UNIT-II

CONTINUOUS WAVE AND FREQUENCY MODULATED RADAR

THE DOPPLER EFFECT

Radar detects the presence of objects and locates their position in space by transmitting electromagnetic energy and observing the returned echo. Pulse radar transmits a relatively short burst of electromagnetic energy, after which the receiver is turned on to listen for the echo. The echo not only indicates that a target is present, but the time that elapses between the transmission of the pulse and the reception of its echo is a measure of the distance to the target. Separation of the echo signal from the transmitted signal is made on the basis of differences in time.

The radar transmitter may be operated continuously rather than pulsed if it is possible to separate the strong transmitted signal from the weak echo.

The received echo-signal power is considerably smaller than the transmitter power (as low as 10^{-18} times the transmitter power - or sometimes even less). Separate antennas for transmission and reception help isolate the weak echo from the strong leakage signal, but this isolation is usually not sufficient. A feasible technique for separating the received signal from the transmitted signal, when there is relative motion between radar and target, is based on recognizing the change in the echo-signal frequency caused by what is known as the Doppler effect.

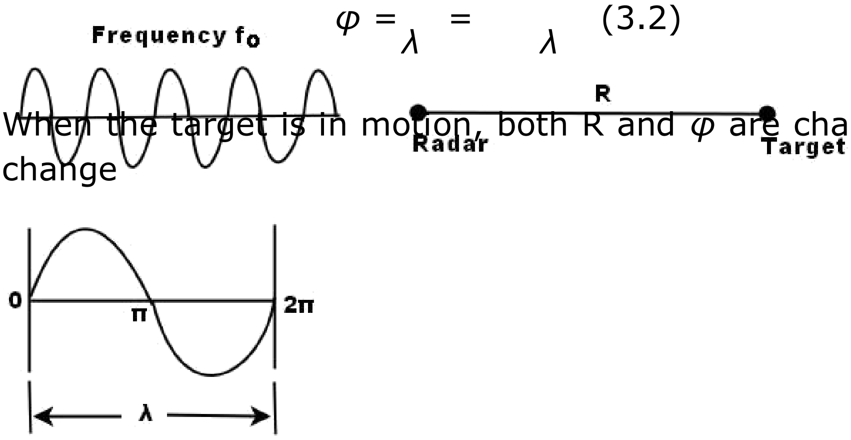
It is well known in the field of optics and acoustics that if there is relative motion between the source of a signal and the observer of the signal, along the line joining the two, then an apparent shift in frequency will result. This is the Doppler Effect and is the basis of CW (Continuous Wave) radars.

Consider Fig.2.1 above in which a CW radar and a target are placed at a distance of R from each other. The target is moving with a speed V_r relative to the radar and along the line joining the radar and the target (also known as the line-of-sight - LOS). Note that the transmitted signal is not in the form of a train of pulses but a continuous wave with frequency f_o. Let the total number of wavelengths (given by λ) contained in the to-and -fro path between the radar and the target be denoted by n. Then,

$$n = \frac{2R}{\lambda} \quad (3.1)$$

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

$$\varphi = \frac{2R.2\pi}{\lambda} = \frac{4\pi R}{\lambda} \quad (3.2)$$



When the target is in motion, both R and φ are changing. Now a change

Figure 2.1: The doppler effect

in φ with respect to time is equal to an angular frequency. This, in fact, is the doppler angular frequency W_d,

$$W_d = 2\pi f_d = \frac{d\varphi}{dt} = \frac{4\pi}{\lambda} . \frac{dR}{dt} = \frac{4\pi V_r}{\lambda} \quad (3.3)$$

From which we get

$$f_d = \frac{2V_r}{\lambda} = \frac{2V_r\, f_0}{c} \quad (3.4)$$

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

$$V_r = V \cos \theta \qquad (3.5)$$

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, $\theta = {}^{\pi}2 = 90^{o}$). 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).

THE CW RADAR

In Fig. 2.2 we give the block diagram of a simple CW radar.

The transmitter generates a continuous (unmodulated) oscillation of frequency f_0, which is radiated by the antenna. A portion of the radiated energy is intercepted by the target and is scattered. some of it in the direction of the radar, where it is collected by the receiving antenna. If the target is in motion with a velocity V_r relative to the radar, the received signal frequency

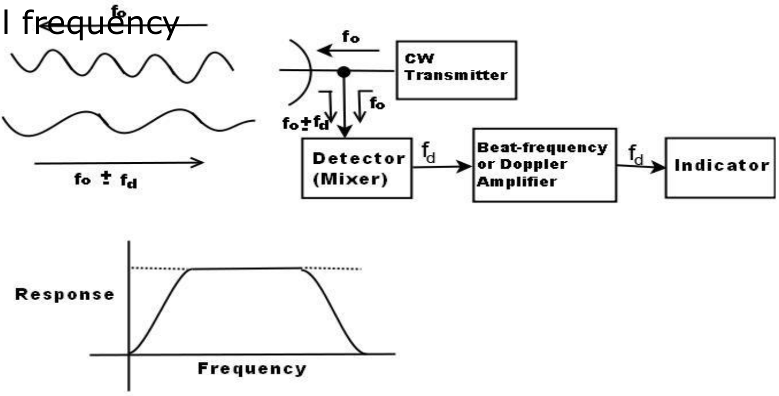


FIG 2.2: A simple CW radar block diagram

will be shifted from the transmitted signal frequency f_0 by an amount $\pm f_d$. The plus sign applies if the distance between the radar and the target is decreasing (that is, an approaching target) and the minus sign applies when this distance is increasing (that is, a receding target). The received echo signal at a frequency $f_0 \pm f_d$ enters the radar via the antenna and is hetero-dyned in the detector (mixer) with a portion of the transmitted signal f_0 to produce a doppler beat note of frequency f_d. However, the sign of f_d is lost in this process.

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. Its frequency response characteristics is as shown in Fig. 3.2(b). The low-frequency cut-off must be high enough to reject the d-c component caused by stationary targets, and yet it must be low enough to pass the smallest doppler frequency expected. Sometimes both conditions cannot be met simultaneously and a compromise is necessary. The doppler cutoff frequency (on the higher side) is usually selected to pass the highest doppler frequency expected.

The indicator could be a pair of earphones or a frequency meter. Ear-phones are used when an exact knowledge of the doppler frequency is not required. The ear then acts as a selective (narrow) bandpass filter with a passband of the order of 50 Hz centered about the signal frequency. This is of use for subsonic aircraft targets when the transmitter frequency falls in the middle range of the microwave frequency region.

If audio detection is desired for those combination of target velocity and transmitter frequency which do not result in audible doppler frequencies, the doppler signal could be heterodyned to the audible range. The doppler frequency can be detected and measured by conventional frequency meters, usually one that counts cycles.

ISOLATION BETWEEN TRANSMITTER AND RECEIVER

A single antenna serves the purpose of both transmission and reception in the simple CW radar described above. Though, in principle, a single antenna is suffcient as the necessary isolation is obtained by the separation in frequency (as a result of doppler effect), in practice there is considerable transmitter leakage. But this leakage is beneficial too since it supplies the reference fre-quency necessary for the detection of the doppler frequency shift. Otherwise a sample of the transmitted signal must be made available at the receiver. However, there are two reasons why the amount of transmitter leakage power should be kept at a low value.

- The maximum power the receiver input circuitry can withstand, with-out being physically damaged or having its sensitivity reduced, is quite low.

- The transmitter noise which enters the receiver from the transmitter reduces receiver sensitivity.

The amount of isolation required depends on the transmitter power and the accompanying transmitter noise as well as the ruggedness and sensitivity of the receiver. If the safe value of power which might be applied to a receiver were 10mw and if the transmitter power were 1 kw, the isolation between transmitter and receiver must be at least 50 dB.

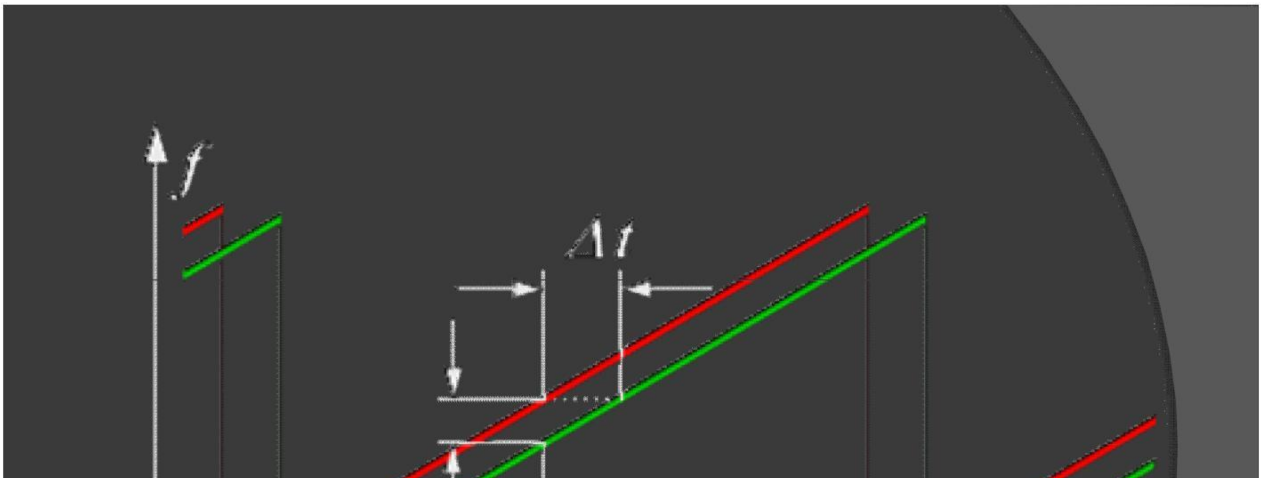
In long range CW applications, it is the level of the noise accompanying the transmitter leakage signal, rather than the damage this leakage might cause to the receiver circuitry, which determines the amount of isolation required. For example, suppose the isolation between the transmitter and receiver were such that 10mw of leakage signal appeared at the receiver. If the minimum detectable signal were 10^{-13} watt, the transmitter noise must be at least 110 dB below the transmitted carrier.

APPLICATIONS OF CW RADAR:

The chief use of the simple unmodulated CW radar is for the measurement of the relative velocity of a moving target. The principal advantage of a CW doppler radar over other non-radar methods of measurement of speed is that there need not be any physical contact between the measuring device and the object whose speed is being measured. Another advantage is that the CW radar, when used for short or moderate ranges, is characterized by simpler equipment than a pulse radar. Among its disadvantages is the fact that 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 since the transmitter noise that finds its way into the receiver limits the receiver sensitivity. This limits the maximum range of the radar. The pulse radar has no similar limitations to its maximum range because the transmitter is not operative when the receiver is turned on. One of the greatest shortcomings of the simple CW radar is its inability to obtain a measurement of range. This limitation can be overcome by modulating the CW carrier, as in the frequency-modulated radar described in the next section.

FREQUENCY MODULATED CW RADAR (FM-CW):

CW radars have the disadvantage that they cannot measure distance, because it lacks the timing mark necessary to allow the system to time accurately the transmit and receive cycle and convert the measured round-trip-time into range. In order to correct for this problem, phase or frequency shifting methods can be used. In the frequency shifting method, a signal that constantly changes in frequency around a fixed reference is used to detect stationary objects and to measure the rage. In such Frequency-**M**odulated **C**ontinuous **W**ave radars (**FMCW**), the frequency is generally changed in a linear fashion, so that there is an up-and-down or a sawtooth-like alternation in frequency. If the frequency is continually changed with time, the frequency of the echo signal will differ from that transmitted and the difference f will be proportional to round trip time t and so the range R of the target too. When a reflection is received, the frequencies can be examined, and by comparing the received echo with the actual step of transmitted frequency, you can do a range calculation similar to using pulses:



$R = c_0| t|/2 = c_0|\Delta f|/(2df/dt)$

Where: c_0 = speed of light = $3\text{x}10^8\ ^m/_s$

t = measured time-difference [s]

u R = distance altimeter to terrain [m]

df/dt = transmitters frequency shift per unit time

Characteristic Feature of FMCW radar:

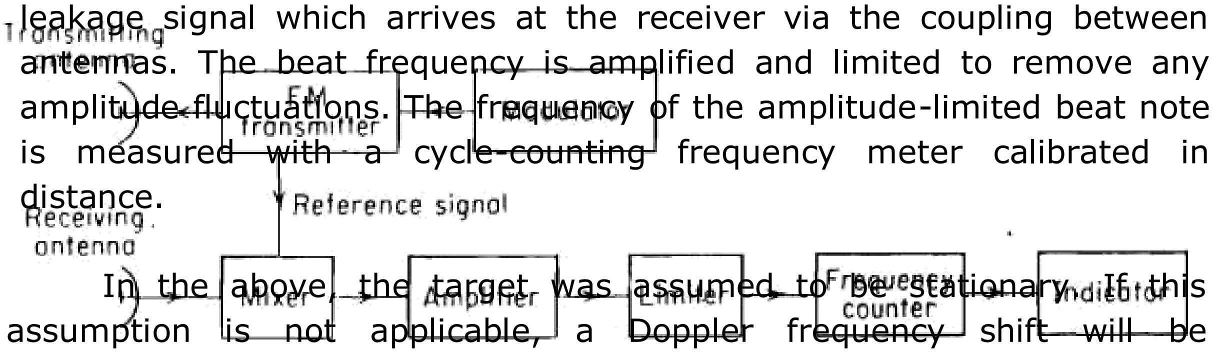
1. The distance measurement is done by comparing the actual frequency of the received signal to a given reference (usually direct the transmitted signal)

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

Fig: Frequency-time relation-ships in FM-CW radar when the $f_r + f_d$ received signal is shifted in frequency by the Doppler effect (a) Transmitted (solid curve) and echo (dashed curve); (b) beat frequency.

Doppler direction in FMCW radar:

A block diagram illustrating the principle of the FM-CW radar is shown in Fig. A portion of the transmitter signal acts as the reference signal required to produce the beat frequency. It is introduced directly into the receiver via a cable or other direct connection. 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 fluctuations. The frequency of the amplitude-limited beat note is measured with a cycle-counting frequency meter calibrated in distance.

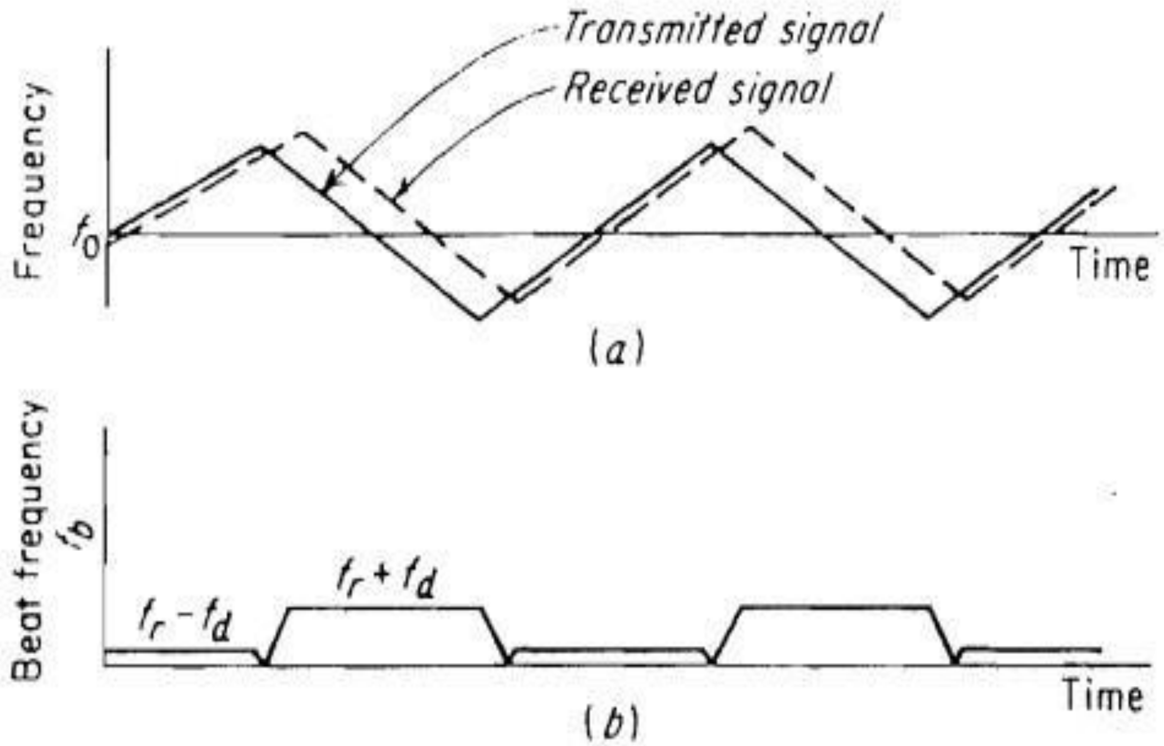


In the above, the target was assumed to be stationary. If this assumption is not applicable, a Doppler frequency shift will be superimposed on the FM range beat note and an erroneous range measurement results.

The Doppler frequency shift causes the frequency-time plot of the echo signal to be shifted up or down (Fig. 4.1.2 (a)). On one portion of the frequency-modulation cycle the heat frequency (Fig, 4.1.2 (b)) is increased by the Doppler shift, while on the other portion it is decreased. If for example, the target is approaching the radar, the beat frequency fb(up) produced during the increasing, or up, portion of the FM cycle will be the difference between the beat frequency due to the range from and the doppler frequency shift fd. Similarly, on the decreasing portion, the beat frequency, f_b(down) is the sum of the two.

$$f_b(\text{up}) = f_r - f_d \quad \text{and} \quad f_b(\text{down}) = f_r + f_d$$

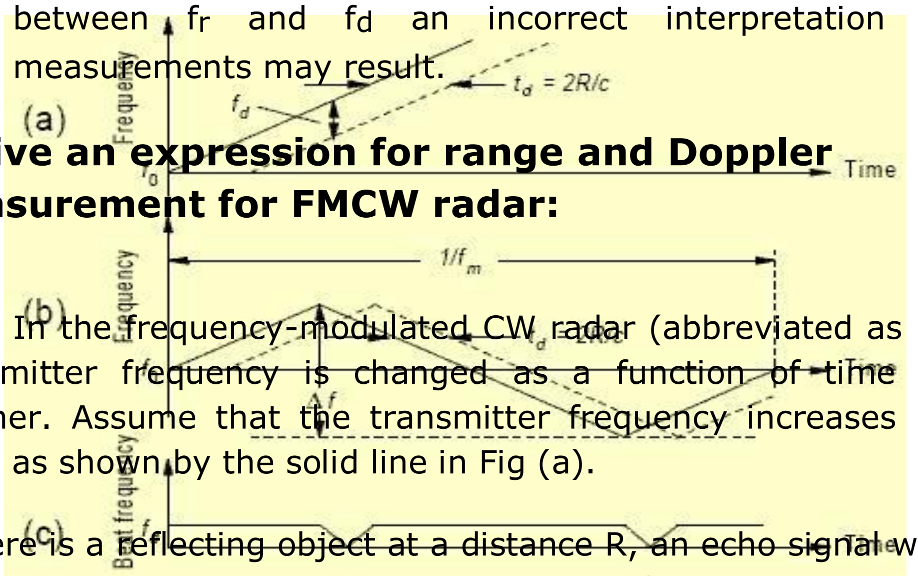
The range frequency f_r, may be extracted by
measuring the average beat frequency;
That is, $f_r = 1/2[f_b(\text{up}) + f_b(\text{down})]$.



If f_b(up) and f_b(down) are measured separately, for example, by switching a frequency counter every half modulation cycle, one-half the difference between the frequencies will yield the doppler frequency. This assumes $f_r > f_d$.

If, on the other hand, $f_r < f_d$ such as might occur with a high-speed target at short range,the roles of the averaging and the difference-frequency measurements are reversed; the averaging meter will measure Doppler velocity, and the difference meter, range. If it is not known that the roles of the meters are reversed because of a change in the inequality sign between f_r and f_d an incorrect interpretation of the measurements may result.

Derive an expression for range and Doppler measurement for FMCW radar:



In the frequency-modulated CW radar (abbreviated as FM-CW), the transmitter frequency is changed as a function of time in a known manner. Assume that the transmitter frequency increases linearly with time, as shown by the solid line in Fig (a).

If there is a reflecting object at a distance R, an echo signal will return after a time T =2R/c. The dashed line in the figure represents the echo signal. If the echo signal is heterodyned

with a portion of the transmitter signal in a nonlinear element such as a diode, a beat note f_b will be produced.

If there is no Doppler frequency shift, the beat note (difference frequency) is a measure of the target's range and $f_b = f_r$ where f_r is the beat frequency due only to the target's range. If the rate of change of the carrier frequency is f_0, the beat frequency is

$$f_r = f_0 T = 2Rf_0/c$$

In any practical CW radar, the frequency cannot be continually changed in one direction only. Periodicity in the modulation is necessary, as in the triangular frequency-modulation waveform shown in Fig(b).

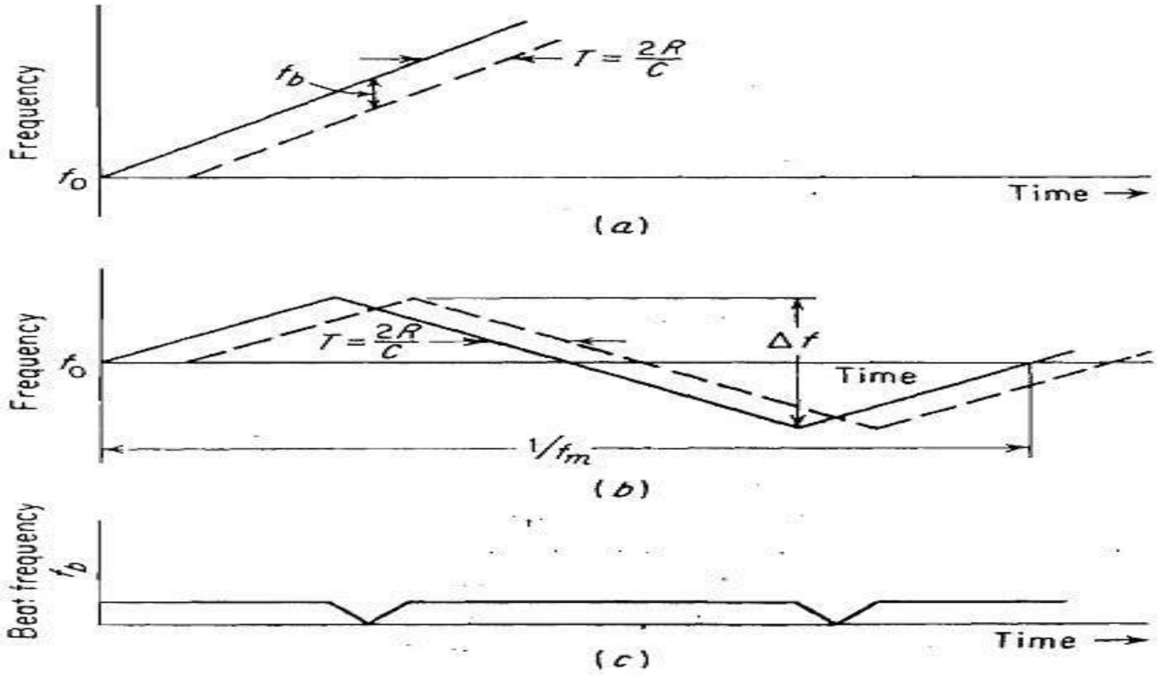
The modulation need not necessarily be triangular; it can be sawtooth, sinusoidal, or some other shape. The resulting beat frequency as a function of time is shown in Fig(c) for triangular modulation. The beat note is of constant frequency except at the turn around region. If the frequency is modulated at a rate f_m over a range f, the beat frequency is

$$f_r = 2*2Rf_m/c = 4Rf_m \;\; f/c$$

Thus the measurement of the beat frequency determines the range R.

$$R = cf_r/4f_m \;\; f$$

Fig: Frequency-time relationships in FM-CW radar. Solid curve represents transmitted signal, dashed curve represents echo. (a) Linear frequency modulation; (b) triangular frequency modulation; (c) beat note of (b).



Principle of operation of FMCW Altimeter:

The FM-CW radar principle is used in the aircraft radio altimeter to measure height above the surface of the earth. The large backscatter cross section and the relatively short ranges required of altimeters permit low transmitter power and low antenna gain. Since the relative motion between the aircraft and ground is small, the effect of the Doppler frequency shift may usually be neglected.

The band from 4.2 to 4.4 G Hz is reserved for radio altimeters, although they have in the past operated at UHF. The transmitter power is relatively low and can be obtained from a CW magnetron, a backward-wave oscillator, or a reflex klystron, but these have been replaced by the solid state transmitter.

The altimeter can employ a simple homodyne receiver, but for better sensitivity and stability the superheterodyne is to be preferred whenever its more complex construction can be tolerated.

A block diagram of the FM-CW radar with a sideband superheterodyne receiver shown in Fig. A portion of the frequency-modulated transmitted signal is applied to a mixer along with the oscillator signal. The selection of the local-oscillator freq uency is a bit different from that in the usual superheterodyne receiver.

The local-oscillator frequency f_{IF} should be the same as the intermediate frequency used in the receiver, whereas in the conventional superheterodyne the LO frequency is of the same order of magnitude as the RF signal.

The output of the mixer consists of the varying transmitter frequency $f_0(t)$ plus two sideband frequencies, one on either side of $f_0(t)$ and separated from $f_0(t)$ by the local-oscillator frequency f_{IF}. The filter selects the lower sideband $f_0(t) - f_{IF}$ and rejects the carrier and the upper sideband.

The sideband that is passed by the filter is modulated in the same fashion as the transmitted signal. The sideband filter must have sufficient bandwidth to pass the modulation, but not the carrier or other sideband. The filtered sideband serves the function of the local oscillator.

When an echo signal is present, the output of the receiver mixer is an IF signal of frequency $f_{IF} + f_b$ where f_b is composed of the range frequency f_r and the doppler velocity frequency f_d. The IF signals is amplified and applied to the balanced detector along with the localoscillator signal f_{IF}. The output of the detector contains the beat frequency (range frequency and the Doppler velocity frequency), which is amplified to a level where it can actuate the frequency measuring circuits.

In Fig. the output of the low-frequency amplifier is divided into two channels: one feeds an average-frequency counter to determine range, the other feeds a switched frequency counter to determine the doppler velocity (assuming fr > fd) Only the averaging frequency counter need be used in an altimeter application, since the rate of change of altitude is usually small.

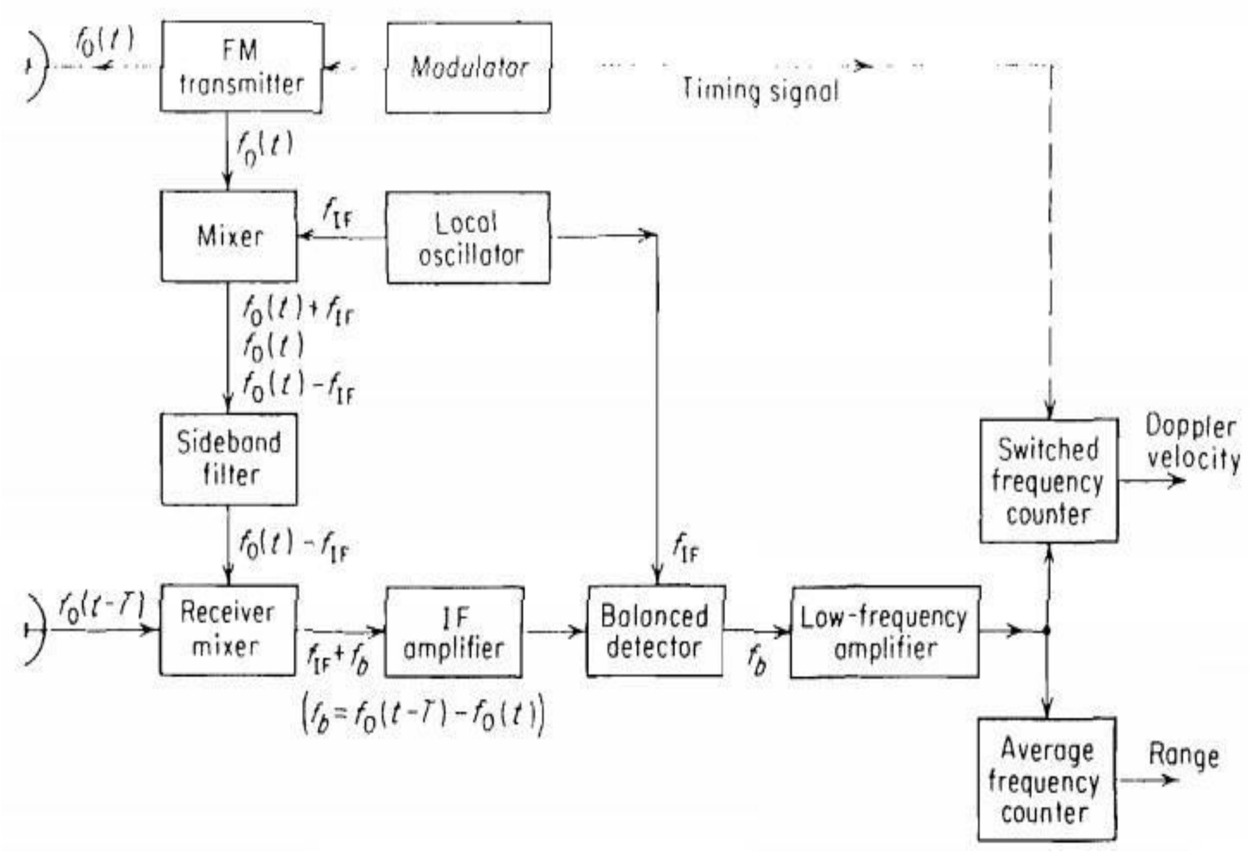


Fig: Block diagram of FM-CW radar using sideband superheterodyne receiver

EFFECT OF NOISE SIGNALS ON FM ALTIMETER:

The different noise signals occurring in a typical FM altimeter are:

Due to the mismatch in impedance a part transmitted signal gets reflected from the space causing error in the altimeter.

The mismatch between the sideband filter and receiving gives rise to standing wave pattern.
The leakage signal due to the transmitting and receiving antennas reach the receiver and cause error.

The double bounce signal.

Hence the different noise signals accompanying the transmitted signal may reach the receiver and effect its.

Advantages of FMCW altimeter over pulse based altimeter and compare both?

What is the difference between altimeter and cabin altimeter: The main difference between altimeter and cabin altimeter is the place where they take their pressure: Altimeter takes the pressure from static ports, while cabin altimeter takes it's pressure from the cabin.

Difference of radio altimeter to radar altimeter**:** They're both the same thing

What is an altimeter:

The altimeter is basically a specialized pressure gauge. It measures the pressure of the column of air above it. As the altitude varies, the air column height varies, which registers on the altimeter. Since the air pressure also varies with changes in the barometric pressure, altimeters must have an adjustment to compensate for changes in local barometric pressure.

Multiple frequency CW radar:

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

The transmitted waveform is assumed to consist of two continuous sine waves of frequency f_1 and f_2 separated by an amount *f*. Let the amplitudes of all signals are equal to unity. The voltage waveforms of the two components of the transmitted signal v_{1r} and v_{2r}, may be written as

$$v_{1r} = \sin(2\pi f_1 t + \varphi_1)$$

$$v_{2r} = \sin(2\pi f_2 t + \varphi_2)$$

Where φ_1 and φ_2 are arbitrary (constant) phase angles.

The echo signal is shifted in frequency by the Doppler Effect. The form of the dopplershifted signals at each of the two frequencies f_1 and f_2 may be written as

$$v_{1R} = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{c} + \phi_1\right]$$

$$v_{2R} = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{c} + \phi_2\right]$$

Where, R_o = range to target at a particular time $t = t_0$ (range that would be measured if target were not moving)

f_{d1} = Doppler frequency shift associated with frequency f_1

f_{d2} = Doppler frequency shift associated with frequency f_2

Since the two RF frequencies f_1, and f_2 are approximately the same the doppler frequency shifts f_{d1} and f_{d2} are approximately equal to one another. Therefore, $f_{d1} = f_{d2} = f_d$

The receiver separates the two components of the echo signal and heterodynes each received signal component with the corresponding transmitted waveform and extracts the two doppler-frequency components given below:

$$v_{1D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_1 R_0}{c}\right)$$

$$v_{2D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_2 R_0}{c}\right)$$

The phase difference between these two components is

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

Hence

$$R_0 = \frac{c\ \Delta\phi}{4\pi\ \Delta f}$$

A large difference in frequency between the two transmitted signals improves the accuracy of the range measurement since large f means a proportionately large change in Δφ for a given range. However, there is a limit to the value of f, since Δφ cannot be greater than 2п radians if the range is to remain unambiguous. The maximum unambiguous range R_{unamb} is $\mathbf{R_{unamb} = c/2\ f}$

The two-frequency CW radar is essentially 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.

Measurement Errors:

The absolute accuracy of radar altimeters is usually of more importance at low altitudes than at high altitudes. Errors of a few meters might not be of significance when cruising at altitudes of 10 km, but are important if the altimeter is part of a blind landing system.

The theoretical accuracy with which distance can be measured depends upon the bandwidth of the 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, the residual path-length error caused by the circuits and transmission lines, errors caused by multiple reflections and transmitter leakage, and the frequency error due to the turn-around of the frequency modulation.

A common form of frequency-measuring device is the cycle counter, which measures the number 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 a cycle. The discreteness of the frequency measurement gives rise to an error called the fixed error, or step error. It has also been called the quantization error, a more descriptive name. The average number of cycles N of the beat frequency fb in one period of the modulation cycle *fm* is fb /*fm* , where the bar over, denotes time average.

$$R = cN/4\Delta f$$

Where, R = range (altitude). m

c = velocity of propagation. m/s

f = frequency excursion. Hz

Since the output of the frequency counter N is an integer, the range will be an integral multiple of $c/4\Delta f$ and will give rise to a quantization error equal to

$$\delta R = c/4\Delta f$$

$$\delta R\ (m) = 75/\Delta f\ (\text{MHz})$$

Since the fixed error is due to the discrete nature of the frequency counter, its effects can be reduced by wobbling the modulation frequency or the phase of the transmitter output. Wobbling the transmitter phase results in a wobbling of the phase of the beat signal so that an average reading of the cycle counter somewhere between N and N + 1 will be obtained on a normal meter movement. In one altimeter, the modulation frequency was varied at a 10-Hz rate, causing the phase shift of the beat signal to vary cyclically with time. The indicating system was designed so that it did not respond to the l0-Hz modulation directly, but it caused the fixed error to be averaged. Normal fluctuations in aircraft altitude due to uneven terrain, waves on the water, or turbulent air can also average out the fixed error provided the time constant of the indicating device is large compared with the time between fluctuations. Over smooth terrain, such as an airport runway, the fixed error might not be averaged out.

Target motion can cause an error in range equal to vr T0, where vr, is the relative velocity and To is the observation time. The residual path error is the error caused by delays in the circuitry and transmission lines.

Multipath signals also produce error. Reflections from the landing gear can also cause errors.

The unwanted signals in FM altimeter:

The fig. shows some of the unwanted signals that might occur in the FM altimeter. The wanted signals are shown by the solid line while unwanted signals are shown by the broken arrows.

The unwanted signals include:

1.The reflection of the transmitted signals at the antenna caused by impedance mismatch.

2. The standing-wave pattern on the cable feeding the reference signal to the receiver, due to poor mixer match.

3. The leakage signal entering the receiver via coupling between transmitter and receiver antennas. This can limit the ultimate receiver sensitivity, especially at high altitudes.

4. The interference due to power being reflected back to the transmitter, causing a change in the impedance seen by the transmitter. This is usually important only at low altitudes. It can be reduced by an attenuator introduced in the transmission line at low altitude or by a directional coupler or an isolator.

5. The double-bounce signal.