1.1 Introduction

The acronym for radar is radio detection and ranging. It is a remote Sensing System. It uses EM waves for detection and location of reflecting objects such as aircraft, ship, vehicle or Natural environment.

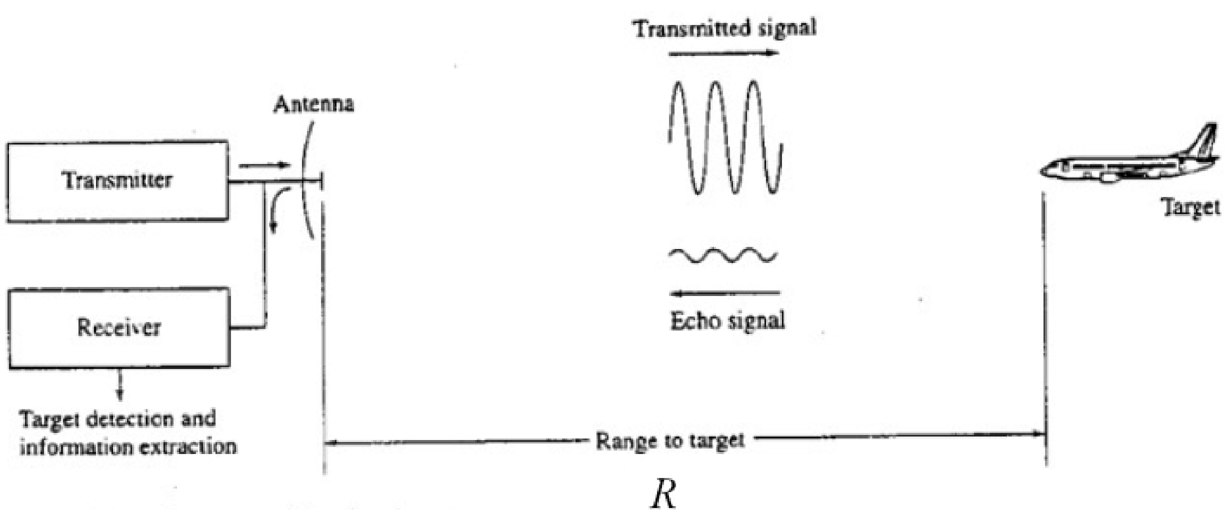
If an EM wave encounters sudden change in conductivity, permittivity, permeability in the medium, a part of the EM energy is as absorbed by the Second medium and is re-radiated. This sudden change in the electrical property of the medium constitutes target.

The reradiated / scattered energy on being received back by the Radar gives information about location of the target. Location includes range, bearing or angle (elevation/ azimuth) and velocity parameters.

Though the development of Radar is as a full-fledged technology did not occur till World War II, the basic principle of Radar detection is almost as old as the subject of electromagnetism itself.

1.2 Nature of Radar

Radar can function in darkness, haze, fog, rain or snow. One of the most important attributes is its capability of measuring distance (ranges) with high accuracy in all conditions even in the adverse weather conditions. The basic principle of Radar is illustrated in figure



Transmitter Tx generate am signal that is radiated into free space buy antenna, a portion of the transmitted energy is intercepted by the target and scattered in all directions. Part of the scattered energy directed back towards the radar is collected by the antenna A which delivers the energy to the receiver Rx. There it is process to detect the target on the display. If the transmitter and Receiver are co-located at the same place, then the radar is said to be mono static radar. If the transmitter and receiver are separated, then it is called bistatic radar. If the transmitter send the continuous wave then it is CW radar. If the transmitter sends the EM energy in bursts or pulses then the radar is Called pulse radar.

1.3 Radar waveforms:

Radar can use a continuous EM wave then the radar is termed as CW radar.
Radar may use the electromagnetic energy in short bursts i.e., the transmitter sends the energy for a brief period of few microseconds and such brief duration bursts can be a few hundred or thousand in a second. Such brief bursts are called pulses and the radar is called pulse radar.

Radar may use the CW but modulated either frequency modulated or amplitude modulated or phase modulated.
If it is frequency modulated the radar is known as FMCW radar. If it is amplitude modulated it may be a pulse radar. In case of a pulse radar

a) The duration Of transmitted pulse is called pulse width(pw)
b) The number of pulses transmitted per second is known as pulse repetition frequency (PRF) or pulse repetition rate.
c) The time from beginning of the first pulse to the beginning of the next pulse is called pulse repetition time(PRT)

$$PRT=1/PRF$$

d) The time duration between two successive transmitted pulses is called rest time IR receiver time (RT)
e) The product of PW and PRF is called duty cycle.

The most common radar waveform is a train narrow, rectangular shaped pulses modulating sine wave carrier.

1.4 Maximum unambiguous range

1.4.1 Range

The distance or Range to the target from radar is determined by measuring the time tr taken by the pulse to travel to the target and back to the radar. Since the EM energy propagate at velocity of light C, the range of the target R is given by

R= (C.TR)/2

the factor 2 appears in the denominator because of the two way propagation of the radar pulse, with range in km and TR in micro seconds. The above equation becomes

R (km) =0.15tr (us).

Once the transmitted pulse is emitted by the radar, sufficient time must elapse in order to allow any echo to return and be detected before the next pulse is transmitted. Therefore the rate at which the pulses may be transmitted is determined by the longest range at which targets expected. If the pulse repetition frequency is too high, echo signals from some targets may arrive after the transmission of the next pulse and ambiguity in measuring range might results. Echoes that arrived after the transmission of next pulse are called second time around a course. Such an echo would appear to be of much shorter range than the actual range and could be misleading if it were not known to be a second time around echo.

The range beyond which the targets appear as second time around echoes is called the maximum unambiguous range.

Maximum unambiguous range:

The maximum unambiguous range is given by

R_{unamb} = (c/2).f_p

where f_p is the pulse repetition frequency

Although the typical radar transmitter is simple pulse modulated waveform, there are a number of other suitable modulations that might be used. The Pulse carrier might be frequency or phase modulated to permit The echo signal to be compressed in time after repetition. This achieves the benefits of high range resolution without the need short pulse but with the energy of a long pulse, the range resolution of a short pulse can also be obtained by a technique of using long modulated pulse. This technique is called pulse compression technique.

Continuous waveforms CW also can be used by taking advantage of The Doppler frequency shift to separate the received echo from the modulated signal and Echoes from the stationary clutter. Unmodulated CW waveforms don't measure range, but a range measurement can be made by applying either frequency or phase modulation.

1.4.3 Minimum range

A possible difficulty exists when the target is very close to the transmitter radar and the Echo due to this is returned to the receiver before the transmitter is turned off, because the transmitted pulse has a finite duration called pulse width. If the echo returns while the pulse is still being transmitted, it will not be detected by the receiver. This decides the minimum usable range R_{min}. The minimum usable range for the radar is one half of the distance the signal can travel during the time it takes to transmit the pulse.

$R_{min}= (C. PW)/2$

1.4.4 Range Detection

The pulse rate is the prime factor in the range resolution. Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing (in the same direction).

The degree of range resolution depends on the width of the transmitted pulse, the type and size of the target and the efficiency of the receiver and display systems of the radar

The pulse occupies a distance in free space, depending upon the pulse width. The distance will be pulse width multiplied by the velocity of the light (C.T). Resolution can be understood as the ability to distinguish target separated by half of this distance (= C.T/2). The factor 2 in the denominator because of the to and fro distance.

$R_{resol}=CT/2$

Where C is the velocity of light in meters per second
T is the pulse width in microsecond
R_{resol} is the range resolution in meters.

1.4.5 Bearing Resolution

Bearing or azimuthal Resolution is the ability of a radar system to separately see the objects at the same range but at different bearings. Range is a factor in bearing resolution because the radar beam spreads out as range increases. Radar beam is defined in width in terms of half power points. All the points off the central line of The Beam that are at one half the power level at the centre are plotted to define The Beam width. (angular). The physical size and shape of the antenna determines the beamwidth. The target within the half power points reflects a useful echo.

The Beam width can be defined as $r.\theta/2$
Where R is the range and θ is the beam width in radians.

1.4.6 Target Resolution is the ability of Radar to distinguish between targets that are very close to each other in the range of bearing.

1.4.7 Duty Cycle

The duty cycle of the radar is the ratio of pulse rate to Pulse repetition time. It tells the fraction of total time that the transmitter is on.

1.4.8 Peak power (P_t)

The peak power of the transmitter is The RMS power during the time the pulse is on

1.4.9 Pulse energy (W_p)

it is the energy in the transmitted pulse waveform. it is peak power times the expand pulse width. $W_p = P_t \times T$

1.4.10 Average power (P_{avg})

The average power is defined as the average transmitted power over pulse repetition period. If the transmitted wave is a train of rectangular pulses of width T and Pulse repetition period PRT

$P_{avg}=P_t. T/PRT = P_t \times$ duty cycle

So the duty cycle can also be viewed as the ratio of average power to peak power of the transmitter. Similarly the pulse energy W_p can also be written as the product of average power and Pulse repetition period.

1.5 Radar Range Equation

The radar range equation determines the maximum range at which a target can be detected by the radar. It is an important tool for designing radar system. The radar equation relates the maximum range of the radar with the characteristics of Radar transmitter, receiver, antenna, target and the environment effect on the wave propagation.

Let P_t with the power transmitted by radar transmitter. The transmitter emits radiation through and isotropic antenna which radiates energy uniformly in all directions. The energy Travels as a spherical wave front. Then the surface area of the spherical wavefront at a distance R is $4\pi R^2$

The power density at a distance R is given by

$P_t/4\pi R^2$

If the antenna is direct to antenna 2 channel or direct the radiated power into a particular direction, then there is an increase the power density in that particular direction as defined by the gain of the antenna G_t in relation to an isotropic radiator. so the power density at a distance R from a directive antenna of Gain Gt is given by

$P_tG_t/4\pi R^2$

If the target is located at this distance R, the target intercepts energy and scatters are reradiates some of the incident energy in all directions.

the measure of the amount of incident power intercepted why the target and Re radiated back in the direction of the radar is denoted as radar cross section of scattering σ of the target. Disco signals power density at radar is given by

$P_tG_t.\sigma/(4\pi R^2)^2$

The radar scattering cross section σ of the target has units of area and it is a measure of the size of the target as seen by radar. It is characteristic of the target.

The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is A_e, then the power received by the radar is P_r, given by

$P_t G_t.\sigma.A_e /(4\pi R^2)^2$

The maximum radar range R_{max} is the distance beyond which the target cannot be detected. It occurs when the received echo power P_r just equal to the minimum detectable signal S_{min}

$P_r = S_{min}$

$R_{max} = [P_t G_t.\sigma.\ A_e /((4\pi)^2\ S_{min})]^{1/4}$

This is the fundamental form of Radar equation. The antenna theory gives the relation
$G = 4\pi A_e/\lambda^2$

Between the transmitting antenna gain G and the receiving antenna effective aperture A_e, where λ Is the wavelength of EM wave since Radar generally uses the same antenna for transmission as well as reception of signals the ever Radar equation can be written as

$R_{max} = [P_t G.\ \lambda^2.\sigma /((4\pi)^3\ S_{min})]^{1/4}$

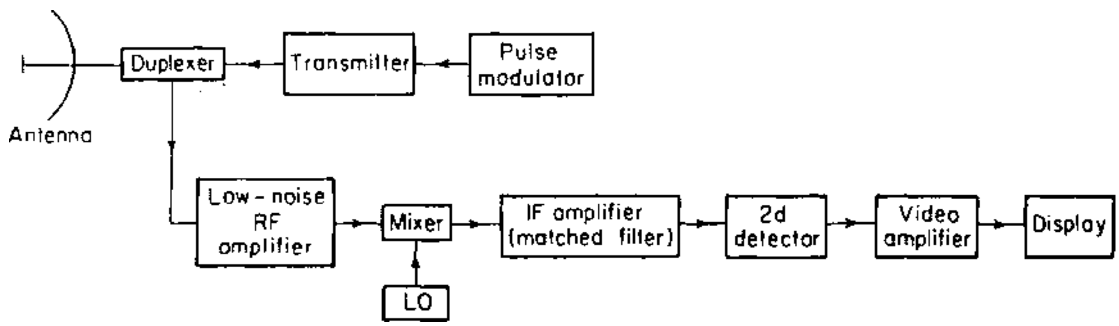
these simplified radar equations Don't predict adequately the range performance of the radar because

i) σ has some fluctuations and uncertainties.
ii) The received noise effects the S_{min}
iii) There are losses experience in the radar system
IV) There are propagation effects of the atmosphere and Earth's curvature.
V) The atmospheric constituents influence the radar power due to absorption of the energy
the observed Max radar range is usually smaller than the range predicted by the radar
equation As given above by the factor of 2

The power P_t. is called peak power. It is not the instantaneous peak power of the Sine wave. Is defined as the power averaged over that carrier frequency cycle which occurs at the maximum of the pulse power. Peak power is usually equals to one half of the maximum instantaneous power.

1.6 Radar block diagram and operation

The operation of a typical pulse radar maybe described with the help of block diagram.



1.6.1 Transmitter Section

The transmitter is an oscillator (Magnetron) that is pulsed (turn on and off) by the pulse modulator to generate a train of pulses.

The waveform generated by the transmitter Travels to antenna through duplexer. Single antenna is generally used for both transmitting and receiving signals. The duplexer serves the purpose of a switch that sense the transmitter pulse to the antenna but not towards the receiver during transmission time and sense the Echo signal coming from antenna towards the Receiver during rest time.

Thus the receiver is protected from the high power transmitted signal.
The duplexer maybe two gas discharge tubes called TR and ATR directs the Echo to receiver during reception. Solid state devices like ferrite circulators, receiver protectors, diode Limiters can also be part of the duplexer.

1.6.2 Antenna System

Antenna radiates the transmitted energy into free space and receives the return signal from the target.

1.6.3 Receiver Section

The receiver is usually a superheterodyne receiver. The first stage is a low noise RF amplifier parametric amplifier. It is not always desirable to have a low noise RF amplifier at 1st Stage especially in military radars since they operate in a noisy environment.

The next stage is mixer stage. The local oscillator and mixture convert RF signal into and IF (30-60 MHz) with a bandwidth of1Mhz.

The IF is designed as matched filter to maximize the peak signal to noise power ratio at the output. After maximizing the signal to noise ratio in IF amplifier, the pulse modulation is extracted by second detector and then amplified by video amplifier to raise the level of the signal to a magnitude where it can be seen on a display or to be the input to a computer for further processing.

1.6.4 Threshold detection

At the output of receiver a decision is made whether or not target is made. There will be a predetermined threshold level set. If the amplitude of the received signal exceeds this threshold level then the target is assumed to be present, otherwise only noise is is used.

1.6.5 Display

the final output of the receiver section is displayed on CRT as PPI display/ A-R scope display giving the portion of the target in polar coordinates(PPI) or as amplitude vs. range (A-R scope).

1.6.8 Determination of coordinates in radar

Radar requires a more precise reference system. Radar surface angular measurements are normally made in clock Direction from true north or from the headline of a ship or aircraft.

The surface of the earth is represented by a flat plane tangential/ parallel to earth surface at the location. This plane is called horizontal plane. All the angles in the up direction are measured in a second Imaginary plane perpendicular to horizontal plane. This plane is called vertical plane. The radar location is the center of this co-ordinate system. The line from the radar set directly to the object is referred to as the line of sight

LOS. The length of this line is called range- the radial distance from the radar to the target. The angle between the horizontal plane and the LOS is the elevation angle. The angle measured in clockwise from true North in the horizontal plane to the target is called the true bearing or azimuth angle. These 3 coordinates of range, bearing and elevation describe the location of an object with respect to the antenna.
The bearing angle to the radar target may also be measured in clockwise direction from Central Line of the ship or aircraft and is referred to the relative bearing.

1.7 Radar frequencies

Conventional radar operate in upper UHF and microwave range [300Mhz-30Ghz], but nowadays Radars operate at frequencies as low as few MHz and also are Experimented at milli wave (>100Ghz) range.

1.8 Radar applications

Radars are employed and ground and sea and in air and space.

Ground based radars: to detect, locate, track aircrafts or space targets.

Shipboard Radars: and navigation aid and safety device to locate shore lines, other ships/ submarines, aircrafts

Airborne radars: to detect other aircrafts, ships, land vehicles, mapping of land, storm avoidance, Terrain avoidance and navigation

Space: to assist in the guidance of spacecraft for Remote Sensing of land and area

Application of Radars:

Civilian:	Military:	Scientific:
airport surveillance marine navigation weather forecasting Altimeter Mapping Police vehicular traffic control (law enforcement) aircraft landing system	Air and Marine navigation detection and tracking of aircraft, missiles guided missiles aircraft landing system	Geographical mapping and imaging Astronomy distance measurement Remote Sensing Weather

1. Air traffic control ATC: To guide a traffic to safe landing of aircraft in bad weather
2. Aircraft navigation: weather avoidance, radar radio altimeter, ground mapping
3. Ship safety: avoiding collisions with other ships on high seas
4. Space: space vehicles use radar for docking, landing on moon. tracking of satellites from ground satellite Bourn Radars for Remote Sensing.
5. Remote sensing: sensing of geophysical objects on environment
6. Law enforcement: vehicular traffic control
7. Military: surveillance, navigation, control and guidance of weapon

Radar frequencies

Radar are being operated at frequencies as low as 2 megahertz just above AM broadcast Band and has high as several hundred gigahertz. More usually radar frequencies might be from 5 MHz to over 95 GHz (Large extent of frequencies). The radar Technology capabilities and applications will vary considerably depending on the frequency range at which the radar operates. Conventional radar corporate in upper uhf and microwave region (300 MHz - 30 GHz). Generally longer range is easier to achieve at the lower frequencies because it is easier to obtain high power transmitters and physically large antenna. on the other hand at the higher frequencies it is easy to achieve accurate measurement of range and location because the higher frequencies provide wideband as well as narrow beam Antennas for a given physical size antenna wider bandwidth determines the range accuracy and range resolution whereas narrow beam width determines angular accuracy and angle resolution.

HF (3 to 30 MHz) to detect targets at long range like 2000 nmi by taking advantage of the refraction of HF by ionosphere. This is referred to as shortwave propagation by radio amateurs. The targets for such HF radars might be aircraft, ships and ballistic missiles as well as echoes from the surface of the sea that provides information about the direction and speed of winds the drive the sea.