ECE 422: RADAR ENGINEERING AND NAVIGATIONAL AIDS

Dr. K.Murali Krishna
B.Tech., M.E., Ph.D, MISTE, MIEEE, Fellow IETE
Professor
Department of Electronics and Communication Engineering

Der Erziehungsrat
des
Kantons Aargau

urkundet hiemit:

Herr **Albert Einstein** von Ulm,

geboren den 14. März 1879,

besuchte die aargauische Kantonsschule & zwar die III. & IV. Klasse

der Gewerbeschule.

Nach abgelegter schriftl. & mündl. Maturitätsprüfung am 18., 19. & 21.

September, sowie am 30. September 1896, erhielt derselbe folgende Noten:

1. Deutsche Sprache und Litteratur	5
2. Französische " " "	3
3. Englische " " "	—
4. Italienische " " "	5
5. Geschichte	6
6. Geographie	4
7. Algebra	6
8. Geometrie (Planimetrie, Trigonometrie, Stereometrie & analytische Geometrie)	6
9. Darstellende Geometrie	6
10. Physik	6
11. Chemie	5
12. Naturgeschichte	5
* 13. Im Kunstzeichnen	4
* 14. Im technischen Zeichnen	4

* Hier gelten die Jahresleistungen

Gestützt hierauf wird demselben das Zeugnis der Reife erteilt.

Aarau, den 3ten Oktober 1896.

Im Namen des Erziehungsrates,
Der Präsident:
Dr. [illegible]

Der Sekretär:
[illegible]

E[illegible]ung [illegible] Noten
6, 5, [illegible] 1.
wovon 6 die beste [illegible] geringste ist.

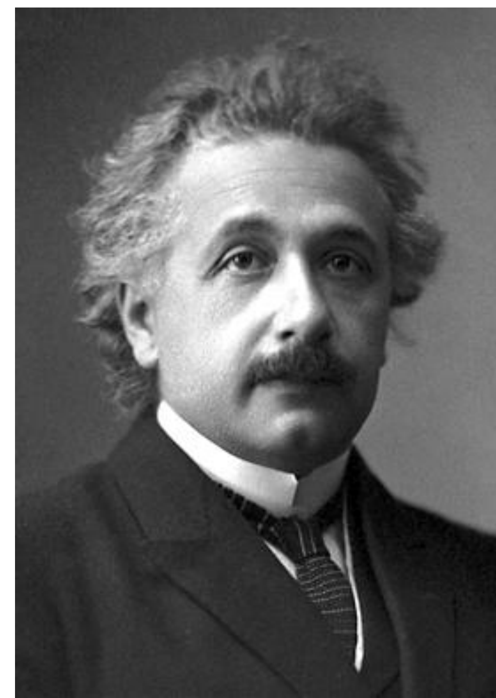
‘’Education is the key success in life, and teachers make a lasting impact in the lives of their students.’’
– Solomon Ortiz

“Good teacher can inspire hope, ignite the imagination and instill a love of learning’’
-Brad Henry

‘’It is the supreme art of the teacher to awaken joy in creative expression and knowledge.’’
–Albert Einstein

Charles Bradford "**Brad**" **Henry** (born July 10,1963) was the 26th Governor of Oklahoma. A member of the Democratic Party, he was elected governor in 2002.

Solomon Ortiz, Jr. (born July 21, 1977) is a Democratic former member of the Texas House of Representatives, serving from 2006 to 2011.



Albert Einstein was a German-born theoretical physicist. He developed the general theory of relativity, one of the two pillars of modern physics.
Einstein's work is also known for its influence on the philosophy of science.

ECE 422 RADAR ENGINEERING AND NAVIGATIONAL AIDS

1. Radar Equation, Radar Block Diagram and Operation, Prediction of Range, Minimum Detectable Signal, Receiver Noise, Probability Density Functions, S/N, Integration of Radar Pulses, Radar Cross-section, Transmitter Power, PRF and Range Ambiguities, Radar Antenna Parameters, System Losses and Propagation Effects.

2. MTI and Pulse Doppler Radar: Introduction, Delay line Cancellers, Moving target Detector, Limitation to MTI performance, MTI from moving platform, Pulse Doppler Radar

3. Tracking Radar, Sequential Lobing, Conical Scan, Monopulse tracking Radar, Low angle tracking, Pulse compression, Block Diagrams of Synthetic Aperture Radar (SAR), Phased array Radars,. MST Radar, ECM, ECCM

4. Radar Receiver, Mixers, Radar Displays, Receiver Protectors.

5. Principles of Direction Finders, Aircraft Homing and ILS, Radio Altimeter, LORAN, DECCA, OMEGA, Inland Shipping Aids.

Text Book:

1. "Microwave and Radar Engineering" by Gottapu Sasi Bhushana Rao, ISBN – 978813179944 Pearson Education Chennai 2013.
2. Radar Engineering and Fundamentals of Navigational Aids, G S N Raju, IK International Publishers, 2008

References

1.Introduction to Radar Systems, Skolnik, McGraw Hill, 2007.

2. Foundations For Microwave Engineering, R. R. Collin, McGraw Hill.

3. Microwave Communications – Components and Circuits, E. Hund, McGraw Hill. 4. Microwave Devices and Circuits, S. Y. Liao, PHI. 5. Microwave Engineering, R. Chatarjee, East – West Press Pvt. Ltd.

Course Objectives

1. To become familiar with basics of Radar.
2. To get complete knowledge about the different types of Radar and their operation.
3. To become familiar with signal detection techniques.
4. To understand the concepts of Radio Navigation techniques

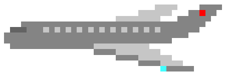
Course Outcomes

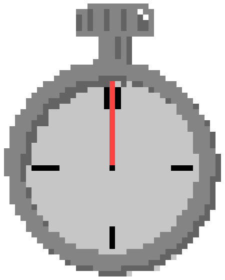
1. Acquired knowledge about Radar and Radar Equations.
2. Understanding the working principal of MTI and Pulse Doppler Radar.
3. ability to work using Detection of Signals in Noise and Radio Direction Finding.
4. ability to work using Instrument Landing System.
5. Ability to work with Satellite Navigation System.

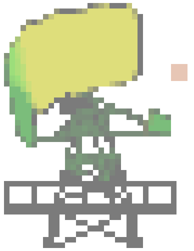
RADAR

1. Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects.
2. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain.
3. A radar transmits radio waves or microwaves that reflect from any object in their path.

Introduction







$$R = ct/2 \text{ meters.}$$

- RADAR- Radio Detection and Ranging
- Higher the frequency better the result
- Theory of reflection (Absorbtion and re-radiation)
- Location parameters: Range, height, direction, direction of motion, relative velocity
- High transmitter power requirement
- Suitable oscillator: Magnetron

Applications

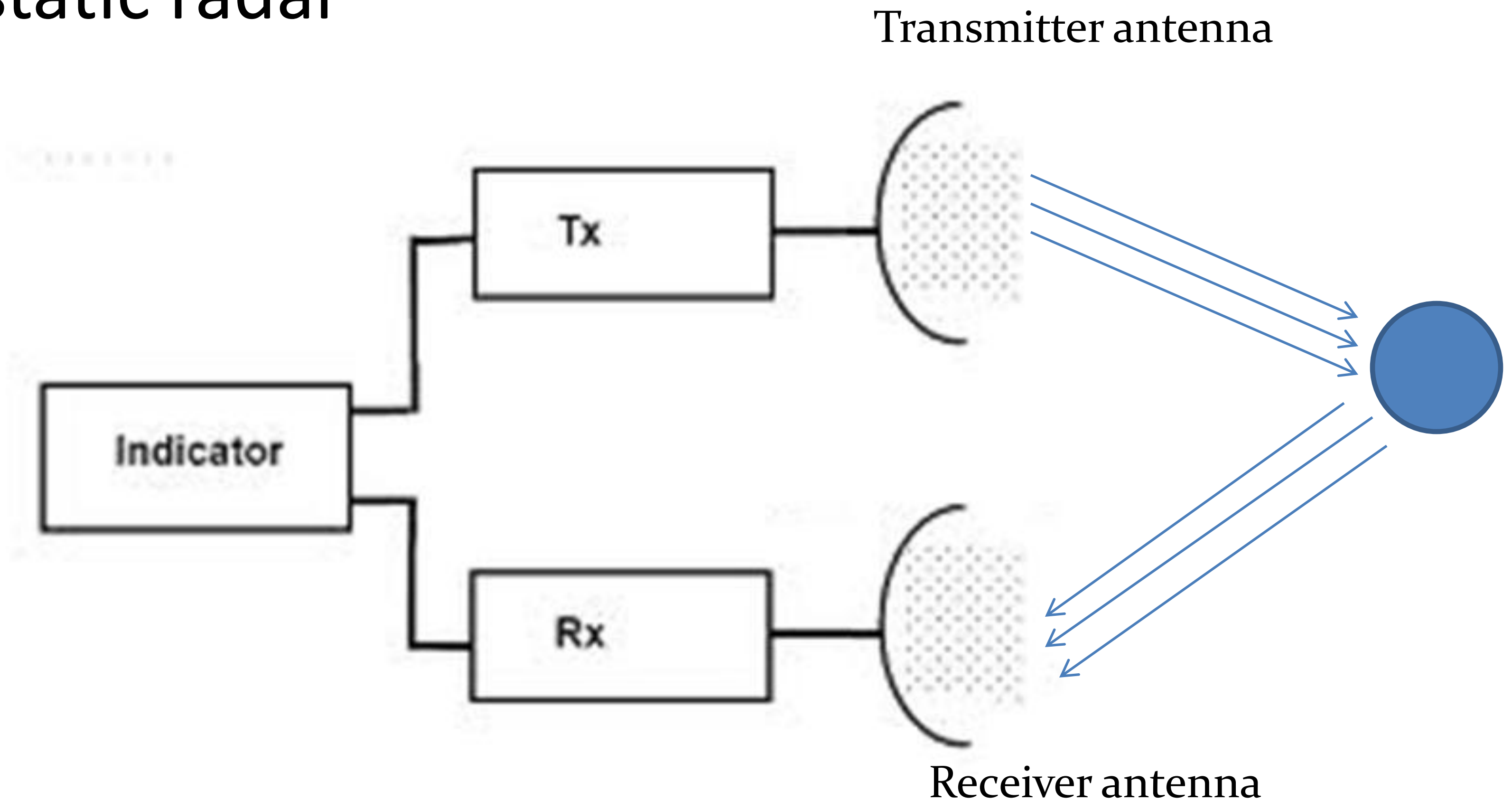
1. Navigational aid on ground and sea
2. Radar altimeters (height measurement)
3. Radar blind lander (aircraft landing during poor visibility)
4. Airborne radar for satellite surveillance
5. Space applications like planetary observations
6. Police radars (Law enforcement and Highway safety)
7. Radars for determining speed of moving targets
8. Remote sensing (weather monitoring)
9. Air traffic control (ATC) and Aircraft safety
10. Ship safety
11. Non-contact method of speed and distance in industry

Military Applications:

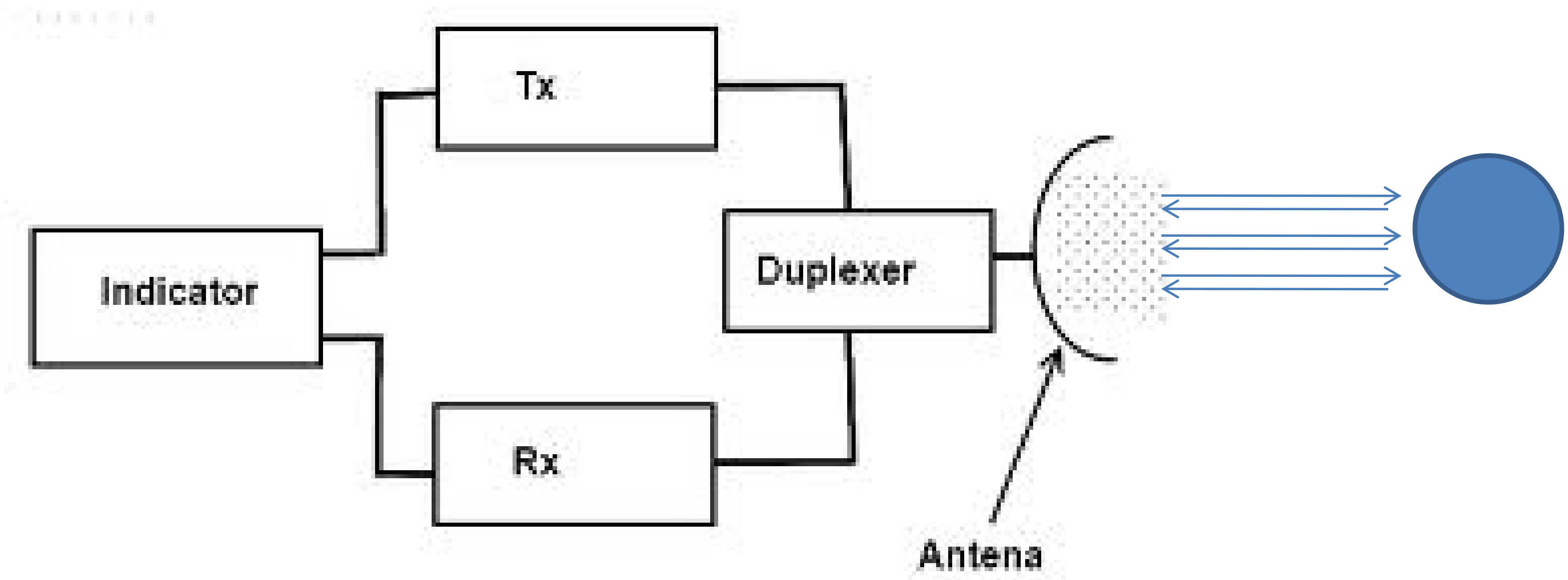
- ✓ Detection and ranging of enemy targets even at night
- ✓ Aiming guns at aircrafts and ships
- ✓ Bombing ships, aircrafts, or cities even during night
- ✓ Early warning regarding approaching aircrafts or ships
- ✓ Directing guided missiles
- ✓ Searching for submarines, land masses and buoys

Radar block digram

- Bistatic radar



- Monostatic radar



- ✓ The distance of the target can be calculated from the total time (t) taken by the pulse to travel to the target and return to its original initial point.
- ✓ Assuming ' c ' to be the velocity of light in free space, the distance traversed by pulse is 'ct' meters. Now this is 2 times the target distance, hence the distance to the target

$$R = ct/2 \text{ meters.}$$

Requirements

- ✓ Automatically operating duplexer
- ✓ Tx should remain silent during echo period
- ✓ Tx pulse should be very powerful
- ✓ Rx should be highly sensitive to echo signals and should be highly immune to noise
- ✓ Antenna should be highly directive with large gain
- ✓ Pulse repetition frequency (prf) should be high compared to the scanning period

prf = duty cycle/pulse width

$P_{av} = P_t$ X duty cycle = Pt X Pulse width X prf

Radar frequency band designations

Band designation	Nominal frequency range	Specific radar bands based on ITU assignment
HF	3 – 30 MHz	
VHF	30 – 300 MHz	138-144, 216-225 MHz
UHF	300 – 1000 MHz	420-450, 590-942 MHz
L	1 – 2 GHz	1215-1400 MHz
S	2 – 4 GHz	2300-2500, 2700-3700MHz
C	4 – 8 GHz	5250-5925 MHz
X	8 – 12 GHz	8500-10680 MHz
Ku	1 2– 18 GHz	13.4-14, 15.7-17.7 GHz
K	18 – 27 GHz	24.05-24.25 GHz
Ka	27 – 40 GHz	33.4-36 GHz

Introduction

– **Radar → Radio detection and ranging**

- **Radar is an electromagnetic system for the detection and location of objects.**
- **It operates by transmitting a particular type of waveform (ex: pulse modulated sine wave) and nature of the echo signal.**
- **Radar has advantage of being able to measure the distance or range to the object. This is probably its most important attribute.**
- **Radar has is used to extend the capability of one's senses for observing the environment, especially the sence of vision.**

Basic Principles

- Transmits an electromagnetic signal modulated with particular type of waveform. (modulation depends on requirements of application)
- Signal is reflected from target
- Reflected signal is detected by radar receiver and analyzed to extract desired information
- Distance can be determined by measuring the time difference between transmission and reception
- Angle (or relative bearing) can be determined by measuring the angle of arrival (AOA) of the signal (Usually by highly directive antenna)
- If there is a radial component of relative velocity between radar and target it can be determined from the Doppler shift of the carrier

Two types of radar

Monostatic - transmitter and receiver use same antenna

Bistatic - transmitter and receiver antennas are separated

- Modulation Types
  - Simple Pulse; one or more repetition frequencies
  - Frequency Modulation FM (radar altimeters)
  - Pulse with Chirp (pulse compression)
  - CW (continuous wave) - police radar (Doppler)

The simple form of the radar range equation

- **Radar equation relates the range of radar to the characteristics of *transmitter* (T_x), *receiver* (R_x), *antenna*, *target* and *environment*.**
- **It is useful not for determining the range from radar to target it can serve both for understanding radar operation and basis for radar design.**

The simple form of the radar range equation

- **If the power of the radar T_x is denoted by P_t, and if an isotropic antenna is used, the power density** **(w/unit area).**
- **The power density at a distance R from the radar is**

σ **Is cross section the target**

$$= \frac{T_x \text{ Power}}{\text{Surface area of imaginary sphere of radius R}}$$

$$\text{The power density from an isotropic antenna} = \frac{P_t}{4\prod R^2}$$

$$\text{The power density from directive antenna} = \frac{P_t G}{4\prod R^2}$$

$$\text{The power density of echo signal at radar} = \frac{P_t G}{4\prod R^2}\frac{\sigma}{4\prod R^2}$$

If the effective area of R_x antenna is denoted A_e , the power P_r received by the radar is

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

$$R_{max} = \left[\frac{P_t\ G\ \sigma\ Ae}{(4\Pi)^2\ P_r}\right]^{1/4}$$

The maximum radar range R_{max}

. P_r is equal to the minimum detectable signal S_{min}

Then the basic radar range equation is

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

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

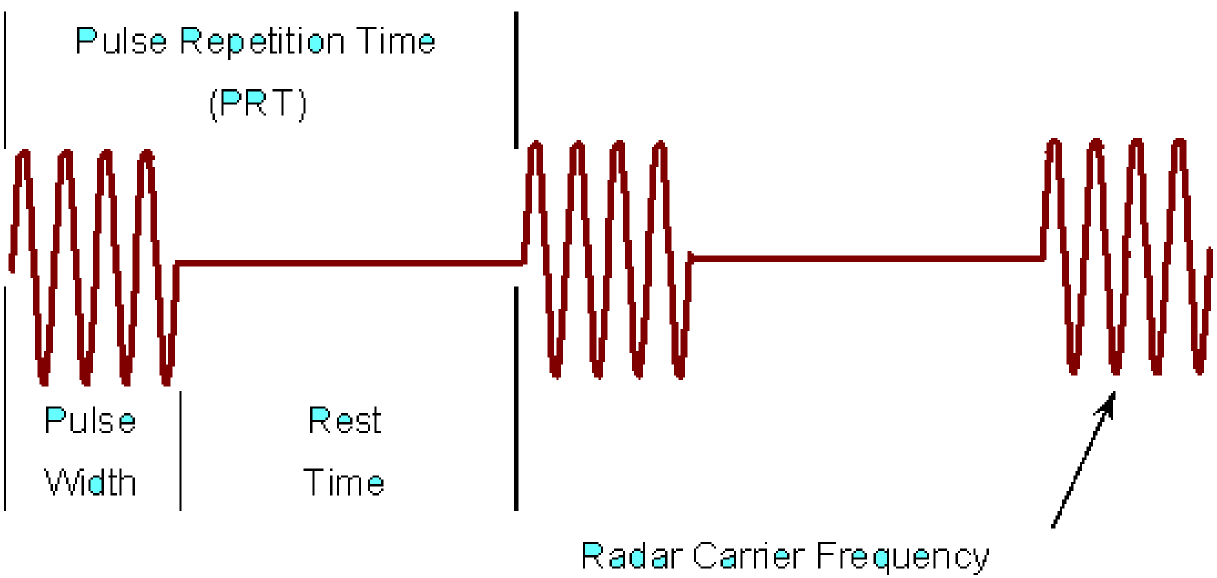
Classification

1. Continuous Wave Radar (CW Radar) or Doppler Radar

Continuous Wave (CW) radars utilize Continuous waveforms, which may be considered to be a pure sine wave of the form cos(2 pi f_0t). Spectra of the radar echo from stationary targets and clutter will be concentrated at the center frequency f_0 for the echoes from moving targets will be shifted by , the Doppler frequency. Thus by measuring this frequency difference CW radars can very accurately extract target relative velocity. Because of the continuous nature of CW emission, range measurement is not possible without some modifications to the radar operations and waveforms

2. Pulsed Radar:

More useful than CW radar. Here the Tx transmits a train of narrow rectangular shaped pulses modulating a sine wave carrier. The range to the target is determined by me… …ulse to tra… …ne radar sta…

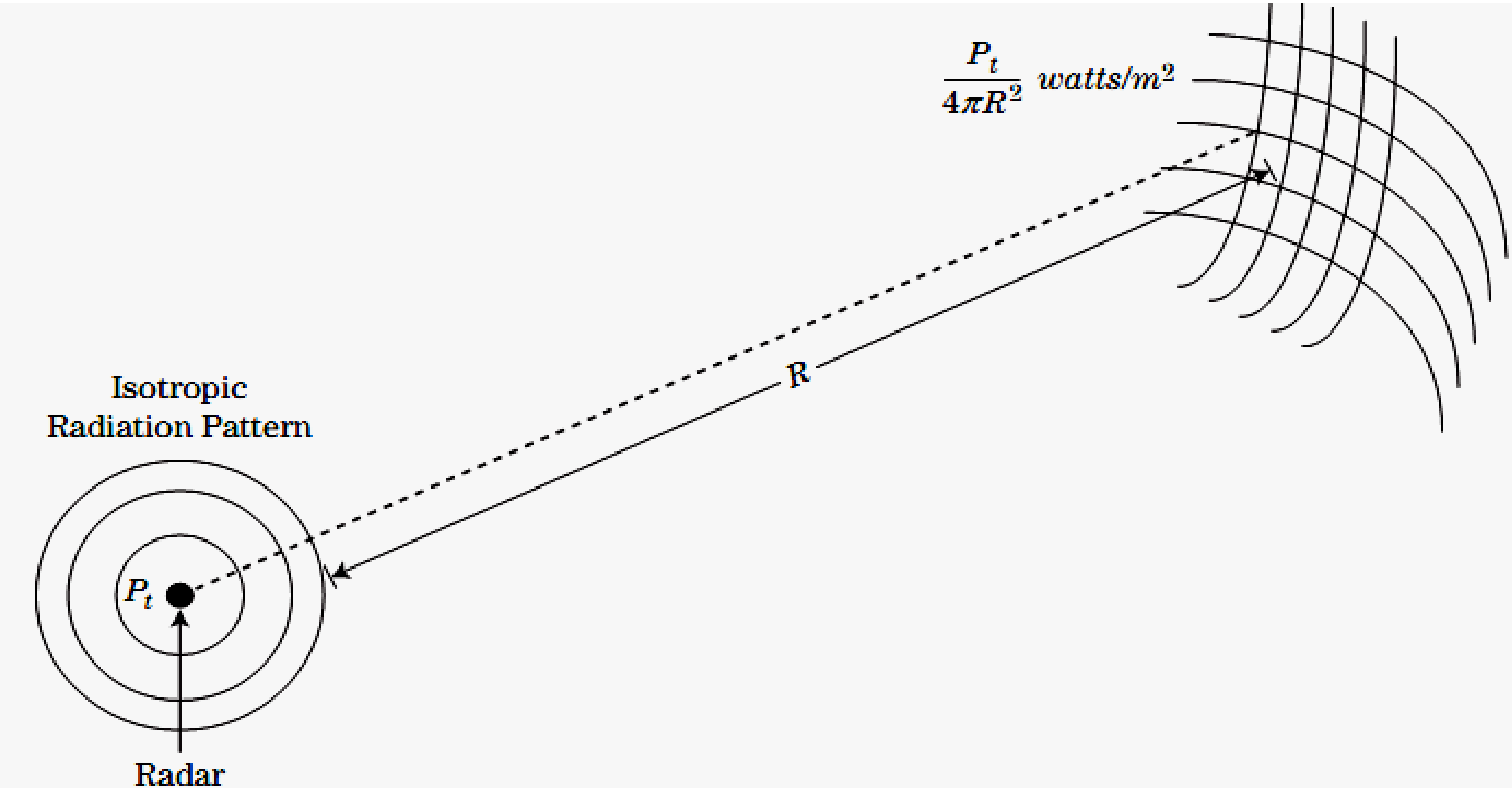


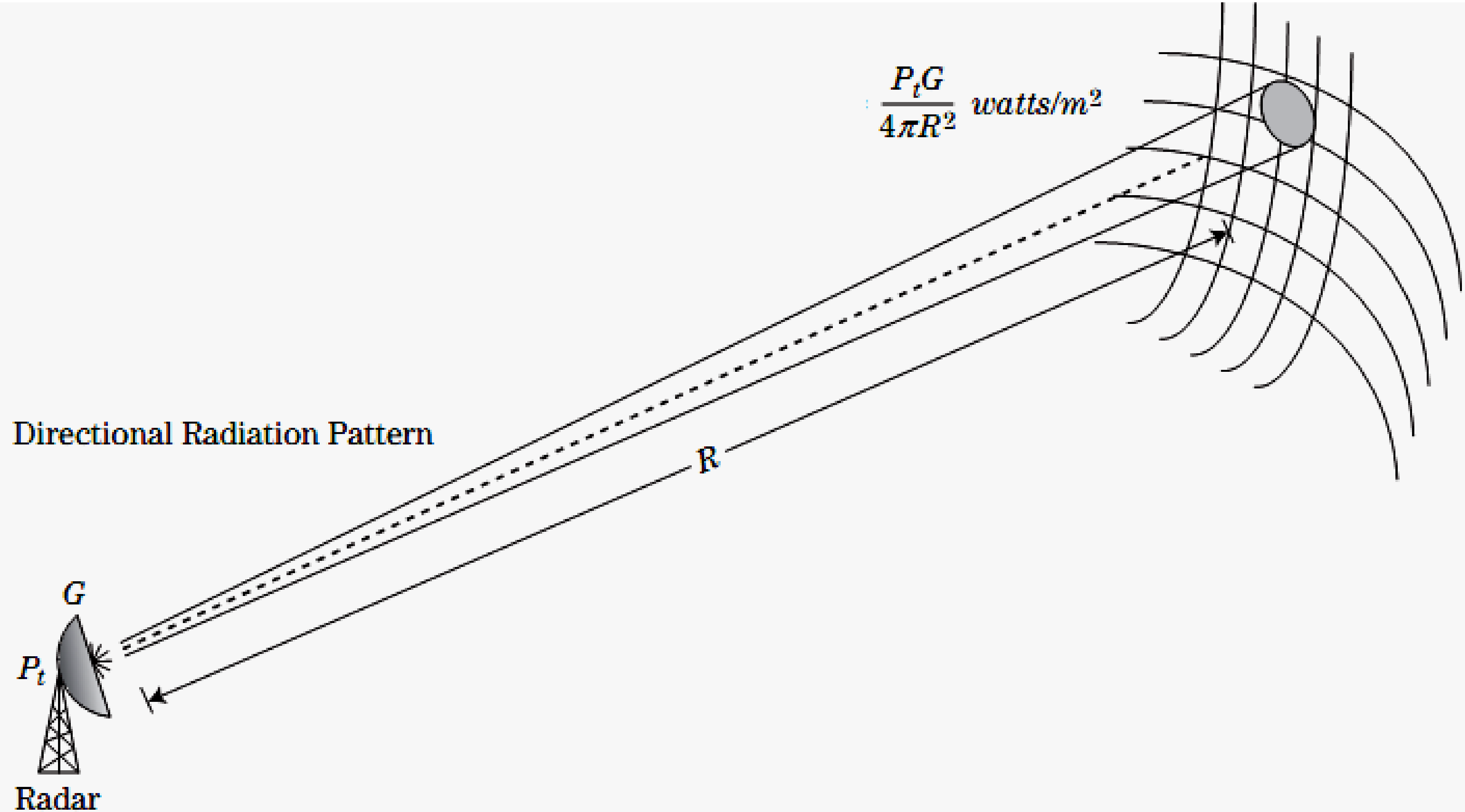
Radar range equation

- Radar range equation relates the range of the radar to the characteristics of the Tx, Rx, antenna, target and the environment. It is used for radar system design.
- P_t = power radiated by an isotropic antenna
- Power density at a range R from $= \dfrac{P_t}{4\pi R^2}$ W/m²

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2}$$

- .. W/m²
- where G is the directive gain


$\frac{P_t}{4\pi R^2}$ watts/m^2
R
Isotropic
Radiation Pattern
P_t
Radar



$\frac{P_t G}{4\pi R^2}$ watts/m^2
Directional Radiation Pattern
R
G
P_t
Radar

- Amount of power intercepted by the target = σ
- It is also called the "radar cross section of the target"
- It depend on the target's shape, size and composition

- Total power intercepted by the target $= \frac{P_t G \sigma}{4\pi R^2}$ W
- Power density of echo signal at radar $= \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2}$
- Received power , $P_r = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$
- Where A_e is the effective area of the antenna.

- The maximum range of the radar R_{max} is the distance beyond which the target cannot be detected. This happens when $P_r = S_{min}$, minimum

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

-

- This is called radar range equation

Factors effecting range of a radar:

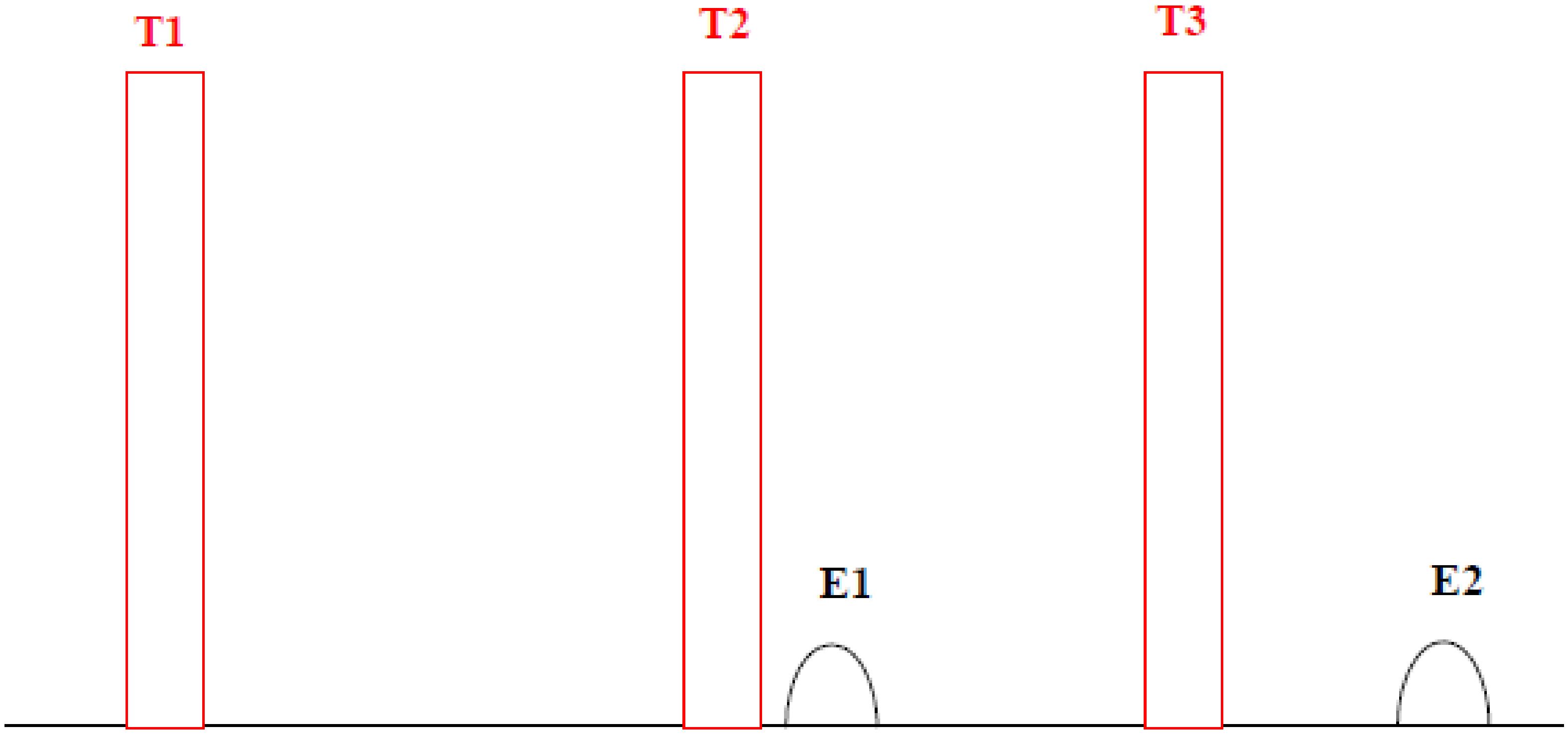
- Transmitter power
- Frequency
- Radar cross-section of the target
- Minimum received signal power Pr (min)

Assignment: Receiver Thermal Noise and Signal to Noise Ratio

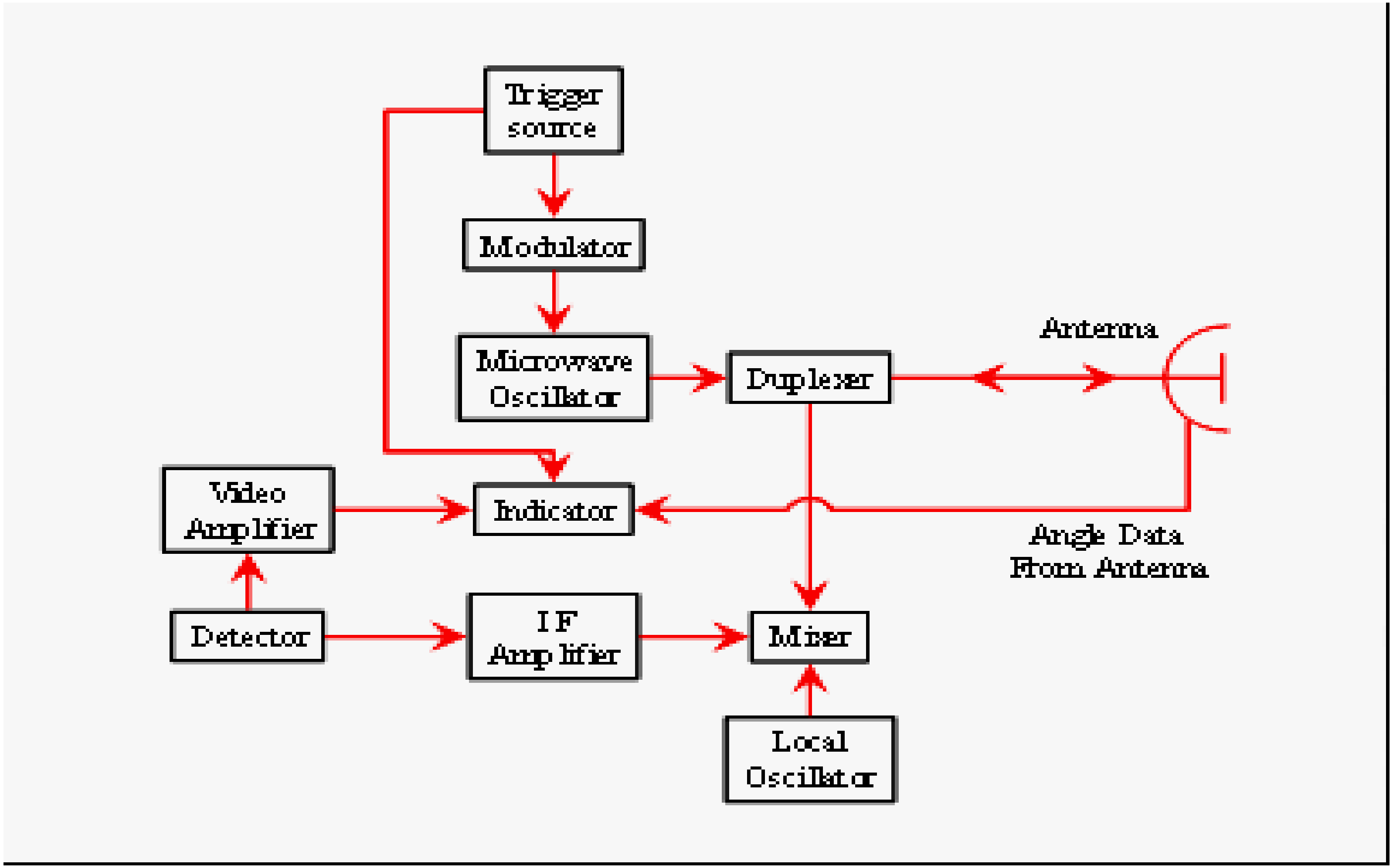
Maximum Unambiguous Range

- Once the radar Tx transmits a pulse, sufficient time should be alloted so that the echo signal due to this pulse may be received and detected before the next pulse is transmitted.
- If the prf is too high echoes may arrive after the transmission of the next pulse. Such echoes are called “Second time around echoes”

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


T1
T2
T3
E1
E2

Pulsed Radar



- Trigger source
- Pulse modulator
- Microwave oscillator
- Duplexer
- Low Noise amplifier
- Mixer and local oscillator
- IF amplifier
- Detector and Video amplifier
- Indicator or display
- Direction indication from angle data

UNIT-II

MTI RADAR

- Instrumentation Radars for RCS measurement
- Types of Instrumentation Radars
- Doppler effect
- Doppler frequency shift.
- CW radar
  - block diagram
  - Operation
  - **CW homodyne radar.**

UNIT-II

MTI RADAR

- Instrumentation Radars for RCS measurement

  Instrumentation Radar is specially designed to measure the RCS level of a target at a known range.

- Types of Instrumentation Radars

  1. CW Radar
  2. FMCW Radar
  3. Gated CW Radar
  4. Pulse Radar

The Doppler Effect

- The shift in frequency of the received echo signal from a moving target compared to the transmitted frequency of a radar station is called Doppler frequency shift and phenomena is called Doppler effect

Let R be the Range of the target

- The number of wavelengths contained in the two way path between the radar and the target is $2R/\lambda$

- Total phase shift ϕ = $4\pi R/\lambda$ radians

If the moving target then the phase path is ω_d

R ang R and ϕ changes continuously.

Rate of change of ϕ is angular frequency.

$$\omega_d = 2\pi f_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi v_r}{\lambda}$$

Where v_r is the relative velocity of the target w.r.t. radar.

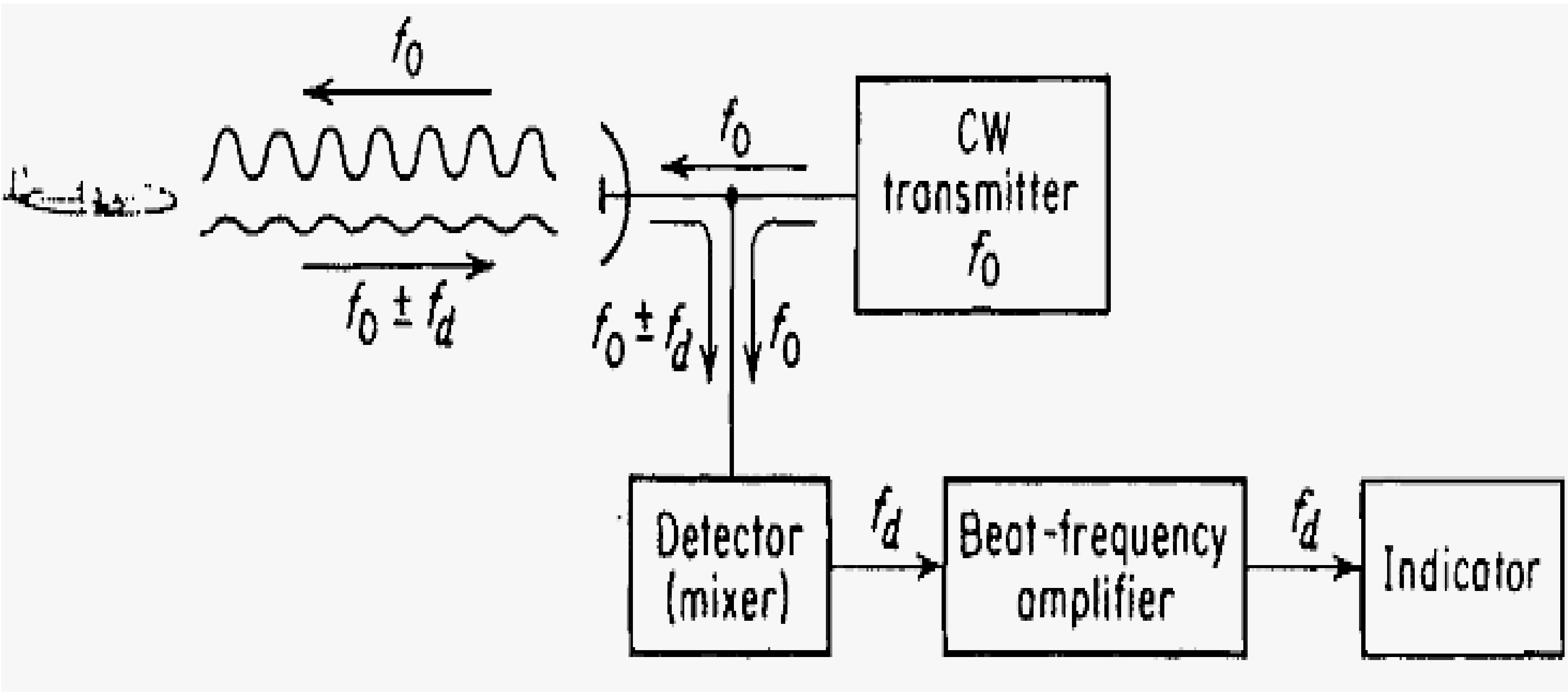
f_d is the Doppler frequency shift.

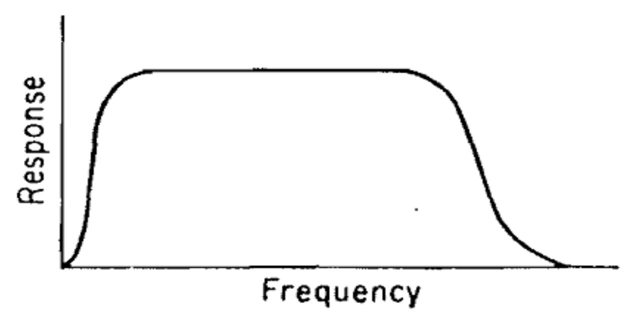
$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}$$

Where

$$v_r = v \cos\theta$$

Continuous Wave Doppler Radar





- **Tx generates continuous sinusoidal oscillations of frequency f_o. It is radiated by the antenna.**
- **CW radar receives the echo signal while it transmits.**
- **If the target is in motion the received echo signal will be shifted in frequency by an amount f_d** ($f_0 \pm f_d$)
- **Mixer isolates the Doppler frequency note f_d.**
- **Beat frequency amplifier eliminates the echoes from stationary targets and amplifies the Doppler echo signal.**
- **This radar is also called CW radar with zero IF or CW Super-heterodyne radar with Zero IF or Simple doppler radar or CW** homodyne radar.

- Echoes from natural environment such as land, sea, and weather are called clutter.

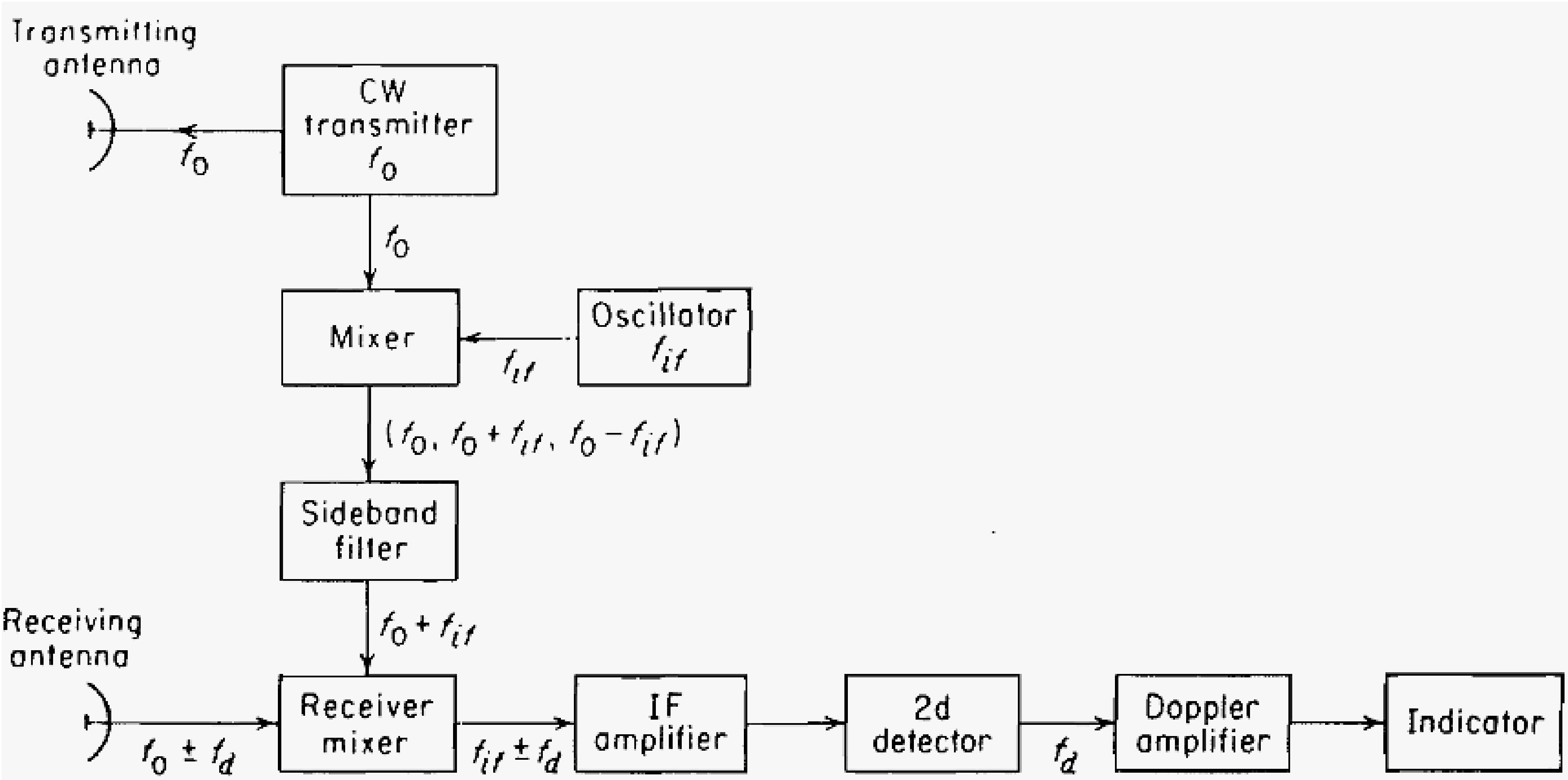
Isolation between Tx and Rx:

- Isolation required depends on Tx power, Tx noise and sensitivity of the receiver
- Large distance CW radar introduce more Tx noise
- Transmitter clutter: Tx noise that enters the radar receiver via back scatter from the clutter.
- False targets: Tx signal is not a pure CW. The associated side bands may mask the desired signals or generated false targets.

Limitations of simple CW Radar

- Lack of isolation between Tx and Rx.
  - Receiver burn out
  - Masking of wanted signals by Tx noise
- Introduction of flicker noise ($1/f$ noise) due to homodyne
- Lack of matched filter in the receiver
- Unable to identify whether the target is approaching or receding
- Increased clutter compared to pulsed radar
- Measurement of range is not possible

CW Radar with Non-zero IF



It is not simple as ordinary CW radar.

Isolation between Tx and Rx

- Separate antennas are used for Tx and Rx to reduce Tx leakage
- Local oscillator in the Rx is derived from the Tx signal mixed with locally generated signal of frequency equal to that of the receiver IF.
- Tx leakage can occur due to Tx clutter also.

Reduction in flicker noise:

- ✓ Flicker effect noise reduces the receiver sensitivity of a CW Radar with zero IF (Simple doppler radar). In order to increase the sensitivity and efficiency we go for CW Radar with Non-zero IF.
- ✓ Doppler frequency usually falls in the audio or video frequency range which is more susceptible to flicker noise.
- ✓ Flicker noise is inversely proportional to frequency. So as we shift the doppler freq to IF flicker noise reduces.

- ✓ Super-heterodyne receiver with non zero IF increases the receiver **sensitivity above 30 dB**
- ✓ Receiver bandwidth:
- ✓ IF amplifier should be wide enough to pass the expected range of Doppler frequencies.
- ✓ Usually expected range of Doppler frequencies will be much higher than the doppler frequency. So a wide band amplifier is needed.
- ✓ But as bandwidth of Rx in increased noise increases and sensitivity degrades.
- ✓ Also the Tx signal band width is also not narrow.
- ✓ So Rx signal bandwidth again increases.

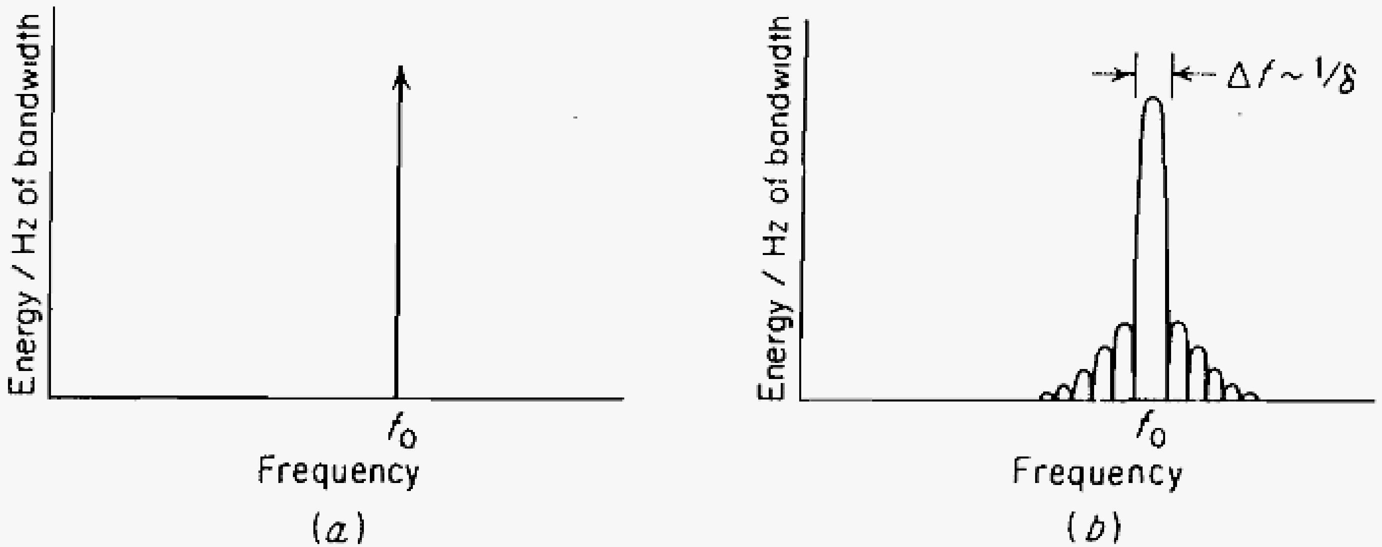
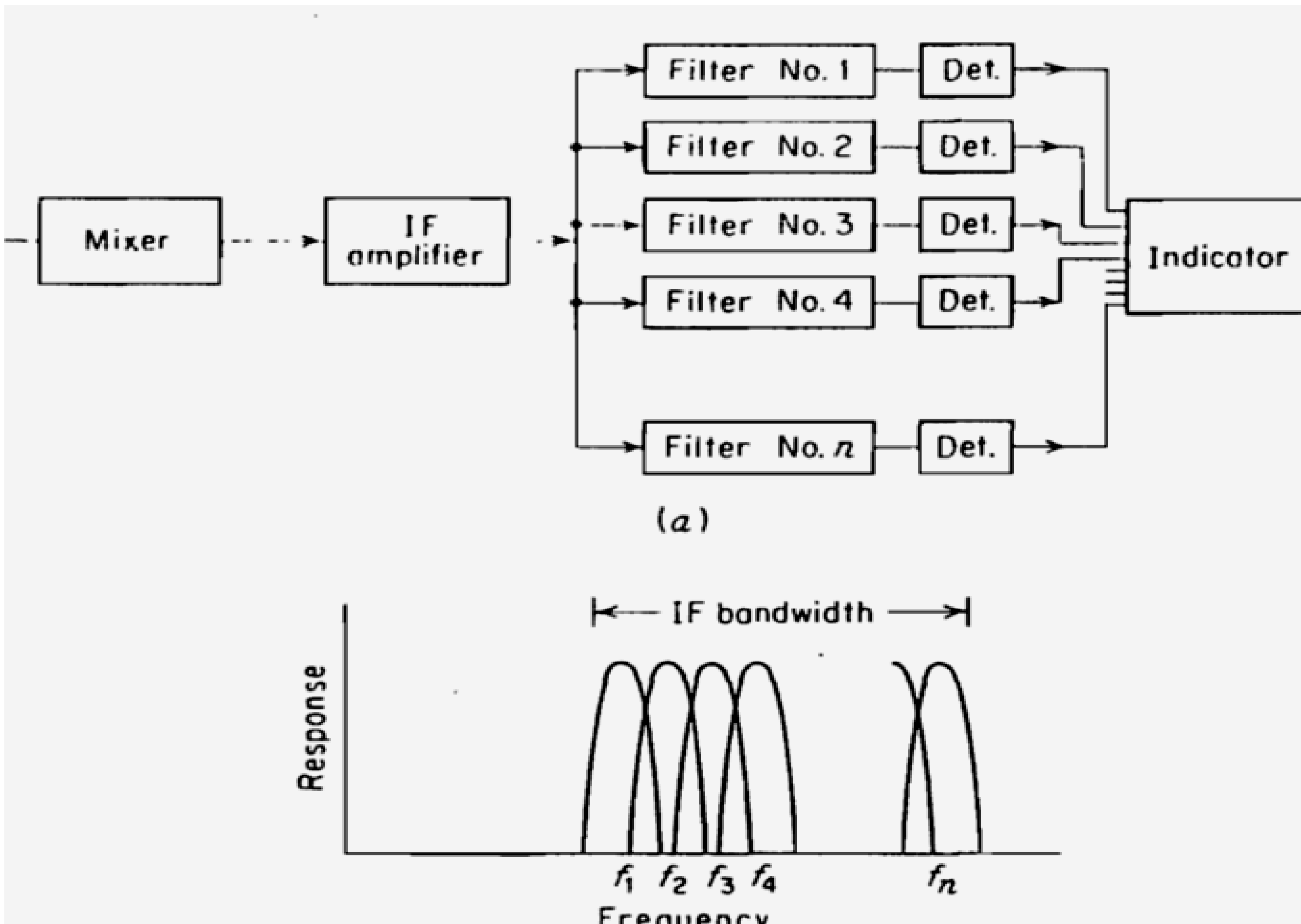


Figure 3.5 Frequency spectrum of CW oscillation of (*a*) infinite duration and (*b*) finite duration.

- SNR can be enhanced by using filter banks for Doppler amplifier. It approximates a matched filter



- BW of each filter is wide enough to accept the signal energy. But not so wide to accept the noise.
- The more the filters used less will be the SNR loss and less chance of missing a target

Direction of target motion:

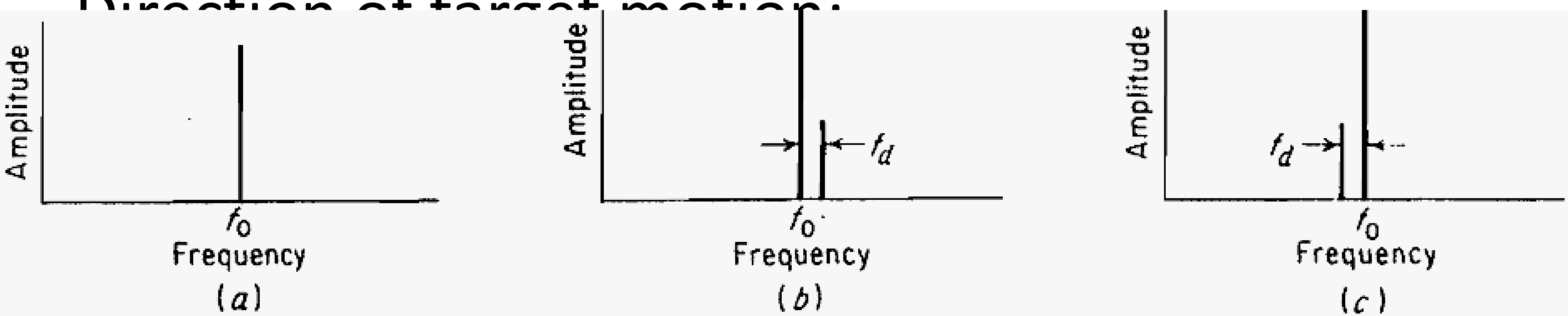
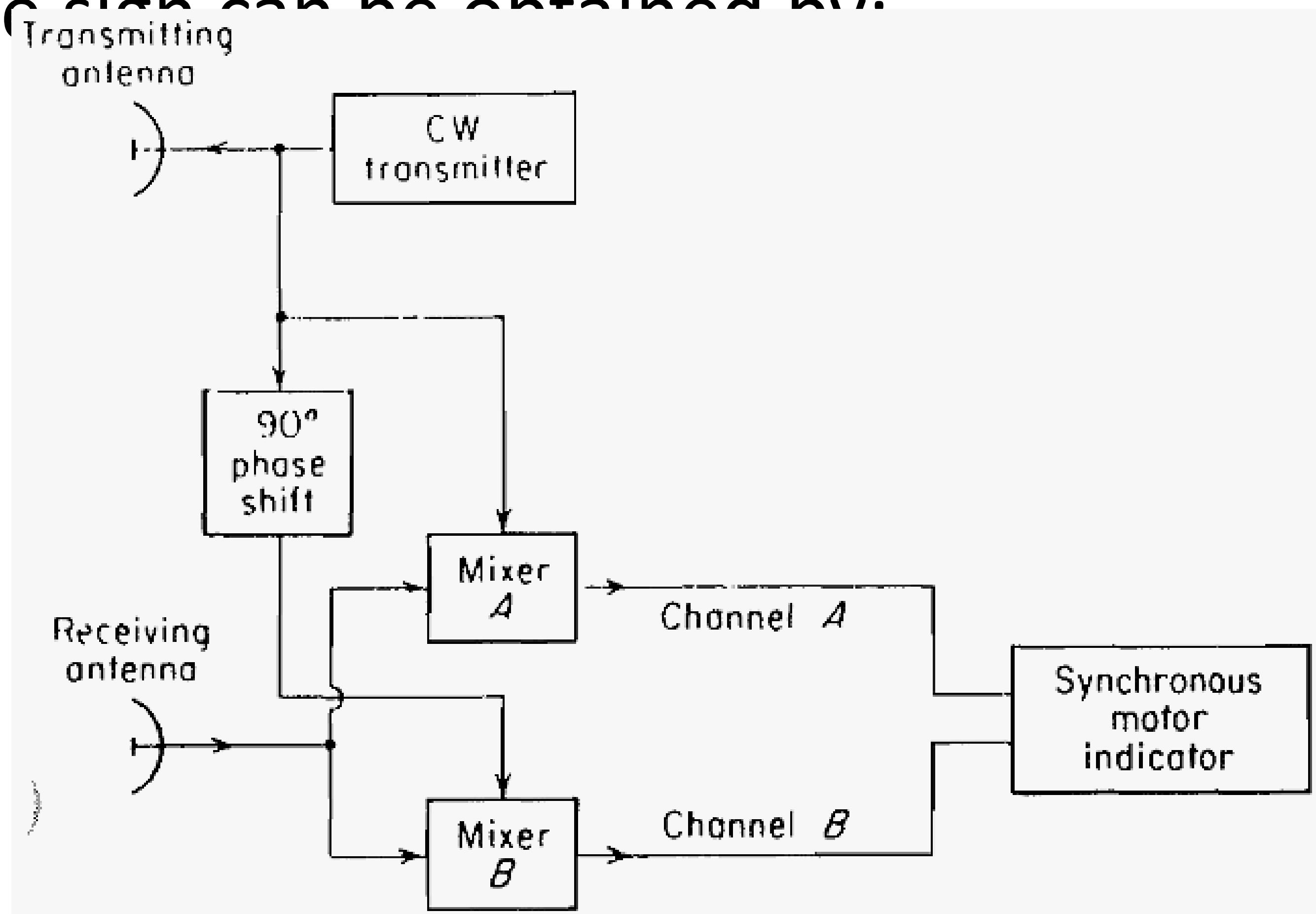


Figure 3.7 Spectra of received signals. (*a*) No doppler shift, no relative target motion; (*b*) approaching target; (*c*) receding target.

- A simple CW radar loses the sign of doppler shift during mixing.
- The sign can be obtained by:



- If the output of channel B leads the output of channel A , the doppler shift Positive. Approaching Target
- If the output of channel B lags the output of channel A, the doppler shift Negative. Receding Target

Applications of CW radar with Non-zero IF

- Police speed monitor
- Rate-of-climb meter (During aircraft take off)
- Vehicle counting
- Antilock braking system
- Collision avoidance
- In railways as speedometer instead of tachometer
- Advance warning system for approaching targets
- Docking speed measurement of large ships
- Intruder alarms
- Measurement of velocity of missiles, baseball etc

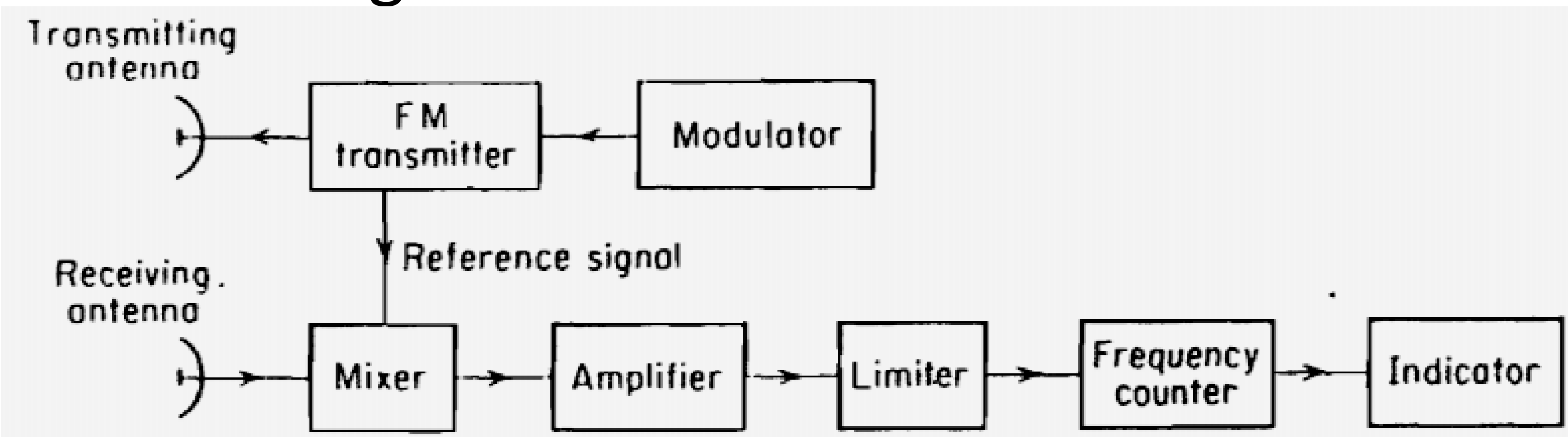
Limitations of CW radar with Non-zero IF

- False targets
- Unable to detect the range of the target

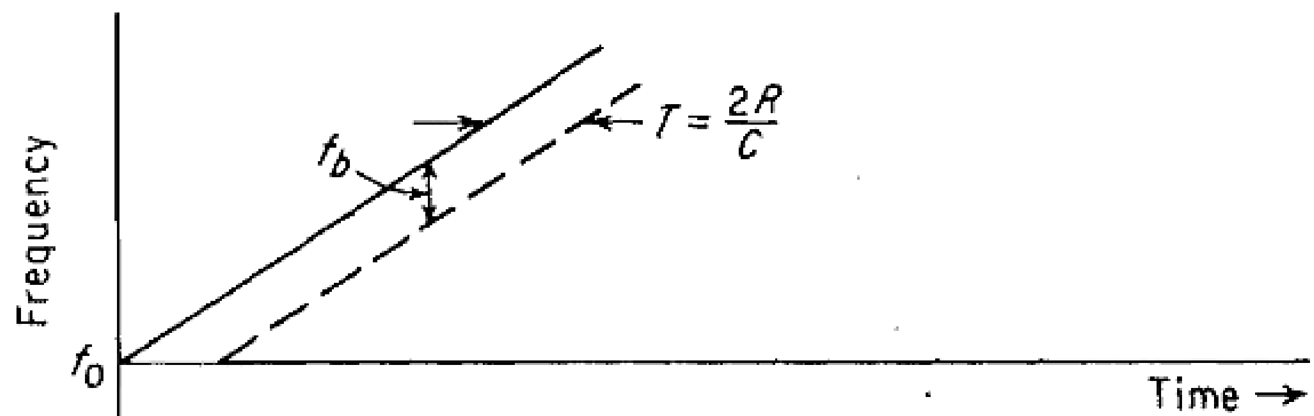
Frequency Modulated CW radar

- FM CW radar is capable of measuring the relative velocity and the range of the target with the expense of bandwidth.
- By providing timing marks into the Tx signal the time of transmission and the time of return can be calculated. This will increase the bandwidth
- More distinct the timing, more accurate the result will be and more broader will the Tx spectrum
- Here it is done by frequency modulating the carrier and the timing mark is the change in frequency

- Block diagram:



- ne



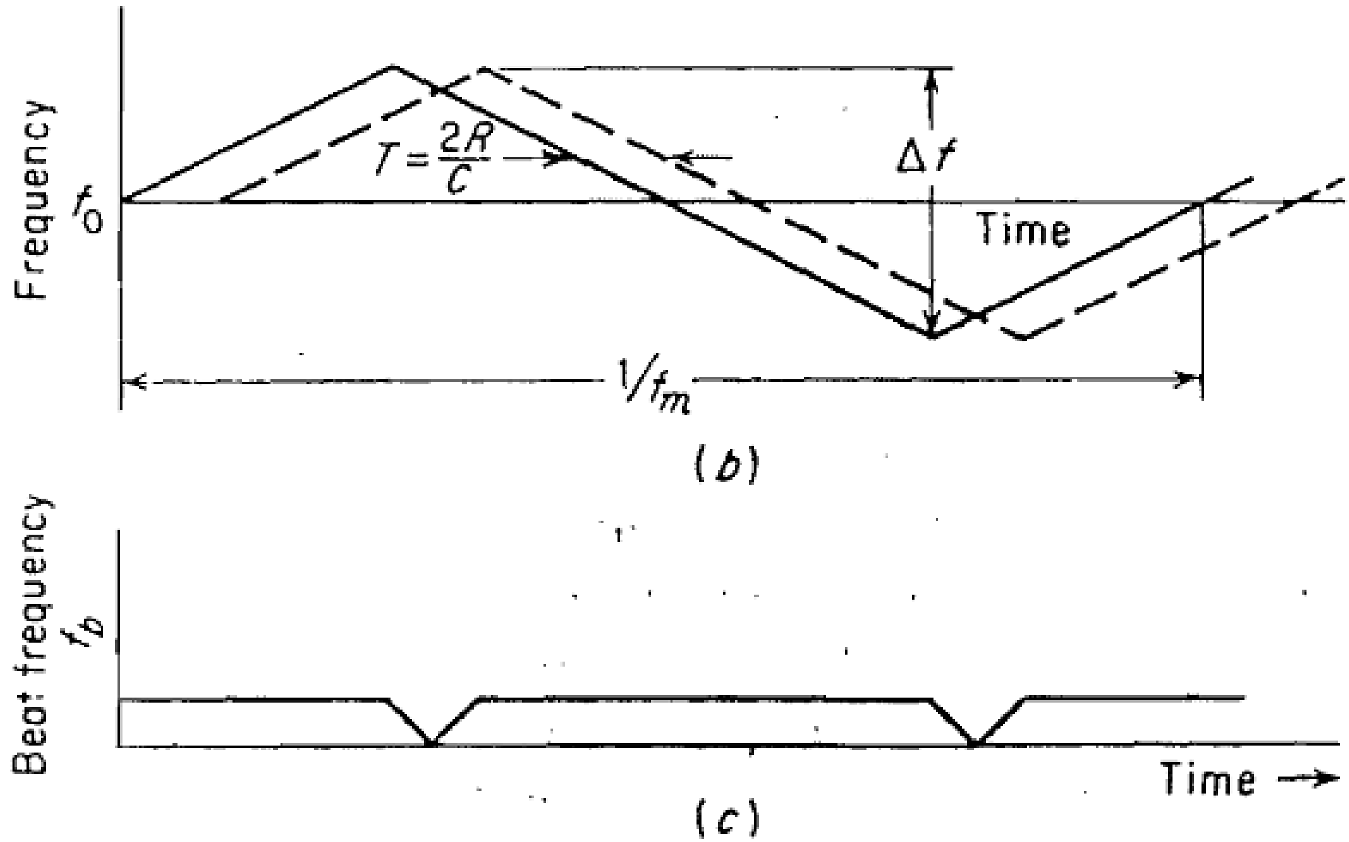
(a)

- The echo signal will return after a time $T = 2R/c$ (dashed line)
- 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 is a measure of the target's range and $f_b = f_r$,

$$f_r = \dot{f}_0 T = \frac{2R}{c} \dot{f}_0$$

- If the rate carrier frequency is $\dot{f}_0$, the beat frequency is

- In practical receivers triangular frequency modula



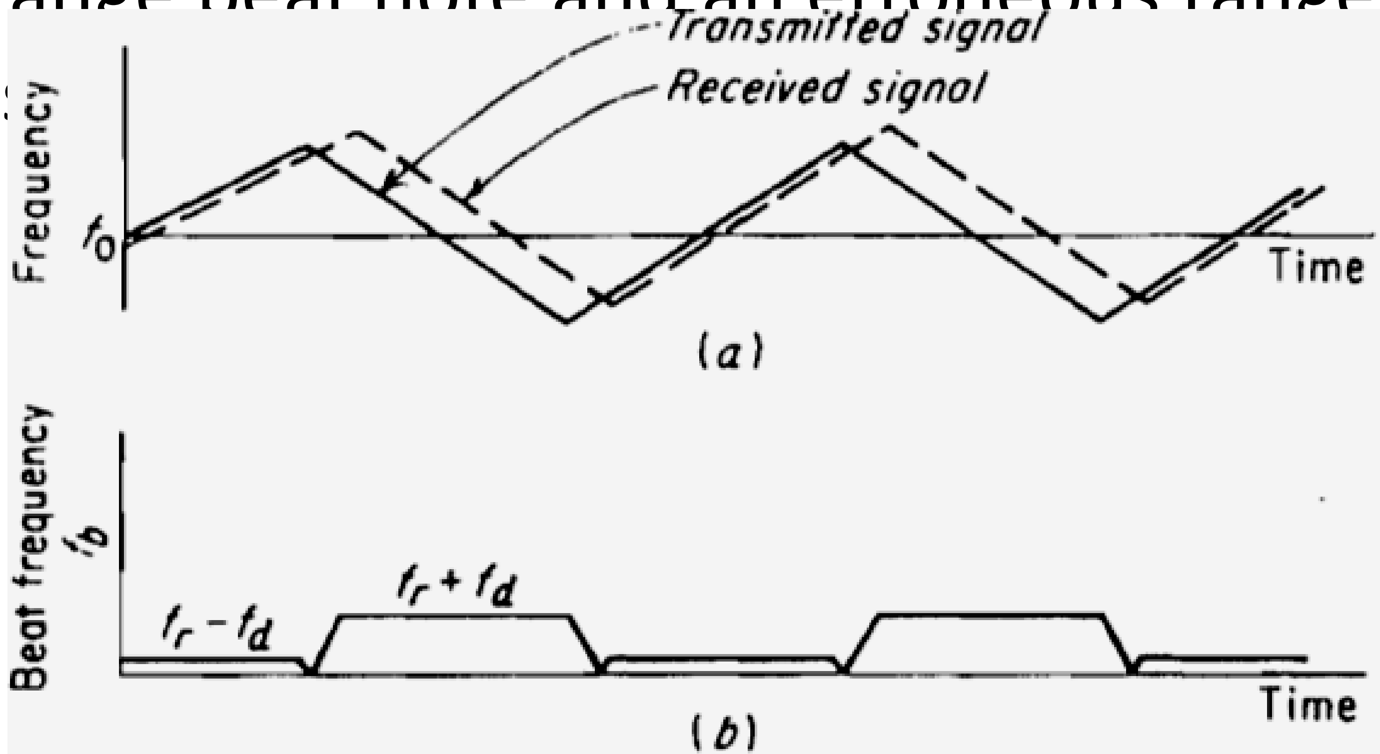
- (b)= Triangular freq modulation
- (c)= Corresponding beat note

- If the frequency is modulated at a rate $\boldsymbol{f_m}$ over a range $\Delta \boldsymbol{f}$ the beat frequency is

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

- The reference signal from the transmitter is used to produce the beat frequency note
- Beat frequency is amplified and limited to eliminate any amplitude fluctuations.
- The freq of the amp-limited beat note is measured with a cycle counting frequency meter calibrated in distance

- If the target is not stationary doppler frequency shift will be superimposed on the FM range beat note and an erroneous range meas



$$f_b(\text{up}) = f_r - f_d$$

$$f_b(\text{down}) = f_r + f_d$$

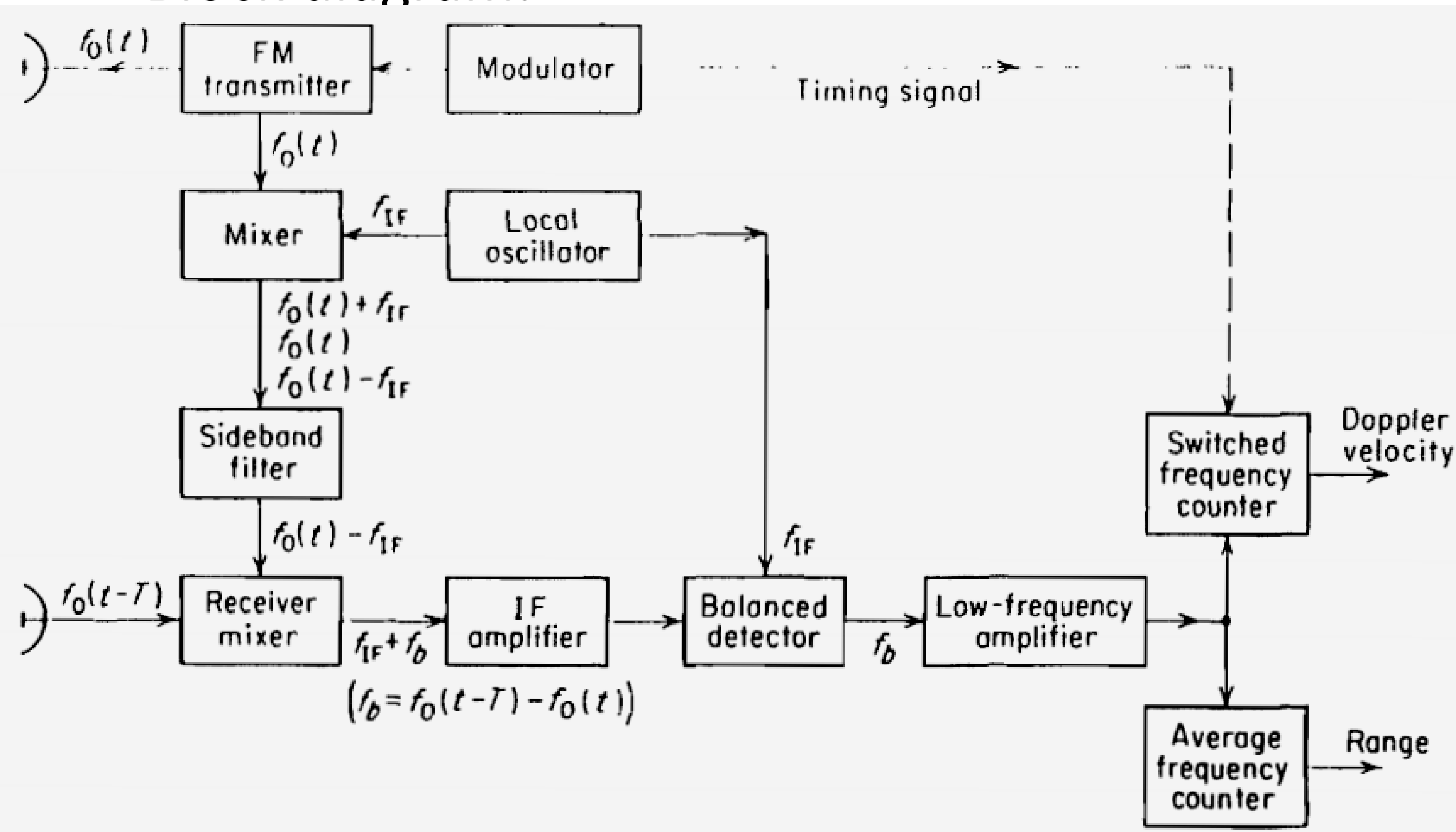
- The beat frequency due to range f_r can be calculated $\frac{1}{2}[f_b(\text{up}) + f_b(\text{down})] = f_r$

- One-half the difference between the frequencies will yield the doppler frequency.
- If there are more than one target, the range to each target may be measured by measuring the individual frequency components by using a bank of narrow band filters.
- If the targets are moving the task of measuring the range of each becomes complicated

FM CW Altimeter

- To measure the height above the surface of the earth FM CW radar is used as aircraft radio altimeter.
- Low Tx power and low antenna gain is needed because of short range.
- Since the relative motion between the aircraft and ground is small, the effect of the Doppler frequency shift may usually be neglected.
- Frequency range: 4.2 to 4.4 GHz (reserved for altimeters)
- Solid state Tx is used here.
- High sensitive super-heterodyne Rx is preferred for better sensitivity and stability

- Block diagram:



- The output of the detector contains the beat frequency which contains doppler frequency and the range frequency.
- It is amplified to a level enough to actuate the frequency measuring circuits.
- The average frequency counter determines the range

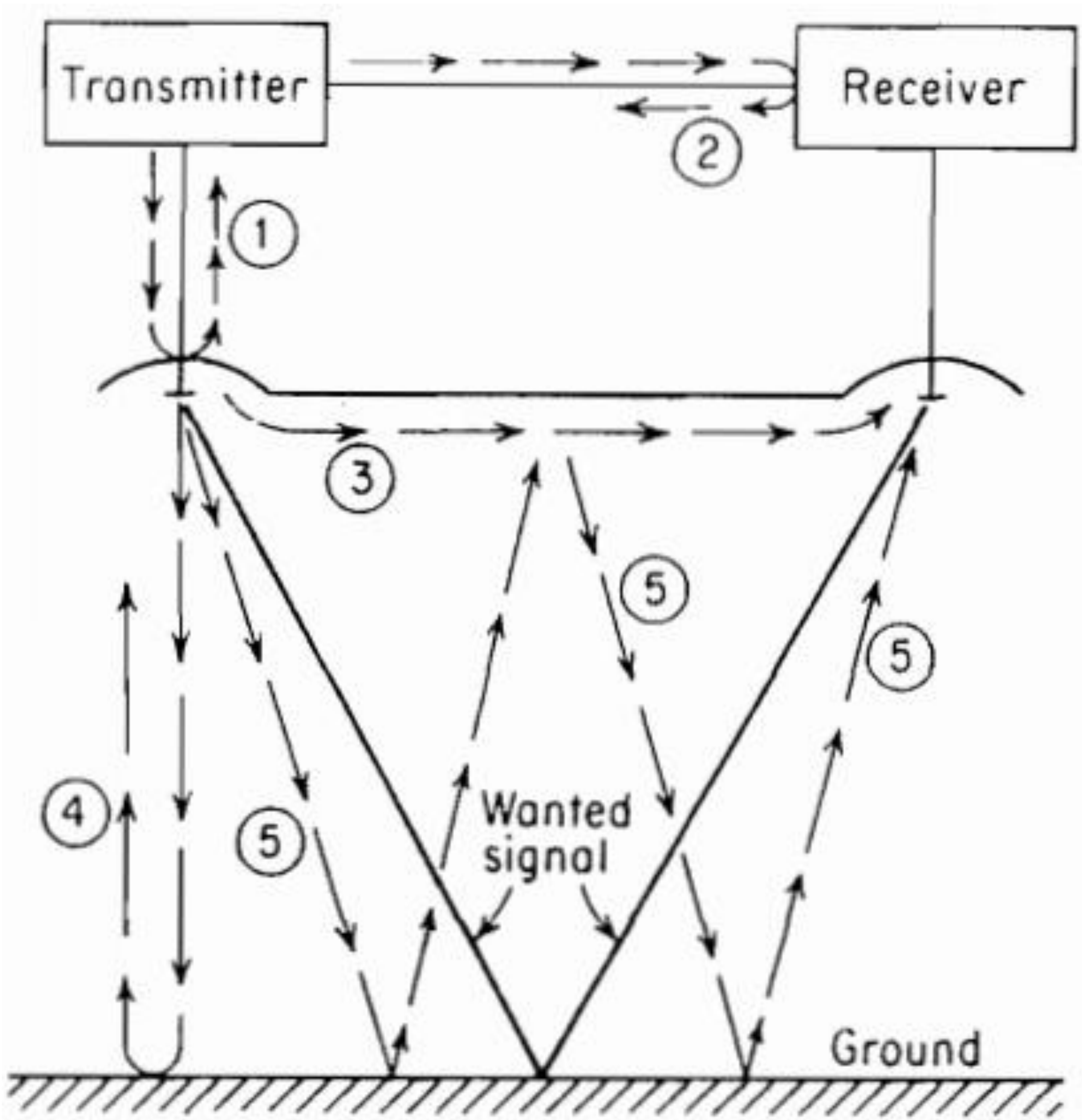
$$\frac{1}{2}[f_b(\text{up}) + f_b(\text{down})] = f_r$$

- The switched frequency counter determines the Doppler velocity
- Averaging frequency counter is necessary in an altimeter, since the rate of change of altitude is usually small

- In an altimeter, the echo signal from an extended target varies inversely as the square (rather than the 4^{th} power)of the range, because greater the range greater the echo area illuminated by the beam.
- Low frequency amplifier is a narrow band filter which is wide enough to pass the received signal energy, thus reducing the amount of noise with which the signal must compete.
- The average frequency counter is a cycle counter. It counts only absolute numbers. So there may be step errors or quantization errors

- Unwanted signals in FM altimeter:

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.


Transmitter
Receiver
1
2
3
4
5
5
5
5
Wanted
signal
Ground

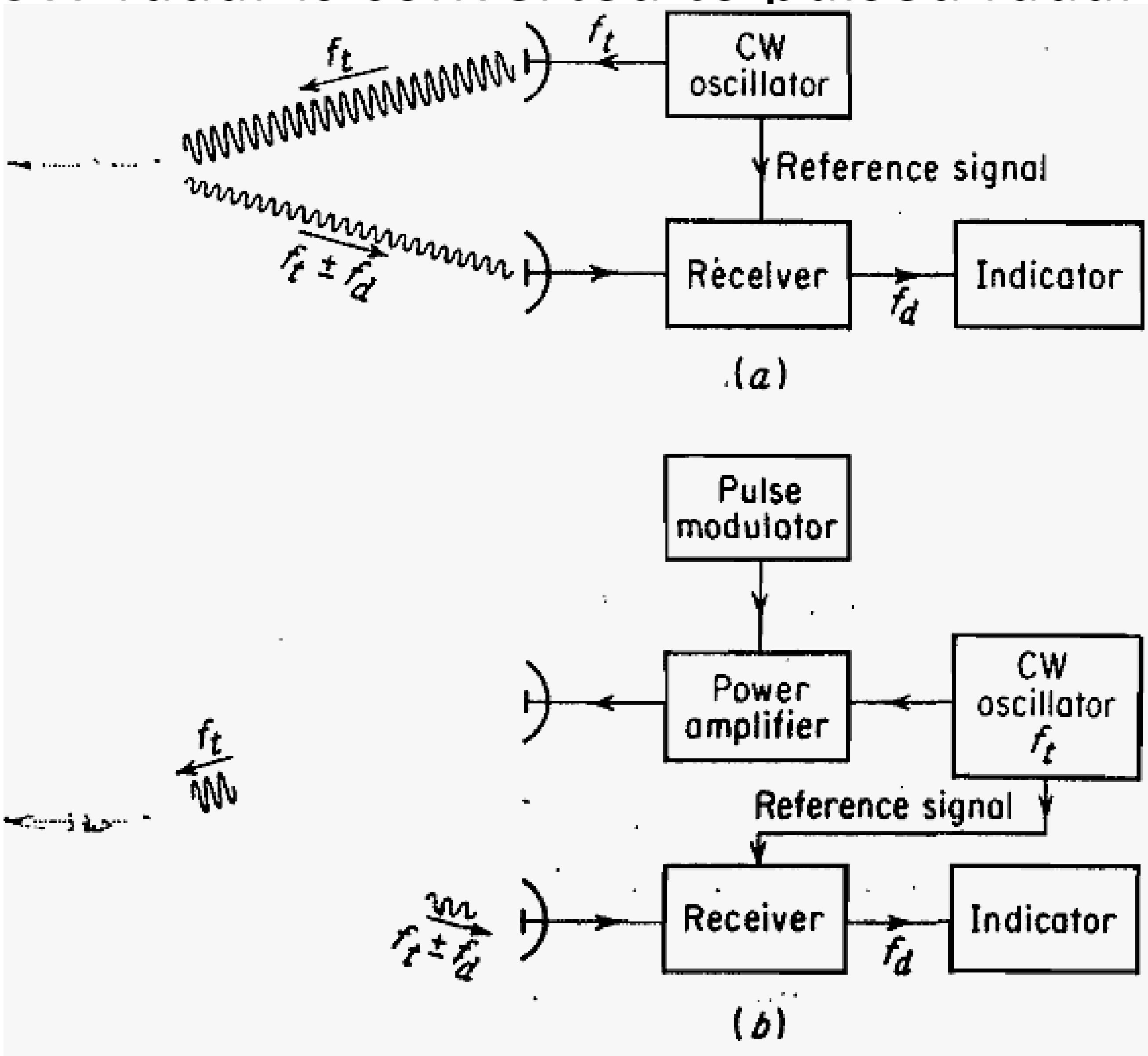
MTI and Pulsed Doppler Radar

- Using the principle of doppler frequency shift in pulsed radar the relative velocity of the target can be determined.

- A pulse radar that utilizes the doppler frequency shift as a means for discriminating moving from fixed targets is called an **MTI** (moving target indication) or a **pulse doppler radar**.

- MTI is a necessity in high-quality air-surveillance radars that operate in the presence of clutter. Its design is more challenging than that of a simple pulse radar or a simple CW radar.

- A CW radar is converted to pulsed radar by,



- The difference between simple pulse radar and pulse doppler radar is that in pulse doppler radar the reference signal at the Rx is derived from the Tx, where as in simple pulse radar the reference signal at the Rx is from a local oscillator.
- Here the reference signal acts as the coherent reference needed to detect the doppler frequency shift. The phase of the transmitted signal is preserved in the reference signal.

Operation:

- Let the CW oscillator signal be $A_1 \sin 2\pi f_t t$
- Then the reference signal is, $V_{ref} = A_2 \sin 2\pi f_t t$

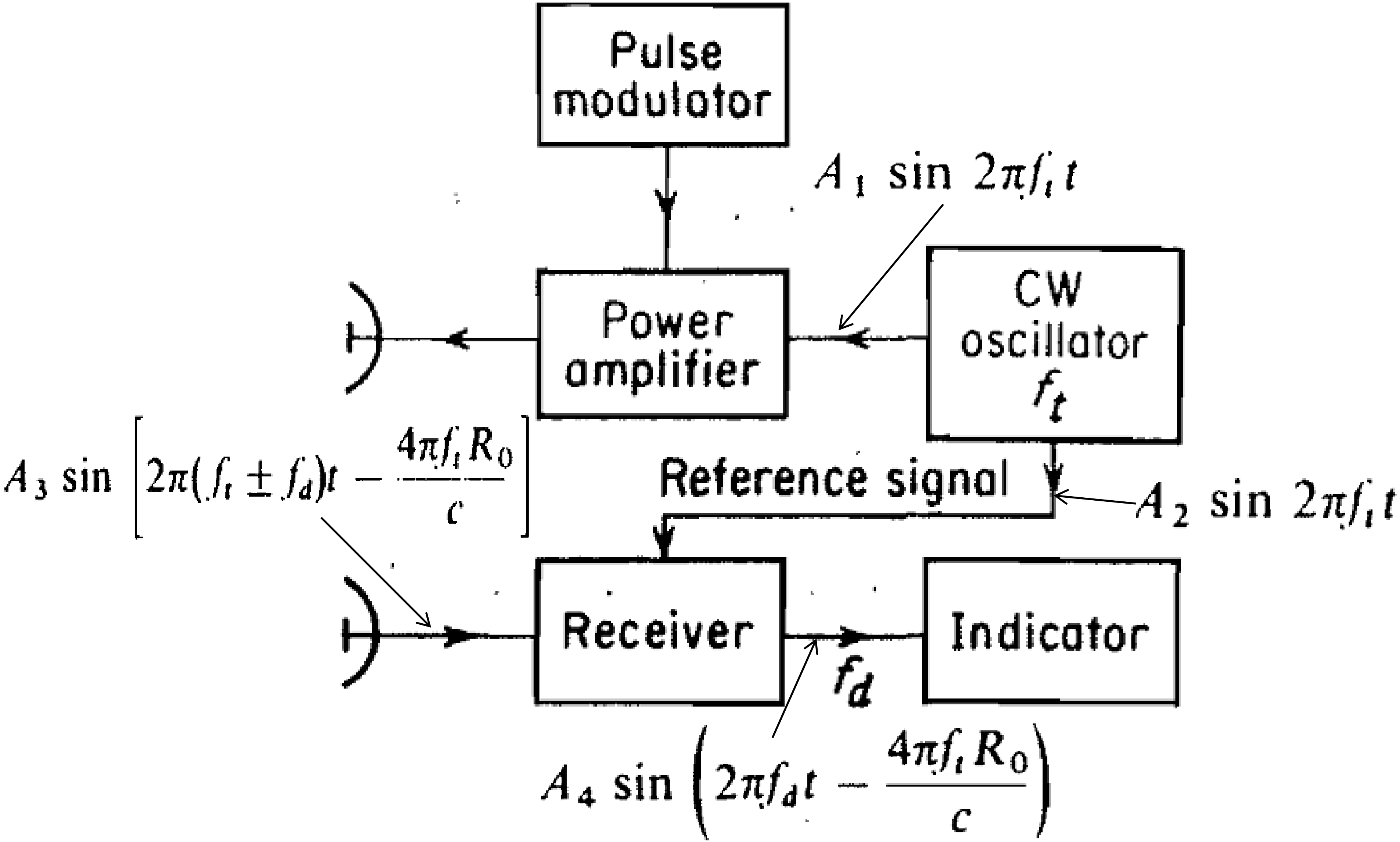
- Doppler shifted echo signal can be represented as,

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

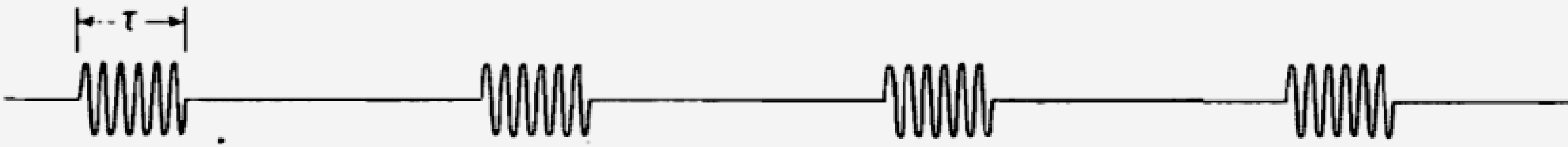
- The reference signal and the target signal are heterodyned in a mixer and the output is the difference frequency component

$$V_{diff} = A_4 \sin\left(2\pi f_d t - \frac{4\pi f_t R_0}{c}\right)$$

- The difference frequency is the doppler frequency.
- For stationary targets $\boldsymbol{V_{diff}}$ is a constant.
- The voltages mentioned above are shown in the fig below.

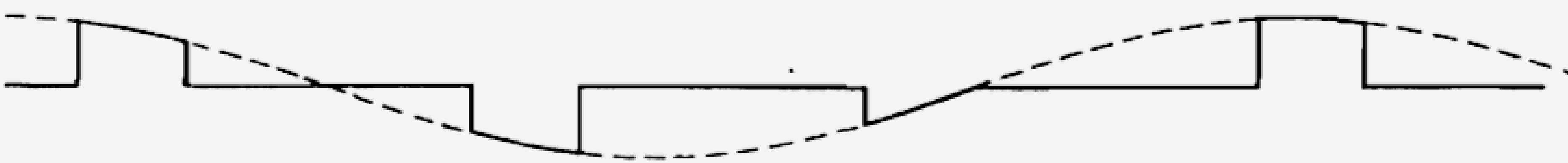

Pulse modulator
$A_1 \sin 2\pi f_t t$
Power amplifier
CW oscillator f_t
Reference signal
$A_2 \sin 2\pi f_t t$
$A_3 \sin \left[2\pi(f_t \pm f_d)t - \frac{4\pi f_t R_0}{c}\right]$
Receiver
f_d
Indicator
$A_4 \sin \left(2\pi f_d t - \frac{4\pi f_t R_0}{c}\right)$

- Sample waveforms (bipolar)



(a) RF echo pulse train

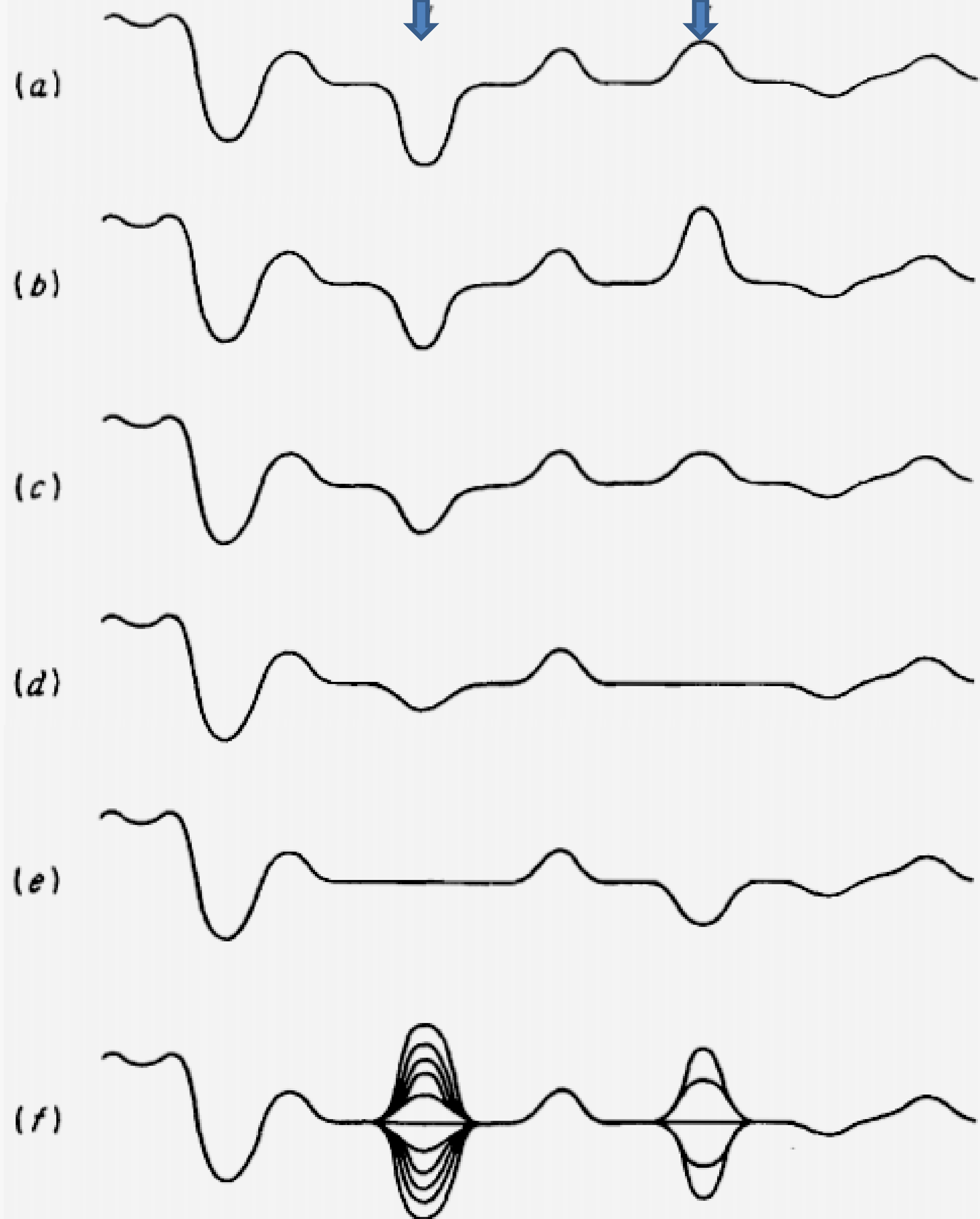
(b) video pulse train for doppler frequency $f_d > 1/\tau$



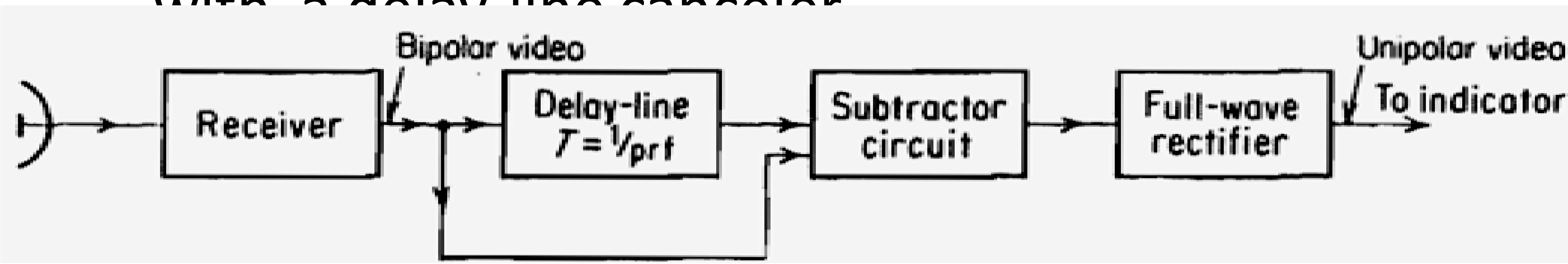
(b) video pulse train for doppler frequency $f_d < 1/\tau$

- Moving targets may be distinguished from stationary targets by observing the video output on an A-scope (amplitude vs. range).
- Echoes from fixed targets remain constant throughout, but echoes from moving targets vary in amplitude from sweep to sweep at a rate corresponding to the doppler frequency.
- The superposition of the successive A-scope sweeps is shown in Fig. The moving targets produce, with time, a " butterfly" effect on the A-scope.
- It is not appropriate for display on the PPI.

Figure (a-e) Successive sweeps of an MTI radar A-scope display (echo amplitude as a function of time); (f) superposition of many sweeps; arrows indicate position of moving targets.



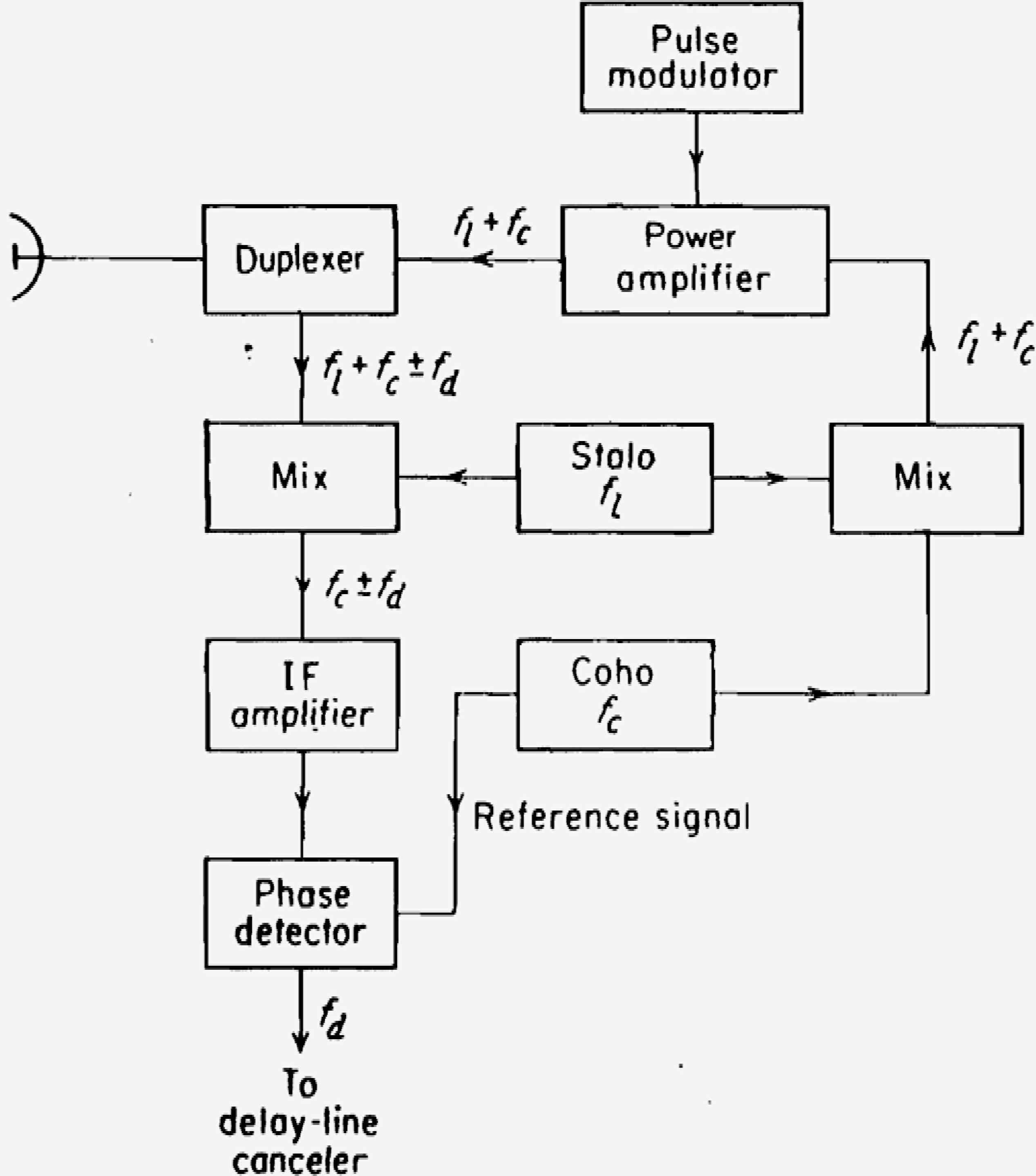
- Delay line cancelers: One method commonly employed to extract doppler information in a form suitable for display on the PPI scope is with a delay line canceler.



MTI receiver with delay-line canceler

- The delay-line canceler acts as a filter to eliminate the dc component of fixed targets and to pass the ac components of moving targets.

Typical MTI radar (With Power Amplifier)



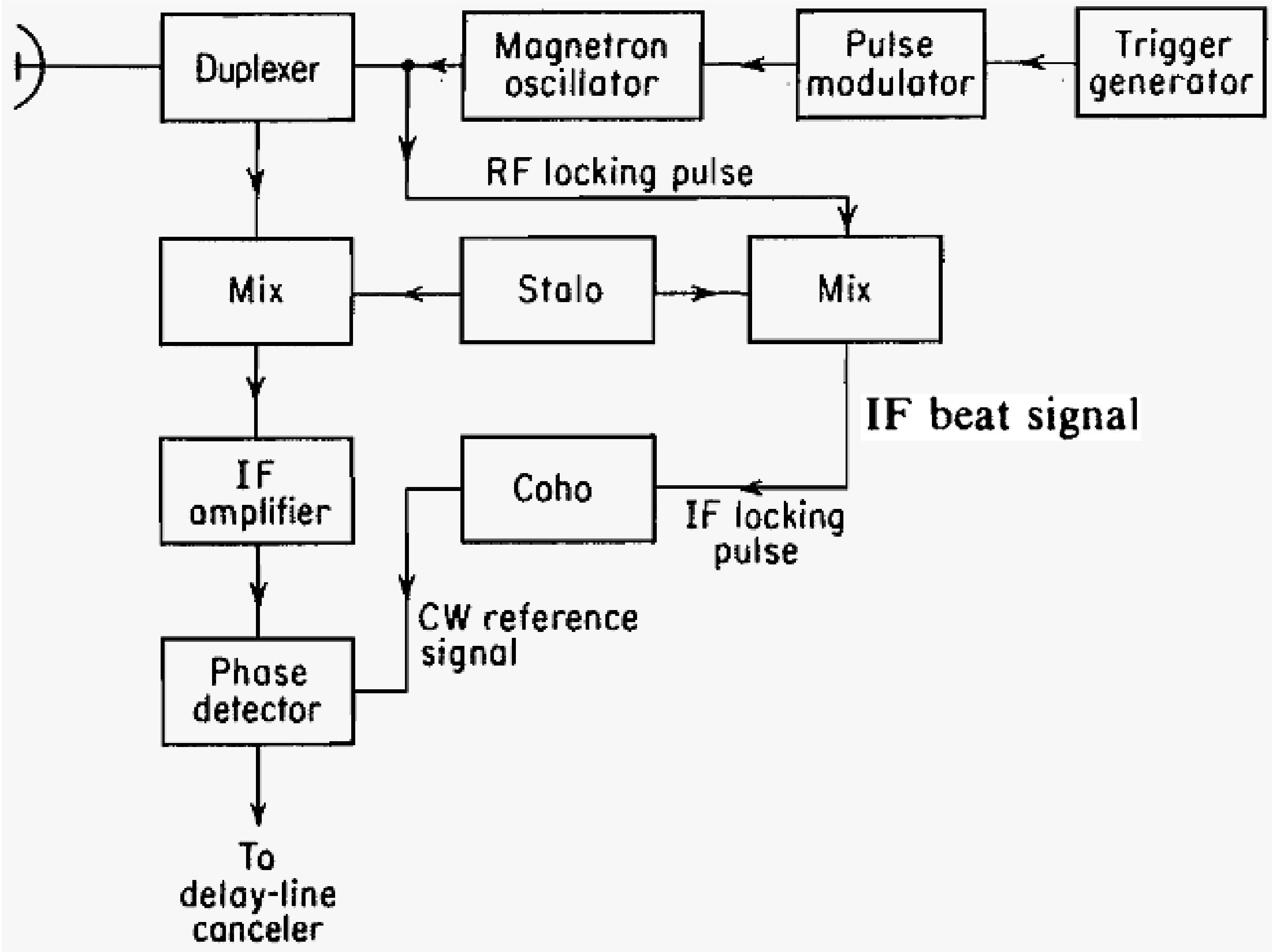
- It differs in the way in which the reference signal is generated.
- The coherent reference is supplied by an oscillator called the coho, which stands for coherent oscillator. The coho is a stable oscillator whose frequency is the same as the intermediate frequency used in the receiver.
- The output of the coho f_c is also mixed with the local-oscillator frequency f_l. The local oscillator must also be a stable oscillator and is called stalo, for stable local oscillator.
- The RF echo signal is heterodyned with the stalo signal to produce the IF signal just as in the conventional super-heterodyned receiver.

- The characteristic feature of coherent MTI radar is that the transmitted signal must be coherent (in phase) with the reference signal in the receiver. This is accomplished by the coho signal.
- The function of the stalo is to provide the necessary frequency translation from the IF to the transmitted (RF) frequency. Any stalo phase shift is canceled on reception.
- The reference signal from the coho and the IF echo signal are both fed into a mixer called the phase detector. Its output is proportional to the phase difference between the two input signals.

- Triode, tetrode, klystron, traveling-wave tube, and the crossed-field amplifier can be used as the power amplifier
- A transmitter which consists of a stable low-power oscillator followed by a power amplifier is sometimes called MOPA, which stands for master-oscillator power amplifier.

MTI radar (with power-oscillator Tx)

- In an oscillator the phase of the RF bears no relationship from pulse to pulse. For this reason the reference signal cannot be generated by a continuously running oscillator. However, a coherent reference signal may be readily obtained with the power oscillator by **readjusting the phase of the coho at the beginning of each sweep according to the phase of the transmitted pulse.** The phase of the coho is locked to the phase of the transmitted pulse each time a pulse is generated.


Duplexer
Magnetron oscillator
Pulse modulator
Trigger generator
RF locking pulse
Mix
Stalo
Mix
IF beat signal
IF amplifier
Coho
IF locking pulse
CW reference signal
Phase detector
To delay-line canceler

- A portion of the transmitted signal is mixed with the stalo output to produce an IF beat signal whose phase is directly related to the phase of the transmitter.
- This IF pulse is applied to the coho and causes the phase of the coho CW oscillation to "lock" in step with the phase of the IF reference pulse.
- The phase of the coho is then related to the phase of the transmitted pulse and may be used as the reference signal for echoes received from that particular transmitted pulse.
- Upon the next transmission another IF locking pulse is generated to relock the phase of the CW coho until the next locking pulse comes along.