RADARS

PRINCIPLES OF RADARS

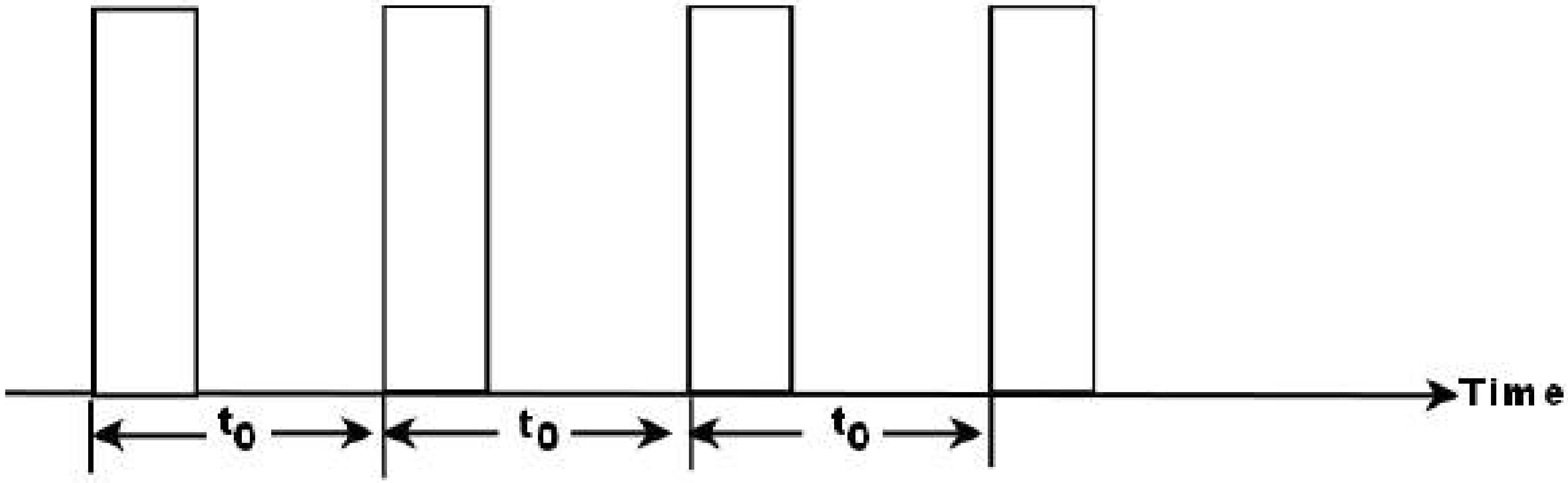
- Radio Detection and Ranging.
- An electromagnetic system for the detection and location of objects.
- Operates by transmitting a particular type of waveform and detects the nature of the echo signal.
- Darkness, fog, rain, or when the object is located far away.
- Distance or range to an object.

A radar consists of three main parts:

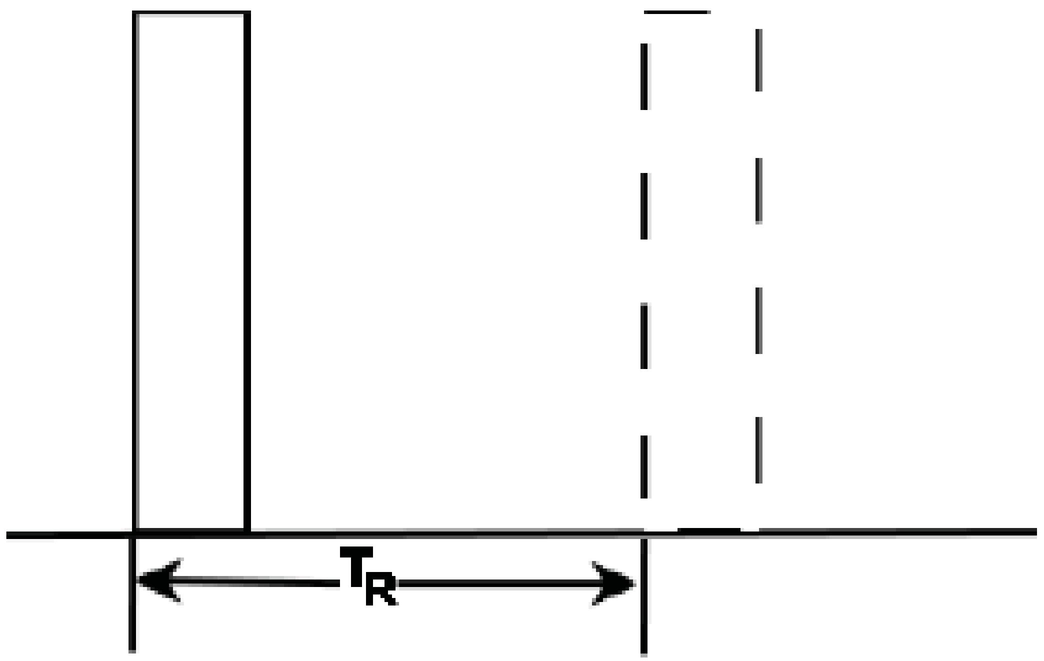
- A transmitting antenna.
- A receiving antenna
- An energy detecting device, or a receiver.

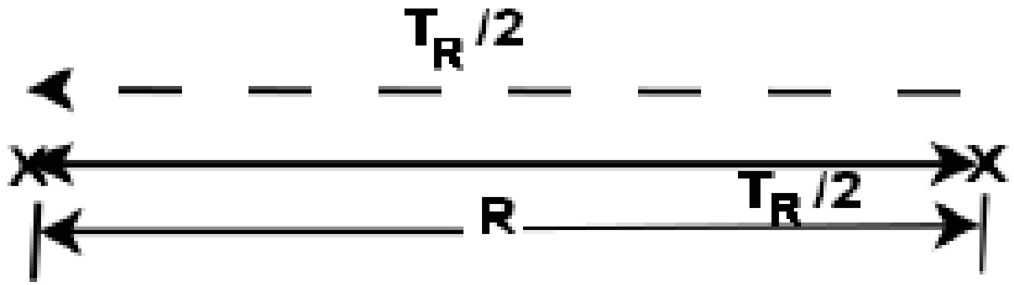
- The transmitting antenna emits electromagnetic radiation, a portion of which is reflected back by the target.
- The receiving antenna receives this reflected energy and delivers it to the receiver.
- The receiver processes this energy to detect the presence of the target and to extract its location, relative velocity, and other information.

The energy emitted by the radar is usually in the form of a train of narrow, rectangular-shaped pulses.



The frequency of transmission: $$f_p = \frac{1}{t_0}$$


T_R


T_R /2
T_R /2
R

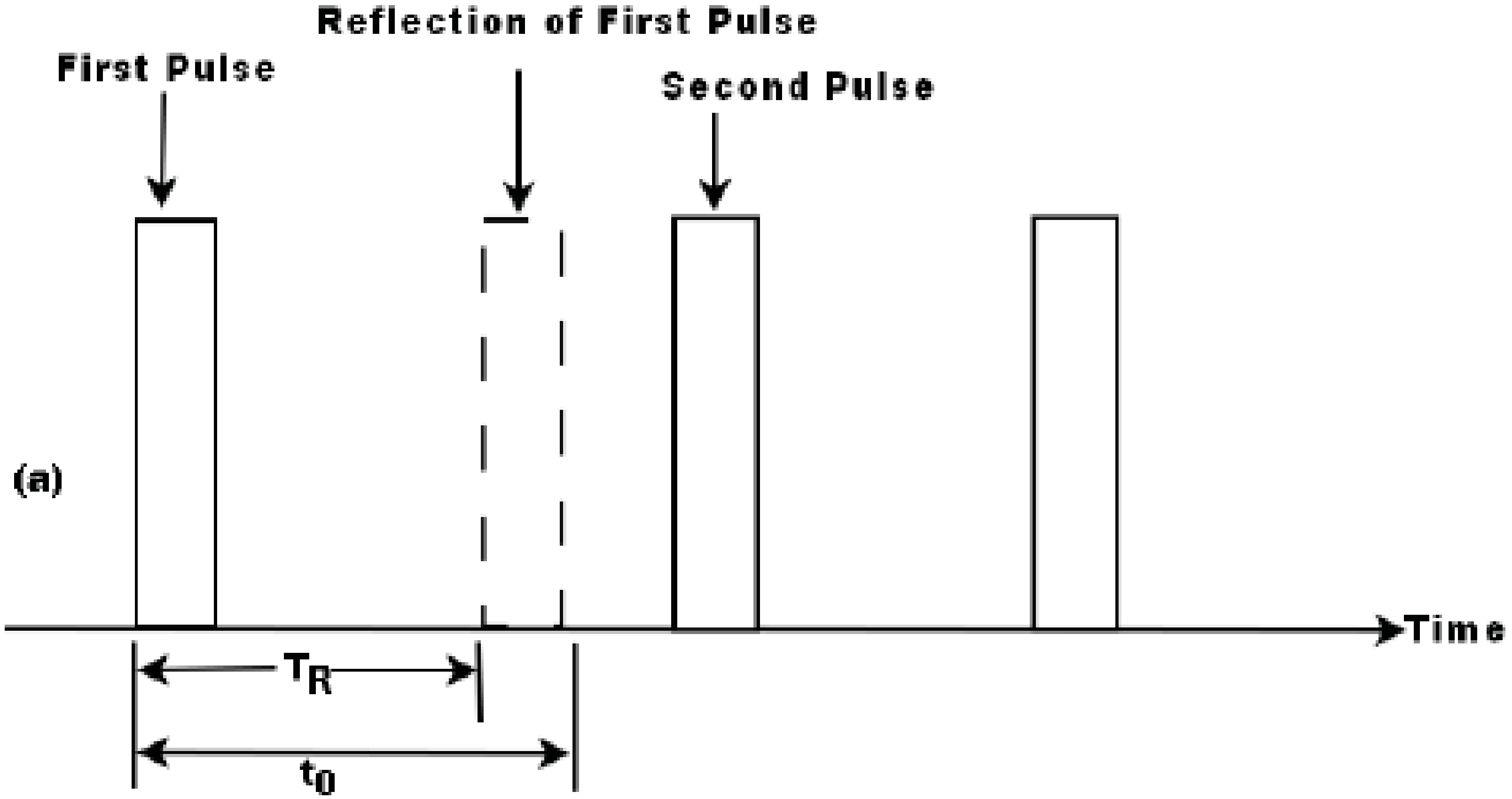
Then , the distance or range R to the target is given by

$$R = \frac{cT_R}{2}$$

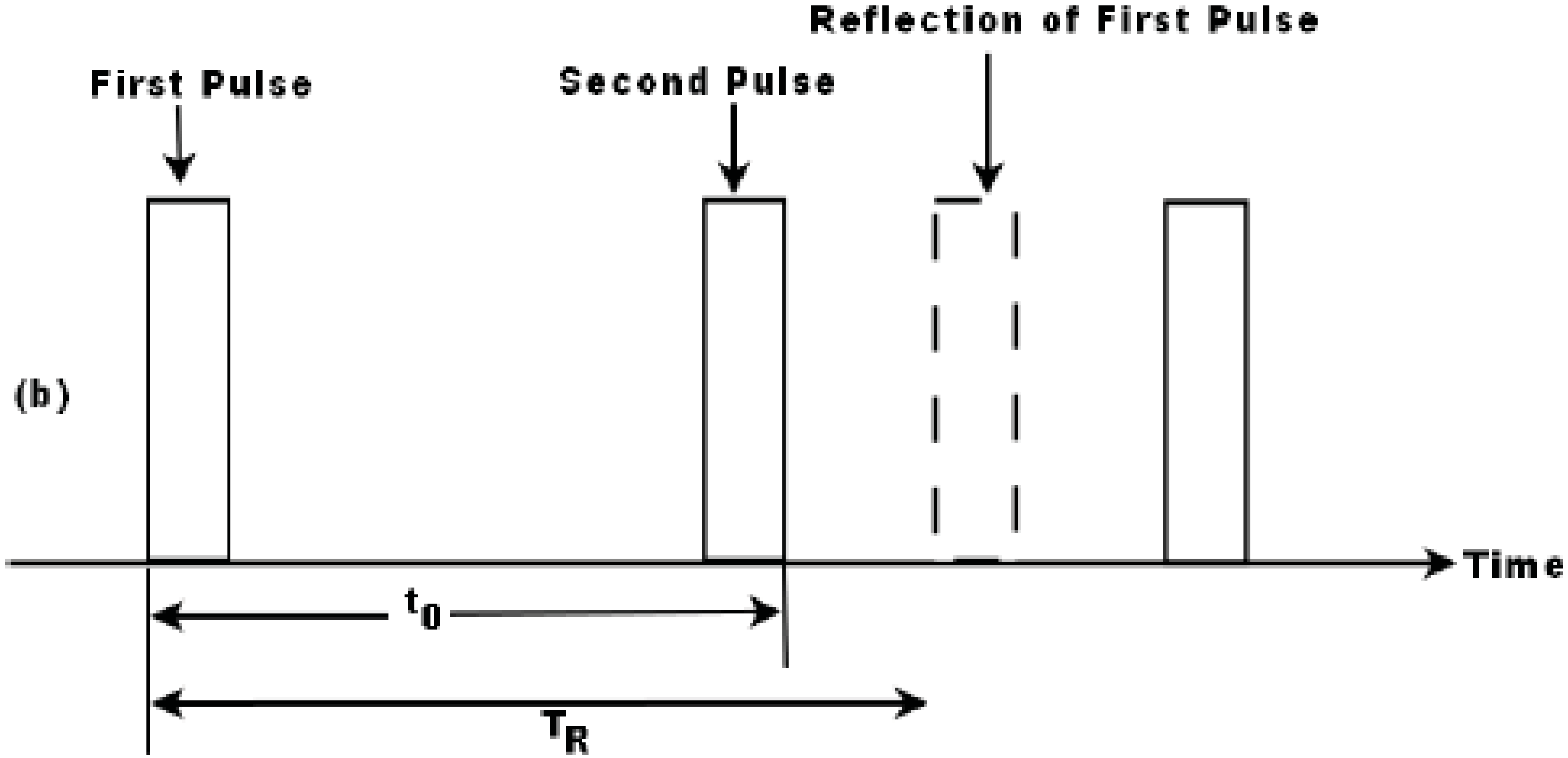
where, R is in meters and c is usually taken to be the speed of light and is assumed to be $c = 3 \times 10^8 m/sec$

In deriving the above equation we assumed that only one pulse was transmitted and was later received after reflection from the object.

But usually a number of pulses are sent at regular intervals



(a) No ambiguity in range measurement



(b) ambiguity in range measurement

- Thus, the maximum range or distance of the target which does not cause any ambiguity is denoted by *Runamb* and is given by,

$$R_{unamb} = \frac{ct_0}{2} = \frac{c}{2f_p}$$

This is known as the <u>maximum</u> <u>unambiguous</u> <u>range</u> of the radar.

If the target is beyond this distance then the reflection of a pulse is received after the next pulse has been transmitted. This is known as the **second-time-around echoes effect.**

EXAMPLE 2.1 : Consider a radar with pulse repetition frequency 1000 Hz. (a) Find the time duration between two pulses. (b) Suppose an echo from a distant object is received 20 μ sec after a pulse is transmitted, what is the distance of the object from the radar? (c) Is there a second -time-around echo from this object?

ANSWERS The pulse repetition frequency fp = 1000 Hz. (a) The time duration between pulses is given by

$$t_0 = \frac{1}{f_p} = \frac{1}{1000} = 0.001 sec = 1 msec \tag{2.4}$$

(b) The echo is received after $T_R = 20\mu sec = 20 \times 10^{-6}$ sec. Remember that T_R is the time taken by the pulse to cover the distance from the radar to the object and back. Hence, the time taken by the pulse to travel one way (i.e., from the radar to the object) is half of T_R. Since the speed of propagation is $c = 3 \times 10^8$ m/sec, the distance of the object from the radar is given by,

$$R = \frac{cT_R}{2} = \frac{3 \times 10^8 \times 20 \times 10^{-6}}{2} = 3000m = 3km \tag{2.5}$$

(c) A second-time-around echo occurs only when the distance of the object is more than the maximum unambiguous range of the radar. Also remember that the R_{unamb} is that distance of an object for which the echo comes back exactly t_0 seconds after being transmitted. Hence,

$$R_{unamb} = \frac{ct_0}{2} = \frac{0.001 \times 3 \times 10^8}{2} = 150 \times 10^3 \quad m = 150 \quad km \tag{2.6}$$

Since the distance of the object is much less than R_{unamb}, there is no second-time-around echo.

- Transmitted Power::   1 Mega watt
- Pulse Width ::   1 Micro second
- Pulse Repetition Period ::   1 Milli second
- Average Power can be calculated as

  Transmitted Power * Pulse Width *Pulse Repetition Frequency

- Energy :: Transmitted Power * Pulse Width

The Radar Equation

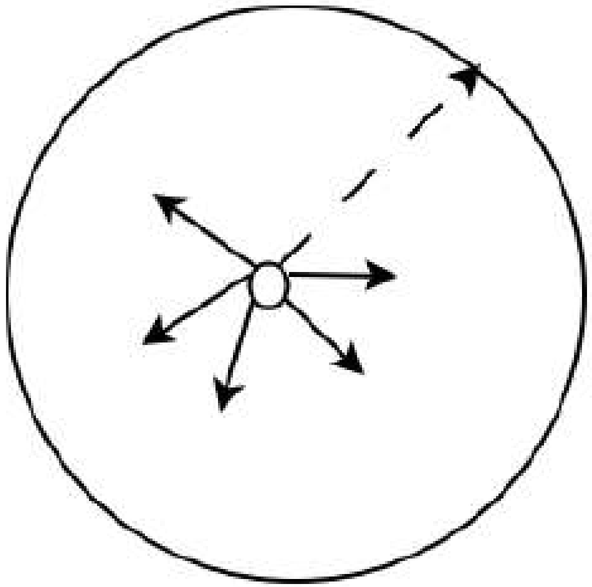
- Relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target, and the environment in which the radar operates.

The radar equation is useful

- in determining the distance of the target from the radar.
- as a tool for understanding radar operation.
- in serving as a basis for radar design.

Consider a radar using a transmitting antenna which radiates power uniformly in all directions. Such antennas are called isotropic antennas. Let P_t be the power radiated by such an antenna. Then the power density at a distance R is given by,

$$\widehat{P}_d = \frac{P_t}{4\pi R^2} \tag{2.7}$$



Power density at distance R from the radar

Note that at a distance R, the power P_t is uniformly distributed over an area given by the surface area of a sphere of radius R. Hence, we get the equation or P_d as above

- **Radiation intensity** is defined as the power radiated per unit solid angle in a given direction.
- The factor G is also known as the **antenna gain**.
- Thus, the **power density** from a directive antenna at a distance R is given by

$$P_d = \widehat{P}_d G = \frac{P_t G}{4\pi R^2}$$

- The measure of the amount of power intercepted by the target is defined as the **radar cross-section of the target,** denoted by σ and has the unit of area.
- The amount of power intercepted by the target at a distance R from the radar is,

$$\widehat{P} = P_d \sigma = \frac{P_t G \sigma}{4\pi R^2}$$

- Now we assume that this power gets radiated in all directions.
- The power density of the reflected signal at the receiving antenna is given by

$$P_d^r = \frac{\widehat{P}}{4\pi R^2} = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

- How much of area of the receiving antenna, *Ae* and has the unit of area.
- It is also known as the **antenna effective aperture**.
- The power *Pr* received by the radar is,
- this power is actually captured by radar antenna depends on the effective

$$P_r = P_d^r A_e = \frac{P_t G \sigma A_e}{(4\pi)^2 R^4}$$

- If the radar receiver can detect only those signals which are greater than a value *Smin* (known as the **minimum detectable signal**), then the maximum range of the radar :

$$S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R_{max}^4}$$

From which,

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{\frac{1}{4}}$$

This is the fundamental form of the radar equation.

- Many radars use the same antenna for both transmission and reception.
- In such cases, the relationship between the antenna gain and the receiving effective area of an antenna is given as,

$$G = \frac{4\pi A_e}{\lambda^2} \tag{2.14}$$

where, λ is the wavelength of the transmitted energy. Substituting this relation in (2.13), we obtain another form of the radar equation.

$$R_{max} = \left[\frac{P_t A_e^2 \sigma}{4\pi\lambda^2 S_{min}}\right]^{\frac{1}{4}} \tag{2.15}$$

If we substitute for A_e instead of G then from (2.14), we get

$$A_e = \frac{G\lambda^2}{4\pi} \tag{2.16}$$

and obtain the radar equation as,

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

EXAMPLE 2.2

(a) Find the power density at a target situated at a distance of 50km from a radar radiating a power of 100 MW from a lossless isotropic antenna.

$\underline{ANSWER}$

(a) Power radiated by the radar P_t= 100 MW = 100×10^6 W.

Distance of the target = R = 50Km = 50×10^3m.

Power density at the target

$$= \widehat{P}_d = \frac{P_t}{4\pi R^2} = \frac{100 \times 10^6}{4\pi \times (50 \times 10^3)^2} \tag{2.18}$$

$$= 0.3183 \times 10^{-2} W/m^2 \tag{2.19}$$

(b) If this radar now employs a lossless isotropic antenna with a gain of 5000 and the target has a radar cross-section of 1.2 m2, then what is the power density of the echo signal at the receiver?

(b)Antenna gain G =5000.

Radar cross-section of the target $= \sigma = 1.2m^2$

Power density at the target when a directive antenna is used

$$= P_d = \widehat{P}_d G = 0.3183 \times 10^{-2} \times 5000 = 15.915 W/m^2. \tag{2.20}$$

The amount of power intercepted by the target

$$= \widehat{P} = P_d \sigma = 15.915 \times 1.2 = 19.098 W. \tag{2.21}$$

This power is now reflected back to the receiving antenna. Hence, the power density of the echo signal at a the receiver

$$= P_d^r = \frac{\widehat{P}}{4\pi R^2} = \frac{19.098}{4\pi \times (50 \times 10^3)^2} = 6.079 \times 10^{-10} W/m^2. \tag{2.22}$$

(c) If the minimum detectable signal of the radar is 10^{-8} MW and the wavelength of the transmitted energy is 0.02 m, then what is the maximum range at which the radar can detect targets of the kind mentioned in (b)?

(c) The wavelength of the transmitted energy, $\lambda = 0.02m$.

The minimum detectable signal $S_{min} = 10^{-8} mW = 10^{-11}$w.

Then the maximum range R_{max} is given by (2.17) as

$$R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4} = \left[\frac{100 \times 10^6 \times (5000)^2 \times (0.02)^2 \times 1.2}{(4\pi)^3 \times 10^{-11}}\right]^{1/4} \tag{2.23}$$

$$= 88183.6m = 88.1836Km. \tag{2.24}$$

(d) What is the effective area of the receiving antenna?

(d)From (2.13), the effective area of the receiving antenna

$$= A_e = \frac{G\lambda^2}{4\pi} = \frac{5000 \times (0.02)^2}{4\pi} = 0.0159 m^2. \tag{2.25}$$

(e) Suppose, due to some modifications made in the radar system components, the antenna gain is doubled while keeping the antenna effective aperture constant. Find the new radar range.

(e) Let the new antenna gain be G' = 2G, and the corresponding wavelength be λ'.The new radar range R'_{max} can be found by using either (2.10),). If we use (2.13) then we get,

$$\frac{R'_{max}}{R_{max}} = \left[\frac{G'}{G}\right]^{1/4} = 2^{1/4} = 1.1892. \tag{2.26}$$

So,

$$R'max = 1.1892 \times R_{max} = 1.1892 \times 88.1836 = 104.8Km. \tag{2.27}$$

(f) What is the new radar range if the antenna gain doubles while λ remains constant?

(f) Here, we will use (2.17) to obtain,

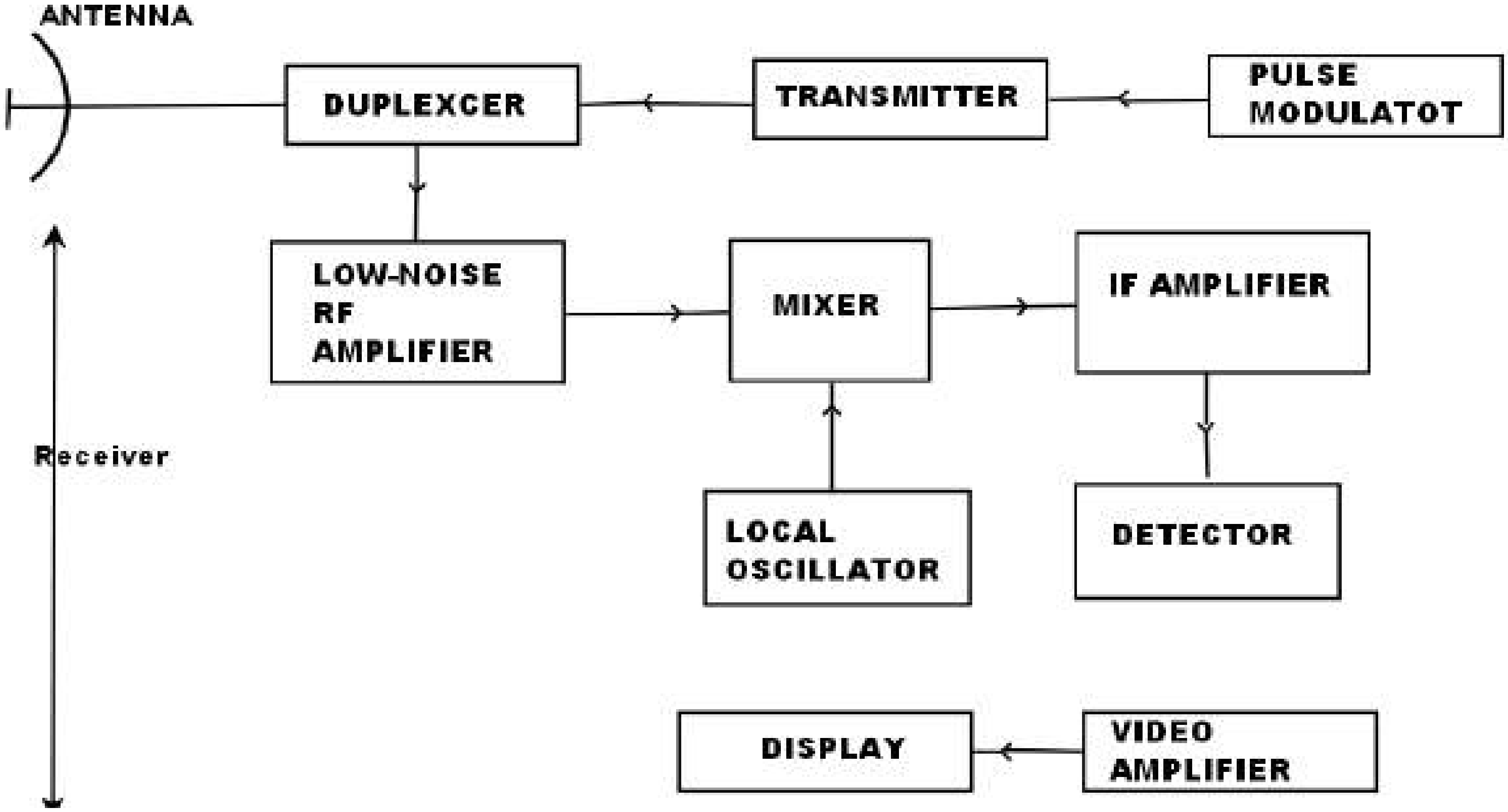
$$\frac{R'_{max}}{R_{max}} = [\frac{G'^2}{G^2}]^{1/4} = (2^{2)1/4} = 1.414 \tag{2.29}$$

Hence,

$$R'_{max} = 1.414 \times R_{max} = 1.414 \times 88.1836 = 124.7Km \tag{2.30}$$

RADAR BLOCK DIAGRAM AND OPERATION

- The block diagram shows the main components of pulse radar.



- The transmitter may be an oscillator, such as a magnetron, which is pulsed (turned on and off) by the modulator to generate a repetitive train of pulses.
- The duplexer consists of two devices, one known as TR (Transmit-Receive) and the other as ATR (Anti-Transmit-Receive).
- The TR protects the delicate circuits of the receiver from the high power of the transmitter during transmission and the ATR channels the returned echo signal to the receiver, and not to the transmitter, during reception.

- The first stage of the receiver is a low-noise RF (radio frequency) amplifier. The mixer and the local oscillator convert the RF signal to an IF (intermediate frequency) signal.
- This signal is passed through an IF amplifier which is designed to maximize the signal-to-noise ratio at its output.
- The pulse modulation of the echo signal is extracted by the detector and amplified by the video amplifier to a level at which the signal can be properly displayed on a CRT (Cathode Ray Tube).
- Timing signals are also supplied for range reference.
- Angle information is obtained from the pointing direction of the antenna.

Radar Frequencies

- Conventionally, radars are usually operated at frequencies between 220 MHz and 35 GHz.
- Millimeter wave radars may operate at 94 GHz. Laser radars have been known to operate at even higher frequencies.

Band designation	Nominal frequency range	Specific radiolocation (radar) bands based on ITU assignments for region 2
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz
		216–225
UHF	300–1000 MHz	420–450 MHz
		890–942
L	1000–2000 MHz	1215–1400 MHz
S	2000–4000 MHz	2300–2500 MHz
		2700–3700
C	4000–8000 MHz	5250–5925 MHz
X	8000–12,000 MHz	8500–10,680 MHz
K_u	12.0–18 GHz	13.4–14.0 GHz
		15.7–17.7
K	18–27 GHz	24.05–24.25 GHz
K_a	27–40 GHz	33.4–36.0 GHz
mm	40–300 GHz	

Range Performance of Radars

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{1/4}$$

where, P_t = Transmitted power, in watts,

G = Antenna gain,

A_e = Antenna effective aperture, in m^2.

σ = Radar cross-section of the target, in m^2.

S_{min} = Minimum detectable signal, in watts.

All the above parameters, except σ, are to some extent under the control of the radar designer.

- In many cases the actual range might be half of that predicted by the above equation.

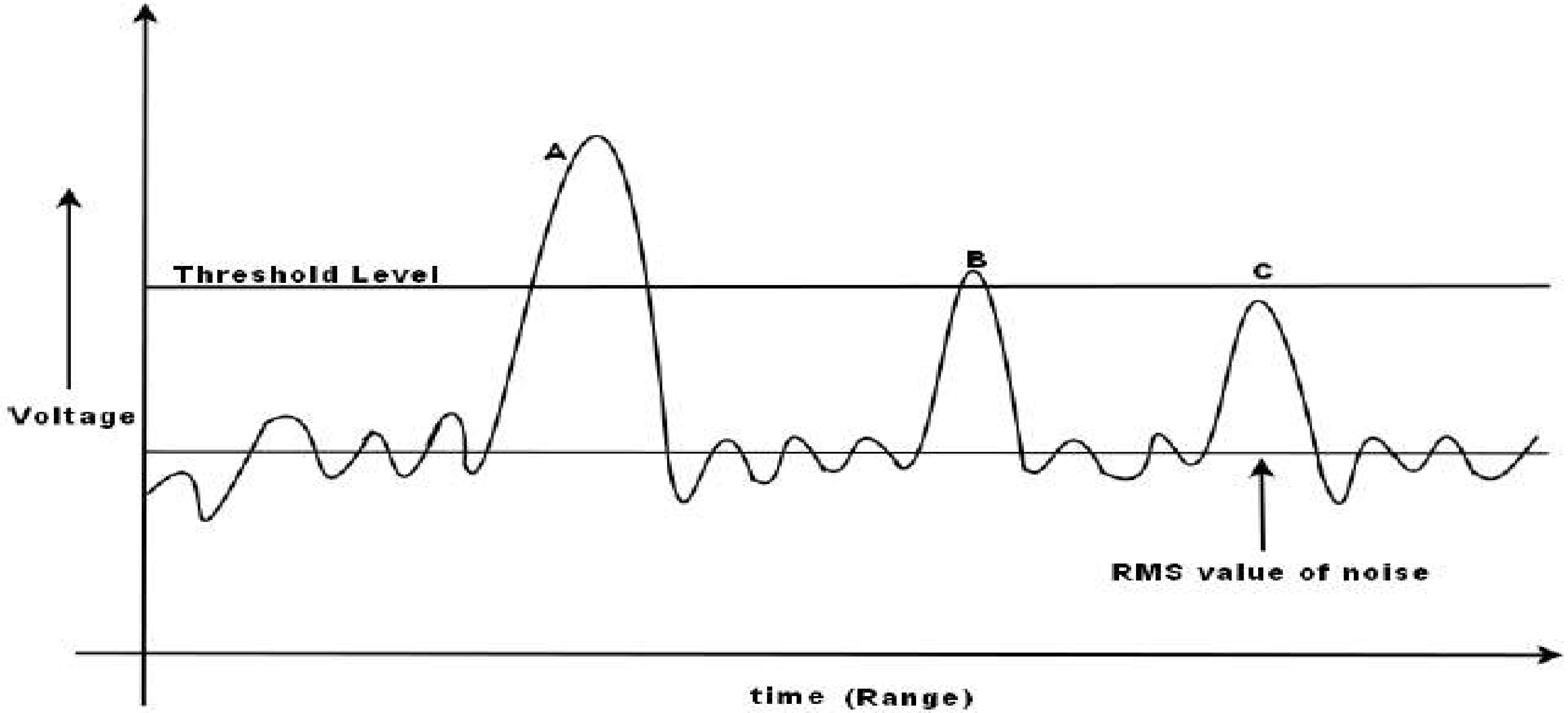
Reasons:

- Failure of the equation to explicitly include various losses
- Loss of performance usually experienced when electronic equipment are operated in the field.
- Statistical and unpredictable nature of the various parameters.

- Both *Smin* and *σ* are statistical in nature and must be expressed as such in statistical terms.
- **Other statistical factors:** meteorological conditions along the propagation path and performance of the radar operator.

Minimum Detectable Signal

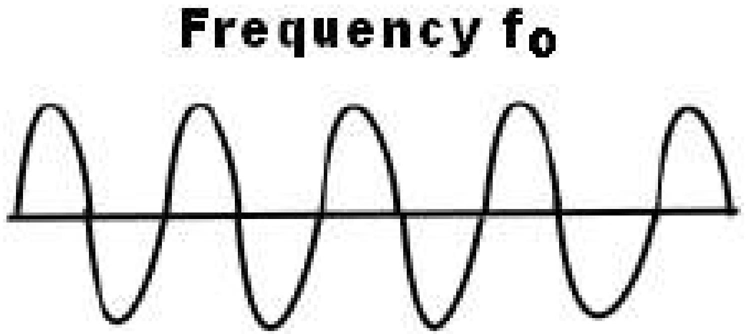
- The weakest signal the receiver can detect is *Smin* (minimum detectable signal).
- Detection is usually done by specifying a threshold at the output of the receiver.
- If the signal exceeds this threshold then a target is assumed to be present. This is known as **threshold detection.**

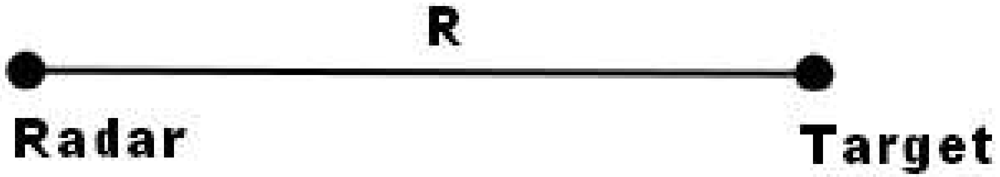

Voltage
Threshold Level
A
B
C
RMS value of noise
time (Range)

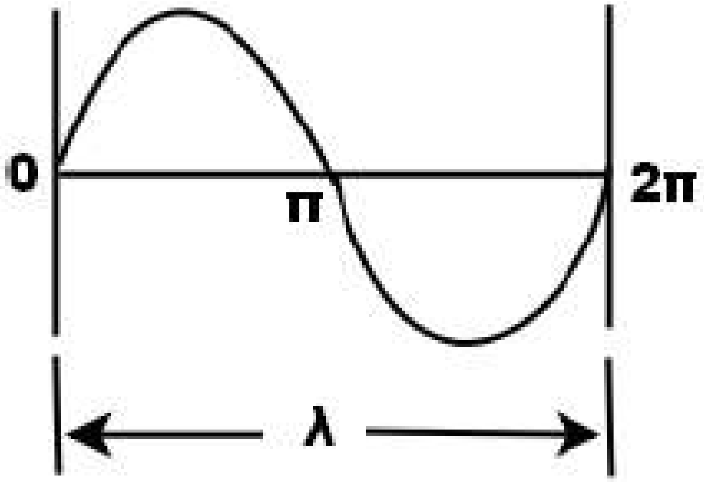
CONTINUOUS WAVE RADAR

Doppler Shift

- If there is relative motion between the source of a signal and the observer of the signal, along the line joining the two, then an apparent shift in frequency will result.
- This is the **doppler effect** and is the basis of CW (Continuous Wave) radars







$$n = \frac{2R}{\lambda}$$

One wavelength corresponds to an angular excursion of 2π radians. Thus, the total angular excursion ϕ made by the electromagnetic wave during its transit to the target and back to the radar is

$$\phi = \frac{2R}{\lambda}.2\pi = \frac{4\pi R}{\lambda} \tag{3.2}$$

When the target is in motion, both R and ϕ are changing. Now a change in ϕ with respect to time is equal to an angular frequency. This, in fact, is the doppler angular frequency W_d,

$$W_d = 2\pi f_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda}.\frac{dR}{dt} = \frac{4\pi V_r}{\lambda} \tag{3.3}$$

From which we get

$$f_d = \frac{2V_r}{\lambda} = \frac{2V_r f_o}{c} \tag{3.4}$$

Where,

f_d = doppler frequency shift, in Hz

c = velocity of propagation = $3 \times 10^8 m/s$

V_r = relative velocity of the target with respect to the radar along the line-of-sight.

For a stationary radar and a moving target the relative velocity may be written as

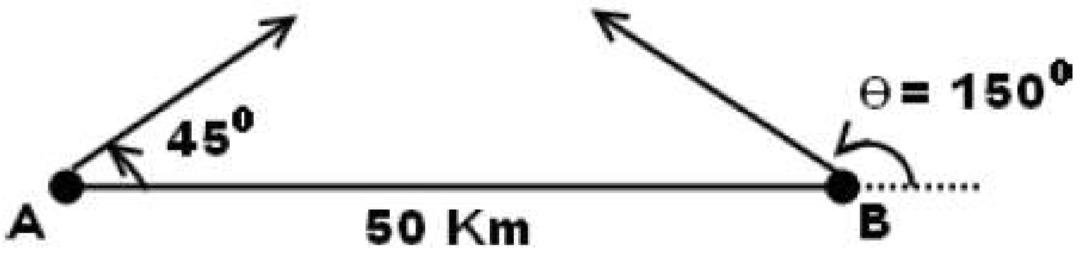
$$V_r = V \cos\theta \tag{3.5}$$

where, V is the target speed and θ is the angle made by the target velocity vector with the LOS. When $\theta = 0$, the doppler frequency is a maximum.

The doppler frequency is zero when the trajectory is perpendicular to the radar-target line-of-sight (that is, $\theta = \frac{\pi}{2} = 90^o$). Also note that the doppler frequency shift positive for an approaching target (that is, V_r is considered to be positive) and negative for a receding target (that is, V_r is considered to be negative).

EXAMPLE 3.1: Positions of the two aircraft, A and B, are as shown in the figure below. Aircraft A has a speed of 600 m/sec and carries a CW radar transmitting at 300 MHz frequency and tracking aircraft B which has a speed of 800 m/sec.

(a) What is the doppler frequency shift recorded by the radar in aircraft A?



ANSWER

(a) The transmitted frequency $= f_0 = 300MHz = 300 \times 10^6 Hz.$

The relative velocity of aircraft A with respect to aircraft B along the LOS is given by,

$$v_r = 600\cos 45^0 + 800\cos 30^0 = 1117.08m/sec. \tag{3.6}$$

The doppler frequency shift

$$= f_d = \frac{2v_r f_0}{c} = \frac{2 \times 1117.08 \times 300 \times 10^6}{3 \times 10^8} = 2234.16Hz \tag{3.7}$$

(b) Is this shift positive or negative?

(b) Note that aircraft B is actually moving towards aircraft A in a relative sense and hence it is an approaching target, that is, the LOS between A and B is shrinking with time. Thus, the doppler shift is positive, which means

that the frequency of the received signal is more than the frequency of the transmitted signal.

(c) What should be the flight direction of aircraft B for the doppler frequency shift to be zero?

(c) The doppler frequency shift will be zero when the relative velocity v_r is zero. This can happen when

$$V_r = 600cos45^0 - 800cos\theta = 0. \tag{3.8}$$

From which we get

$$\theta = \pm 57.97^0. \tag{3.9}$$

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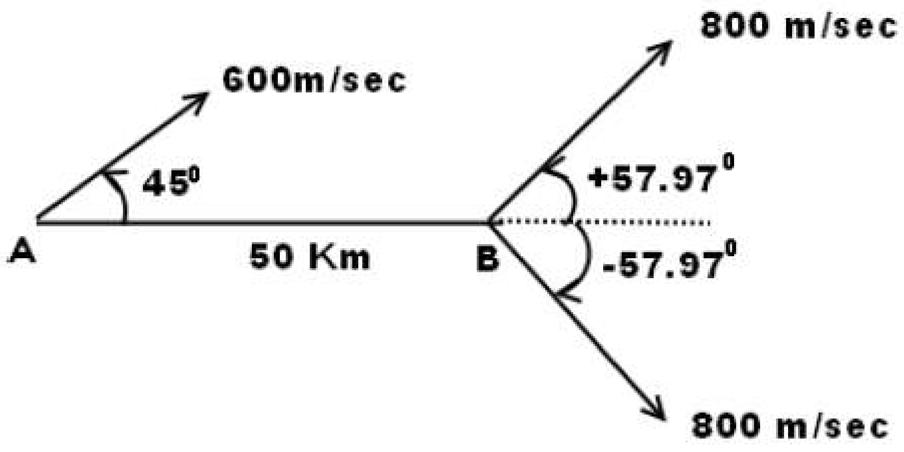


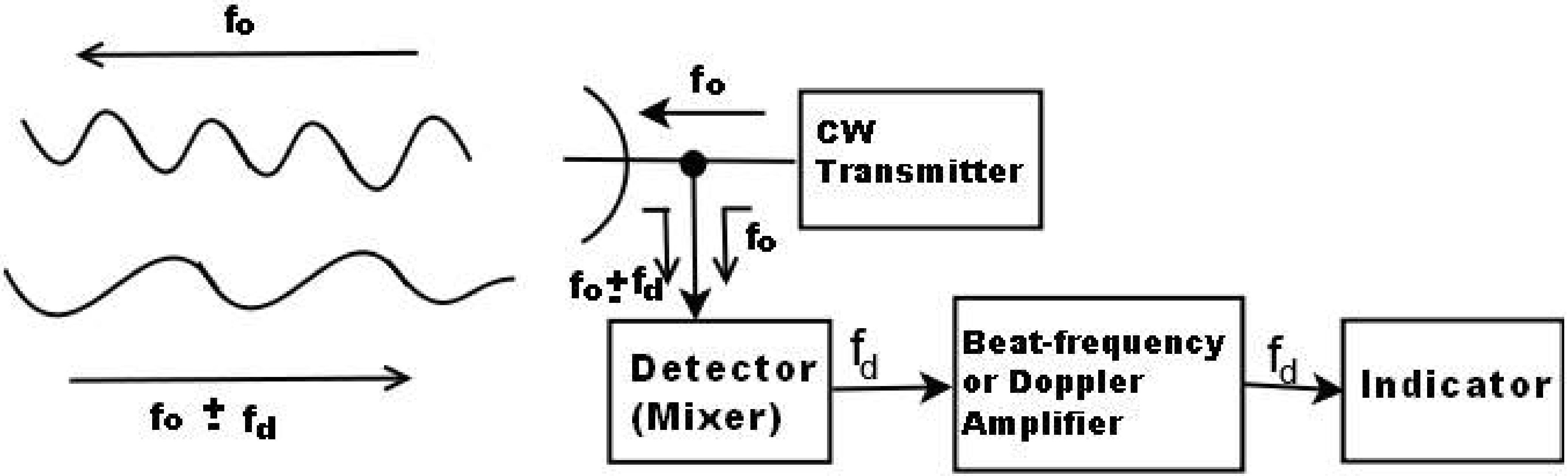
- The change in frequency between the transmitted signal and the received signal allows the received signal to be separated from the transmitted signal.
- Apart from this, the CW radar also provides a measurement of relative velocity which may be used to distinguish moving targets from stationary objects and clutter.

The expression for doppler frequency shift given in (3.4) is somewhat approximate, though it serves quite well for most practical purposes. The correct expression for the frequency f^* of the echo signal from a target, moving with relative velocity V_r, when the transmitted frequency is f_o, is given by

$$f^* = f_0 \cdot \frac{1 + V_r/c}{1 - V_r/c} \tag{3.10}$$

which, on expansion by Taylor's series and truncation beyond the first order term, reduces to

$$f^* = f_0(1 + 2V_r/c) \tag{3.11}$$



fo
fo
CW Transmitter
fo
fo ± fd
fo ± fd
Detector (Mixer)
fd
Beat-frequency or Doppler Amplifier
fd
Indicator

- The received echo signal at a frequency $f_0 \pm f_d$ enters the radar via the antenna and is heterodyned in the detector (mixer) with a portion of the transmitted signal f_0 to produce a doppler beat note of frequency f_d.

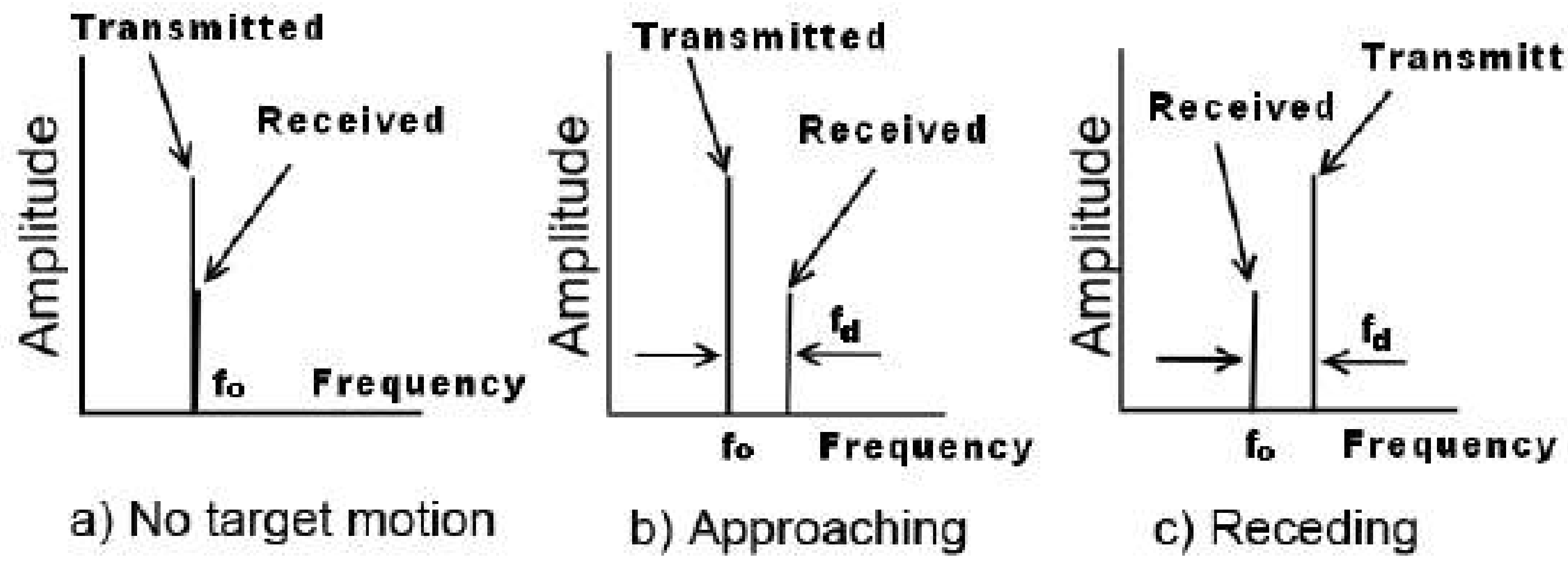
- The purpose of the doppler amplifier (beat frequency amplifier) is to eliminate echoes from stationary targets and to amplify the doppler echo signal to a level where it can operate and indicating device.

ISOLATION BETWEEN TRANSMITTER AND RECEIVER

- The amount of isolation required depends on **the transmitter power and the accompanying transmitter noise as well as the sensitivity of the receiver.**
- In long range CW applications, it is the level of the noise accompanying the transmitter leakage signal which determines the amount of isolation required.

SIGN OF THE RADIAL VELOCITY

- If the echo-signal frequency lies below the carrier, then the target is receding; whereas if the echo frequency is greater that the carrier, then the target is approaching.



Advantages of CW Radars

- Measurement of the relative velocity of a moving target.
- Simpler equipment than a pulse radar.

Disadvantages

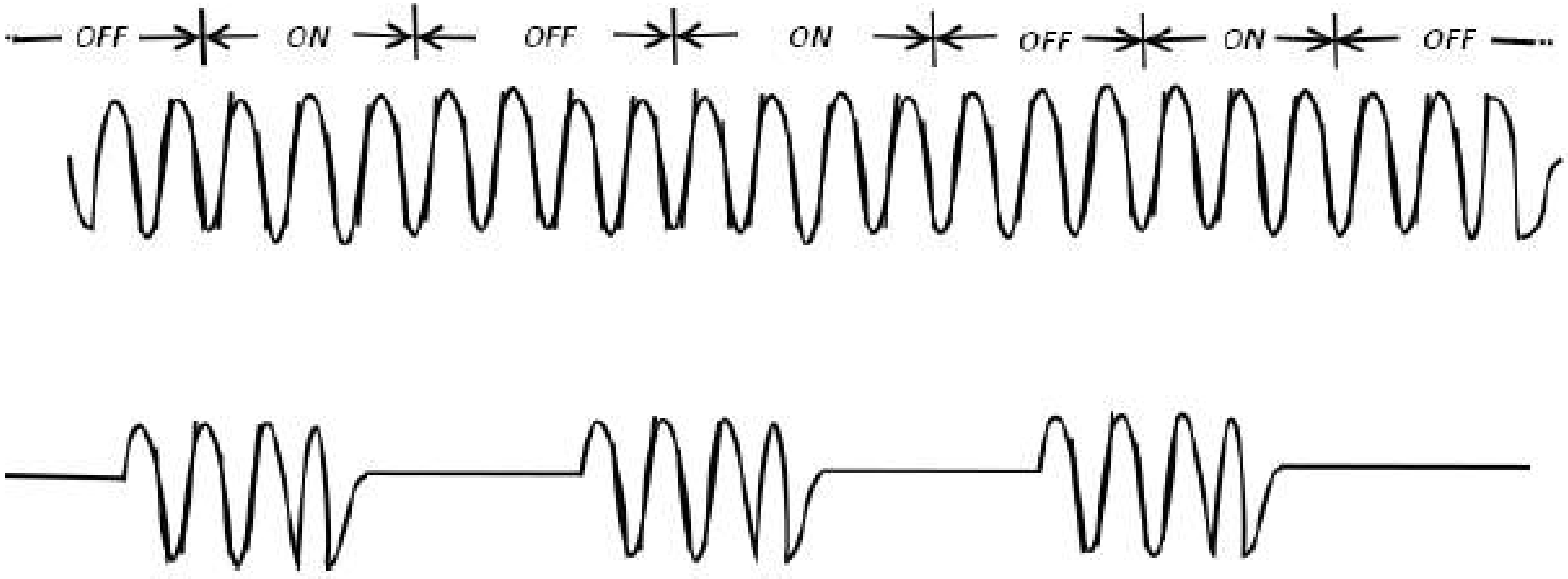
- The amplitude of the signal that can be transmitted by a CW radar is dependent on the isolation that can be achieved between the transmitter and the receiver.
- Inability to obtain a measurement of range.
- This limitation can be overcome by modulating the CW carrier, as in the frequency-modulated radar.

MTI RADARS

- The doppler frequency shift produced by a moving target may also be used in a pulse radar to determine the relative velocity of a target or to separate desired signals from moving targets and undesired signals from stationary objects (clutter).
- Pulse radars which use the doppler frequency shift to distinguish between moving and fixed targets are called MTI (Moving Target Indicators)

DESCRIPTION OF OPERATION

- In principle, the CW radar can be converted to a pulse radar by providing a pulse modulator which turns on and off the amplifier to generate pulses. The output of this operation is



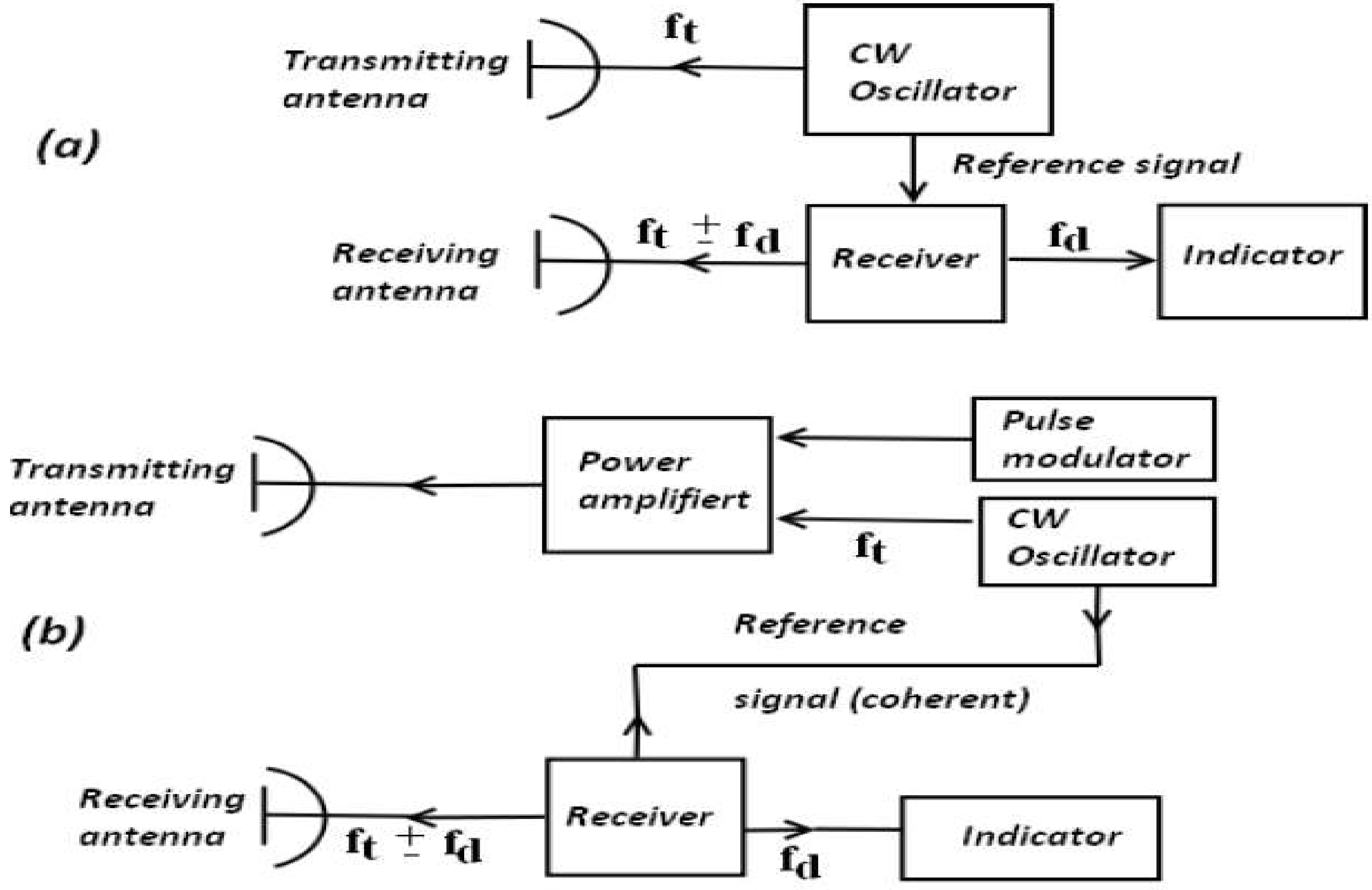


Figure 4.1: Block Diagram of (a) Simple CW Radar and (b) pulse radar using doppler information

- There is no local oscillator here since the reference signal is supplied directly from the CW oscillator.
- Apart from this function the CW oscillator also supplies a coherent reference needed to detect the doppler frequency shift.
- By coherent we mean that the phase of the transmitted signal is preserved in the reference signal.

- Let the CW oscillator voltage be

$$V_{osc} = A_1 sin(2\pi f_t t)$$

The reference signal is

$$V_{ref} = A_2 sin(2\pi f_t t)$$

The doppler-shifted echo-signal voltage is

$$V_{echo} = A_3 sin\left[2\pi(f_t \pm f_d)t - \frac{4\pi f_t R_0}{c}\right]$$

where,

A_1 = amplitude of oscillator voltage

A_2 = amplitude of reference signal

A_3 = amplitude of echo signal

R_0 = range (distance between radar and target)

f_d = doppler frequency shift

f_t = frequency of the transmitted carrier signal

t = time

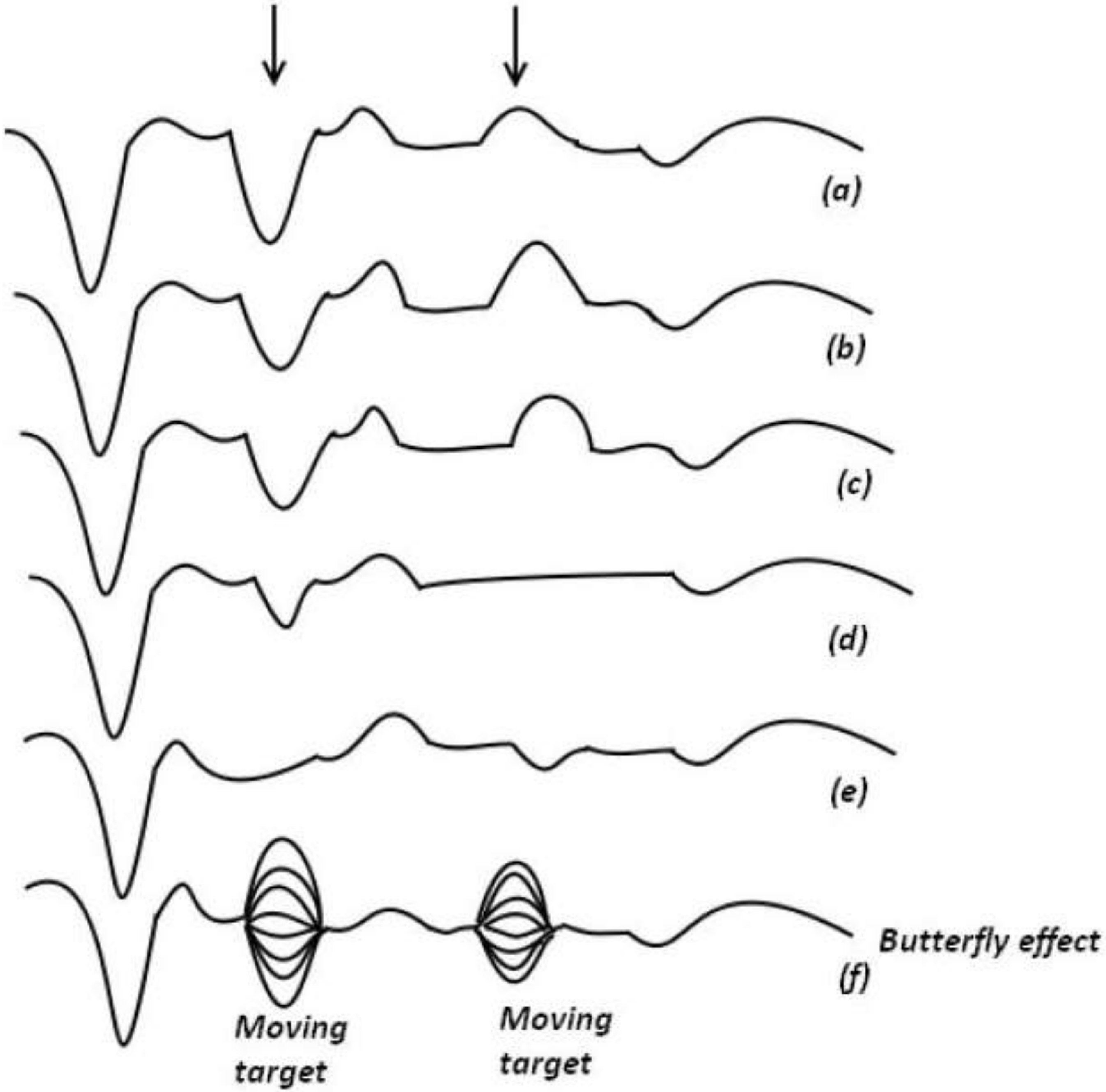
c = velocity of propagation.

The reference signal and the target echo signal are heterodyned in the mixer stage. The difference frequency component is

$$V_{diff} = A_4 sin\left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right] \tag{4.1}$$

- For stationary targets the doppler frequency shift *fd* will be zero; hence *Vdiff* will not vary with time and may take on any constant value including zero.
- But when the target is in motion relative to the radar, *fd* has a value other than zero and the voltage corresponding to the difference frequency from the mixer will vary with time.

- The difference signal is the output of the mixer and is also called the video output, which is displayed on an A-scope (amplitude vs. time or range) in successive sweeps.
- Note that the amplitude of the signals from stationary targets do not change with the number of sweeps. But the echo signals from moving targets will change in amplitude over successive sweeps .
- When these sweeps are superposed over each other due to the effect of persistence of vision, the moving targets will produce signals which on the A-scope display will look like a butterfly opening and closing its wings.


(a)
(b)
(c)
(d)
(e)
(f)
Butterfly effect
Moving target
Moving target

- One method to extract the Doppler information is to employ delay-line cancelers.
- In this the current signal is delayed by one pulse time period and subtracted from the signal coming next.

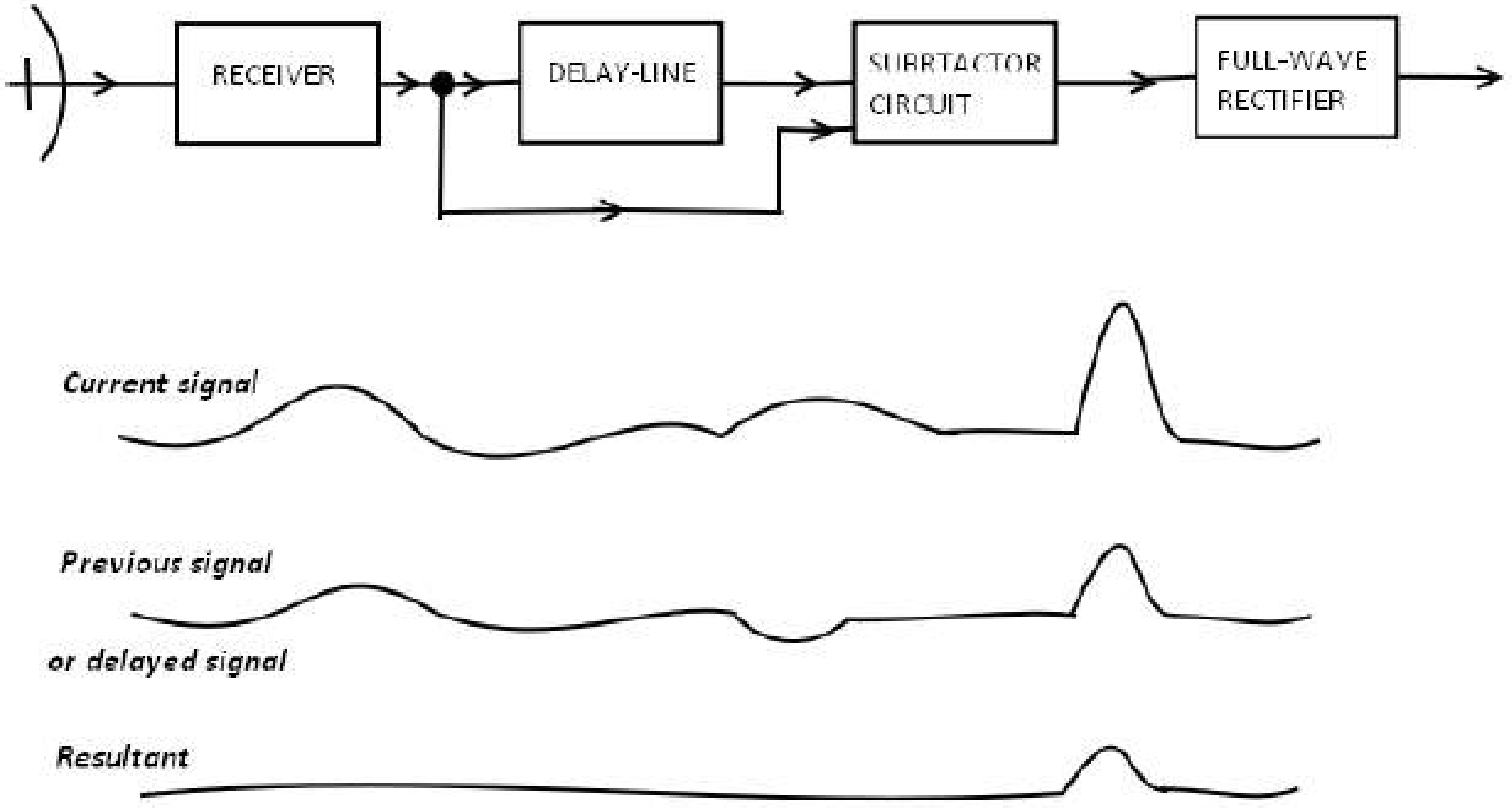
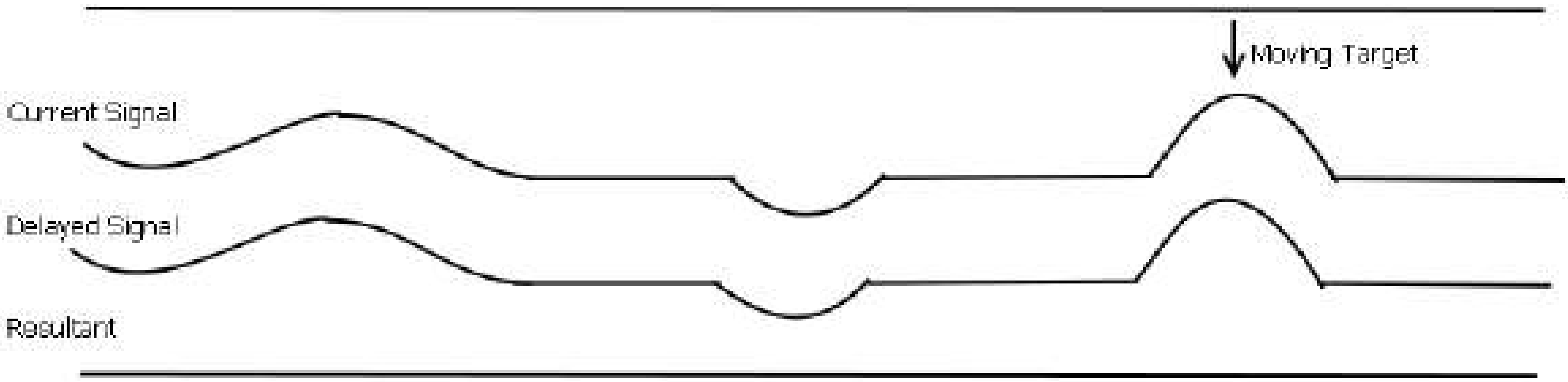


Figure 4.5: (a)Basic delay line canceller block diagram (b) Effect of delay line canceller on the signal

- Only the fluctuating signal from the moving target remains and the signals from the stationary targets are cancelled out.
- Use of delay line cancellers cause problems of **blind speeds**.
- The signal is delayed by one pulse time period and then subtracted.
- Suppose the signal from the moving target fluctuates in such a way that the signal after this time delay is the same as the signal before this time delay. This will happen whenever *fd* is a multiple of *fp* (the pulse repetition frequency), that is,

$$f_d = \mathrm{n} f_p, \quad n = 1, 2, \ldots$$


Moving Target
Current Signal
Delayed Signal
Resultant

When this happens the resultant signal after subtraction is Zero. Thus the radar fails to detect, or is blind to, the presence of such a moving target. Doppler frequency shifts f_d which cause this phenomenon are themselves caused by certain specific target velocities. Substituting the expression for doppler frequency in (4.5), we get,

$$f_d = nf_p = 2v_r/\lambda \tag{4.2}$$

From which we get

$$v_r = \frac{n\lambda f_p}{2} = \frac{n\lambda}{2T}, n = 1, 2, \ldots \tag{4.3}$$

where, T is the pulse time period.

EXAMPLE 4.1: In a MTI radar the pulse repetition frequency is 200 Hz and the carrier transmission frequency is 100 MHz. Find its first, second and third blind speeds.

ANSWER:

The pulse repetition frequency, $f_p = 200$ Hz

The carrier transmission frequency, $f_t = 100$ MHz.

The carrier wavelength,

$$= \frac{c}{f_t} = \frac{3 \times 10^8}{(100 \times 10^6)} = 3m \tag{4.4}$$

The n-th blind speed,

$$v_{rn} = \frac{n\lambda fp}{2} \tag{4.5}$$

So, the first blind speed =

$$\frac{1 \times 3 \times 200}{2} = 300m/sec \tag{4.6}$$

The second blind speed =

$$\frac{2 \times 3 \times 200}{2} = 600m/sec \tag{4.7}$$

The third blind speed =

$$\frac{3 \times 3 \times 200}{2} = 900m/sec \tag{4.8}$$

Summary

- MTI radars operate on low pulse repetition frequencies and thus are prone to blind speeds, but they do not have the problems of range ambiguities.
- MTI radars are usually used as high-resolution surveillance radars.

AIRBORNE RADARS

Typical airborne radars are:

1. Radio Altimeter to detect the altitude at which the aircraft is flying. It can measure altitudes up to 600 m (~2000 ft). This is particularly useful during landing of the aircraft.

2. Weather radar based on strong absorption of radio frequency radiation at X-band (8-10 GHz) frequencies by precipitation-as in rain, clouds, ice, sleet and hail.

3. Surveillance radar for early warning as in Airborne Warning And Control System (AWACS), which provides all-weather surveillance, command, control and communications.

Radio Altimeter (RA)

- Radio Altimeters operate in the S-band (4 GHz) frequency band.
- They are used in instrument landing (ILS) for instrumented approaches and landing.
- Altitudes up to 760 m (-2500 ft) can be very accurately measured (within submeter accuracy). This accuracy is sufficient even for the flare (transition from glide slope to runway landing), during an autoland manoeuvre of a large commercial jet aircraft.
- The operating principle of RA is shown in Figure 11.1.

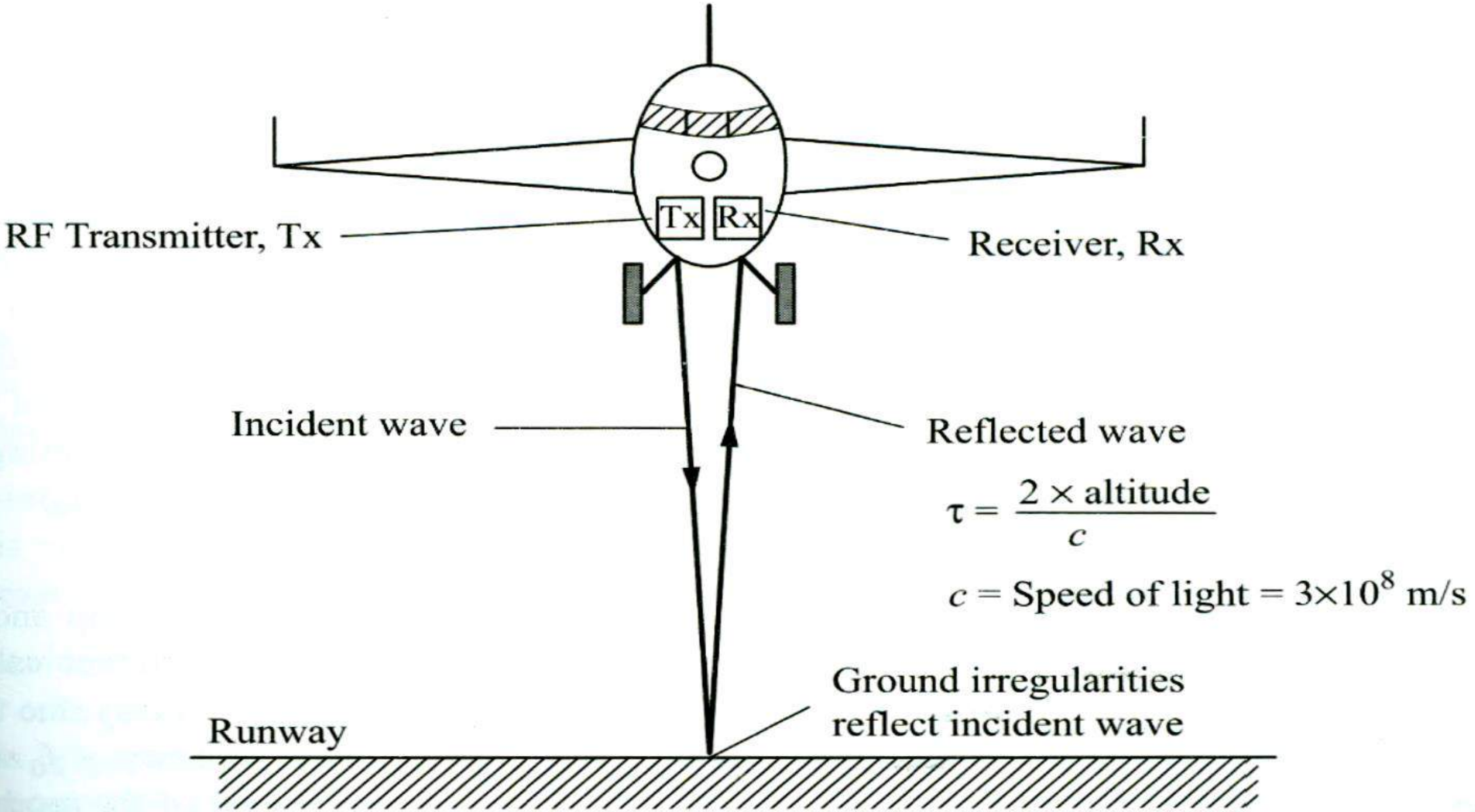


Fig. 11.1 Operating principle of radio altimeter.

- Radio altimeters are short-range, low-power, continuous wave (CW) radars and normally require separate transmit and receive antennas.
- RF signal is beamed towards the terrain and is scattered (reflected). The weak reflected wave is processed to compute altitude as follows: The delay between Tx frequency and Rx frequency is a measure of height of the aircraft and the terrain directly below the aircraft.

- Figure shows the block schematic diagram of FM radio altimeter.
- The sweep generator issues a triangular wave at 400 Hz to a voltage controlled oscillator (VCO). The output of VCO is high frequency rf signal, fo.
- The RF signal is amplified in a buffer amplifier and then coupled to the Tx antenna, located at the bottom of the aircraft.
- The transmitted RF signal is reflected by the terrain. The weak reflected wave is received by a separate Rx antenna.

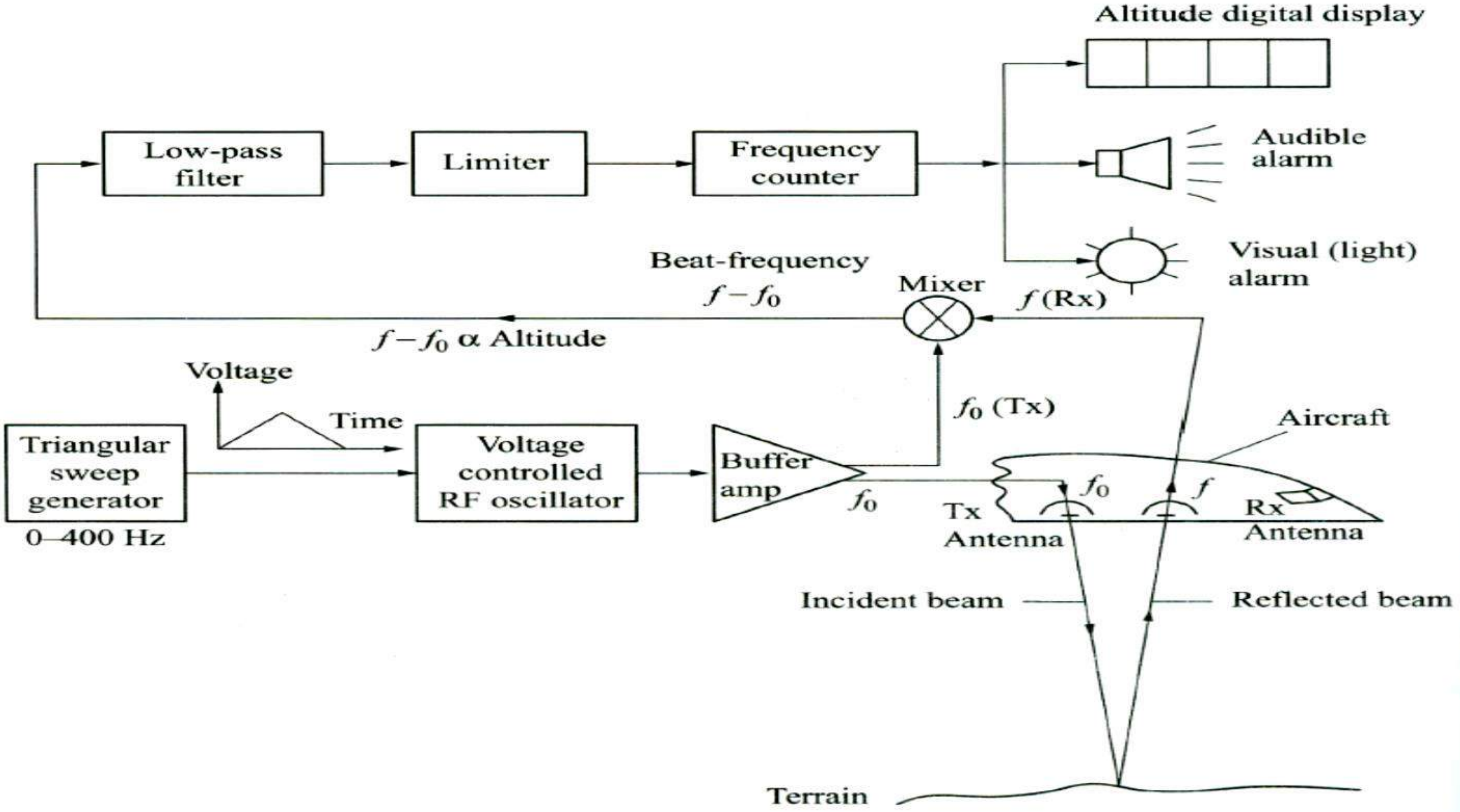


Fig. 11.2 Block schematic of FM radio altimeter.

- The frequency-modulated carrier signal, fa is sent out from Tx antenna, and received by yet another separate antenna, as already mentioned.
- Both Tx and Rx antennas are located at the bottom of the aircraft. The received signal is continuously compared with f0 of the transmitting signal, using a simple beat-frequency modulator, which mixes both fo and f and generates (f-fo)-the beat frequency i.e. the difference between Tx and Rx frequencies.

- Since the transmitter RF frequency is linearly changing (due to sweep generator ramp and VeO), by the time the RF signal returns to the aircraft,fo would have shifted to a different value.
- The magnitude of this shift is greater if the altitude is higher, because of the longer delay due to travel up and down of the transmitted (incident) and reflected waves.
- The beat-frequency, f-fo will thus be proportional to the altitude of the aircraft.
- The beat-frequency output signal of the modulator is passed through a low-pass filter to eliminate noise beyond a certain cut-off frequency.

- The signal is then passed through a limiter to minimise interfering signals due to ground clutter, multipath reflections, etc.
- The signal output from the limiter is then fed into a frequency counter, whose output is
- (i) digitally displayed to indicate the flying altitude
- (ii) to issue an audible alarm if the altitude crosses a predetermined limit and also
- (iii) to give a visual (blinking light) cue to the pilot once the altitude crosses the above predetermined limit.

- Earlier Radio Altimeters used to operate in L-band (1 GHz) at relatively lower frequencies than the present-day RAs, which work in S band (~4 GHz). L-band is also used in UHF television.
- The use of L-band was important in the early development of RAs, since at that time, high-frequency signal generation was both difficult and expensive.
- Present-day RAs use S-band (~4 GHz), since the high-frequency technology has matured.
- Higher frequency is desirable to obtain better accuracy and resolution in the altitude measurement.

Interference

- The received signal is corrupted by unwanted signals due to both internal and external sources.
- The internal noise is due to random variation of signal which is generated by all electronic components. Noise Figure (NF) is a measure of noise produced by a receiver compared to an ideal receiver, and NF should be as low as possible.
- The external noise is due to natural thermal radiation of the background space, surrounding the radar target of interest. If the radar is beamed at clear sky, where the background is very cool, then the noise generated will be very small.

- There is another noise source called flicker noise due to electrons' random transit.
- Flicker noise is very much lower than the thermal noise, particularly when the frequency is very high as is the case in Radio Altimeters.
- The received signal will be corrupted by clutter which are radio frequency echoes returned from targets other than the intended, such as ground, sea, precipitation (rain, snow, hail), sand storms, animals (especially birds) atmospheric turbulence and other atmospheric effects.
- Clutter may also be generated by man-made objects, like buildings. During wars, radar counter measures such as "chaffs" (small pieces of reflectors) are deployed to confuse the enemy radar.

- Clutter tends to be mostly static (not moving) compared to moving targets.
- Static clutter is eliminated by comparing successive radar scans, to distinguish moving targets.
- Sea clutter can be minimised by horizontal polarisation of electric wave (E-field), while the effect of rain is reduced with circular polarisation.

- Clutter may also be generated by multipath echoes from undesirable but valid targets such as ground, atmospheric reflection/refraction, atmospheric ducting, etc.
- Such clutters are particularly troublesome since these appear to move like other normal (point) targets of interest. Such interferences cause "ghost" images.
- Such clutters, particularly ground clutter is minimised by incorporating a ground map of the radar's neighbourhood and eliminating all echoes which appear to originate above at a certain specified height.

Jamming

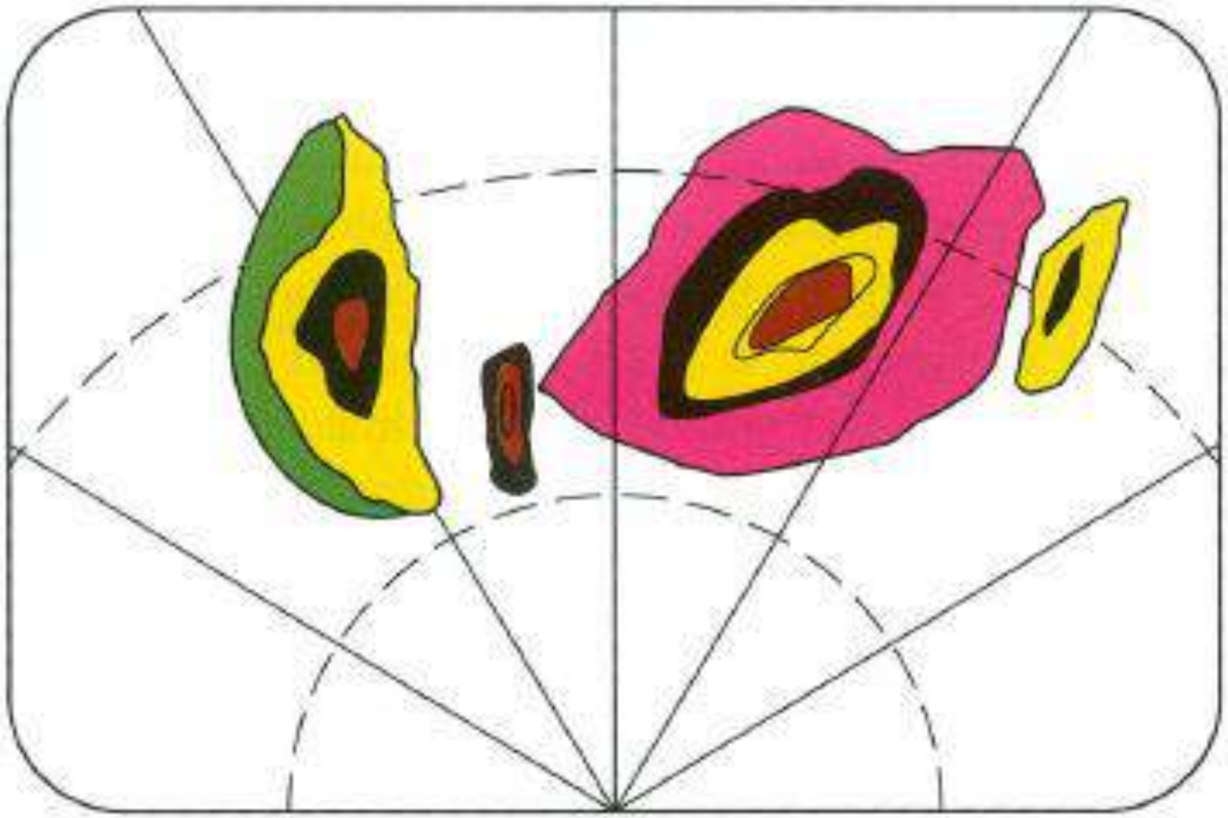
- Like in any other radars, Radio Altimeters also can be easily jammed out of action, by a low-cost jammer which transmits at the same radar frequency.
- Sometimes jamming can be unintentional by friendly forces operating their radar at the same frequency as own radar.
- Jamming happens to be an active interference since it originates outside the radar and it is a random signal uncorrelated to the radar signals.
- Jammers can transmit at lower r.f. power since it is a one-way communication from jammer to the target; on the other hand radar signal should be a two-way path (radar-target-radar).

- In fact, a 2-watt jammer can obstruct even a powerful radar.
- Jammers obstruct targets situated between the jammer and the receiver, along the Line-of-Sight (LOS). This is known as main lobe jamming.
- Jammers can affect side lobes as well--such interference is called side lobe jamming.
- Main lobe jamming is minimised by reducing the solid angle coverage of the main lobe. Side lobe jamming is eliminated largely by using an omnidirectional receiver antenna to detect and reject all lobes other than main lobe.
- Jamming can be countered (eliminated) using randomised frequency hopping (spread-spectrum) and polarisation. Such techniques are known as Electronic Counter Measures (ECMs).

Weather Radar (WSR)

- A weather radar or weather surveillance radar (WSR) is intended to detect and display hazardous weather systems that are potentially dangerous to the safe flight of aircraft--such as wind shear, microbursts, heavy turbulence, multiple conventional storms, etc.
- Being aware of the hazardous weather ahead (up to about 300 km), pilot will be able to avoid bad weather.

- The weather data is displayed in a dedicated colour monitor as shown in Figure; it can also be displayed in HSI, for pilot's convenience, to evade enroute bad weather.
- The display will be in colour to highlight varying intensities of precipitation.



Colour coding used	
Black	Very light rain
Green	Light rain
Yellow	Medium rain
Red	Strong rain
Megenta	Heavy turbulence

Fig. 11.3 Typical weather display in WSR, in colour.

- The basic principle of operation is, in X -band (8-10 GHz) of electromagnetic spectrum, there will be strong echoes (reflections) due to precipitation.
- While these echoes are a noise source in normal radar target identification, they actually form the basis of weather radar, to display weather ahead of the aircraft up to a distance of 300 km (~180 nm).
- The principle of operation is like that of a primary surveillance radar, in which a strong microwave signal is transmitted, which is then reflected back and picked up by an extremely sensitive receiver. The electrical signal picked up by the receiving antenna is called the echo or return.

Airborne weather RADAR

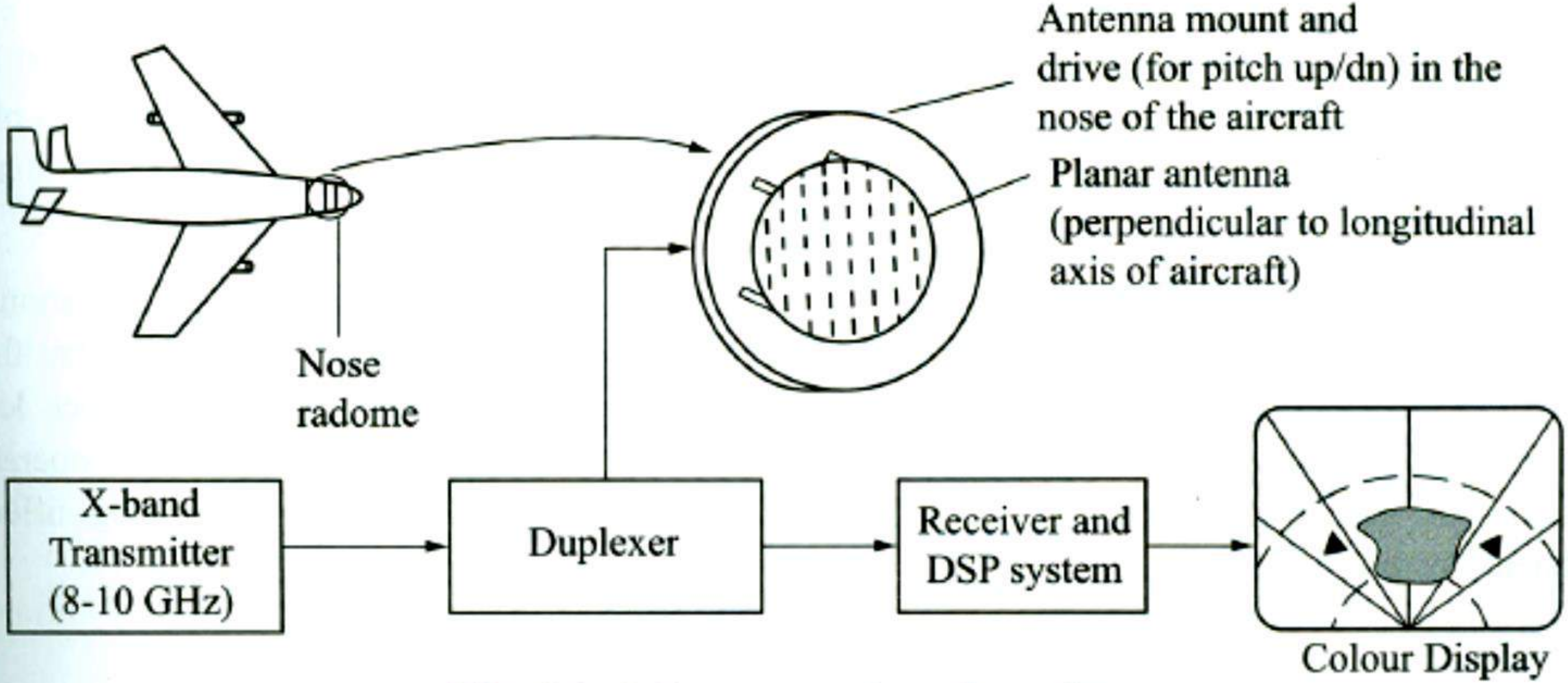


Fig. 11.4 Nose-mounted weather radar.

- Airborne weather radar is mounted within the nose radome.
- Planar slotted antennas are used, an they can be pitched up and down by a precision electric motors, as in older weather radar.
- Modern radars use electronic steering, using phased-array principle.
- The radar beam is electronic all steered, without any mechanical movement of the antenna, by altering the phase of electrical feed to each element of the planar array antenna.

- Further, modem weather radars use multiscan at different tilt angles, as shown in Figure to observe the prevailing weather and store data in computer memory.
- Using DSP techniques, stored multiscan data is merged with ground clutter, using ground suppression algorithms.

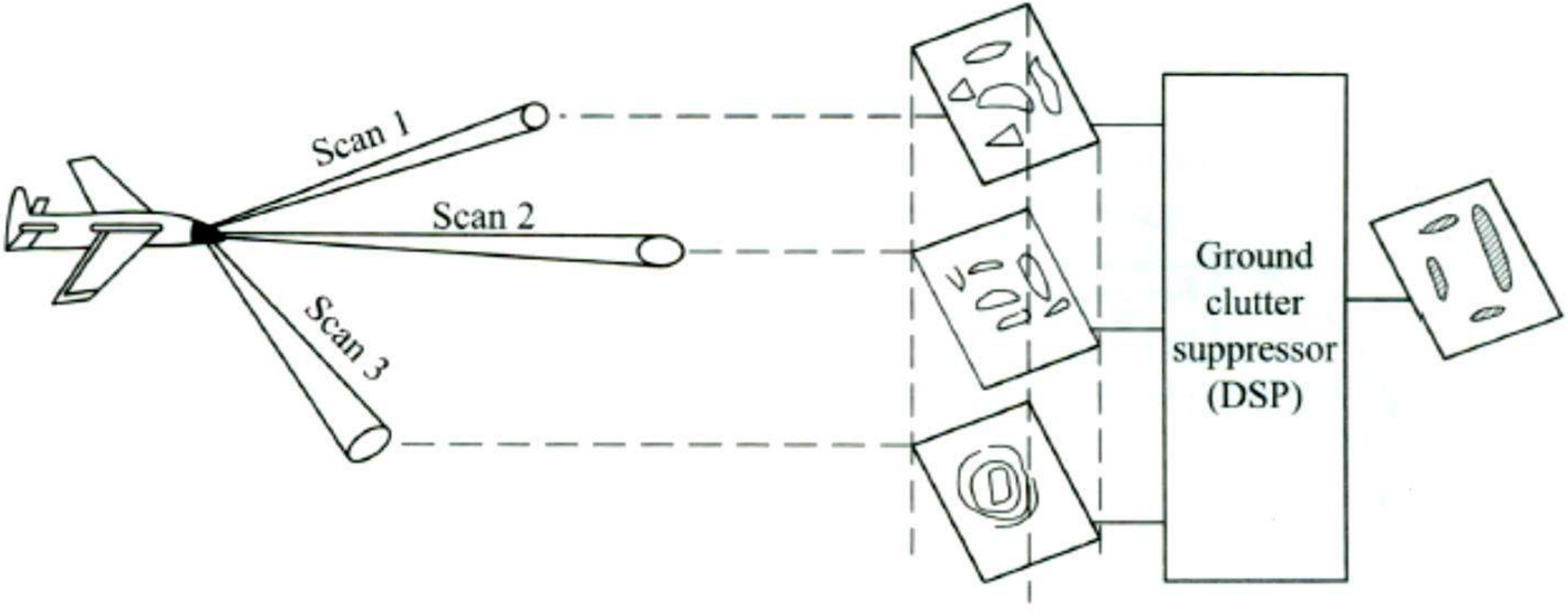


Fig. 11.6 Multiscan weather radar.

- The final computed weather scenario is then displayed on a colour monitor.
- Pilots will then be able to view all significant weather systems existing directly ahead of the aircraft up to a distance of 300 km, essentially free from spurious echoes (ground clutter particularly).
- This whole process takes place automatically and is completely transparent, to the pilot allowing him to focus his attention on weather avoidance, rather than on weather detection and analysis.

Airborne Surveillance Radars

- Airborne surveillance radar, which is of tremendous use for military operations--Airborne Early Warning and Control System-AEW&C.
- Previously it was known as Airborne Warning and Control System-AWACS, and Airborne Early Warning System (AEW).
- AWACS provides all-weather surveillance, command, control and communications, needed by commanders of air tactical forces.
- It is a premier air battle command and control aircraft in the world today.
- It is used at high altitude for offensive and defensive operations.
- Offensively to direct fighters to their targets, and defensively for counter attacks.

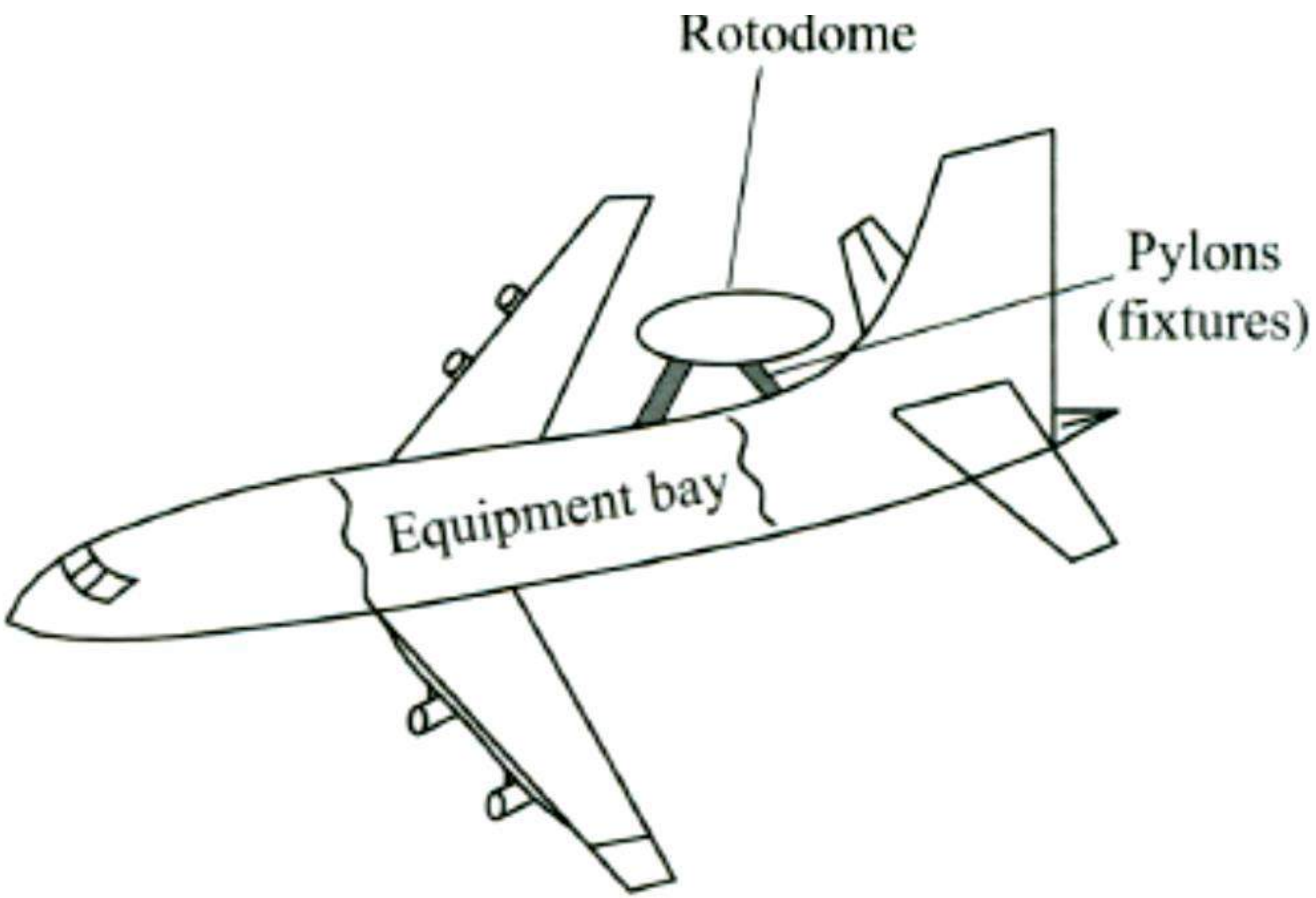


Fig. 11.7 A typical AWACS aircraft with rotodome.


USAF

- AWACS comprises
- (i) rotating dome (rotodome) which houses the transmitter array and associated electronics, mounted atop an aircraft platform (earlier Boeing 707, and now Boeing 767 aircraft)
- (ii) on-board equipment (analog and digital) within the fuselage to provide transmission signal, receive and process return echoes from targets.

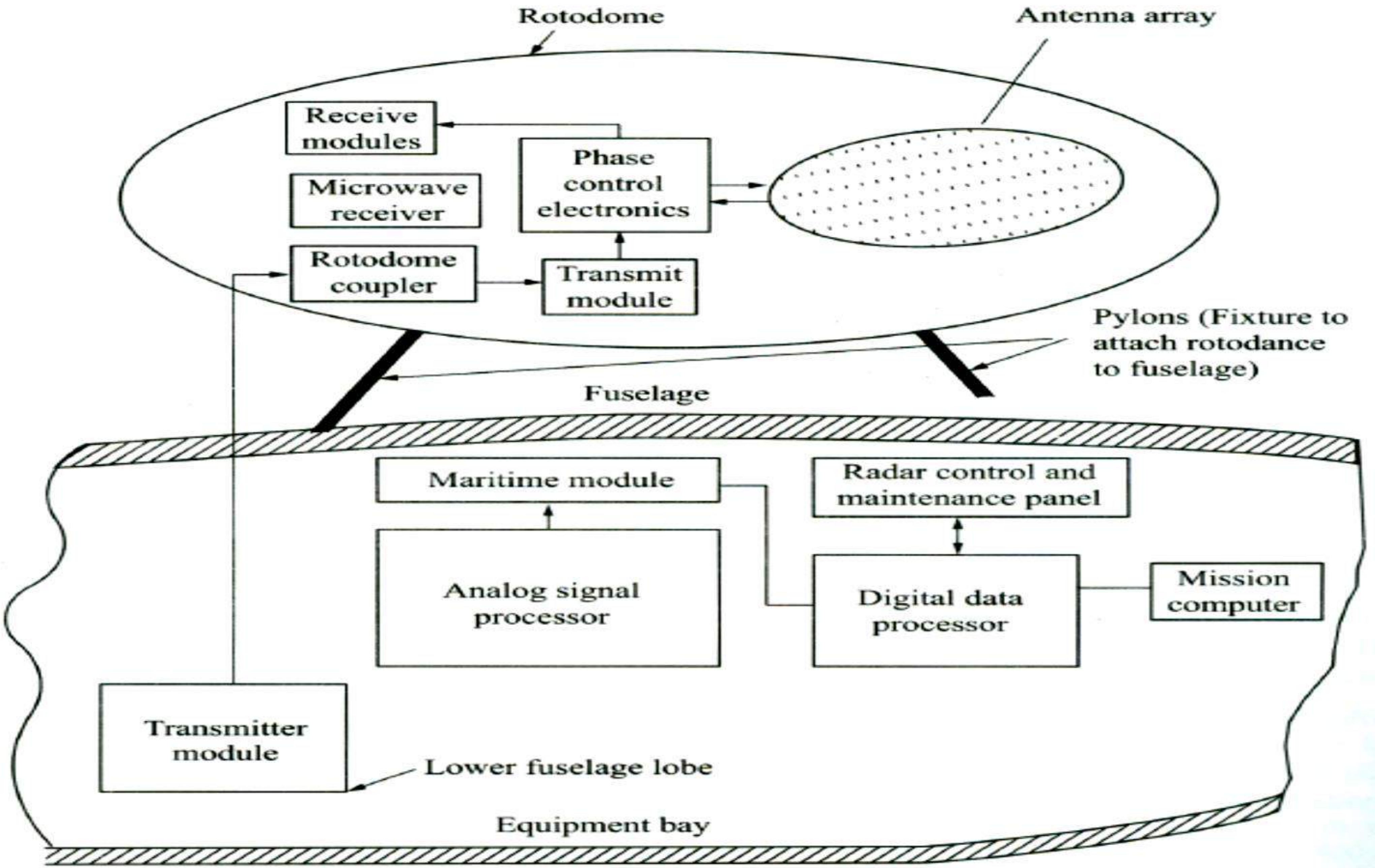


Fig. 11.8 Block diagram of a typical AWACS system.

- The AWACS surveillance radar comprises several units grouped together in three locations of the aircraft platform.

(i) Rotodome containing the planar antenna array and associated phase shifter and beam steering electronics.

(ii) Main Cabin (in fuselage) contains the equipment bay housing the RF receivers, radar analog and digital processors and radar control and maintenance panel.

(iii) Lower fuselage lobe has the transmitter module containing klystron power amplifier, high-voltage power supplies and transmitter pulse drives.

- Modem AWACS have Boeing 767 aircraft with four jet engines as the basic platform modified to carry rotodome and associated electronic systems to carry out C3 (command, control, and communication) functions mentioned above.
- They fly at an altitude of up to 9150 m (30,000 ft), and has detection capability of any aircraft (friend or foe) flying 400 km away. Further, they communicate and command the friendly aircraft.
- However, AWACS send out such strong signals, that enemy forces beyond 800 km range can readily detect the presence of AWACS, and this is a disadvantage.

- Each of the four engines of the aircraft has a generator to provide a total power of about 1 mega watt required for the radars.
- The radar itself is a Pulsed Doppler Radar (PDR) which measures the slant range to the target, as well as, the radial velocity along the RF beam.
- The PDR is of great use in detecting moving targets, by eliminating the ground clutter which are static as against moving targets. This capability is known as MTI--Moving Target Indication, which is of great tactical advantage.

- Earlier AWACS used standard TTL (Transistor-transistor logic) and Emitter coupled logic (ECL) logic circuits.
- An improved design uses commercial off the shelf (COTS) computer, using high level language instead of earlier assembler language.
- The FFT resolution is also enhanced from 8-bit FFT to 24-bit FFT and I2-bit ADC to IS-bit ADC.
- These hardware and software upgrades, improve radar performance and give enhanced detection of even targets with low-Radar Cross

- There is another type of electronically scanned array radar, designed to be carried on board fighter aircraft, such as Sukhoi 30 MKI (meant for India).
- This radar is capable of simultaneously tracking up to 20 targets and engaging up to 6 targets simultaneously.
- The radar primarily consists of passive electronically scanned array antenna and associated electronics to search and track targets.
- The radar is of Pulse-Doppler type, capable of detecting moving targets such as other aircraft, helicopters and missiles.
- It uses X-band (8-10 GHz) part of the electromagnetic spectrum.
- The radar has a typical range of 200 km for a target with RCS of about 20 m2.

Thank You