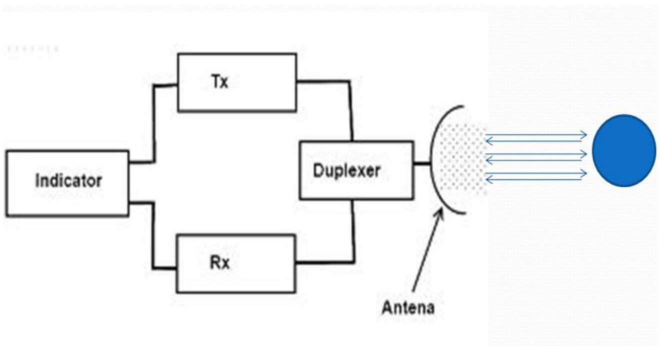
RADAR Systems

Introduction:

RADAR is basically a means of gathering information about distant objects or targets which are beyond the range of human vision. This is done by sending electromagnetic waves at them and analyzing the echo received. The term "RADAR" means "Radio Detection and Ranging". A RADAR system is very rapid and precise. The presence of clouds, fog or darkness does not affect the function of RADAR. At first it was used as a method to detect an approaching aircraft and later on for many other purposes.

Basic principle of Radar:



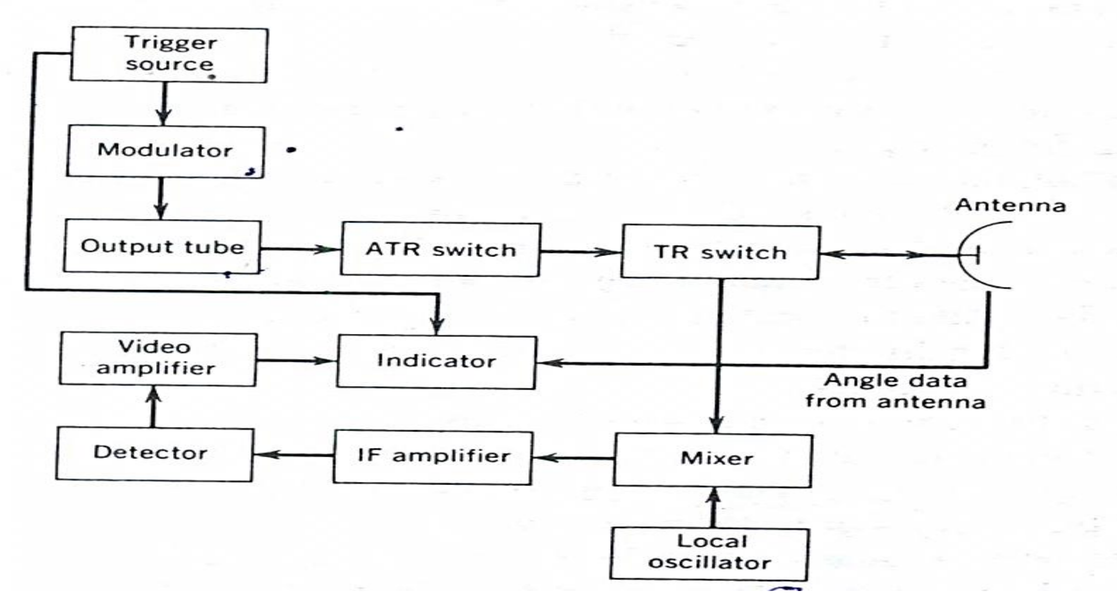
Basically RADAR consists of a transmitter and a receiver each connected to a directional antenna. The transmitter sends (microwave) power through the antenna. The receiver collects as much energy as possible from the echo reflected from the target and analyses the information received and later on displays it.

Frequencies and powers used in RADAR:

The frequencies used by RADAR lie in the upper UHF and microwave ranges. For war time securities, names grew up for the various frequency ranges as L, S, C, X etc. and these names are still being used.

BAND NAME	FREQUENCY RANGE, GHz	MAXIMUM AVAILABLE PEAK POWER† MW
UHF	0.3–1.0	5.0
L	1.0–1.5	30.0
S	1.5–3.9	25.0
C	3.9–8.0	15.0
X	8.0–12.5	10.0
Ku	12.5–18.0	2.0
K	18.0–26.5	0.6
Ka	26.5–40.0	0.25
V	40.0–80.0	0.12
N	80.0–170.0	0.01
A	Above 170	—

Pulsed RADAR system:



The block diagram below shows the arrangement of a high power pulsed RADAR set. The *trigger source* provides pulses for the modulator. The *modulator* provides rectangular voltage pulses (used as the supply voltage) for the *output tube,* switching it ON and OFF as required. The *output tube* may be a magnetron oscillator or an amplifier such as the klystron, travelling wave tube or crossed field amplifier, depending on specific requirements. Finally, the transmitter portion of the RADAR passes the output pulse to the TR switch for transmission.

As soon as a small fraction of the pulse power is fed to the duplexer (*TR & ATR switch*), the transmitter is connected to the antenna. The antenna moves in a predetermined pattern called scanning patter. The antenna is highly directional and sends out the generated pulses towards the target. The scanning speed is high but it is small compared to the time taken by the pulses to return from the normal range of the targets. Thus when echoes are received from the target the antenna still points in the right directions to receive them. Now the duplexer disconnects the transmitter from the antenna and connects the receiver with the antenna.

The received echo is processed in the receiver. The RADAR receiver is a super-heterodyne receiver. Here the received echo is mixed with the signal generated by the local oscillator at the *mixer* to produce Intermediate Frequency (IF). The IF is usually 30 to 60 MHz. IF signal is then amplified by *IF amplifier* and then fed to *detector*. A diode is used as a detector. The *video amplifier* raises the signal amplitude to the required level to be applied to the indicators.

The *indicators* panel of the RADAR is provided with the various measuring instruments and indicators like Pulse Position Indicator (PPI). It is also provide with a sweep generator for range measurements.

Radar range equation To determine the maximum range of a radar set, it is necessary to determine the power of the received echoes, and to compare it with the minimum power that the receiver can handle and display satisfactorily. If the transmitted pulsed power is P_t (peak value) and the antenna is isotropic, then the power density at a distance r from the antenna will be given by

$$\mathcal{P} = \frac{P_t}{4\pi r^2} \tag{16-6}$$

However, antennas used in radar are directional, rather than ~~isotropic~~. If A_p is the maximum power gain of the antenna used for transmission, so the power density at the target will be

$$\mathcal{P} = \frac{A_p P_t}{4\pi r^2} \tag{16-7}$$

The power intercepted by the target depends on its *radar cross section*, or effective area . If this area is S, the power impinging on the target will be

$$P = \mathcal{P}S = \frac{A_p P_t S}{4\pi r^2} \tag{16-8}$$

The target is not an antenna. Its radiation may be thought of as being omnidirectional. The power density of its radiation at the receiving antenna will be

$$\mathcal{P}' = \frac{P}{4\pi r^2} = \frac{A_p P_t S}{(4\pi r^2)^2} \tag{16-9}$$

The receiving antenna intercepts a portion of the reradiated power, which is proportional to the cross-sectional area (*capture area*) of the receiving antenna. The received power is

$$P' = \mathcal{P}' A_0 = \frac{A_p P_t S A_0}{(4\pi r^2)^2} \tag{16-10}$$

where A_0 = capture area of the receiving antenna.

If the same antenna is used for both reception and transmission, the maximum power gain is given by

$$A_p = \frac{4\pi A_0}{\lambda^2} \tag{16-11}$$

Substituting Equation (16-11) into (16-10) gives

$$P' = \frac{4\pi A_0}{\lambda^2} \frac{P_t S A_0}{16\pi^2 r^4}$$

$$= \frac{P_t A_0^2 S}{4\pi r^4 \lambda^2} \tag{16-12}$$

The maximum range r_{max} will be obtained when the received power is equal to the minimum receivable power of the receiver, P_{min}.

Substituting this into Equation (16-12)

$$P_{min} = \frac{P_t A_0^2 S}{4\pi r_{max}^4 \lambda^2}$$

$$r_{max} = \left(\frac{P_t A_0^2 S}{4\pi \lambda^2 P_{min}}\right)^{1/4} \tag{16-13}$$

Alternatively, if Equation (16-11) is turned around so that $A_0 = A_p\lambda^2/4\pi$ is substituted into Equation (16-13), we have

$$r_{max} = \left[\frac{P_t A_p^2 \lambda^2 S}{(4\pi)^3 P_{min}}\right]^{1/4} \tag{16-13a}$$

Equations (16-13) and (16-13a) represent two convenient forms of the *radar range equation*,

Factors affecting range of RADAR:

It is found that the maximum range of radar system is

- Directly proportional to the fourth root of the power transmitted
- Directly proportional to the square root of the power gain
- Directly proportional to the square root of the wavelength
- Directly proportional to the fourth root of the cross section area
- Inversely proportional to the fourth root of minimum received power

Doppler Effect:

Doppler in 1842 gave a postulate known as 'Doppler Effect', which says :

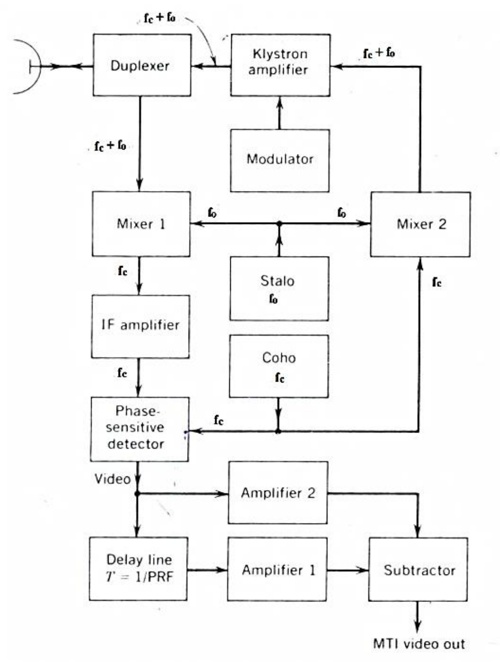
"The apparent frequency of an electromagnetic wave depends on the relative motion of source and the observer".

If the source and the observer are moving away from each other, the apparent frequency will decrease and if they are moving towards each other, the apparent frequency will increase.

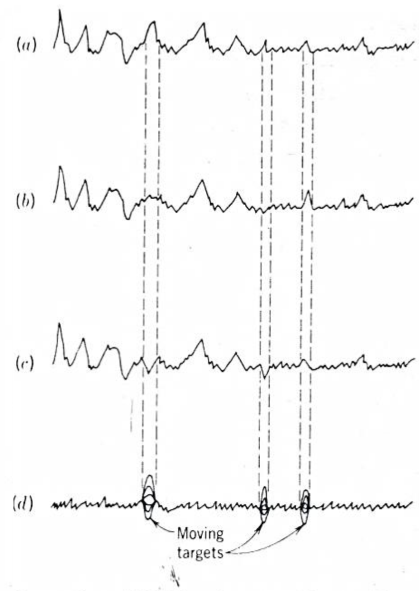
MTI RADAR:

In this RADAR system, only moving targets are displayed on the screen, and the echo obtained from stationary targets is not displayed at all. The MTI RADAR employs Doppler's effect, here the signal undergoes a change due to moving target.

The block diagram of MTI RADAR is shown in the figure below.



Block diagram of MTI radar using power amplifier output.



Operation of MTI radar. (*a*), (*b*), (*c*) Phase detector output for three successive pulses; (*d*) subtractor output.

Basically, a MTI RADAR system compares a set of received echoes with those received during previous sweep. The echoes whose phase remains constant are cancelled out as they are obtained from stationary targets, but the echoes obtained from moving targets show a phase difference due to Doppler effect and hence not cancelled. It also helps in the detection of moving targets whose echoes are very small due to long distance than those of nearby stationary targets.

The transmitted frequency is the sum of the outputs of two oscillators (fc+fs). The first oscillator is called *Stalo* (stable) and other a Coho (Coherent). The *stalo* is a local oscillator and *coho* operates at IF and provides coherent signal. The mixers I and II are identical and both use the *stalo* thus phase relations of their inputs are preserved in their outputs also. The output of the IF amplifier and signal of *coho* oscillator is fed to a detector circuit.

The *coho* oscillator is used to generate RF signal as well as the signal for the detector. Since the output of the detector is phase sensitive, an output will be obtained for all fixed and moving targets. The phase difference between transmitted and received signals will be constant for stationary targets and it will be changing for moving targets as per the Doppler Effect.

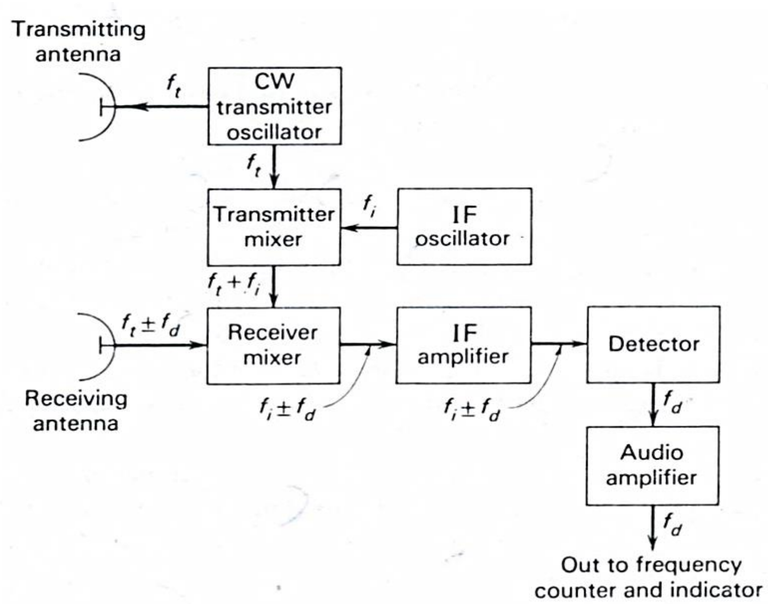
Blind speeds in MTI RADAR:

In an MTI RADAR, the phase difference between transmitted pulse and the echo remains constant from the pulse to pulse in case of stationary targets. The phase differences, however varies in case of moving target.

If the target happens to be moving with a velocity such that its velocity component along the RADAR axis results in a phase difference of 2π radians or its integral multiple between successive sets of pulses of the RADAR, the target appear as stationary. These target velocities are said to be blind speeds.

Continuous wave (CW) RADAR:

CW RADAR transmits continuous sine waves instead of pulses. It utilizes the Doppler effect to detect the change in frequency caused by a moving target and then displays this change as a relative velocity. Fig below shows the block diagram of CW RADAR with IF amplifier.



CW Doppler radar with IF amplification.

A small portion of the output of the transmitter is mixed with the output of a local oscillator. The sum is fed into the receiver mixer. This mixer also receives the Doppler shifted signal from the antenna. This produces an output difference frequency. This output frequency is about 30 MHz plus or minus the

Doppler frequency. The output of this mixer is amplified and demodulated. The demodulated signal generally being audio range, the detector output is amplified with an audio amplifier and then fed to the frequency counter and indicator.

Advantages:

1. CW Doppler RADAR uses low transmitting power
2. The power consumption is small
3. The circuitry is simple and hence the size of the equipment is comparatively small.
4. The performance is not affected by the presence of stationary targets
5. It is capable of measuring target speeds of a long range quickly and accurately.
6. It can measure the direction of the target along its speed.

Limitations:

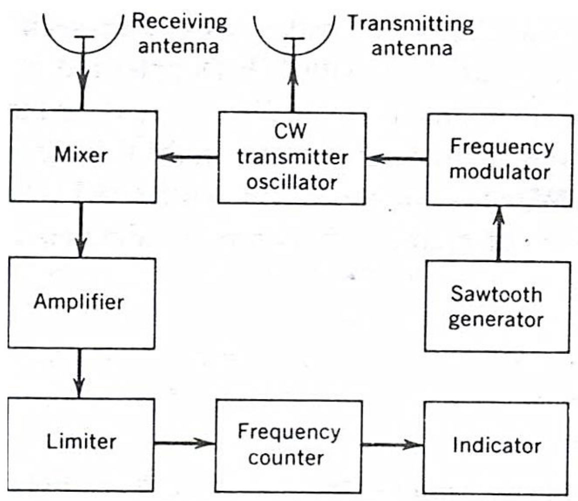
1. There is a limit to the maximum power that the device can transmit. As a result there is a limit to the maximum range
2. The device gets easily confused if there are more number of targets
3. This RADAR can only show the velocity of the target and not capable of indicating the range.

Applications:

1. CW RADAR is used in aircraft navigation for speed measurement.
2. It is used in rate-of-climb meter for vertical takeoff planes
3. It is most commonly used in RADAR speed meters used by police.

Frequency-Modulated CW RADAR:

The greatest limitation of Doppler RADAR is its inability to measure range. To overcome this, the transmitted carrier is frequency modulated. Figure below shows the block diagram of FM CW RADAR system.



Block diagram of simple FM CW radar

A small portion of the output of the transmitter oscillator is mixed with the received signal at the mixer. The output of the mixer produces the difference frequency, which is then amplified by amplifier. The amplified signal is fed to frequency counter and then to an indicator whose output is calibrated in meters or feet. If the target is stationary with respect to the plane, a frequency difference proportional to the height of the plane will exist between the received and the transmitted signals.