CW AND FMCW RADAR

Topics :-

* Doppler Effect
* CW Radar – Block Diagram.
* Isolation between Transmitter and Receiver
* Non-zero IF Receiver
* Receiver Bandwidth Requirements.
* Applications of CW Radar
* Range and Doppler Measurement
* FMCW Radar Block diagram, characteristics.
* FM-CW altimeter
* Multiple frequency CW Radar
* problems

→ The radar which operates with continuous signal or wave is called continuous wave radar.

- They use doppler effect for detecting non-stationary targets.
- Continuous wave radars can be classified into two types.
  1. Unmodulated continuous wave radar.
  2. Frequency modulated continuous wave radar.

- Unmodulated cw radar :- The radar which operates with continuous signal for detecting non stationary targets is called unmodulated cw radar (or) simply cw radar (or) cw doppler radar.

✓ This type of radar requires two antennas. One antenna for transmitting the signal and other for receiving the signal.

✓ It measures only the speed of the target but not the distance of the target from the radar.

Frequency modulated CW radar (FMCW radar) :- If CW radar uses the frequency modulation then that radar is FMCW radar (or) it can also called as continuous wave frequency modulated radar.

✓ This radar also requires two antennas. This radar measures not only the speed of the target but also the distance of target from the radar.

→ Doppler Effect :-

Doppler effect implies that the frequency of a wave, when transmitted by a source is not necessarily the same as the frequency of the transmitted wave when picked up by a receiver.

✓ The Received frequency depends upon the relative motion between the transmitter and receiver.

✓ If the transmitter and receiver both are moving towards each other, the received frequency is higher. This is true, even if one is moving.

✓ If they are moving apart, the received signal frequency decreases. If both are stationary, the frequency.

remains the same. This change in frequency is known as Doppler shift. Doppler shift depends on the relative velocity between the two.

Doppler shift is given by

$$\boxed{\Delta f = \frac{2V_r}{\lambda}}$$

where V_r = Relative velocity between the source and target.

λ = Transmitted wavelength.

This principle is used in Doppler radar to find the velocity of the moving target.

Doppler frequency shift :-

If the target is in motion, (then the radar can send Electromagnetic (EM) signals) then it results in a frequency shift the resultant frequency shift is called Doppler effect. shift

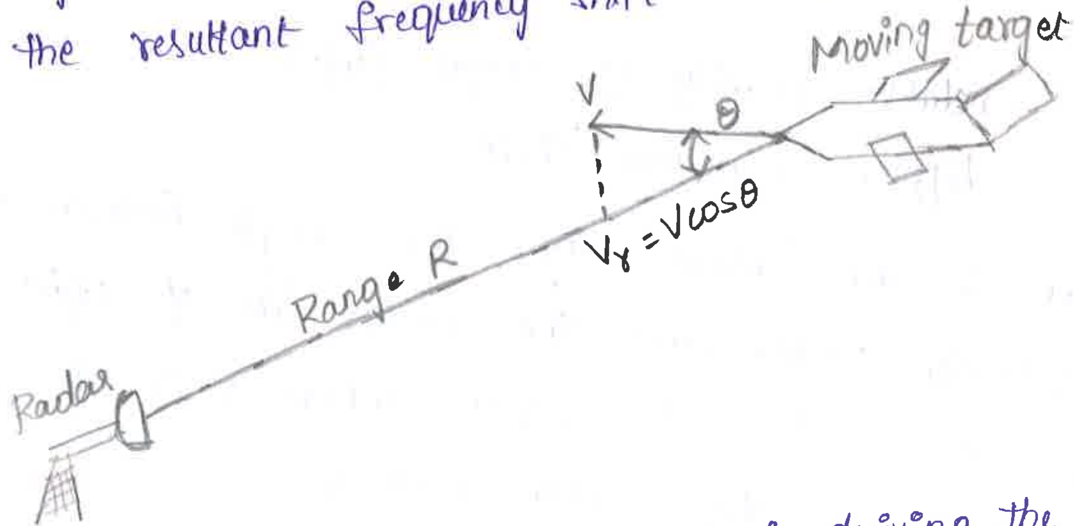


fig : Geometry of radar and target in deriving the Doppler frequency shift.

If 'R' is the distance from radar to the target, the total number of wavelengths λ is contained in the two way path from radar to the target is $\frac{2R}{\lambda}$.

✓ Each wavelength corresponds to ~~phase~~ phase change of 2π radians.

✓ The total phase change in the two-way propagation path is given.

$$\boxed{\phi = 2\pi \times \frac{2R}{\lambda} = \frac{4\pi R}{\lambda}} \quad (1).$$

✓ The target is in motion relative to the radar, R is changing and so will the phase.

✓ Differentiating the above equation with respect to time gives the rate of change of phase, which is the angular frequency (or doppler angular frequency ω_d) is given by

$$\omega_d = \frac{d\phi}{dt} = \frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right) = \frac{4\pi}{\lambda}\frac{dR}{dt}$$

$$= \frac{4\pi V_r}{\lambda} \quad \left(\because \frac{dR}{dt} = V_r\right) \quad (2).$$

where,

V_r = relative velocity of target. (m/s).

f_d = doppler frequency shift.

✓ If as in the above fig, the angle between the radar line of sight to target's velocity vector and the target is θ, the $V_r = V\cos\theta$, where V is the speed (or) magnitude of the vector velocity.

✓ The rate of change of ϕ with time is the angular frequency, $\boxed{\omega_d = 2\pi f_d}$

from equation ②.

$$\omega_d = \frac{4\pi V_r}{\lambda}$$

$$2\pi f_d = \frac{4\pi V_r}{\lambda}$$

$$\boxed{f_d = \frac{2V_r}{\lambda} = \frac{2V_r f_t}{\lambda} \text{ (or) } \frac{2V_r f_o}{\lambda}} \quad (\because \lambda = c/f).$$

where, f_o (or) f_t = transmitted frequency and

c = velocity of propagation = 3×10^8 m/s.

✓ If f_d is in Hertz, V_r in knots and λ in metres, we can write

$$f_d\,(Hz) = \frac{1.03\,V_r(kt)}{\lambda(m)} \simeq \frac{V_r(kt)}{\lambda\,(m)}$$

Problems :-

① Find the doppler shift caused by a vehicle moving toward a radar at 96 km/h, if the radar operates at 10GHz

sol Relative velocity $V_r = 96\text{ km/h} = \frac{96\times1000}{3600} = 26.7$ m/sec.

$f = 10\text{GHz} = 10\times10^9$ Hz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\text{ m}$$

Doppler shift is given by

$$f_d \text{ (or) } \Delta f = \frac{2V_r}{\lambda} = \frac{2\times26.7}{0.03} = 1.78\text{ KHz}$$

② what is the Doppler shift when tracking a car moving away from radar at 100 miles/hour? The radar is operating at 1GHz.

sol $V = 100$ miles/hr $\quad$ 1 mile/hr $= 0.5$ m/s

$\therefore 100$ miles/hr $= 100 \times 0.5 = 50$ m/sec.

$f = 1$ GHz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{1\times10^9} = 0.3 \text{ m/sec.}$$

Car is moving away from radar, therefore $\theta = 0^\circ$ and $\cos 0^\circ = 1$.

→ The doppler shift is given by

$$f_d \text{ (or) } \Delta f = \frac{2V\cos\theta}{\lambda} = \frac{2\times50\times1}{0.3} = 333.34 \text{ Hz}$$

→ CW radar / CW Doppler radar :-

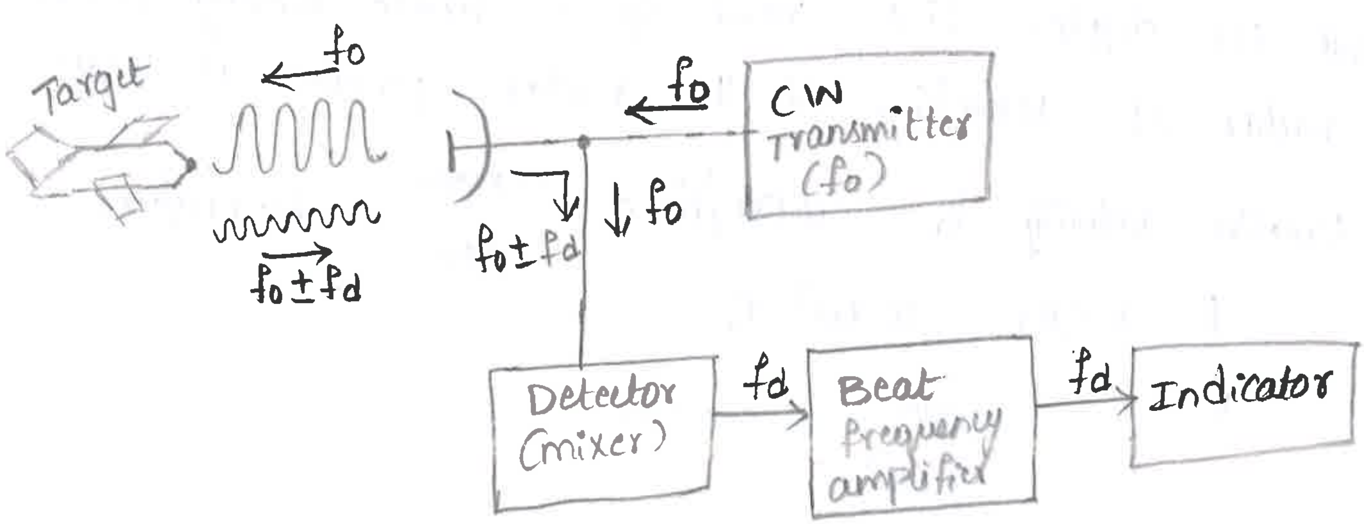


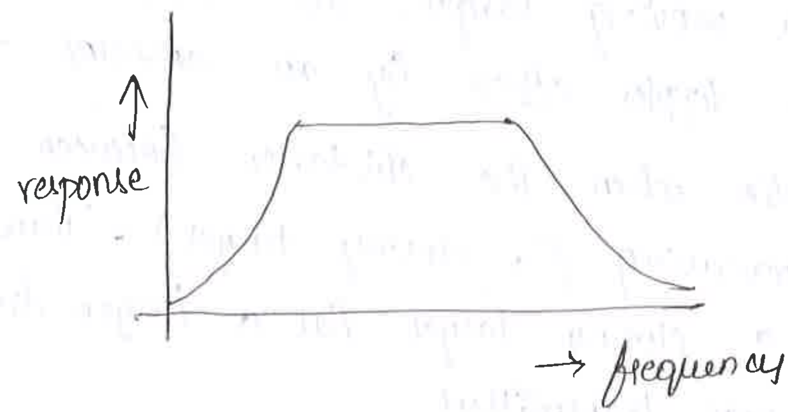
fig : Block diagram of CW radar

✓ The transmitter generates a continuous wave of oscillation frequency fo, which is radiated by an antenna.

✓ The amount of radiated energy is intercepted by the target and some of the energy is scattered back in the direction of radar. This energy is collected by the receiving antenna.

- On reflection by a moving target, the transmitted signal is shifted by the doppler effect by an amount $\pm f_d$.
- The plus sign applies when the distance between raddar and target is decreasing (a closing target). Thus the echo signal from a closing target has a larger frequency than that which was transmitted.
- The minus sign applies when the distance is increasing (a receding target).
- To utilize doppler frequency shift a radar must be able to recognize that the received echo signal has a frequency different from that which was transmitted.
- This is the function of that portion of the transmitter signal that finds its way (or leaks) into the receiver,
- as the transmitter leakage signal acts as a reference to determine that a frequency change has taken place.
- The Received signal (echo signal) $f_o \pm f_d$ is mixed in the detector, to produce doppler frequency f_d.
- It is given to the doppler amplifier, which eliminates echoes from stationary targets and amplify the doppler echo signals.

- The doppler filter allows the difference frequency from the detector to pass and rejects the higher frequencies.
- The filter characteristic is shown in below fig.



- It has a lower frequency cut-off, it must be high to reject DC components. and the upper frequency cut-off is selected to pass highest doppler frequency.
- The Indicator must be used as a pair of earphones (or) frequency meter.
  * Ear phones provided doppler frequencies like with in the audio frequency response of the ear.
  * Frequency meters are used to count the cycles.

→ Difference between CW Radar and pulse radar :-

CW Radar	Pulse radar
→ The radar which employes continuous transmission for detecting target is called CW radar.	→ The radar which employes a pulse transmission i.e during the transmission receiver is in off state, during the reception, transmitter is in OFF state for detecting targets is called pulse radar

→ Using CW radar it cannot measure the range at which the target is detected.	→ we can measure range along with the relative velocity of the target.
→ simple circuitary.	→ complex circuitary
→ small size	→ large size.
→ CW radar most likely used IF doppler filter banks.	→ Pulsed radar used range gated doppler filter banks.
→ It is more sensitive to clutter and they cannot used gating to ignore clutter.	→ These radars are more capable of reducing clutter.

→ Isolation between Transmitter and Receiver :-

The main purpose of Providing Isolation between Transmitter and Receiver is to eliminate the Transmitter leakage signal.

✓ Generally separate antennas are used for Transmission and reception, so that there is no chance of leakage entering the Receiver.

✓ The isolation between Transmitter and receiver is possible using single antenna as in CW radar.

✓ In CW radar, separation of frequency as a result of doppler effect. In practice, it is not possible to eliminate completely the Transmitter leakage. A moderate ~~of~~ amount of leakage entering the Receiver along with the echo signal for the detection of doppler frequency shift.

- If the transmitter having leakage power then the receiver sensitivity can be reduces.
- There are 2 practical effects which limit the amount of power which can be tolerated at the receiver.

i) The maximum amount of power the receiver i/p circuitary can withstand before its sensitivity reduced.

ii) The amount of transmitter noise due to hum, microphonics, stray pick up, instability which enters the receiver from the transmitter.

- The noise that accompanies the transmitter leakage signal will determine the amount of Isolation needed in a long range CW radar.
- For Example, 10mw of leakage signal is appeared at the Receiver. for a proper Isolation b/w Transmitter and Receiver. The transmitter noise must be 110dB below the transmitted carrier for a minimum detectable signal of 10^{-13} watt.
- The Isolation between Transmitter and Receiver can be obtained with a single antenna (like CW radars) by using a hybrid-Junction, circulator, turnstile Junction or with separate polarizations.
- The Isolation achieved by hybrid Junctions such as magic Tee, rat race (or) directional coupler is 60dB in extreme cases, the isolation in practical cases is order of 20 (or) 30dB.

✓ The limitation of hybrid junction is 6dB loss in overall performance which results waste half of Transmitted power & half of received power. Thus hybrid junctions are applicable to short-range radars.

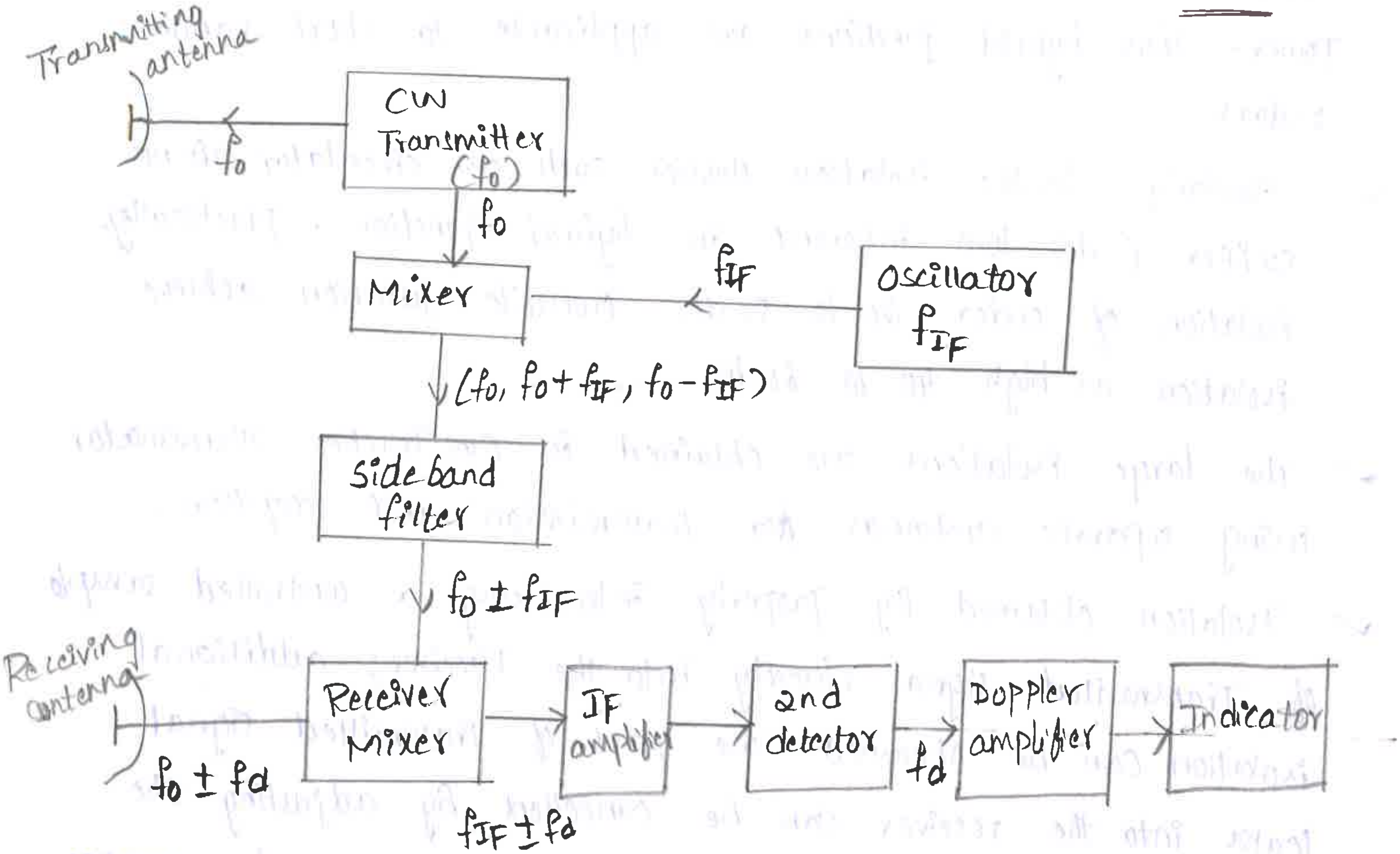
✓ Similarly, ferrite isolation devices such as circulator do not suffer 6-dB loss inherent in hybrid junction. practically isolation of order 20 to 50 dB. Turnstile junction achieve isolation as high 40 to 60dB.

✓ The large isolations are obtained in CW Tracker - illuminator using separate antennas for Transmission and reception.

✓ Isolation obtained By Properly introducing a controlled sample of Transmitted signal directly into the Receiver; additional isolation can be obtained. The part of Transmitted signal leaks into the receiver can be cancelled by adjusting the phase and amplitude of the "buck-off" signal. The arrangement introduces additional 10dB isolation, but the amplitude and phase of leakage signal may vary as the antenna scans.

✓ Thus a dynamic canceller can be used that senses the proper phase and amplitude of leakage signal for obtaining the additional isolation. Thus, the dynamic cancellation of leakage signal can exceed isolation to 30dB.

→ Non-zero IF Receiver (or) Homodyne Receiver (or) Superheterodyne Receiver :-



To remove the transmitter leakage, we are using two separate antennas in the section for Transmission and reception.

✓ CW Transmitter can generates continuous wave of frequency f_0 is given to transmitting antenna.

✓ some portion of Transmitted signal is mixed with a locally generated signal of frequency equal to that of receiver IF is given by local oscillator.

✓ The output of mixer is given by f_0 and $f_0 \pm f_{IF}$. This output is given to sideband filter. At this stage, it can select one of the sideband from output of mixer which contains two side bands on either side of carrier and higher harmonics., then side band filter can eliminate frequency f_0 and passes $f_0 \pm f_{IF}$ to the receiver mixer.

- ✓ In receiver mixer, can combine two outputs one from side band filter i.e $f_0 \pm f_{IF}$ and other is from receiving antenna i.e $f_0 \pm f_d$.
- ✓ At this stage, we detect f_0 frequency and passes $f_{IF} \pm f_d$ to the IF amplifier.
- ✓ To amplify the IF signals and passes this frequency $(f_{IF} \pm f_d)$ to the second detector at this stage.
- ✓ At this stage, to detect IF frequencies and passes only doppler frequencies f_d to the doppler amplifier. and it is used to increase the strength of the signal.
- ✓ Finally, an indicator (A-scope (or) PPI display) is used to find the doppler frequency shift f_d.
- ✓ The improvement in receiver sensitivity with a non-zero IF receiver might be around 30dB over the zero IF receiver.

<u>Advantages</u>

1. The effects of flicker noise can be drastically reduced
2. Because of the high receiver sensitivity, it is preferred in maximum efficiency CW radar.
3. The sensitivity of non-zero IF receiver is much higher than simpler CW receivers i.e around 30dB.

→ Receiver bandwidth requirements (or) IF doppler filter bank :-

A relative wideband of frequencies called as bank of narrow band filters are used to measure the frequency of echo signal. These are used to improve the signal-to-noise ratio of Receiver.

The Bandwidth of each individual filter is such that,

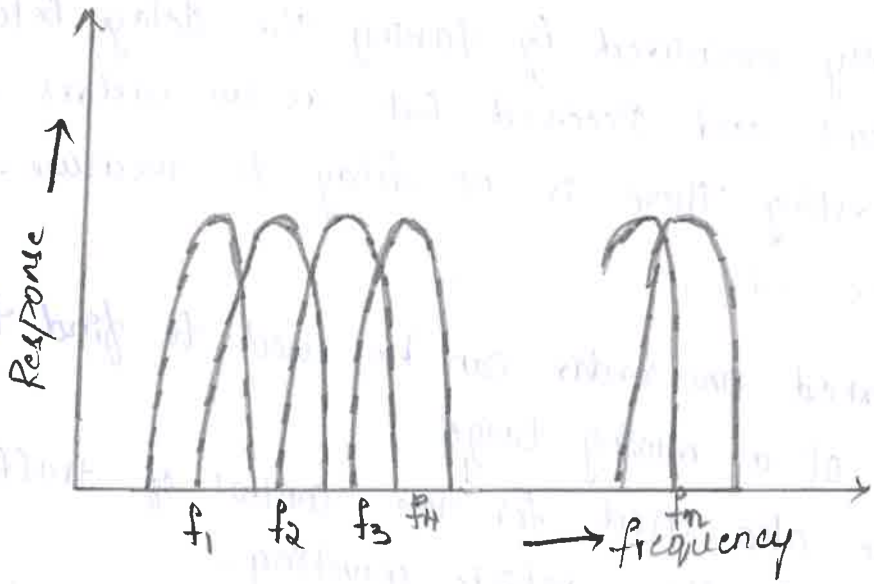
- The Bandwidth of each individual filter is such that it accepts the signal energy But should be taken that it doesnot introduce more noise because of wide bandwidth.
- The center frequencies of filters are staggered to cover the entire range of doppler frequencies.
- If the filters are spaced with their half power points overlapped, the maximum reduction in signal-to-noise ratio of signal which lies midway between adjacent channels compared with signal to noise ratio of midband is 3dB.
- By using large no. of filters, the maximum loss will be reduced. ~~But~~ ~~sometimes~~ noise is introduced also the probability of false alarm is more.

The figure shows block diagram of IF doppler filter bank.

- A bank of narrow band filters may be used after the detector in the video of sample CW radar instead of in the IF. The ability to measure the magnitude of doppler frequency and improvement in signal-to-noise ratio better in IF filter bank.
- The sign of doppler shift is lost in video filter bank and it can't be directly determined whether the doppler frequency corresponds to an approaching (or) to a receding target.

- One disadvantage of IF filter Bank has it requires more no. of filters. The complexity of Receiver increases by the bank of overlapping doppler filters whether in IF (or) video.
- The bank of doppler filters may be replaced by a single narrow band Tunnable filter, when the System requirements permit a time sharing of the doppler frequency range.

The frequency response characteristics of doppler filter bank as shown in figure.



Advantages of CW radar :-

① CW radars are not pulsed and simple to manufacture.
② These radars have no minimum (or) maximum range and maximize power on a target because they are always Broadcasting.
③ These are having the ability to measure velocity with extreme accuracy by means of the doppler shift in the frequency echo.
④ The detected, reflected wave is shifted in frequency by an amount which is a function of relative velocity between the target and Transmitter power.
⑤ Range data are extracted from the change in doppler frequency.

Dis advantages of cw radar :-

① when a single antenna is used for both transmission & reception, It is difficult to protect the receiver against the transmitter Because in constant to pulse radar, both are ON all the time.

② These are able to detect only moving targets, at stationary targets will not cause doppler shift & reflected signals will be filtered out.

③ cw radars are not able to measure the range, where the range is normally measured by timing the delay between a pulse being sent and Received but as cw radars are always broadcasting there is no delay to measure.

Applications of cw radar :-

① simple unmodulated cw radar can be used to find the relative velocity of a moving target.

② cw radars are also used for the control of traffic lights, regulations of toll booths, vehicle counting.

③ In railways cw radars can be used as a speed meter, to replace the conventional axle - driven tachometer.

④ In measurement of rail road frieght car velocity during humping operations in marshalling yards.

⑤ It can be used as detection device to give track maintenance personnel advance warning of approaching trains.

⑥ It also employed for monitoring the docking speed of large ships.

⑦ In Industry has been applied to measurement of Peripheral speed of grinding wheels & monitoring of vibrations in the cabels of suspension bridges.

⑧ Measurement of velocity of missiles, ammunition and Base balls the CW radars are used.

⑨ Measuring motion of waves on water level.

⑩ Find weather an object is approaching (or) moving away from the target.

⑪ Monitoring respiration rate of humans.

⑫ Scatterometer (used to measure scattering properties of target (or) clutter).

→ FM-CW Radar (Frequency Modulated CW radar):-

In CW radars have the disadvantage that they cannot measure distance.

characteristic features of FM-CW radar:-

1. The distance measurement is done by comparing the actual frequency of Received signal to a given reference signal (usually the transmitted signal).

2. The duration of Transmitted signal is much larger than the time required for measuring the maximum range of radar.

Operation :- The block diagram of FMCW radar shown in below figure:

→ A portion of the transmitted signal act as the reference signal required to produce the beat frequency. It is Introduced directly into Receiver.

→ Ideally the isolation between transmitting and receiving antennas is made sufficiently large so as to reduce to a negligible level the transmitter leakage signal which arrives at the Receiver via the coupling between antennas.

→ The beat frequency is amplified and limited to remove any amplitude fluctions.

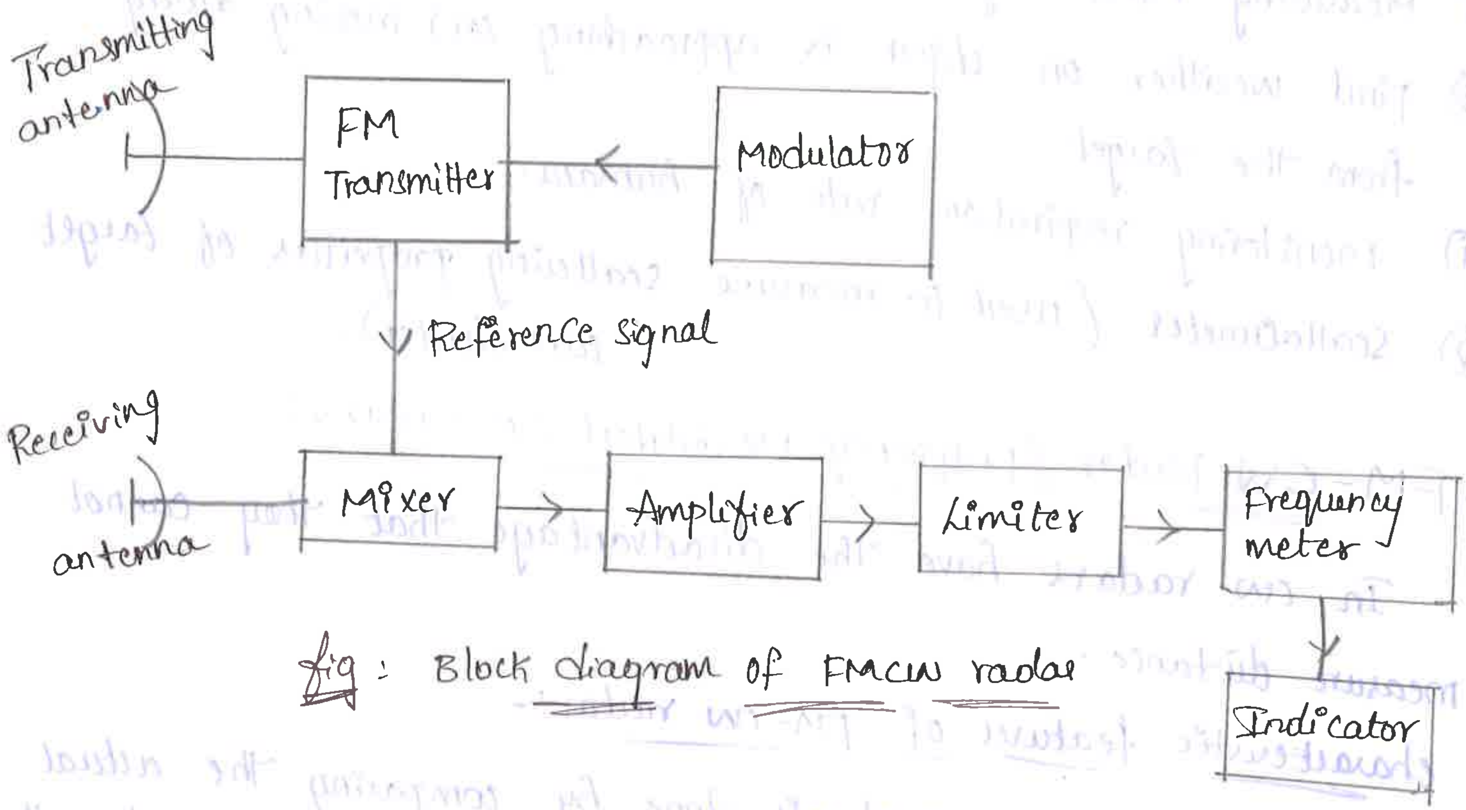


fig: Block diagram of FMCW radar

→ The frequency of amplitude-limited Beat note is measured with a cycle counting frequency meter calibrated in distance.

→ In the above, target was assumed to be stationary. If the assumption is not applicable, a doppler frequency shift will be super imposed on the FM range beat note and an erroneous range measurement results.

→ The doppler frequency shift causes the frequency-time plot of the echo signal to be shifted up (or) down [fig 2(a)] on one portion of the frequency-modulation cycle the beat frequency (fig 2(b)) is increased by doppler shift, while on the other portion it is decreased.

For example,

Target is approaching the radar, the beat frequency $f_b(up)$ produced during the increasing portion and $f_b(down)$ produced during the decreasing portion of FM cycle.

$$f_b(up) = f_r - f_d$$

$$f_b(down) = f_r + f_d.$$

when the target is moving away from the radar, the beat frequency $f_b(up)$ is produced during the decreasing portion and $f_b(down)$ is produced during the increasing portion of FM cycle.

$$f_b(up) = f_r + f_d$$

$$f_b(down) = f_r - f_d.$$

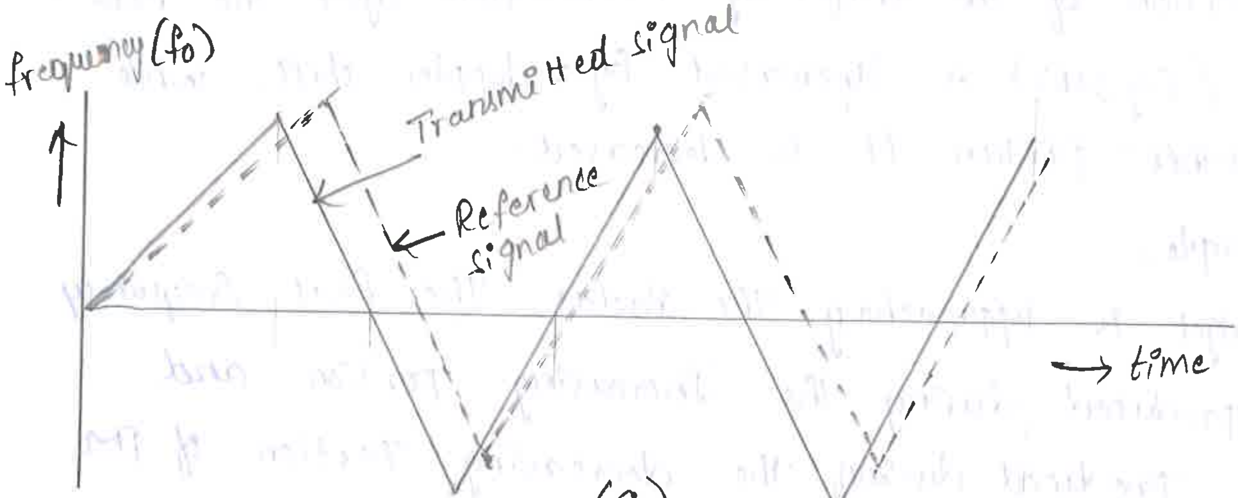
The range frequency (f_r) may be extracted by measuring the average beat frequency.

$$\text{i.e } f_r = \frac{1}{2}\left[f_b(up) + f_b(down)\right]$$

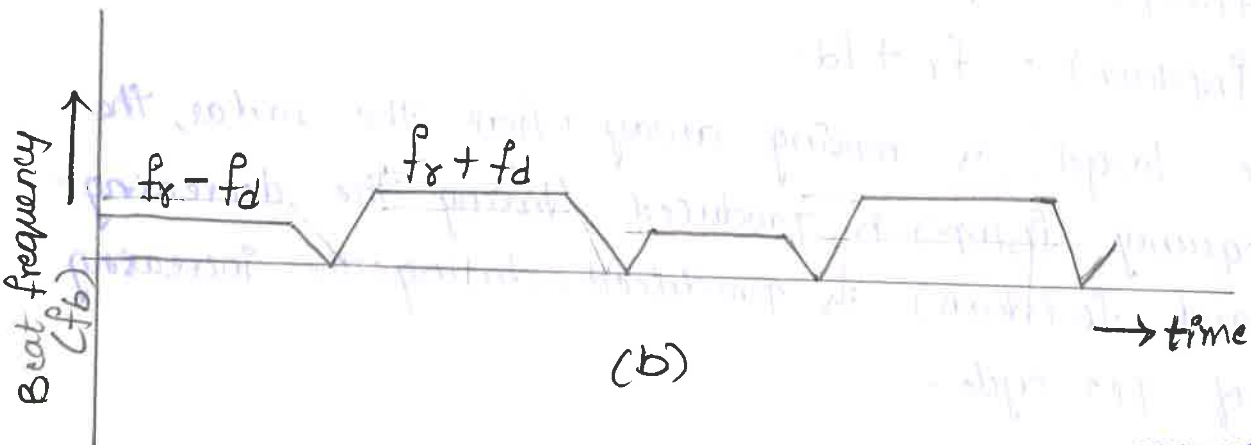
and subtracting condition,

$$f_d = \frac{1}{2}\left[f_b(down) - f_b(up)\right].$$

The frequency-time relations ships in FM-CW radar is shown in below fig. when the received signal is shifted in frequency by the doppler effect (a) Transmitted (solid curve) and echo (dashed curve) frequencies (b) beat frequency.



(a)



(b)

→ when $f_r > f_d$, f_b(up) and f_b(down) are measured separately, By switching a frequency counter every half modulation cycle, one half the difference between the frequencies will yield doppler frequencies.

→ If $f_r < f_d$, that is occurence of high-speed target at short range.

→ The roles of averaging and difference frequency measurements are reversed:

→ The average meter will measure doppler velocity and difference meter will measure range. the roles of the meters are reversed

→ It is not known that the roles of the inequality sign b/w f_r & f_d are Because of change in the inequality sign b/w f_r & f_d an Incorrect Interpretation of the measurements may result.

Expression for Range and doppler Measurement :-

In the frequency modulated cw radar, the transmitted frequency is changed as a function of time in a known manner.

- Assume that the transmitted frequency increases linearly with time as shown in fig (a).
- If there is a reflecting object at a distance R, an echo signal will return after a time $T = \frac{2R}{C}$. The dashed line in the fig. represents the echo signal in a nonlinear element such as diode, a beat note f_b will be produced.
- If there is no doppler frequency shift, the beat note (diff. frequency) is measure of the targets range and $f_b = f_r$, where f_r is the beat frequency due to only targets range.

$$f_r = \dot{f_0} T = \frac{2R\dot{f_0}}{C}$$

- In any practical cw radar, the frequency cannot be continuously changed in one-direction only. It introduces the necessity of periodicity in modulation.

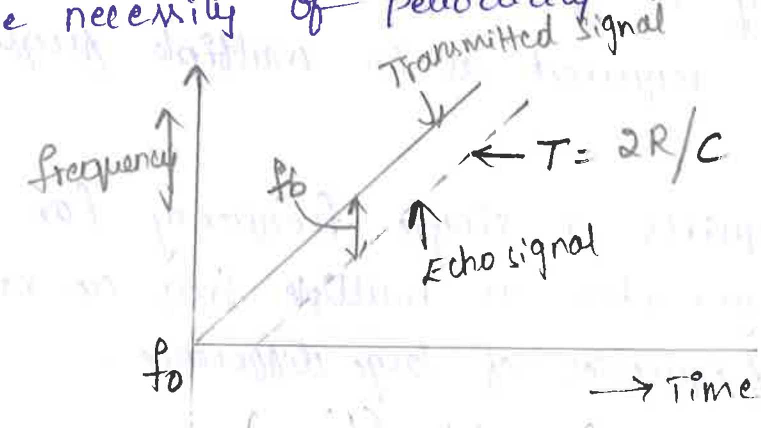
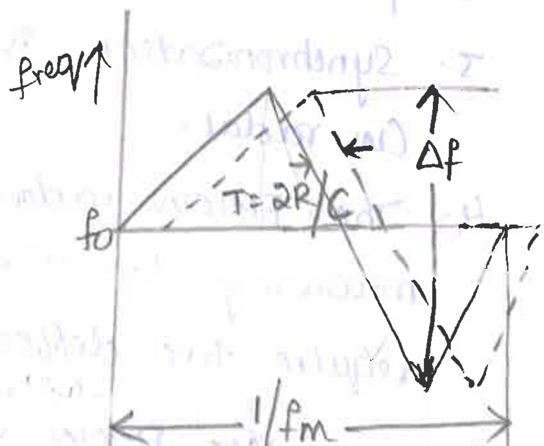


fig (a): Linear frequency modulation.



fig(b): Triangular freq. modulation

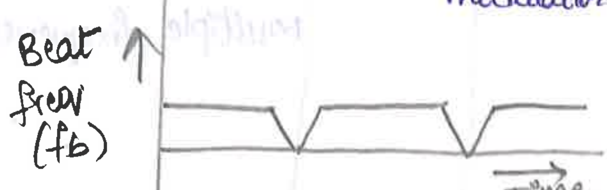


fig (c): Beat note of fig(b)

fig (b) shows triangular frequency modulation. It can be anything like sawtooth, sinusoidal (or) some other shape. The resulting beat frequency as a function of time is shown in fig (c). The beat note is of constant frequency except at the turn around region.

If the frequency is modulated at a rate f_m over a range Δf, beat frequency is.

$$f_r = 2 \times \frac{2R}{C} f_m = \frac{4R f_m \Delta f}{C}$$

$$\therefore \text{Range} \quad \boxed{R = \frac{C f_r}{4 f_m \Delta f}}$$

Advantages of FMCW Radar :-

1. Range can be measured by simple broadening of frequency spectrum.
2. FM modulation is easy to generate than linear modulation.
3. Synchronization is not required as in multiple frequency CW radar.
4. The FMCW radar requires a single frequency for measuring ~~the~~ the range, where as multiple freq. CW radar require two different frequencies of large difference.

For FMCW radar, $R = \frac{C\Delta\phi}{4\pi f_0}$.

Multiple frequency CW radar, $R = \frac{C\Delta\phi}{4\pi\Delta f}$, $\Delta f = f_2 - f_1$

Disadvantages of FM CW radar :-

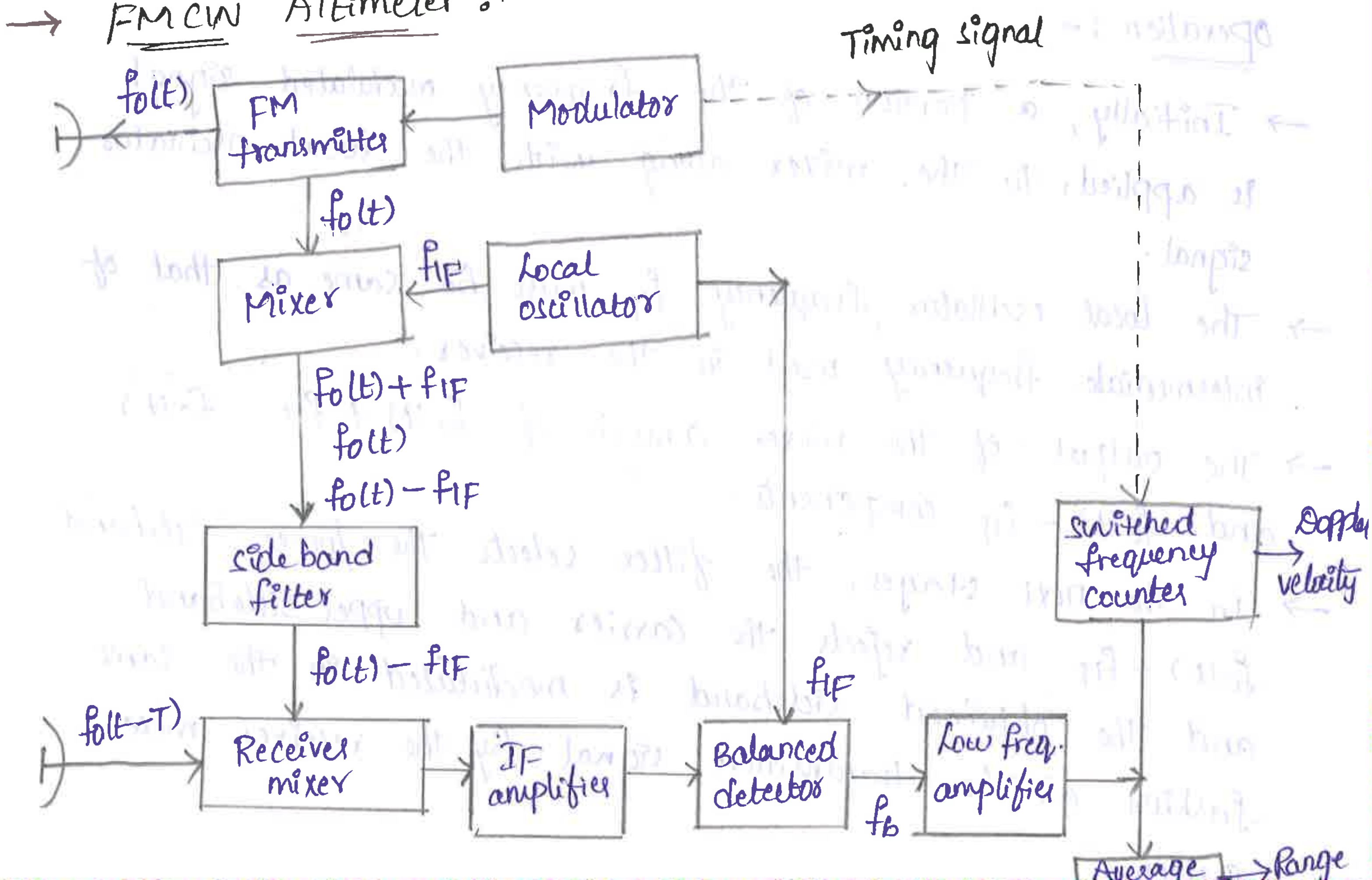
1. FM CW radar can be used to detect single targets only
2. Accuracy of FMCW radar is less compared to multiple frequency CW radar.
3. Measurement of range is more difficult, when FM signal is non-uniform or mixer is not operating in linear region.

Applications of FMCW Radar :-

FMCW Radar is used to measure

→ slant range of the target.
→ Bearing and elevation angles of target and
→ Height of the target.

→ FMCW Altimeter :-



→ The FMCW radar principle is used in the aircraft radio altimeter to measure height above the surface of the earth.

→ To permit low transmitter power and low antenna gain, the altimeter requirements are

1. The large backscatter cross section and
2. The relatively short ranges.

→ There is no effect of doppler frequency shift as the relative motion between the aircraft and the ground is small.

→ The frequency band of radio altimeters over which they be operated is 4.2 to 4.4 GHz.

→ The altimeter can employ a simple homodyne receiver but for better sensitivity and stability the superheterodyne receiver is to preferred.

<u>Operation :-</u>

→ Initially, a portion of the frequency modulated signal is applied to the mixer along with the local oscillator signal.

→ The local oscillator frequency f_{IF} must be same as that of intermediate frequency used in the receiver.

→ The output of the mixer consists of $f_0(t) + f_{IF}$, $f_0(t)$ and $f_0(t) - f_{IF}$ components.

→ In the next stages, the filter selects the lower-sideband $f_0(t) - f_{IF}$ and rejects the carrier and upper sideband and the obtained sideband is modulated in the same fashion as the transmitted signal by the receiver mixer fashion.

→ The output of the receiver ~~must~~ mixer is an IF signal of frequency $f_{IF} + f_b$.

→ The IF signal is amplified to a certain level applied to the balanced detector with local oscillator signal f_{IF}.

→ The output of detector is a beat frequency f_b which can be amplified by a low frequency amplifier.

→ The output of the low frequency amplifier is divided into two channels.

1. An average frequency counter to measure range.
2. A switched frequency counter to determine Doppler velocity.

Different noise signals occuring in a FM altimeter are,

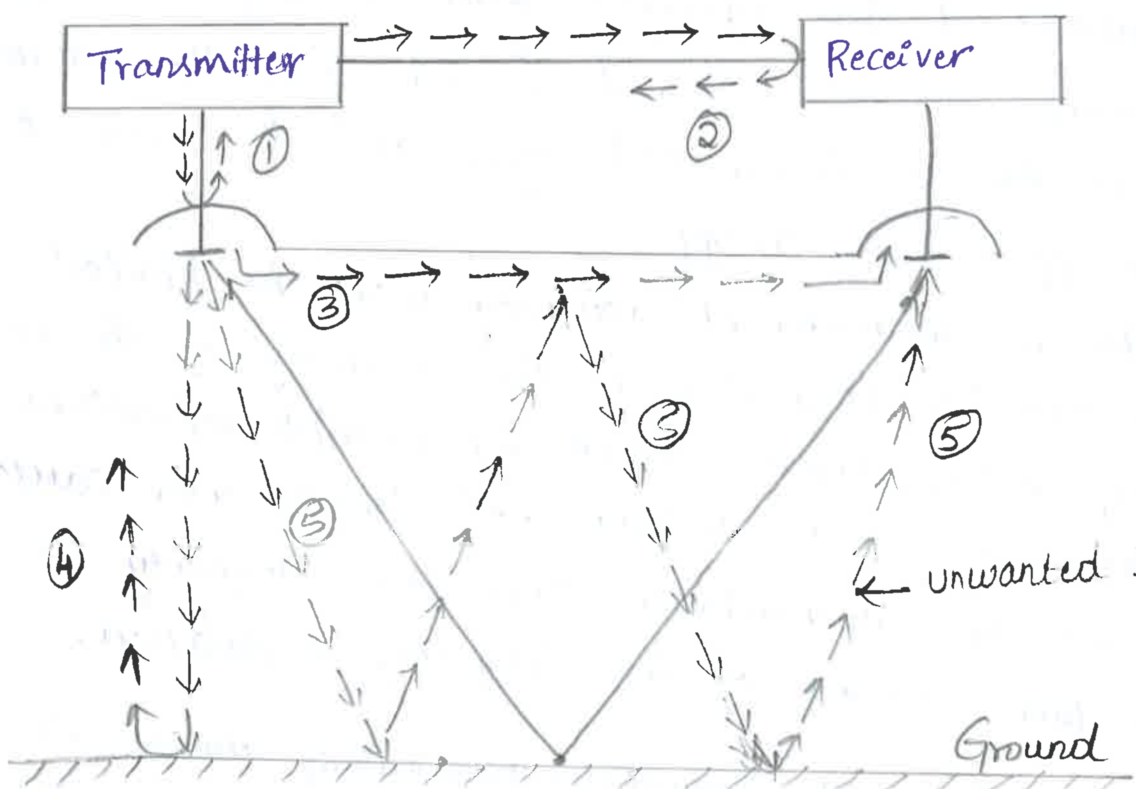


fig: Unwanted signals in FM altimeter

⟶ wanted signals

⇢ ⟶ unwanted signals.

i) Due to mismatch in Impedance a part of the Transmitted signal gets reflected from the space causing error in the altimeter.

ii) The mismatch between the sideband filter and Receiver gives rise to standing wave pattern.

iii) The leakage signal due to Transmitting and Receiver antennas reach the receiver and cause error.

iv) The Interference due to power being reflected back to the transmitter cause a change in the impedance seen by the transmitter.

v) The double-bounce signal.

Measurement Errors :-

→ The absolute accuracy of radar altimeters is usually of more importance at low altitudes than at high altitudes.

→ The distance can be measured depends upon the parameters like bandwidth of transmitted signal and the ratio of signal energy to noise energy.

→ In addition, measurement accuracy might be limited by such Practical restrictions as the accuracy of the frequency measuring device, errors caused by multiple reflections & Transmitter leakage, the residual path length error caused By circuits and transmission lines and frequency error due to turn-around of the frequency modulation.

→ A common form of frequency-measuring device is the cycle counter, which measures the no. of cycles (or) half cycles of the beat during the modulation period.

→ The total cycle count is a discrete number. since the counter is unable to measure fractions of cycle.

The discreteness of frequency measurement gives rises to an error called fixed error (or) step error. It also called quantization error.

The average number of cycles 'N' of the beat frequency f_b in one period of modulation cycle f_m is $\overline{f_b}/f_m$.

where, $f_b \rightarrow$ beat frequency.

$\overline{f_b} \rightarrow$ Time average of beat frequency.

$f_m \rightarrow$ modulating frequency.

The range is given by $R = \dfrac{CN}{4\Delta f}$ —— (1)

$C \rightarrow$ velocity of propagation (m/s) $R \rightarrow$ Range (altitude) (m)

$N \rightarrow$ No. of cycles $\Delta f \rightarrow$ frequency excursion (Hz).

The output of frequency counter 'N' is an Integer and range will be an Integral multiple of $C/4\Delta f$, which gives Quantization error equal to $\delta R = \dfrac{C}{4\Delta f}$.

$$\delta R\,(m) = \frac{75}{\Delta f\,(MHz)} \quad \text{—— (2)}$$

from Eqn (2), Note that the fixed error is Independent of the range and carrier frequency. At the same time, for small fixed error large frequency excursions are required.

→ Target is in motion can cause an error in range equal to $V_r \cdot T_0$ where $V_r \rightarrow$ relative velocity $T_0 \rightarrow$ Time

Problems

① Determine the range & doppler velocity for FMCW radar. If the target is approaching radar. Given that $f_b(up) = 20 KHz$ & $f_b(down) = 30 KHz$ for triangular modulation, modulating freq. is 1MHz & doppler frequency shift is 1KHz.

Sol $R = ?$ $V_r = ?$

Target approaching to radar,

$f_b(up) = f_r - f_d$. $f_b(down) = f_r + f_d$.

$\Rightarrow f_r = \frac{1}{2}[f_b(up) + f_b(down)] = \frac{1}{2}[20\times10^3 + 30\times10^3] = 25 KHz$.

$f_d = \frac{1}{2}[f_b(down) - f_b(up)] = \frac{1}{2}[30\times10^3 - 20\times10^3] = 5KHz$.

$f_r = \frac{4R f_m \Delta f}{c} \Rightarrow R = \frac{f_r c}{4 f_m \Delta f} = \frac{25\times10^3\times3\times10^8}{4\times1\times10^6\times1\times10^3} = \underline{1.875 km}$.

$f_d = \frac{2V_r f_r}{c} \Rightarrow V_r = \frac{c f_d}{2 f_r} = \frac{3\times10^8\times5\times10^3}{2\times25\times10^3} = \underline{3\times10^7 m/sec}$.

② An FMCW radar operates at a frequency of 9.25 GHz. A symmetrical triangular modulating waveform is used. The magnitude of slope being 800MHz/sec. The return from a moving target produces a beat freq 3.85 KHz over the +ve slope & 3.5KHz over the −ve slope. Determine i) Target range ii) Range rate iii) whether the targets is moving towards (or) away from the radar.

Sol G.T $f_0 = 9.25 GHz$, $m = 800 MHz/sec$

i) Target range $R = \frac{f_0 c}{2m} = \frac{9.25\times10^9\times3\times10^8}{2\times8\times10^8} = \underline{1.73\times10^9 m}$

ii) W.K.T $f_d = \frac{2V_r f_0}{c}$ $\Rightarrow f_d = \frac{1}{2}[f_b(down) - f_b(up)]$

$f_d = \frac{1}{2}(3.85\times10^3 - 3.5\times10^3) = \underline{175 Hz} \Rightarrow f_d$

$\therefore V_r = \frac{c f_d}{2 f_0} = \frac{3\times10^8\times175}{2\times9.25\times10^9} = \underline{2.837\times10^3 m}$

iii) $f_d = 175$

$f_r = \frac{1}{2}[3.85\times10^3 + 3.5\times10^3] = \frac{1}{2}[7350] = \underline{3675 Hz}$.

$\therefore$ $f_r > f_d$. Therefore, the target is moving towards the radar.

→ Multiple frequency CW radar :-

The multiple frequency cw radar is used to measure the accurate range.

✓ consider multiple frequency cw radar, Transmitting two continuous sinewaves of frequency f_1 & f_2 seperated by an amount Δf.

✓ consider amplitudes of all signals as unity, The corresponding two voltage signals are given by,

$$V_{T1} = \sin(2\pi f_1 t + \phi_1) \quad \text{--- (1)}$$

$$V_{T2} = \sin(2\pi f_2 t + \phi_2) \quad \text{--- (2)}$$

where ϕ_1 & ϕ_2 are phase angles.

The echo signal is shifted in frequency by the doppler effect. The form of the doppler shifted signals at each of two frequencies f_1, f_2 may be written as

$$V_{R1} = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{C} + \phi_1\right] \quad \text{--- (3)}$$

$$V_{R2} = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{C} + \phi_2\right] \quad \text{--- (4)}$$

where, R_0 = Range to target at time t.

f_{d1}, f_{d2} = doppler frequency shifts related to f_1 & f_2.

The frequency seperation b/w f_1 & f_2 is Δf.

$\therefore \Delta f = f_1 - f_2 \Rightarrow f_2 = \Delta f + f_1$

But $\Delta f << f_1$, so it can be neglected

$\therefore f_2 = f_1$

Similarly, doppler frequency shifts f_{d1} & f_{d2} are related to $f_{d1} = f_{d2}$

The Receiver seperates two components of the echo signal & heterodynes each received signal component with the corresponding transmitted waveform & extracts the two doppler frequency components given by.

$$V_{1D} = \sin\left(\pm 2\pi f_{d_1} t - \frac{4\pi f_1 R_0}{c}\right) \quad \text{—— (5)}$$

$$V_{2D} = \sin\left(\pm 2\pi f_{d_2} t - \frac{4\pi f_2 R_0}{c}\right) \quad \text{—— (6)}$$

from eq^n (5) & (6) Phase diff. b/w 2 components is given by

$$\Delta\phi = \frac{4\pi(f_2 - f_1) R_0}{c} = \frac{4\pi \Delta f R_0}{c}$$

$$\therefore \Delta\phi = R_0 \frac{4\pi \Delta f}{c} \Rightarrow R_0 = \frac{c\,\Delta\phi}{4\pi\Delta f}.$$

The range will be unambiguous as long as $\Delta\phi$ does not exceed 2π radians.

$$\therefore \Delta\phi = 2\pi.$$

$$\Rightarrow R_0 = \frac{c\,(2\pi)}{4\pi\,\Delta f} \Rightarrow \frac{c}{2\Delta f}$$

$\therefore$ Maximum unambiguous range

$$R_{unamb} = \frac{c}{2\Delta f}$$

→ Note that when Δf is replaced by the pulse repetition rate (PRF) gives the maximum unambiguous range of a pulse radar.

→ The two frequency cw radar is essentially a single-target radar since only one phase difference can be measured at a time.

→ If more than one target is present the echo signal becomes complicated and the meaning of the phase measurement is doubtful.

→ The theoritical accuracy with which range can be measured with the two-frequency cw radar can be found.

→ The theoritical r.m.s range error is given by

$$\delta R = \frac{c}{4\pi \Delta f (2E/N_0)^{1/2}}$$

where E = Energy contained in received signal.

N_0 = Noise per hertz of bandwidth.