrow, directive beam that is characteristic of most radar antennas not only concentrates the energy on target but also permits a measurement of the direction to the target. A typical antenna beamwidth for the detection or tracking of aircraft might be about 1 or 2°.

Dedicated tracking radar generally has a symmetrical antenna which radiates a pencil-beam pattern. The usual ground-based air surveillance radar that provides the range and azimuth of a target generally uses a mechanically rotated reflector antenna with a fan-shaped beam, narrow in azimuth and broad in elevation [10].

3.2.4 Receiver:

The receiver amplifies the radar returns signal and prepares them for signal processing. The signal collected by the antenna is sent to the receiver, which is almost always of the super heterodyne type .The receiver serves to:

(1) Separate the desired signal from the ever-present noise and other interfering signals.

(2) Amplify the signal sufficiently to actuate a display.

The mixer of the super heterodyne receiver translates the receiver RF signal to an intermediate frequency(IF). The gain of the intermediate frequency (IF) amplifier results increase of the receiver signal level. The IF amplifier also includes the function of the matched filter: one which maximizes the output signal to-noise ratio. Maximizing the signal-to-noise ratio at the output of the IF maximizes the detectability of the signal. Almost all radars have a receiver which closely approximates the matched filter.

There must also be included filters for rejecting the stationary clutter and passing the Doppler frequency shifted signals from moving targets.

The video amplifier raises the signal power to a level where it is convenient to display the information it contains. As long as the video bandwidth is not less than half of the IF bandwidth, there is no adverse effect on signal detectability [11].

3.2.5 Signal Processing:

There has not always been general agreement as to what constitutes the signal-processing portion of the radar, but it is usually considered to be the processing whose purpose is to reject undesired signals (such as clutter) and pass desired signals due to targets. It is performed prior to the threshold detector where the detection decision is made. Signal processing includes the matched filter and the Doppler filters in MTI and pulse Doppler radar. Pulse compression, which is performed before the detection decision is made, is sometimes considered to be signal processing, although it does not fit the definition precisely [12].

3.2.6 Time control:

Generates the synchronization timing signals required throughout the system. This is used in air traffic control systems, and has an influence of the shape of the elevation pattern of the surveillance antenna.

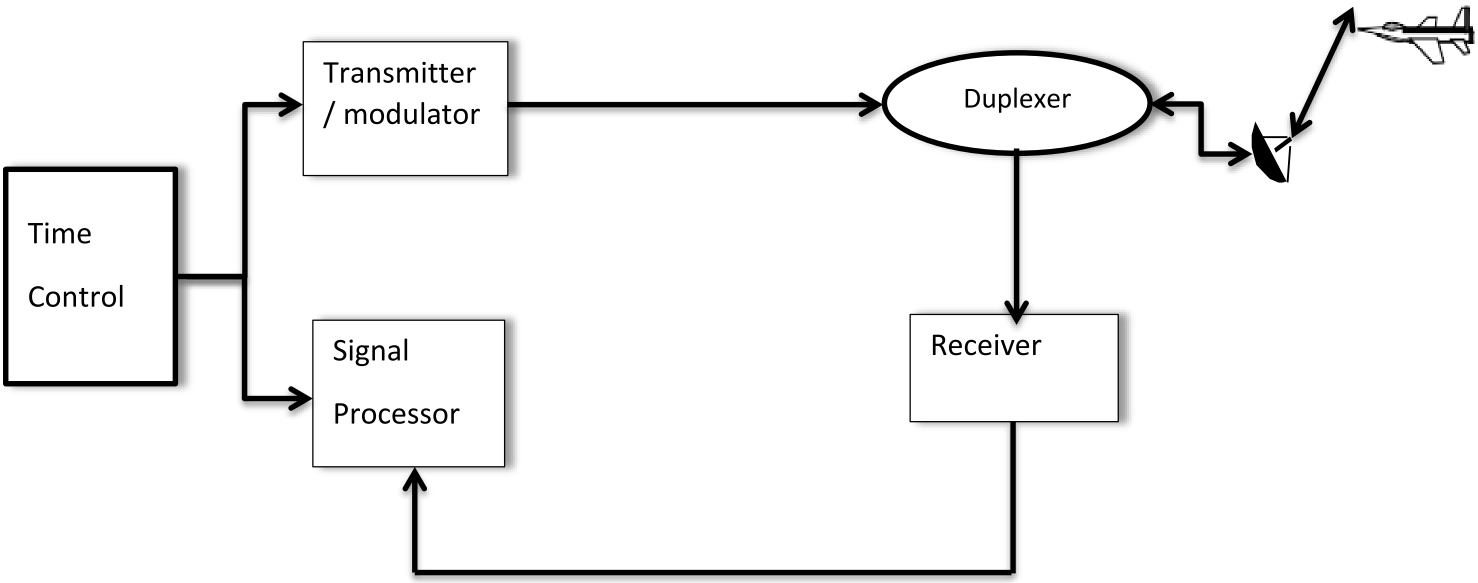

Figure 3.3: pulsed radar block diagram

3.3 Mathematical model:-

3.3.1 Range

The time control box generates the synchronization timing signals required throughout the system. A modulated signal is generated and sent to the antenna by the modulator/ transmitter block. Switching the antenna between the transmitting and receiving modes is controlled by the duplexer. The duplexer allows one antenna to be used to both transmit and receive. During transmission it directs the radar electromagnetic energy towards the antenna. Alternatively, on reception, it directs the received radar echoes to the receiver. The receiver amplifies the radar returns and prepares them for signal processing. Extraction of target information is performed by the signal processor block. The target's range is computed by measuring the time delay, it takes a pulse to travel the two-way path between the radar and the target. Since electromagnetic waves travel at the speed of light, then R

$$R = \frac{C \Delta T}{2} \qquad \text{Eq (3.1)}$$

$$\text{PRF}=1\,\frac{1}{PRI} = \frac{1}{T} \qquad \text{Eq (3.2)}$$

During each PRI the radar radiates energy only for seconds and listens for target returns for the rest of the PRI. The radar transmitting duty cycle (factor) is defined as the ratio. The radar average transmitted power is

$$pav = pt \times dr \qquad \text{Eq (3.3)}$$

The range corresponding to the two-way time delay is known as the radar unambiguous range. Echo 1 represents the radar return from a target at range due to pulse 1. Echo 2 could be interpreted as the return from the same target due to pulse 2, or it may be the return from a faraway target at range due to pulse 1 again. In this case,

$$R_2 = \frac{c\Delta t}{2} \qquad \text{Or} \qquad R_2 = \frac{c(T\Delta t)}{2} \qquad \text{Eq(3.4)}$$

Clearly, range ambiguity is associated with echo 2. Therefore, once a pulse is transmitted the radar must wait a sufficient length of time so that returns from targets at maximum range are back before the next pulse is emitted. It follows that the maximum unambiguous range must correspond to half of the PRI,

$$Ru = c \times \frac{T}{2} = \frac{c}{2fr} \qquad \text{Eq(3.5)}$$

3.3.2 Range Resolution:

Range resolution, denoted as , is radar metric that describes its ability to detect targets in close proximity to each other as distinct objects. Radar systems are normally designed to operate between a minimum range, and maximum range. The distance between and is divided into range bins (gates), each of width

$$M = \frac{R_{\max} - R_{\min}}{\Delta R} \qquad \text{Eq(3.6)}$$

Targets separated by at least will be completely resolved in range. Targets within the same range bin can be resolved in cross range (azimuth) utilizing signal processing techniques.

Consider two targets located at ranges and, corresponding to time delays and, respectively. Denote the difference between those two ranges as ΔR: $\Delta R = R_2 - R_1 = \frac{c(t_2 - t_1)}{2}$

Eq(3.7)

$$\Delta R = \frac{C\tau}{2}$$

$$\Delta R = \frac{C}{2B} \qquad \text{Eq(3.8)}$$

3.3.3 Doppler frequency:

Radars use Doppler frequency to extract target radial velocity (range rate), as well as to distinguish between moving and stationary targets or objects such as clutter.

Consider a pulse of width τ (seconds) incident on a target which is moving towards the radar at velocity. Define d as the distance (in meters) that the target moves into the pulse during the interval Δt,

$$D = V \times \Delta t \qquad \text{Eq(3.9)}$$

Since the pulse is moving at the speed of light and the trailing edge has moved distance cτ-d[9], then

$$\Delta t = \frac{c\tau - d}{c} \qquad \text{Eq(3.10)}$$

$$F_d = \frac{2V \cos\theta}{\lambda}$$

$$F_d = \frac{-2V \cos\theta}{\lambda} \qquad \text{Eq(3.11)}$$

3.3.4 Relationship Between Range and SNR:-

$$\text{Power density} = \frac{\mathrm{Pt}}{4\pi R^2} \qquad \text{Eq(3.12)}$$

$$P_r = \frac{\mathrm{Pt}\, G^2 \,\sigma\, \lambda^2}{(4\pi)^3 R^4} \qquad \text{Eq(3.13)}$$

$$\sigma = \frac{\text{power back scattered to radar}}{\textit{power density at target}} \qquad \text{Eq(3.14)}$$

$$R = R_{MAX} = \left(\frac{\mathrm{Pt}\, G^2 \,\sigma\, \lambda^2}{(4\pi)^3 \; Si,min}\right)^{\frac{1}{4}} \qquad \text{Eq(3.15)}$$

$$F=\frac{Si/Ni}{So/No}$$ Eq(3.16)

$$S_i = KTBF(So/No)$$ Eq(3.17)

$$S_{i,\min} = KTBF(So/No)min$$ Eq(3.18)

$$R_{MAX} = \left(\frac{Pt\,G^2\,\sigma\,\lambda^2}{(4\pi)^3\ KTBF\left(\frac{So}{No}\right)min}\right)^{\frac{1}{4}}$$ Eq(3.19)

$$R_{MAX} = \left(\frac{Pt\,G^2\,\sigma\,\lambda^2\times n}{(4\pi)^3\ KTBF\left(\frac{So}{No}\right)min\times Lsys}\right)^{\frac{1}{4}}$$ Eq(3.20)

$$(SNR)_0 = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 K T_e B F R^4}$$

$$(SNR)_0 = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 K T_e B F L R^4}$$ Eq(3.21)

3.3.5 Low PRF Radar Equation:

Consider a pulsed radar with pulse width τ , PRI ,T and peak transmitted power P_t . The average transmitted power is $P_{av} = P_t \times d_t$, where $d_t = \frac{\tau}{T}$ is the transmission duty factor.

One can define the receiving duty factor d_t as :

$$d_r = \frac{T-\tau}{T} = 1 - \tau f_r$$ Eq(3.22)

Assuming low PRF, the single pulse radar equation is given by

$$(SNR)_1 = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 K T_0 B F L}$$ Eq(3.23)

By using $B = \frac{1}{\tau}$, the low PRF radar equation can be written as

$$(\text{SNR})_{np} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 K T_0 B F L} \qquad \text{Eq(3.24)}$$

3.3.6 High PRF Radar Equation:

In high PRF radars, the transmitted signal is assumed to be a periodic train of pulses, with pulse width of τ and period T. This pulse train can be represented using an exponential Fourier series, where the central power spectrum line (DC component) for this series contains most of the signal's power. Its value is ($\frac{\tau}{T^2}$), and it is equal to the square of the transmit duty factor. Thus, the single pulse radar equation for high PRF radar is

$$(\text{SNR}) = \frac{P_t G^2 \lambda^2 \sigma d_t^{\,2}}{(4\pi)^3 R^4 K T_0 F L} \qquad \text{Eq (3.25)}$$

Where, in this case, one can no longer ignore the receive duty factor, since its value is comparable to the transmit duty factor. In fact, $d_r \approx d_t = \tau f_r$ Additionally, the operating radar bandwidth is now matched to the radar integration time (time-on-target), $B = \frac{1}{T_i}$. It follows that

$$(\text{SNR}) = \frac{P_t G^2 \lambda^2 \sigma \tau T_i f_r}{(4\pi)^3 R^4 K T_0 F L} \qquad \text{Eq(3.26)}$$

$$(\text{SNR}) = \frac{P_{av} T_i G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 K T_0 F L} \qquad \text{Eq(3.27)}$$

Chapter four

Simulation and Results

4.1 Introduction:-

To use MATLAB code and graphic is a good choice because its has a large number of useful function and it is easy to program.

Source code was found in appendix for explanation just executes to understand result.

4.2 Results:-

Table 4.1 Parameter of range, range resolution and Doppler frequency:

Parameter	value
Frequency	10.5GHz
Pulse width	2micro sec
Pulse repeation interval	1ms
Velocity	200m/s
Angle	30deg
Peak power	100 Kw

4.2.1 Range:

The duty cycle = 0.002=0.2%.

The pulse repeation frequency = 1000 HZ.

The pulse average power =200 watt.

The pulse energy =0.2 joules.

The unambiguous range =150 kilometer.

4.2.2 Range resolution:

The result of range resolution is equals to 300 meter.

4.2.3 Doppler frequency:

The result of Doppler frequency is equal to 7424.6 Hz.

The time dilation factor =1

The result of Doppler frequency =0.

This means the target is stationary.

4.2.4 Relationships between Range and SNR:

Figure 4.4 represents the equations (3.19), which are programmed by MATLAB simulation, observation of these plots Shows the detection range versus SNR for several choices like peak transmit power and RCS. As can be seen the detection range decreases exponentially when SNR increases At approximately SNR= < 26dB, we observe that the curve lines are separated and spaced between them gets very clear and significant, but at SNR > = 26dB these curve lines, which represent the detection range be approaching each other and there is a little different. Also we found that the peak power has a little effect on improving the detection range when compared with other radar parameters such as RCS, because the transmitted and received signal power is proportional to the fourth power of the range while in communication systems it is proportional to square power of the range, that means the radar's received energy drops with the fourth power of the distance. In this case, the radar needs high power often in MWatt to be effective at long range, for this reason, it creates great difficulty in designing radar systems particularly at long range. To reduce the signal power in the radar we could use other parameters such as antenna gain, RCS, noise figure … etc.

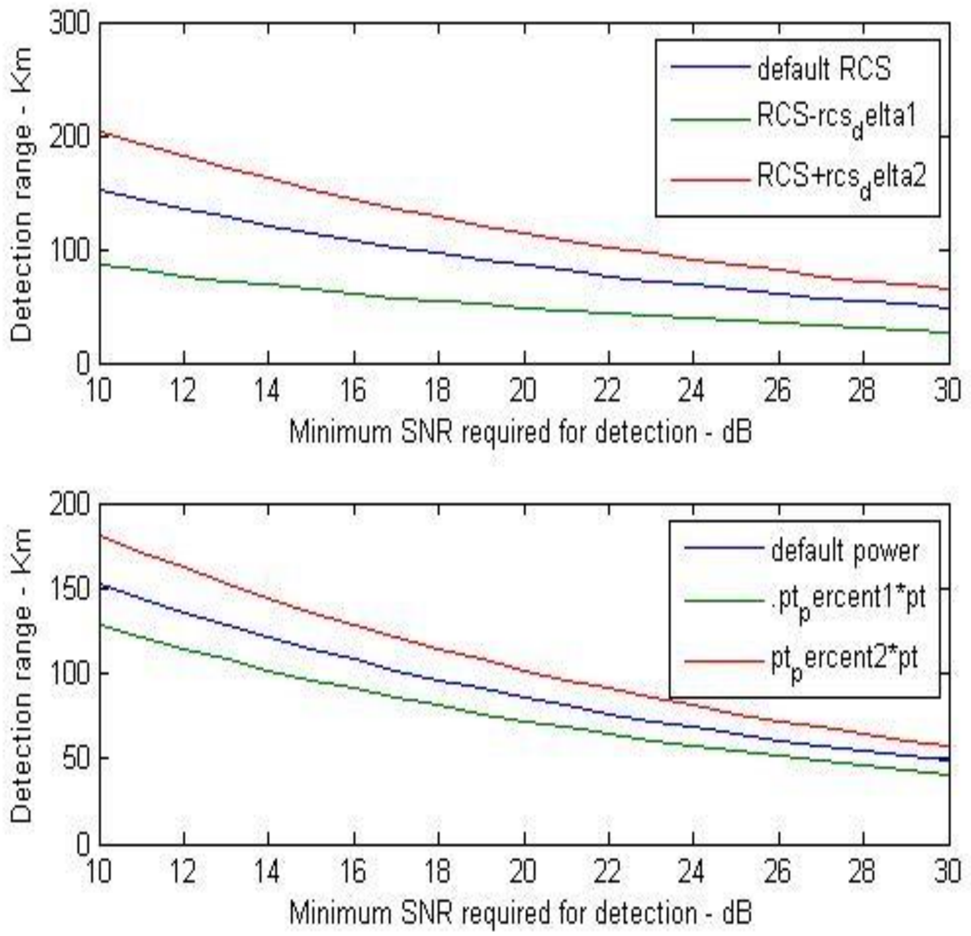

Figure 4.4: result of RSC and peak power transmitted

Table 4.2 parameter of Relationships between Range and SNR

Parameter	**Value**
Peak power	1.5 Mwatt
Frequency	5.6 GHz
Antenna gain	45db
Radar cross section	$0.1\, m^2$

Temperature	290K
Bandwidth	5 MHz
Loss	0 db
Noise figure	3 db
RCS delta1	5
RCS delta2	10
Pt_percent1	0.5
Pt_percent2	0.2

4.2.5 Low PRF RADAR equation:

Figure 4.5 represents the equations (3.24) which are programmed by MATLAB simulation and illustrates SNR versus detection range for three different values of radar cross section.

When RCS = 0dbsm has maximum signal to noise ratio when the rage decreased. When radar cross section has value = -10dbsm the signal to noise ratio is less than RCS=0 db. And at the radar cross section has value =-20dbsm the signal to noise ratio has lowest value. Form this we observe that when radar cross section has large value the signal to noise increased because large object reflect most of transmit power

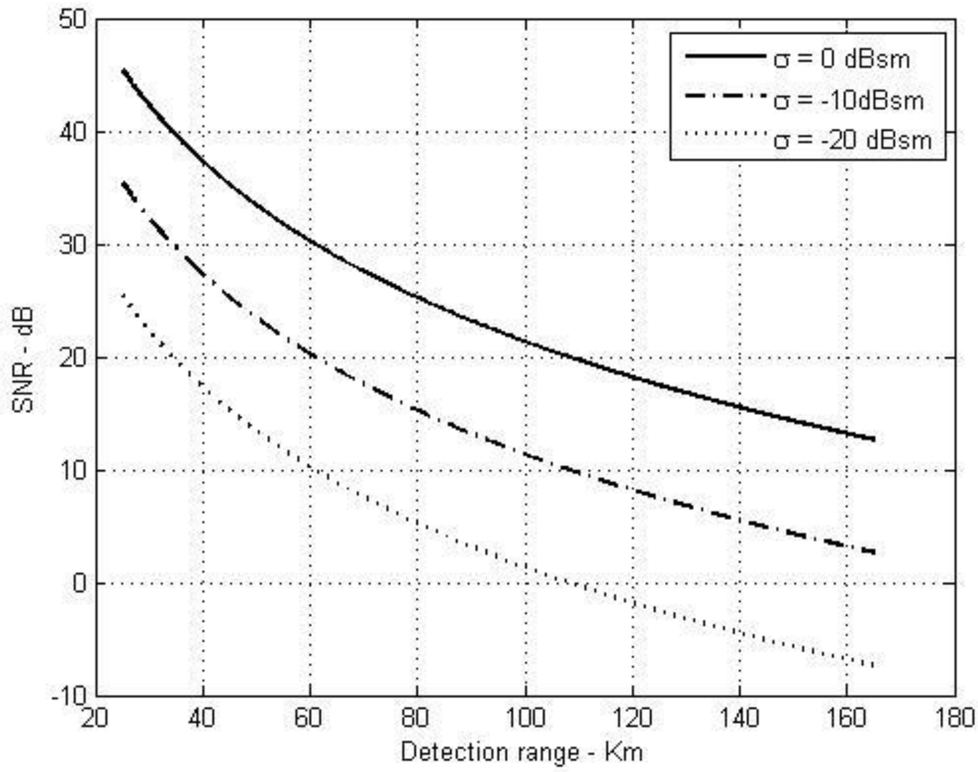

Figure 4.5: Result of relationship between SNR and detection range.

Figure4.6 plots SNR versus detection range for three different values of radar peak power.

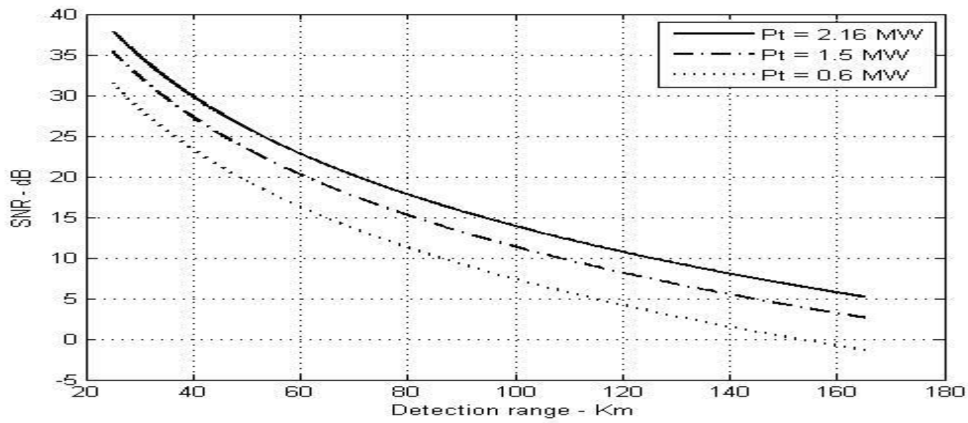

Figure 4.6: result of peak power

When power of signal transmitted has value 2.16Mwatt the signal to noise ratio has maximum value. And when power of signal transmitted has value 1.5 Mwatt the signal to noise ratio has value less than 2.16Mwatt When power of signal transmitted has value =0.6 Mwatt the signal to noise ratio has minimum value. From this we conclude that when power transmitted decrease the signal to noise decreases. Also when signal to noise increase detection range decrease.

Table 4.3 parameter of Low PRF Radar Equation:

Parameter	**Value**
Peak power	1.5Mwatt
Radar operating frequency	5.6 GHz
Antenna gain	45db
Radar cross section	0.1 m^2
Band width	5MHz
Noise figure	3db
Loss	6db
Range	20Km – 180Km

4.2.6 High PRF radar equation:

Figure 4.7 represents the equations (3.27) which are programmed by MATLAB simulation. Which show that when duty cycle decreases the signal to noise ratio decreases too. Also for same value of duty cycle when detection range increases the signal to noise decrease. From figure 4.4 we can calculate the signal to noise ratio according to the range.

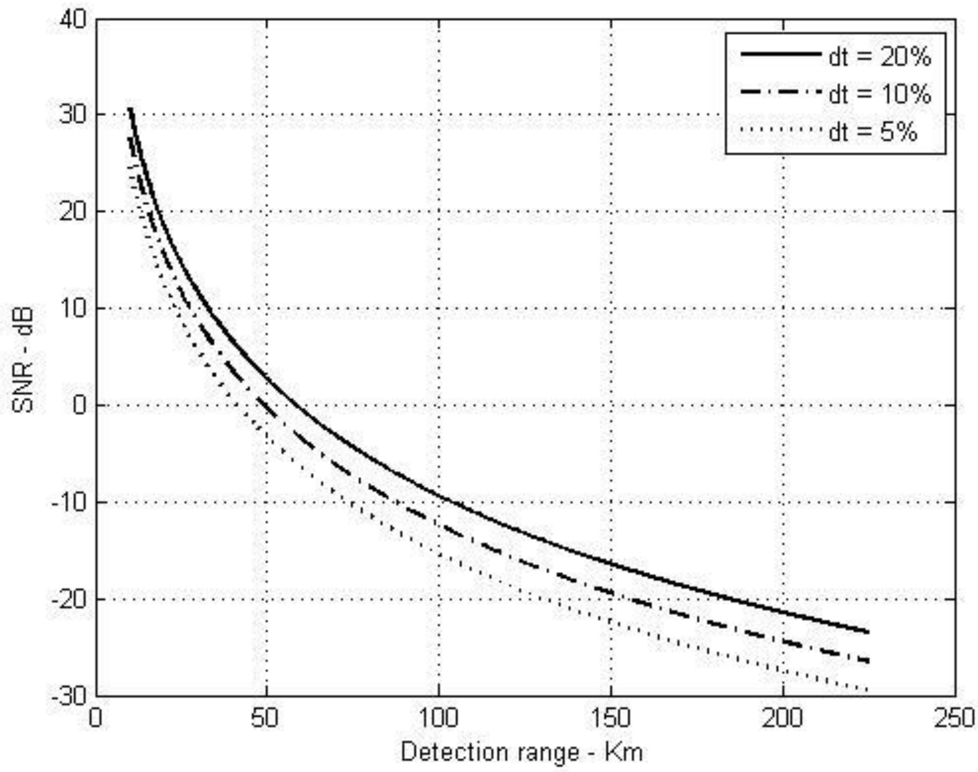

Figure 4.7: result of duty cycle

Table 4.4 parameter of high PRF Radar Equation:

Parameter	**Value**
Peak power	100Kwatt
Antenna gain	20 db
Frequency	5.6GHz
Loss	8db
Noise figure	5db
Time on target	2sec
Duty factor	0.3

Figure4.8 plots radar average power versus power aperture product.

When radar cross section increases the average power decreases, from this we realize clear effect of radar cross section to power average. For same value of radar cross section when aperture size increase power average decrease.

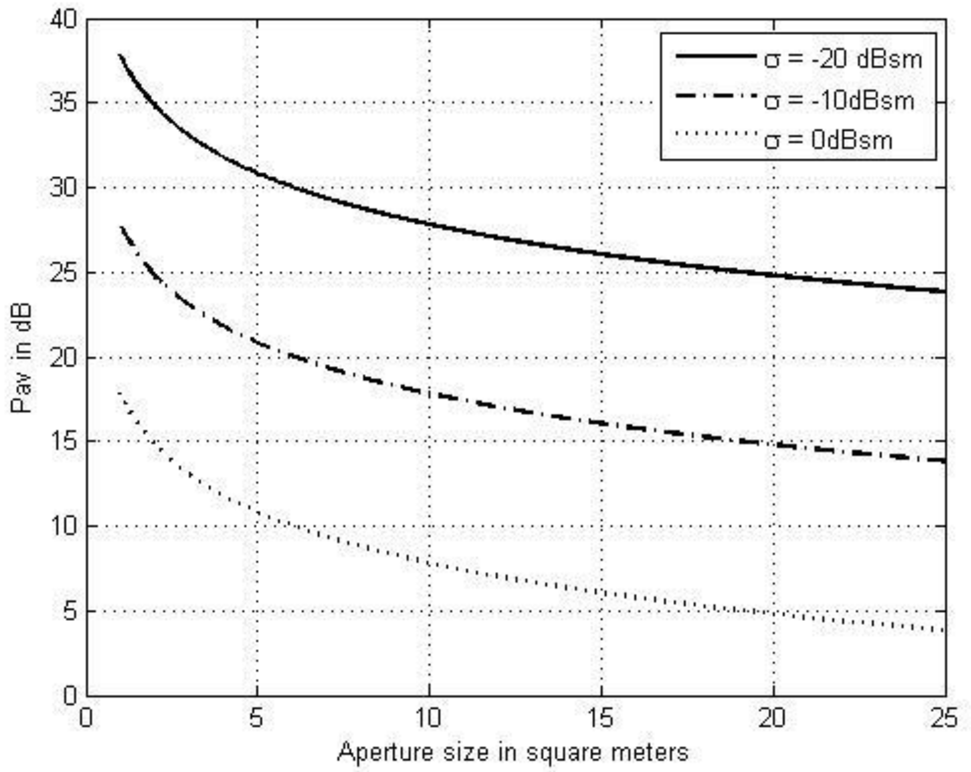

Figure 4.8: relationship between aperture size and power average.

Table 4.5 parameter of relationship between power average and aperture size:

Parameter	**Value**
Scan time	2.5sec
Radar cross section	0.1
Signal to noise ratio	15db
Loss	7db
Range	20Km – 250 Km

Noise figure	6db
Azimuth angle	2 degree
Elevation angle	2degree

Chapter five

Conclusion and Recommendation

5.1 Conclusion:

These thesis have been developed to make them so easy and faster for all users to determine the detection range and signal to noise ratio – SNR for several choices parameters as a function of the radar range equations. They used to plot curves of detection range versus SNR for several choices parameters. Also provides information about the target situation (stationary target or moving target).

This thesis about theoretical study of radar system able to calculate rang, range resolution, high PRF Radar Equation and Low PRF Radar Equation.

5.2 Recommendation:

Study effect of antenna gain and noise figure to signal to noise ratio.

More working on the effect of clutter and jamming.

Use higher frequency to maximize the detections area.

Implantation advance digital signal processing techniques.

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Appendix:

```
function [dt, prf, pav, ep, ru] = pulse_train (tau, pri,
p_peak)
% computes duty cycle, average transmitted power, pulse
energy, and pulse repetition frequency
%% Inputs:
% tau == Pulse width in seconds
% pri == Pulse repetition interval in seconds
% p_peak == Peak power in Watts
%% Outputs:
% dt == Duty cycle - unitless
% prf == Pulse repetition frequency in Hz
% pa == Average power in Watts
% ep == Pulse energy in Joules
% ru == Unambiguous range in Km
%
c = 3e8; % speed of light
dt = tau / pri;
prf = 1. / pri;
pav = p_peak * dt;
ep = p_peak * tau;
ru = 1.e-3 * c * pri /2.0;
return


function [delta_R] = range_resolution (var)
% This function computes radar range resolution in meters
%% Inputs:
% var can be either
% bw == Bandwidth in Hz
% var == Pulse width in seconds
% % Outputs:
% delta_R == range resolution in meters
% Bandwidth may be equal to (1/pulse width)==> indicator =
seconds
%
c = 3.e+8; % speed of light
indicator = input ('Enter 1 for var == Bandwidth, OR 2 for var
== Pulse width \n');
switch (indicator)
case 1
delta_R = c / 2.0 / var; % del_r = c/2B
case 2
delta_R = c * var / 2.0; % del_r = c*tau/2
end
return


function [fd, tdr] = doppler_freq (freq, ang, tv)
% This function computes Doppler frequency and time dilation
factor ratio (tau_prime / tau)
% % Inputs:
% freq == radar operating frequency in Hz
% ang == target aspect angle in degrees
```

```
% tv == target velocity in m/sec
% % Outputs:
% fd == Doppler frequency in Hz
% tdr == time dilation factor; unitless
%
format long
indicator = input ('Enter 1 for closing target, OR 2 for
opening target \n');
c = 3.0e+8;
ang_rad = ang * pi /180.;
lambda = c / freq;
switch (indicator)
case 1
fd = 2.0 * tv * cos(ang_rad) / lambda;
tdr = (c - tv) / (c + tv);
case 2
fd = -2.0 * c * tv * cos(and_rad) / lambda;
tdr = (c + tv) / (c -tv);
end
return
```

```
clc,clear;
frq = 10.5e9;
ang = input('Input angle : ');
tv =  input('Input velocity in m/s : ');
tau = input('Input plused width : ');
pri = input('Input plused repition in sec  : ');
p_peak = input('Input peak pwer: ');
BW =  1/tau;
[dt, prf, pav, ep, ru] = pulse_train (tau, pri, p_peak);
display(['The duty cycle  : ' num2str(dt)])
display(['The pulse repeation frequency  : ' num2str(prf)])
display(['The pulse avarage power  : ' num2str(pav)])
display(['The pulse energy  : ' num2str(ep)])
display(['The range  : ' num2str(ru)])
[fd, tdr] = doppler_freq (frq, ang, tv);
display(['The doppler frequency  : ' num2str(fd)])
display(['The time delation factor  : ' num2str(tdr)])
[delta_R] = range_resolution (tau);
display(['The resolation range  : ' num2str(delta_R)])
```

```
pt = 1.5e+6; % peak power in Watts
freq = 5.6e+9; % radar operating frequency in Hz
g = 45.0; % antenna gain in dB
sigma = 0.1; % radar cross section in m square
te = 290.0; % effective noise temperature in Kelvins
b = 5.0e+6; % radar operating bandwidth in Hz
nf = 3.0; % noise figure in dB
loss = 0.0; % radar losses in dB
option = 1; % 1 ===> input_par = SNR in dB
% 2 ===> input_par = Range in Km
input_par = 20;
rcs_delta1 = 5.0; % rcs variation choice 1
```

```
rcs_delta2 =10.0; % rcs variation choice2
pt_percent1 = 0.5; % peak power variation choice 1
pt_percent2 =2.0;%
[out_par] = radar_eq(pt, freq, g, sigma, te, b, nf, loss,
input_par, option,
rcs_delta1, rcs_delta2, pt_percent1, pt_percent2)
c = 3.0e+8;
lambda = c / freq;
p_peak = base10_to_dB(pt);
lambda_sq = lambda^2;
lambda_sqdb = base10_to_dB(lambda_sq);
sigmadb = base10_to_dB(sigma);
for_pi_cub = base10_to_dB((4.0 * pi)^3);
k_db = base10_to_dB(1.38e-23);
te_db = base10_to_dB(te)
b_db = base10_to_dB(b);
if (option == 1)
temp = p_peak + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - input_par;
out_par = dB_to_base10(temp)^(1/4)
% calculate sigma(+-)10dB (rcs +- rcs_delta1,2)
sigmap = rcs_delta1 + sigmadb;
sigmam = sigmadb - rcs_delta2.;
% calculate.pt_percent1 * pt and pt_percent2% * pt
pt05 = p_peak + base10_to_dB(pt_percent1);
pt200 = p_peak + base10_to_dB(pt_percent2);
index = 0;
% vary snr from.5 to 1.5 of default value
for snrvar = input_par*.5: 1: input_par*1.5
index = index + 1;
range1(index) = dB_to_base10(p_peak + 2. * g + lambda_sqdb +
...
sigmam - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
range2(index) = dB_to_base10(p_peak + 2. * g + lambda_sqdb +
....
sigmadb - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
range3(index) = dB_to_base10(p_peak + 2. * g + lambda_sqdb +
...
sigmap - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
end
index = 0;
for snrvar = input_par*.5: 1: input_par*1.5;
index = index + 1;
rangp1(index) = dB_to_base10(pt05 + 2. * g + lambda_sqdb + ...
sigmadb - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
rangp2(index) = dB_to_base10(p_peak + 2. * g + lambda_sqdb +
...
```

```
sigmadb - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
rangp3(index) = dB_to_base10(pt200 + 2. * g + lambda_sqdb +
...
sigmadb - for_pi_cub - k_db - te_db - b_db - nf - loss -
snrvar) ...
^(1/4) / 1000.0;
end
snrvar = input_par*.5: 1: input_par*1.5;
figure (1)
subplot (2,1,1)
plot (snrvar,range2,snrvar,range1,snrvar,range3)
legend ('default RCS','RCS-rcs_delta1','RCS+rcs_delta2')
xlabel ('Minimum SNR required for detection - dB');
ylabel ('Detection range - Km');
%title ('Plots correspond to input parameters from example
1.4');
subplot (2,1,2)
plot (snrvar,rangp2,snrvar,rangp1,snrvar,rangp3)
legend ('default power','.pt_percent1*pt', 'pt_percent2*pt')
xlabel ('Minimum SNR required for detection - dB');
ylabel ('Detection range - Km')
else
range_db = base10_to_dB(input_par * 1000.0);
out_par = p_peak + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - 4.0 * range_db
% calculate sigma -- rcs_delta1,2 dB
sigma5 = sigmadb - rcs_delta1;
sigma10 = sigmadb - rcs_delta2;
% calculate pt_percent1% * pt and pt_percent2*pt
pt05 = p_peak + base10_to_dB(pt_percent1);
pt200 = p_peak + base10_to_dB(pt_percent2);
index = 0;
% vary snr from .5 to 1.5 of default value
for rangvar = input_par*.5 : 1 : input_par*1.5
index = index + 1;
var = 4.0 * base10_to_dB(rangvar * 1000.0);
snr1(index) = p_peak + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
snr2(index) = p_peak + 2. * g + lambda_sqdb + sigma5 - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
snr3(index) = p_peak + 2. * g + lambda_sqdb + sigma10 - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
end
index = 0;
for rangvar = input_par*.5 : 1 : input_par*1.5;
index = index + 1;
var = 4.0 * base10_to_dB(rangvar * 1000.0);
snrp1(index) = pt05 + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
snrp2(index) = p_peak + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
snrp3(index) = pt200 + 2. * g + lambda_sqdb + sigmadb - ...
for_pi_cub - k_db - te_db - b_db - nf - loss - var;
```

```
end
end
rangvar = input_par*.5 : 1 : input_par*1.5;
figure (2)
subplot (2,1,1)
plot (rangvar,snr1,rangvar,snr2,rangvar,snr3)
legend ('default RCS','RCS-rcs_delta1','RCS-rcs_delta2')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');
%title ('Plots correspond to input parameters from example
1.4');
subplot (2,1,2)
plot (rangvar,snrp2,rangvar,snrp1,rangvar,snrp3)
legend ('default power','.pt_percent1*pt','pt_percent2*pt')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');


pt = 1.5e+6; % peak power in Watts
freq = 5.6e+9; % radar operating frequency in Hz
g = 45.0; % antenna gain in dB
sigma = 0.1; % radar cross section in m squared
b = 5.0e+6; % radar operating bandwidth in Hz
nf = 3.0; %noise figure in dB
loss = 6.0; % radar losses in dB
range = linspace(25e3,165e3,1000); % range to target from 25
Km 165 Km, 1000 points
snr1 = radar_eq(pt, freq, g, sigma, b, nf, loss, range);
snr2 = radar_eq(pt, freq, g, sigma/10, b, nf, loss, range);
snr3 = radar_eq(pt, freq, g, sigma*10, b, nf, loss, range);
% plot SNR versus range
figure(1)
rangekm = range ./ 1000;
plot(rangekm,snr3,'k',rangekm,snr1,'k -
.',rangekm,snr2,'k:','linewidth',1.5)
grid
legend('\sigma = 0 dBsm','\sigma = -10dBsm','\sigma = -20
dBsm')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');
snr1 = radar_eq(pt, freq, g, sigma, b, nf, loss, range);
snr2 = radar_eq(pt*.4, freq, g, sigma, b, nf, loss, range);
snr3 = radar_eq(pt*1.8, freq, g, sigma, b, nf, loss, range);
figure (2)
plot(rangekm,snr3,'k',rangekm,snr1,'k -
.',rangekm,snr2,'k:','linewidth',1.5)
grid
legend('Pt = 2.16 MW','Pt = 1.5 MW','Pt = 0.6 MW')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');



pt = 10e03; % peak power in Watts
freq = 5.6e+9; % radar operating frequency in Hz
```

```
g = 20; % antenna gain in dB
sigma = 0.01; % radar cross section in m squared
b = 5.0e+6; % radar operating bandwidth in Hz
nf = 3.0; %noise figure in dB
loss = 8.0; % radar losses in dB
Ti = 2; % time on target in seconds
dt = .05; % 5% duty cycle
range = linspace(10e3,225e3,1000); % range to target from 10
Km 225 Km, 1000 points
snr1 = hprf_req (pt, Ti, g, freq, sigma, .05, range, nf,
loss);
snr2 = hprf_req (pt, Ti, g, freq, sigma, .1, range, nf, loss);
snr3 = hprf_req (pt, Ti, g, freq, sigma, .2, range, nf, loss);
% plot SNR versus range
figure(1)
rangekm = range ./ 1000;
plot(rangekm,snr3,'k',rangekm,snr2,'k -
.',rangekm,snr1,'k:','linewidth',1.5)
grid on
legend('dt = 20%','dt = 10%','dt = 5%')
xlabel ('Detection range - Km');
ylabel ('SNR - dB');


tsc = 2.5; % Scan time i s2.5 seconds
sigma = 0.1; % radar cross section in m squared
te = 900.0; % effective noise temperature in Kelvins
snr = 15; % desired SNR in dB
nf = 6.0; %noise figure in dB
loss = 7.0; % radar losses in dB
az_angle = 2; % search volume azimuth extent in degrees
el_angle = 2; %serach volume elevation extent in degrees
range = linspace(20e3,250e3,1000); % range to target from 20
Km 250 Km, 1000 points
pap1 =
power_aperture(snr,tsc,sigma/10,range,nf,loss,az_angle,el_angl
e);
pap2 =
power_aperture(snr,tsc,sigma,range,nf,loss,az_angle,el_angle);
pap3 =
power_aperture(snr,tsc,sigma*10,range,nf,loss,az_angle,el_angl
e);
% plot power aperture prodcut versus range
% generate Figure 2.6a
figure(1)
rangekm = range ./ 1000;
plot(rangekm,pap1,'k',rangekm,pap2,'k -
.',rangekm,pap3,'k:','linewidth',1.5)
grid
legend('\sigma = -20 dBsm','\sigma = -10dBsm','\sigma = 0
dBsm')
xlabel ('Detection range in Km');
ylabel ('Power aperture product in dB');
% generate Figure 2.6b
lambda = 0.03; % wavelength in meters
```

```
G = 45; % antenna gain in dB
ae = linspace(1,25,1000);% aperture size 1 to 25 meter
squared, 1000 points
Ae = 10*log10(ae);
range = 250e3; % rnage of interset is 250 Km
pap1 =
power_aperture(snr,tsc,sigma/10,range,nf,loss,az_angle,el_angl
e);
pap2 =
power_aperture(snr,tsc,sigma,range,nf,loss,az_angle,el_angle);
pap3 =
power_aperture(snr,tsc,sigma*10,range,nf,loss,az_angle,el_angl
e);
Pav1 = pap1 - Ae;
Pav2 = pap2 - Ae;
Pav3 = pap3 - Ae;
figure(2)
plot(ae,Pav1,'k',ae,Pav2,'k -.',ae,Pav3,'k:','linewidth',1.5)
grid
xlabel('Aperture size in square meters')
ylabel('Pav in dB')
legend('\sigma = -20 dBsm','\sigma = -10dBsm','\sigma =
0dBsm')
```