RADAR

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UNIT-II
CW RADAR & MTI RADAR

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

UNIT-II
CW RADAR & 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 R be the range of 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.

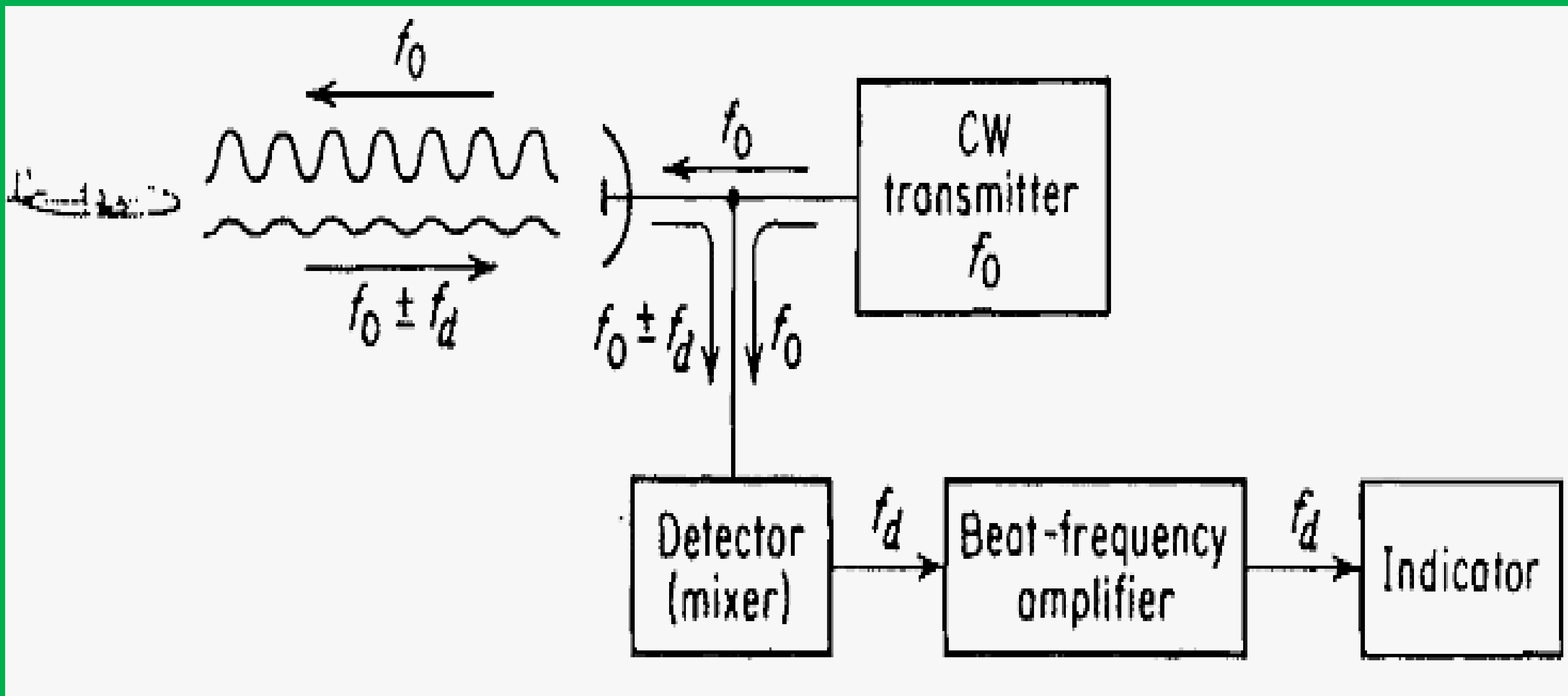
f_d is the Doppler frequency shift.

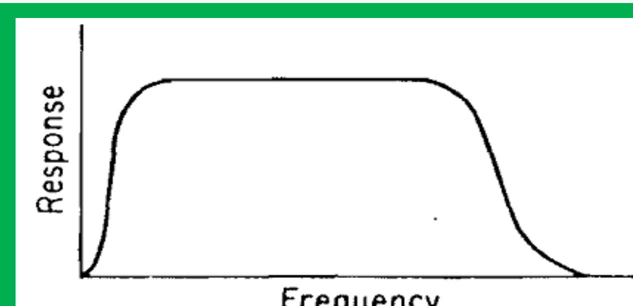
$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}$$

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.

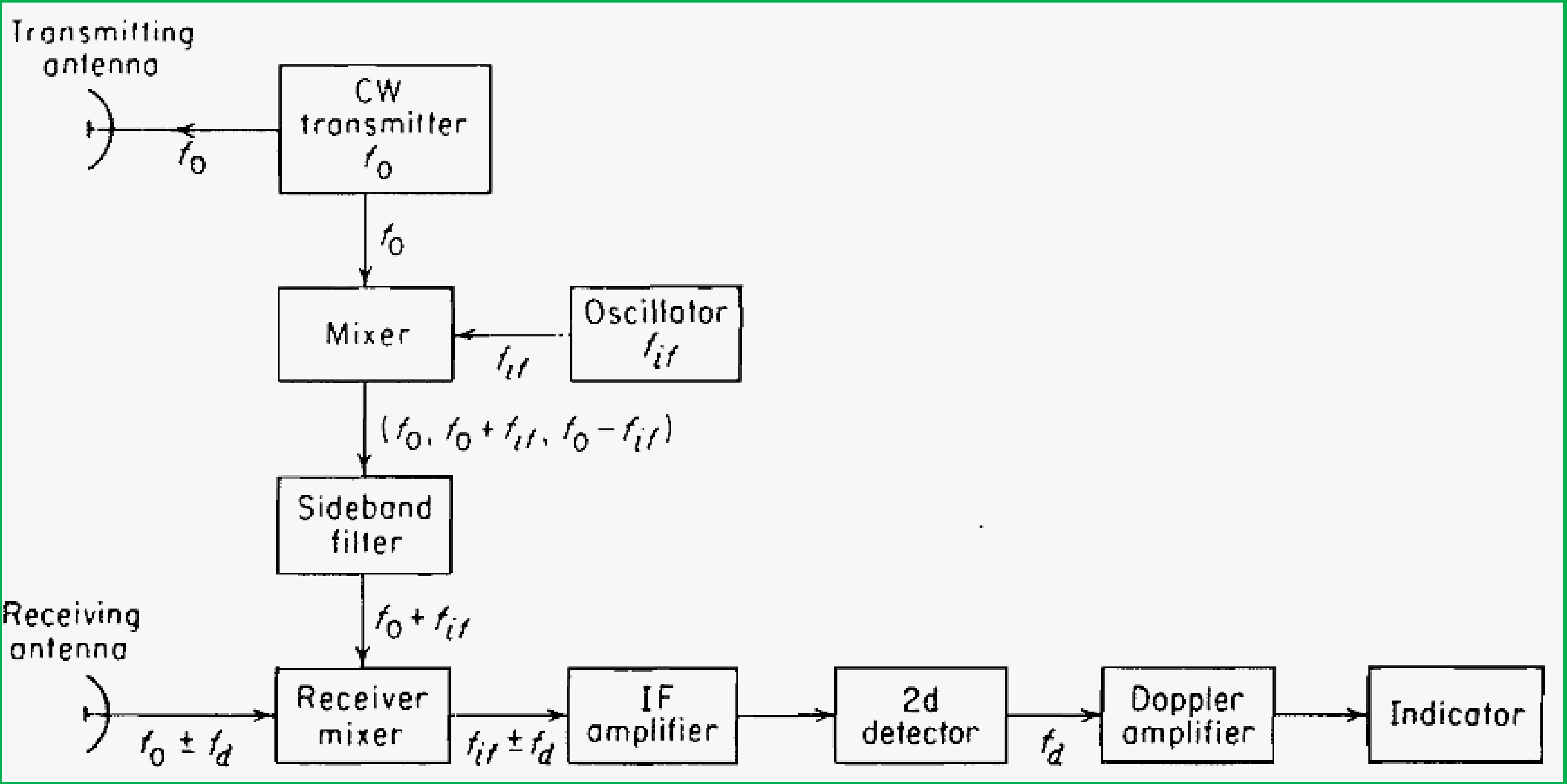
Isolation between Tx and Rx:

- 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

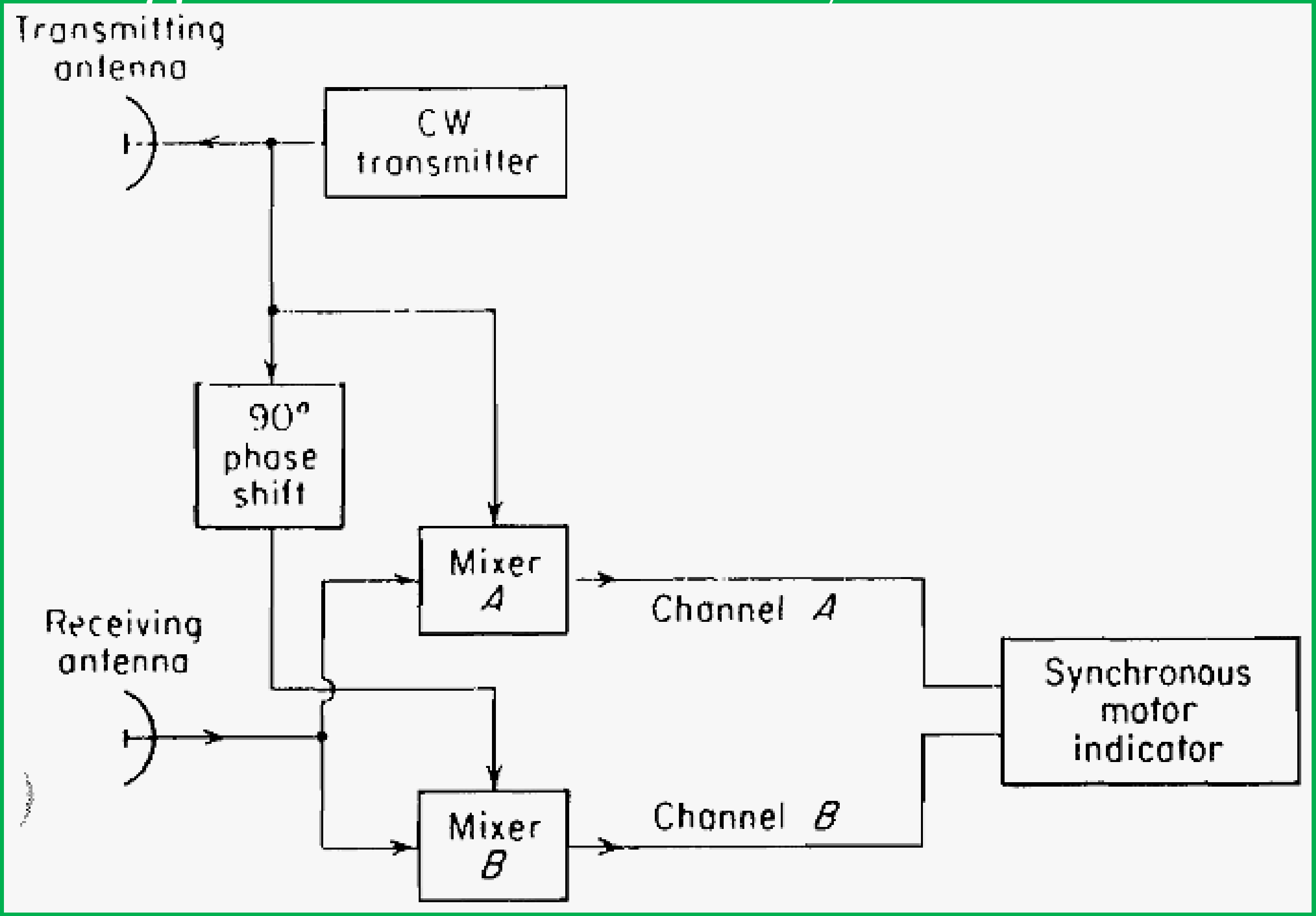
- Separate antennas are used for Tx and Rx to reduce Tx leakage
- Local oscillator in the Rx is derived from the Tx signal mixed with locally generated signal of frequency equal to that of the receiver IF.
- Tx leakage can occur due to Tx clutter also.

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.

- 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

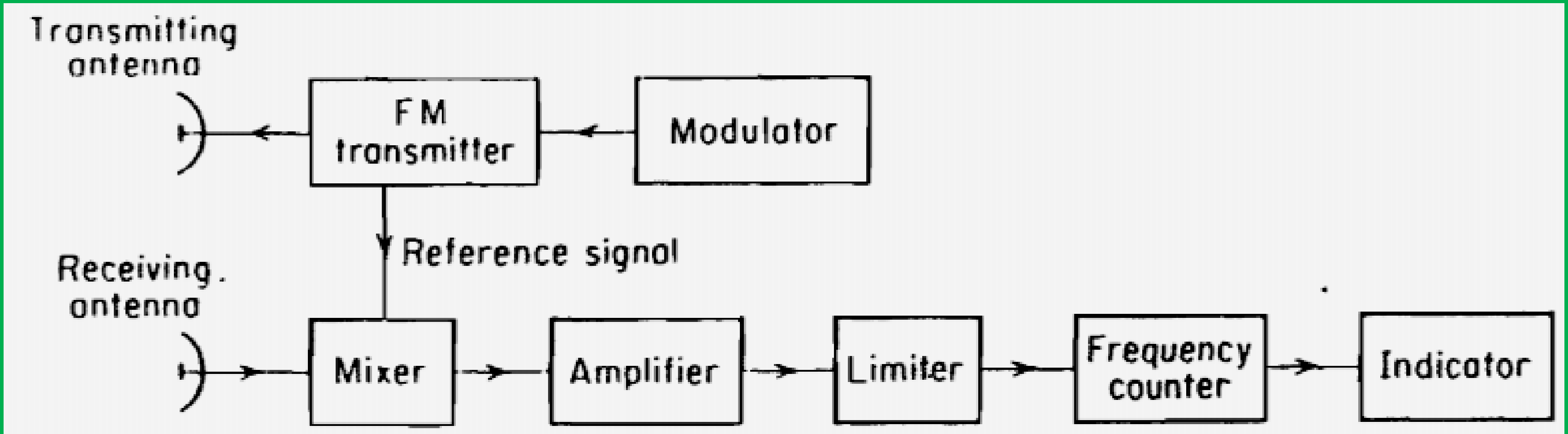
Limitations of CW radar with Non-zero IF

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

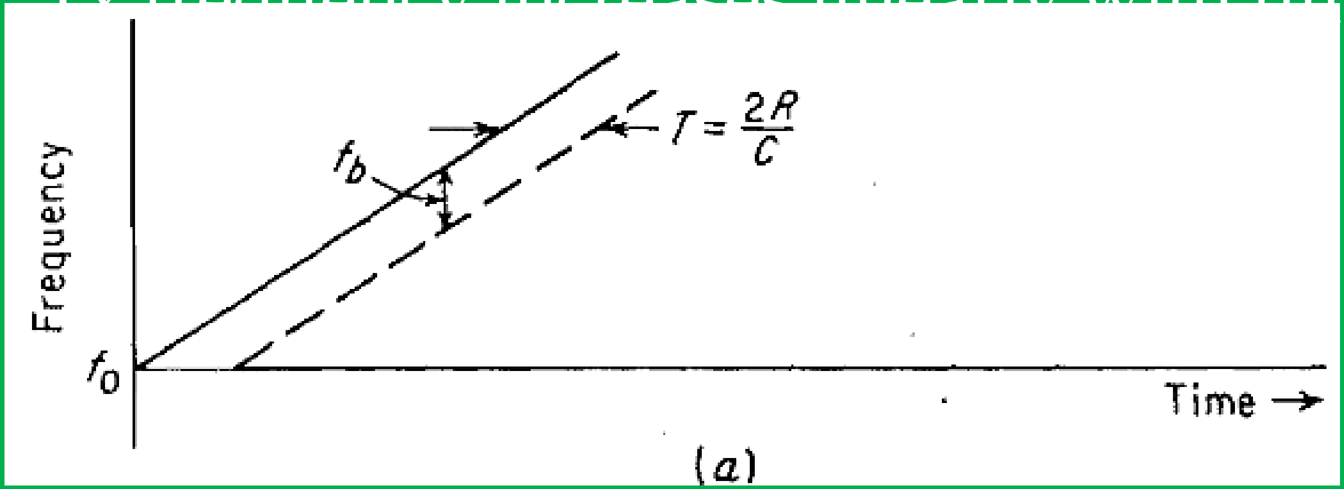
Frequency Modulated CW radar

- 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

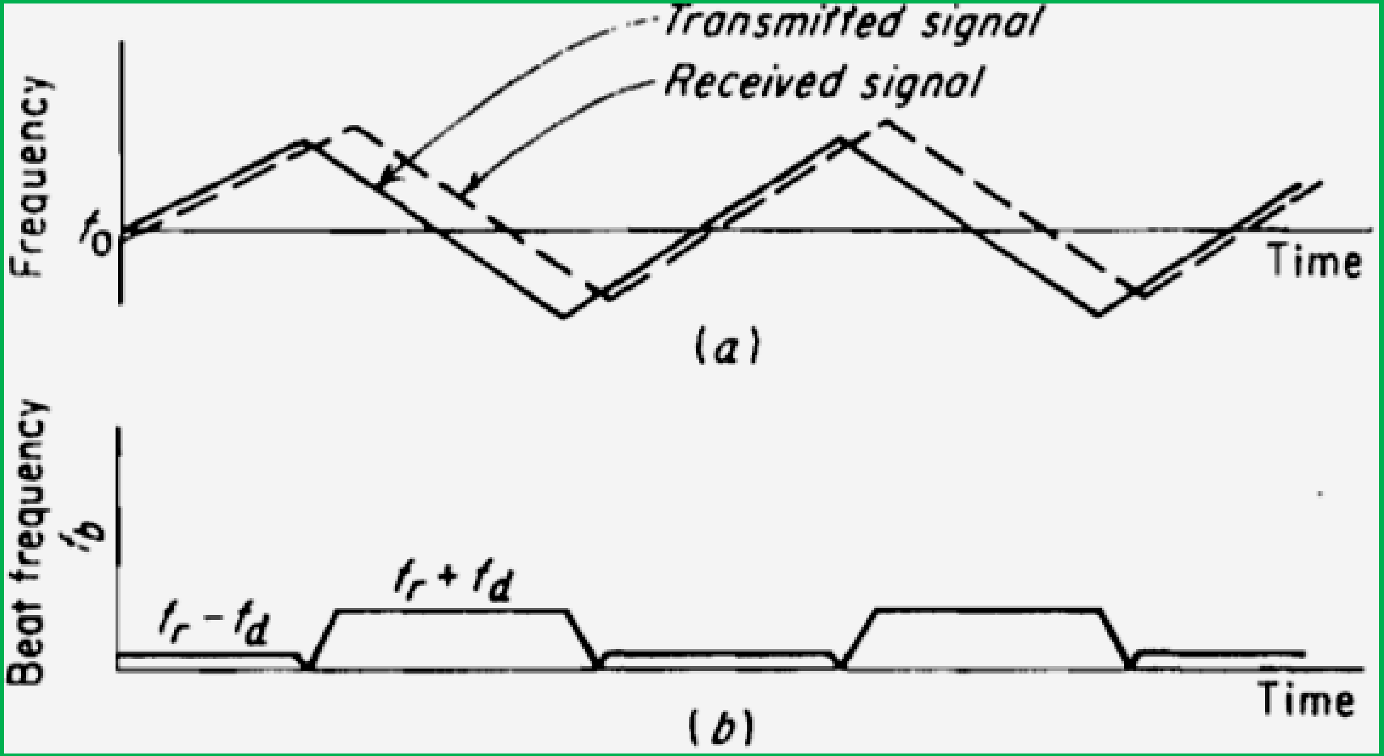
- Block diagram:



- Tx frequency increases linearly with time (solid



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



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

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

- The beat frequency due to range f_r can be calculated as

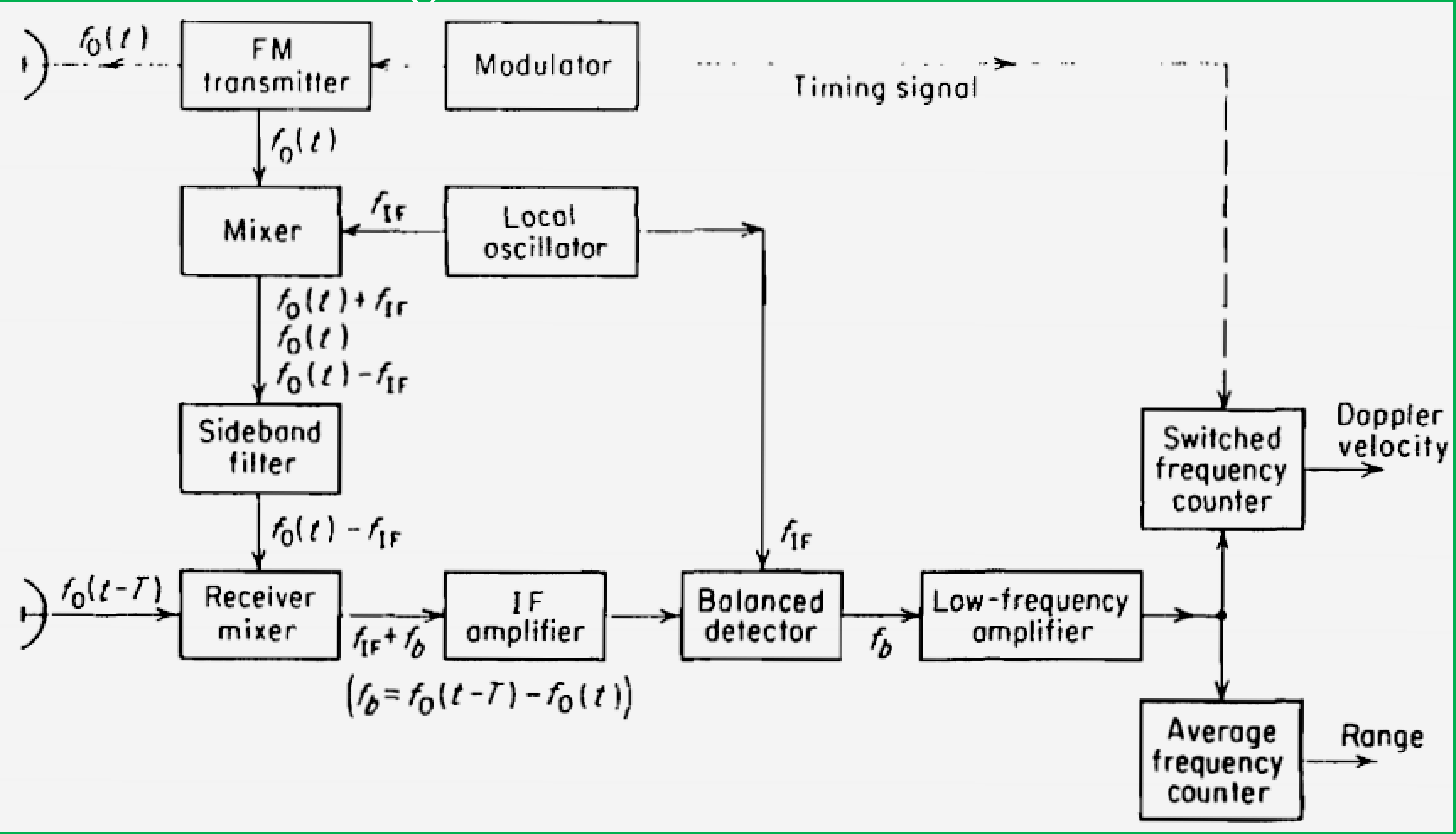
$$\frac{1}{2}[f_b(\text{up}) + f_b(\text{down})] = f_r$$

- 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 4th 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.

MTI and Pulsed Doppler Radar

- **What is MTI or pulse doppler radar**.
- Use of doppler frequency shift
- MTI application
- MTI design

MTI and Pulsed Doppler Radar

What is MTI or pulse doppler radar.

- A pulse radar that utilizes the doppler frequency shift for discriminating moving from fixed targets is called an **MTI** (moving target indication) or a **pulse doppler radar**.
- Using the principle of doppler frequency shift in pulsed radar the relative velocity of the target can be determined.
- MTI is a necessity in high-quality air-surveillance radars that operate in the presence of clutter.
- MTI 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

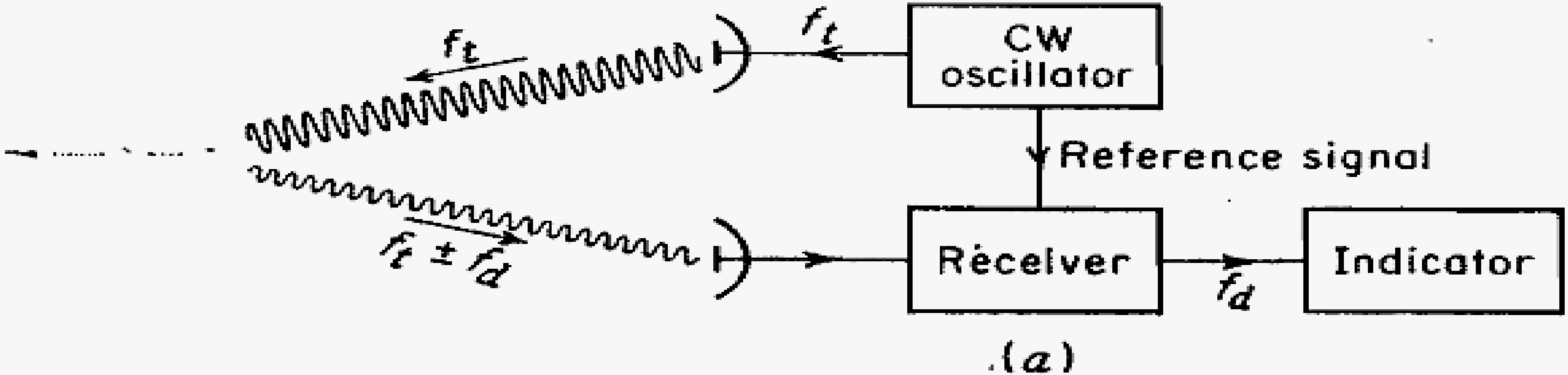


fig (a) Simple CW radar

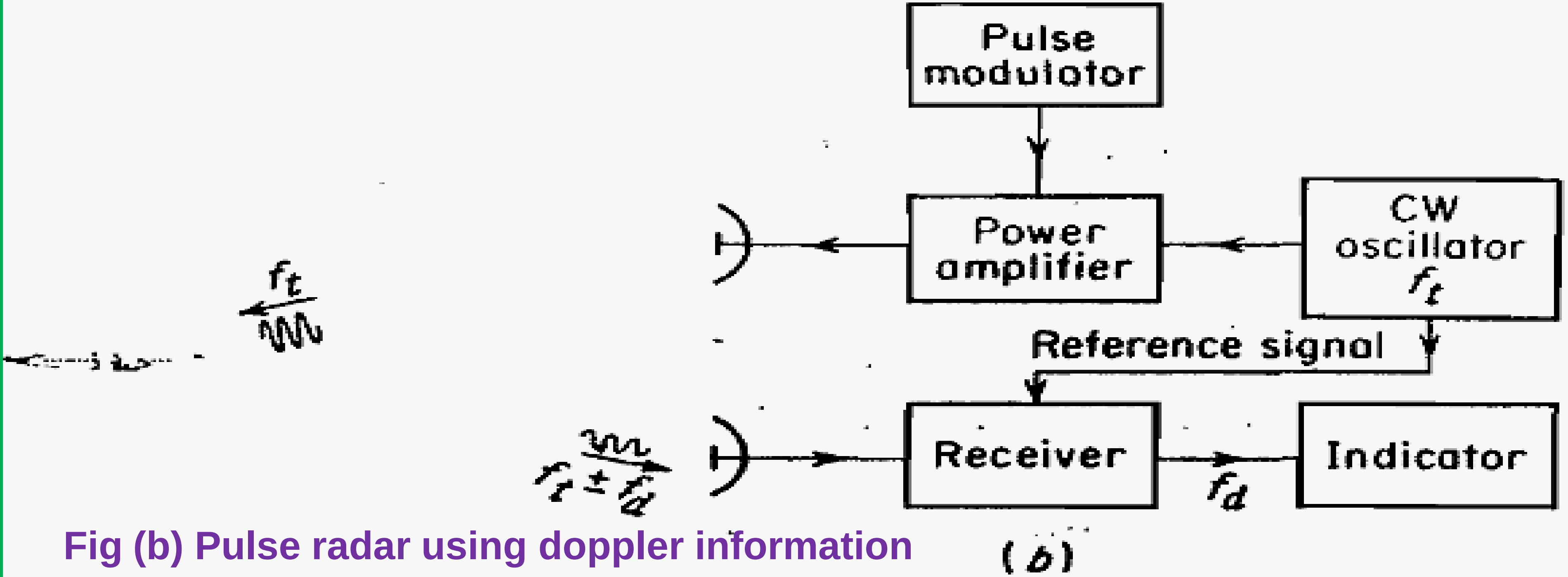


Fig (b) Pulse radar using doppler information

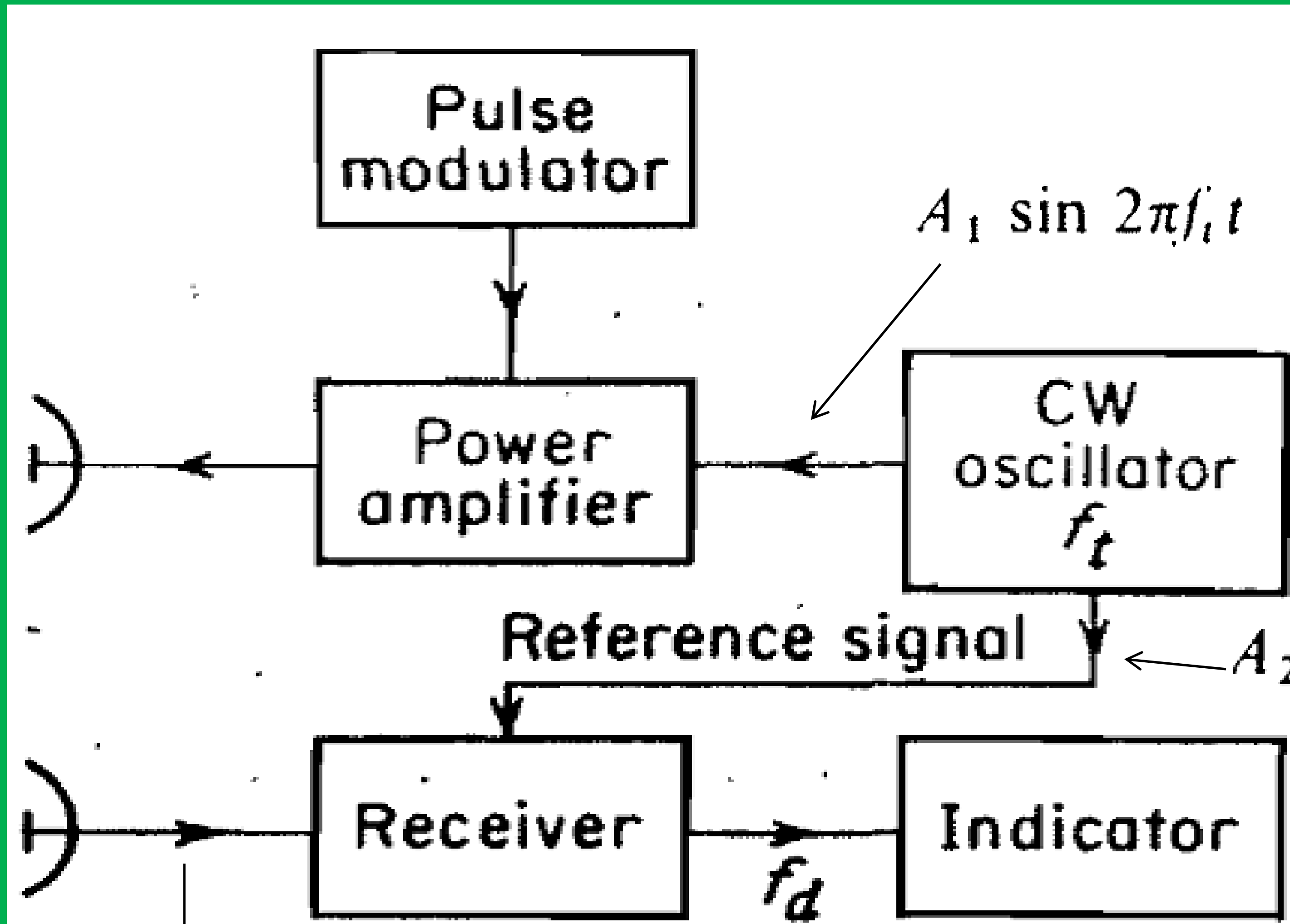
- The difference between

simple pulse radar and pulse doppler radar is

in pulse doppler radar the reference signal at the Rx is derived from the Tx,

in simple pulse radar, the reference signal at the Rx is from a local oscillator.

- In CW, 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.



$A_1 \sin 2\pi f_t t$

$A_2 \sin 2\pi f_t t$

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

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

Pulse doppler radar

Operation

- Let the CW oscillator signal is $A_1 \sin 2\pi f_t t$

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

- Doppler shifted echo signal can be represented as
,

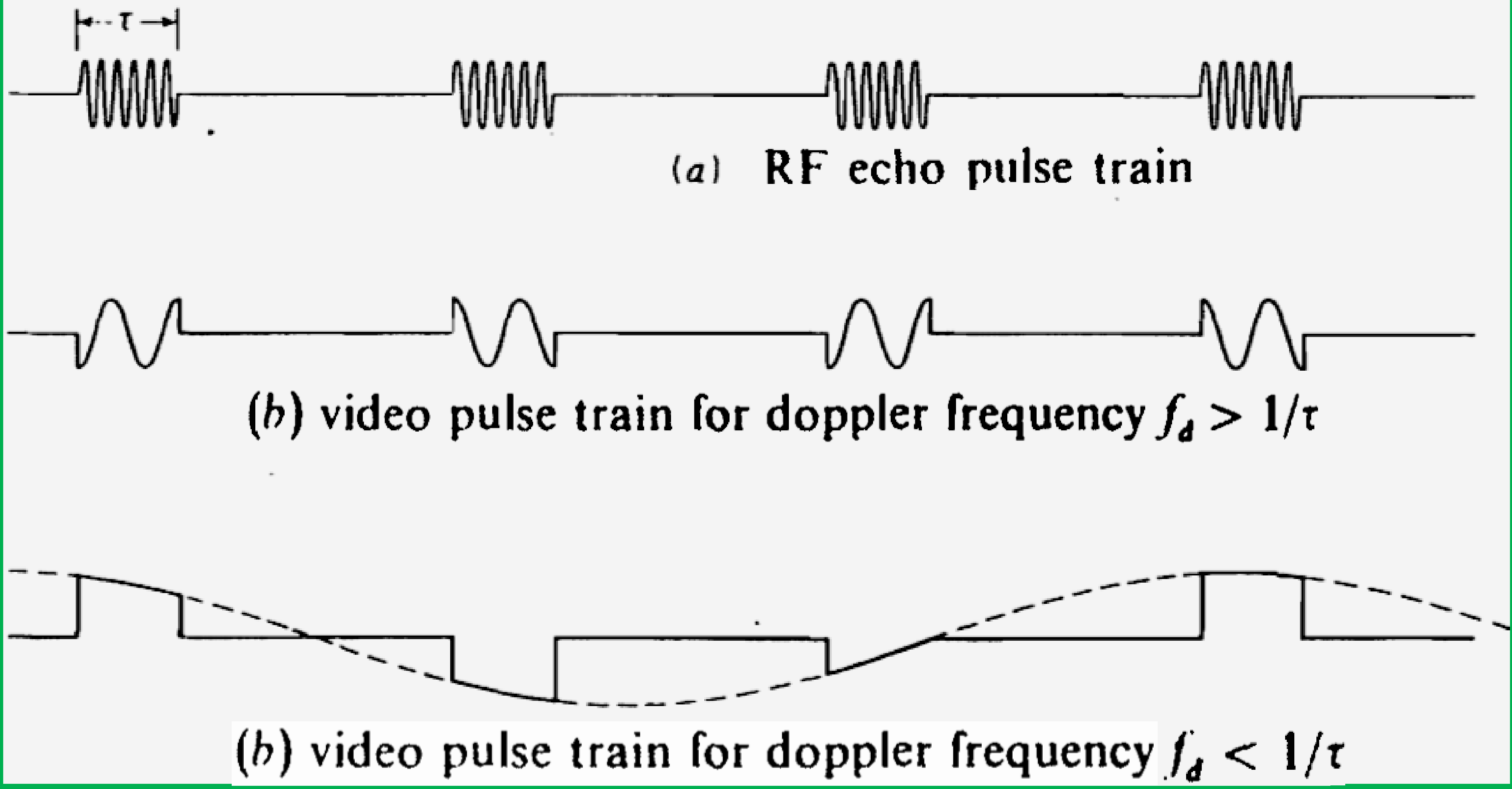
$$V_{echo} = A_3 \sin \left[2\pi(f_t \pm f_d)t - \frac{4\pi f_t R_0}{c} \right]$$

- 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 V_{diff} is a constant.
- The voltages mentioned above are shown in the fig below.

- Sample waveforms (bipolar)



- 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.

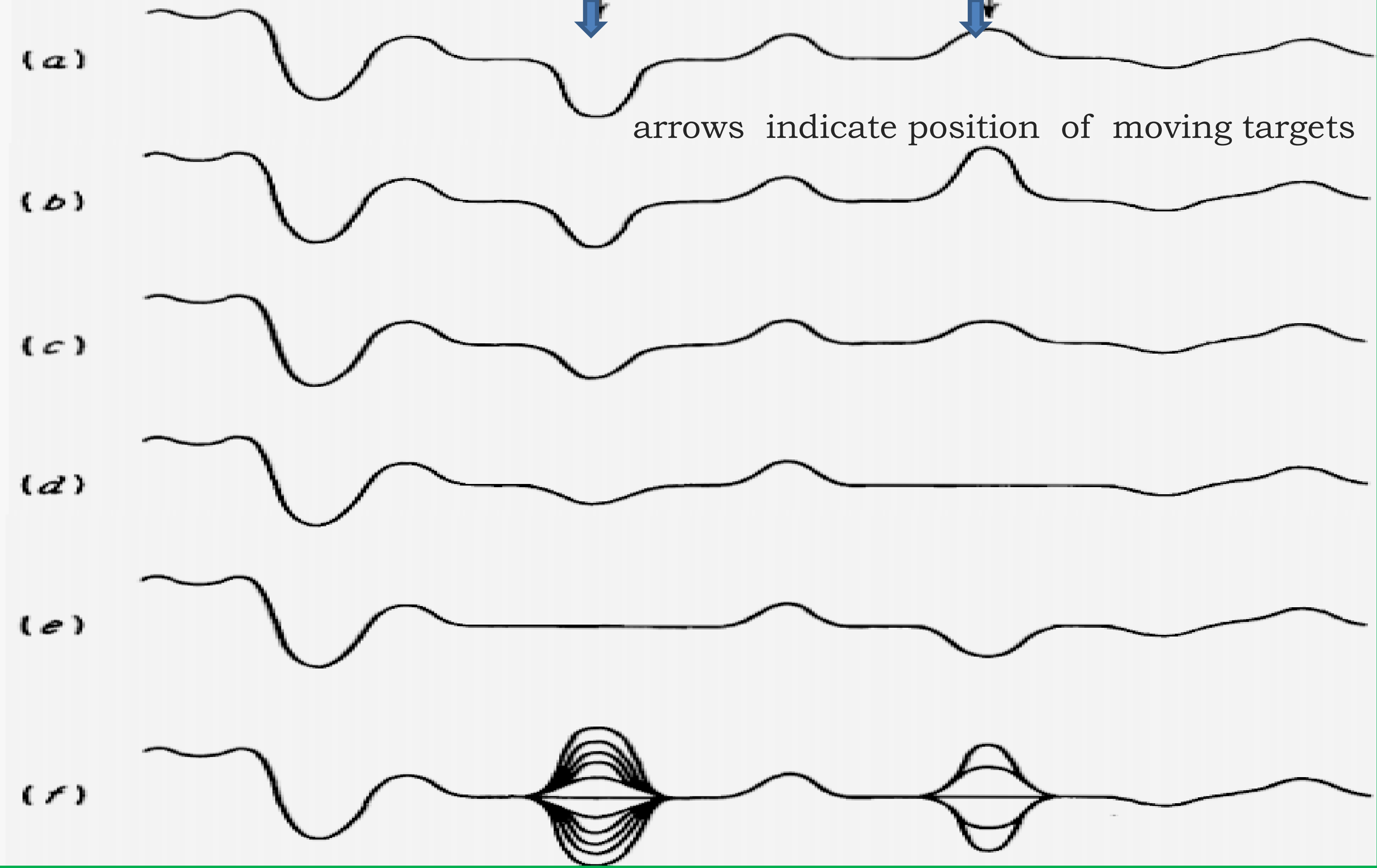
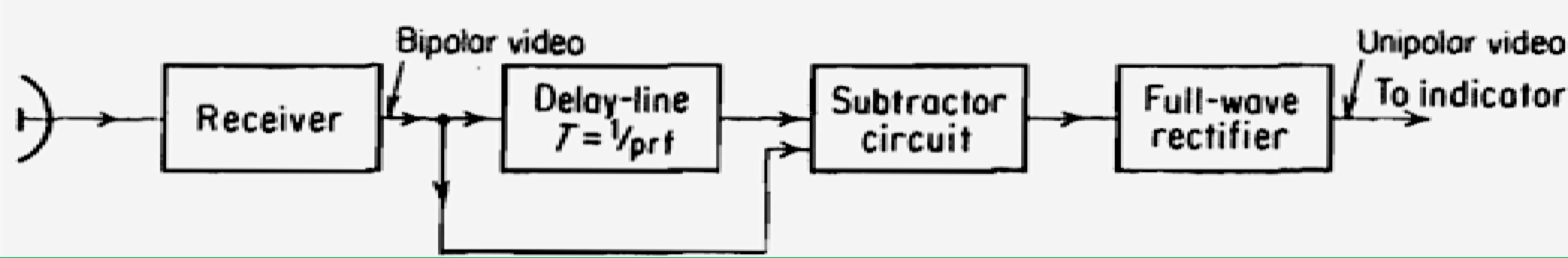


Figure (a-e) Successive sweeps of an MTI radar A-scope display (echo amplitude as a function of time);

(f) superposition of many sweeps

- 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.

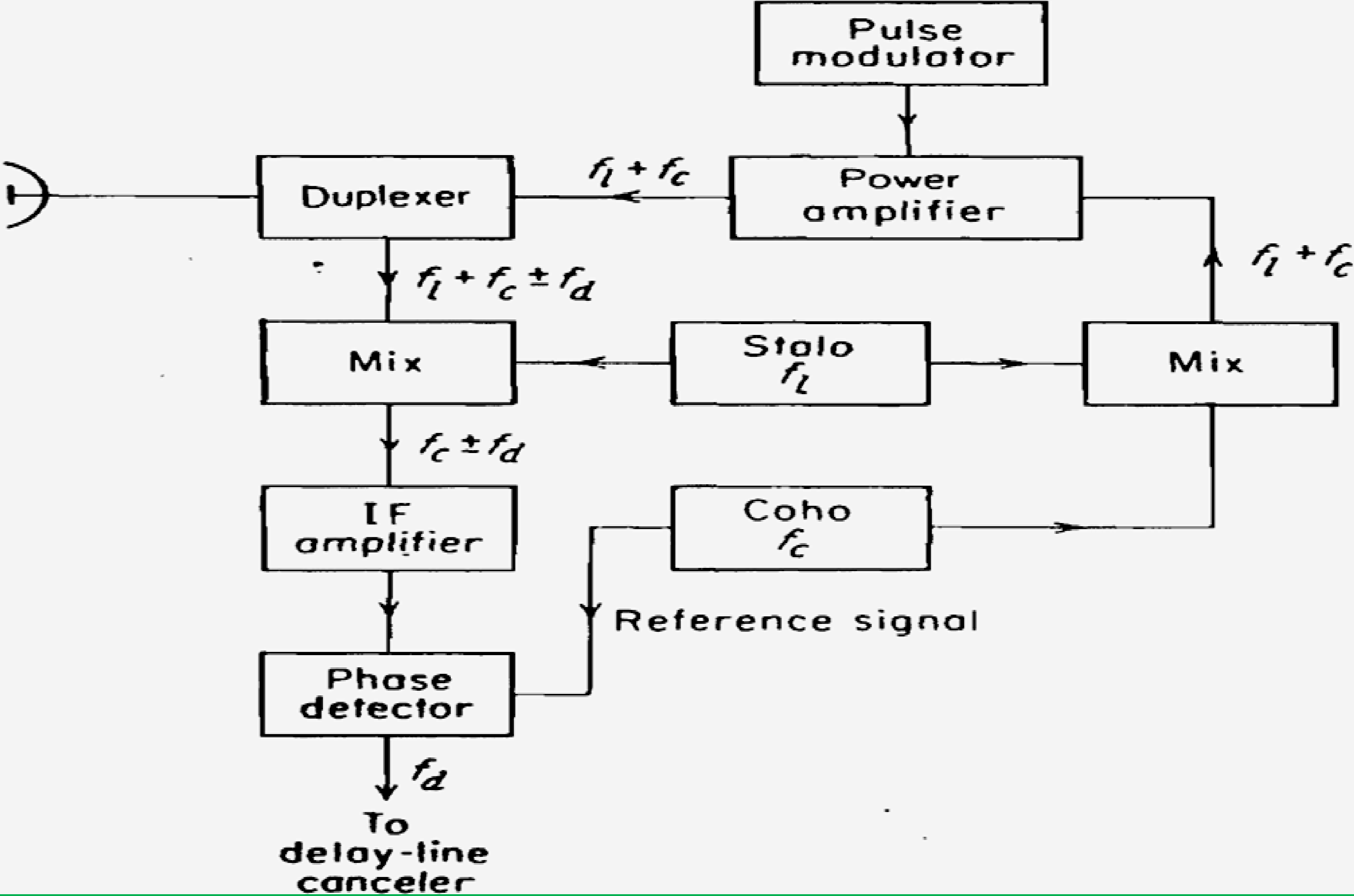


Fig. Typical MTI radar (With Power Amplifier)

- It differs in the way in which the reference signal is generated.
- Coherent oscillator: 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 Stalo: 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.
- Mixer: The RF echo signal is heterodyned with the stalo signal to produce the IF signal just as in the conventional super-heterodyned receiver.

- 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 stalo:** 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.

- phase detector: The reference signal from the coho and the IF echo signal are both fed into a mixer called the phase detector.

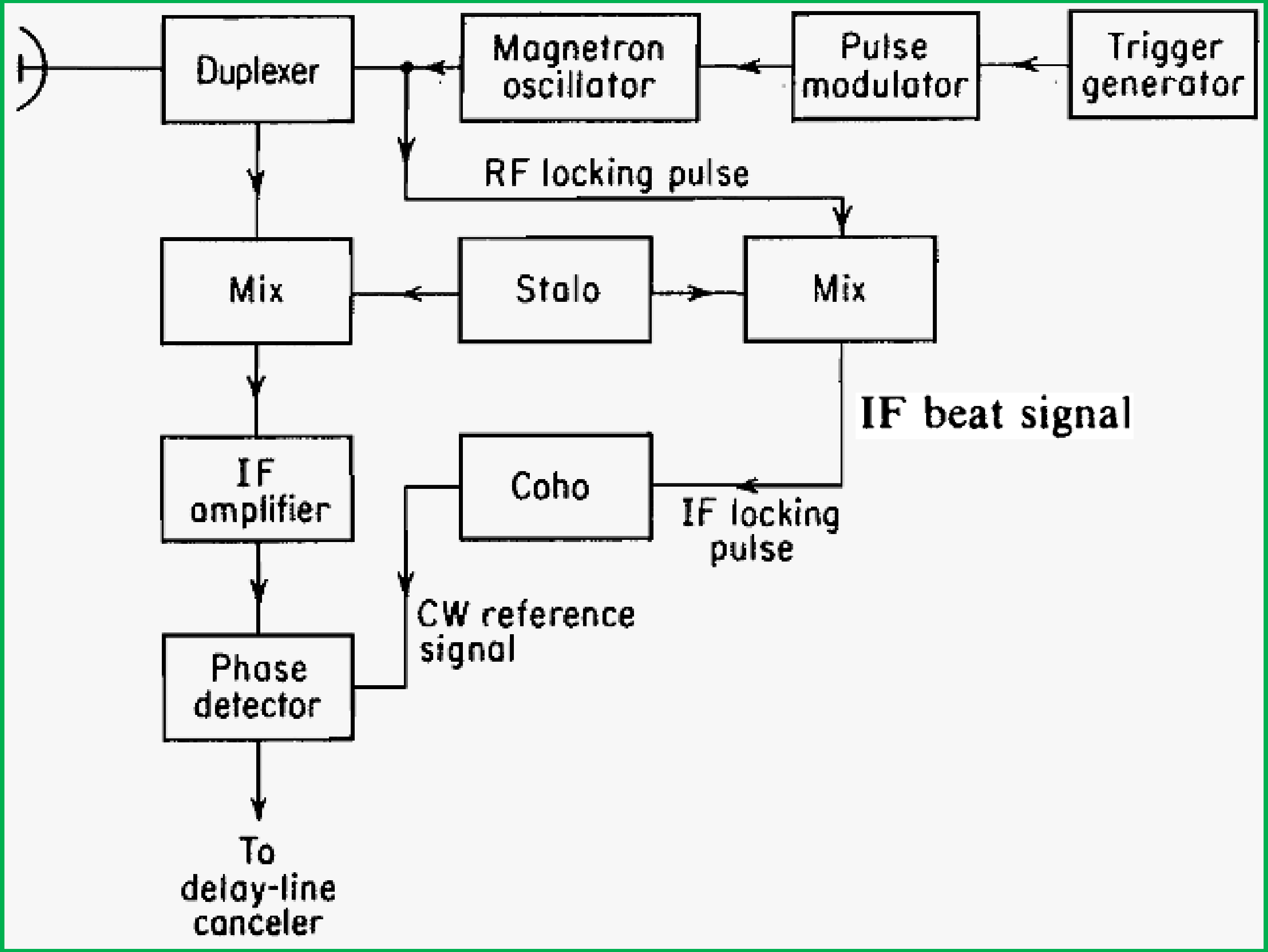
  Its output is proportional to the phase difference between the two input signals.

- **Power amplifier : Triode, tetrode, klystron, traveling-wave tube, and the crossed-field amplifier can be used as the power amplifier**

- **MOPA : 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.

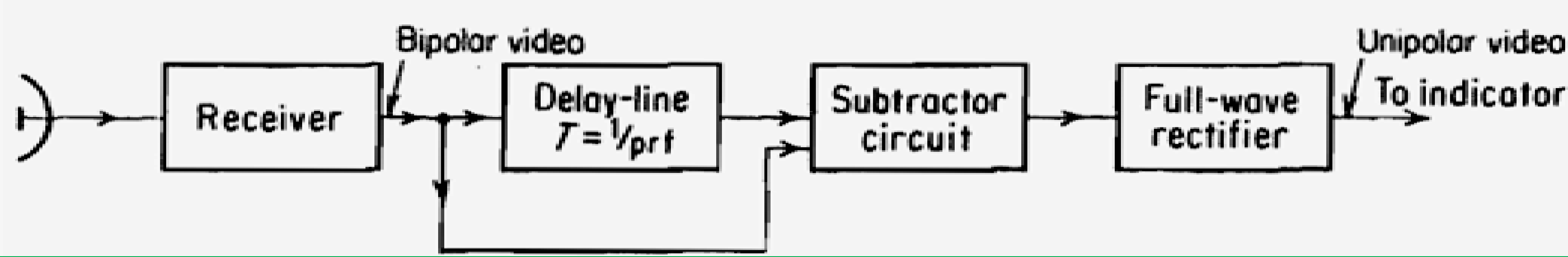


Duplexer
Magnetron oscillator
Pulse modulator
Trigger generator
RF locking pulse
Mix
Stalo
Mix
IF beat signal
IF amplifier
Coho
IF locking pulse
CW reference signal
Phase detector
To delay-line canceler

- 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.

- 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.

DLC

- Time delay=p.r.i.
- Time delay might be several msec for ground-based air serveillance radars

T he capability of DLC depends on the quality of medium used as delay line

1. Liquid delay lines
2. Solid fused-quartz delay linedelay lines

A. Analog delay lines

B. digital delay lines

I. Time domain DLC filter: This network operates at all ranges, and does not required a separate filter for each range resolution cell

II. Frequency domain DLC filter: Requires filter banks to cover range of frequencies in some MTI and PDR

DLC

(1)

DLC : Freq response of a SDL does not always have a broad clutter-rejection null as desired in the vicinity of D.C. The clutter-rejection notches may be widened by passing the o/p of the DLC through a SDLC as shown in fig.

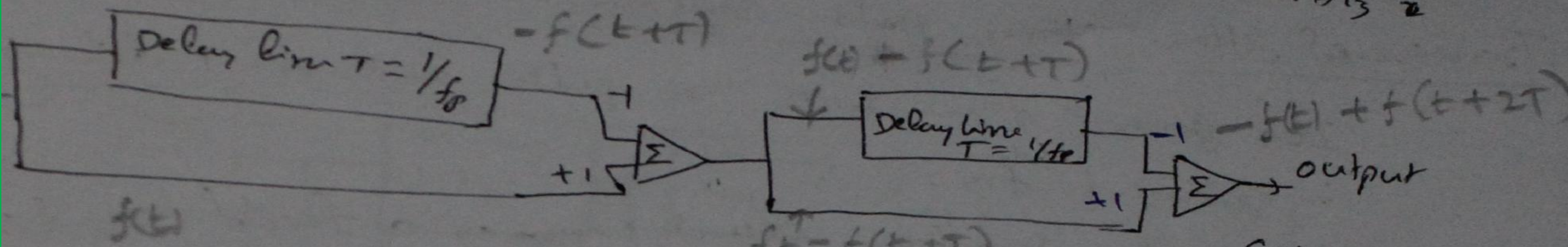


fig Double DLC

O/p of adder is =

$f(t) - 2f(t+T) + f(t+2T)$

weighted factor

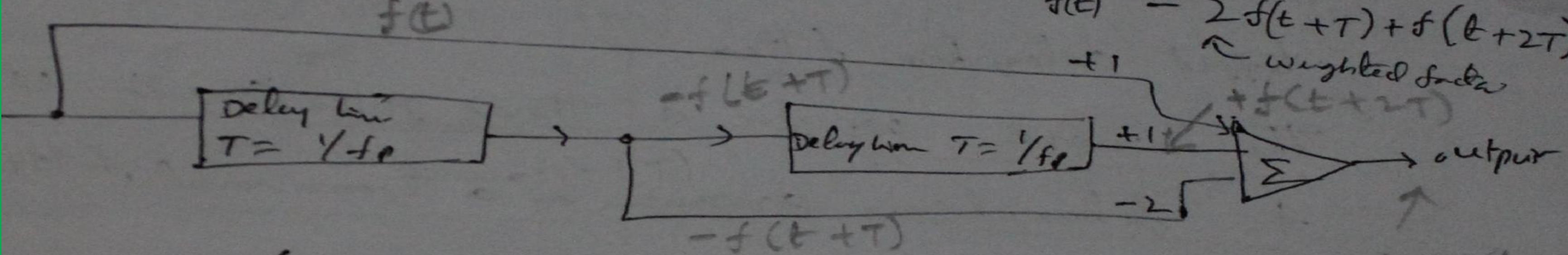


fig Three pulse Canceler

f(t) − f(t+T) − f(t+T) + f(t+2T)

DLC

The o/p of Two SDLCs in cascade is the square of that from a SDLC

Then the freq response is $4 \sin^2 \pi f_d T$. The configuration is called

a DDLC or simply a Double Canceler.

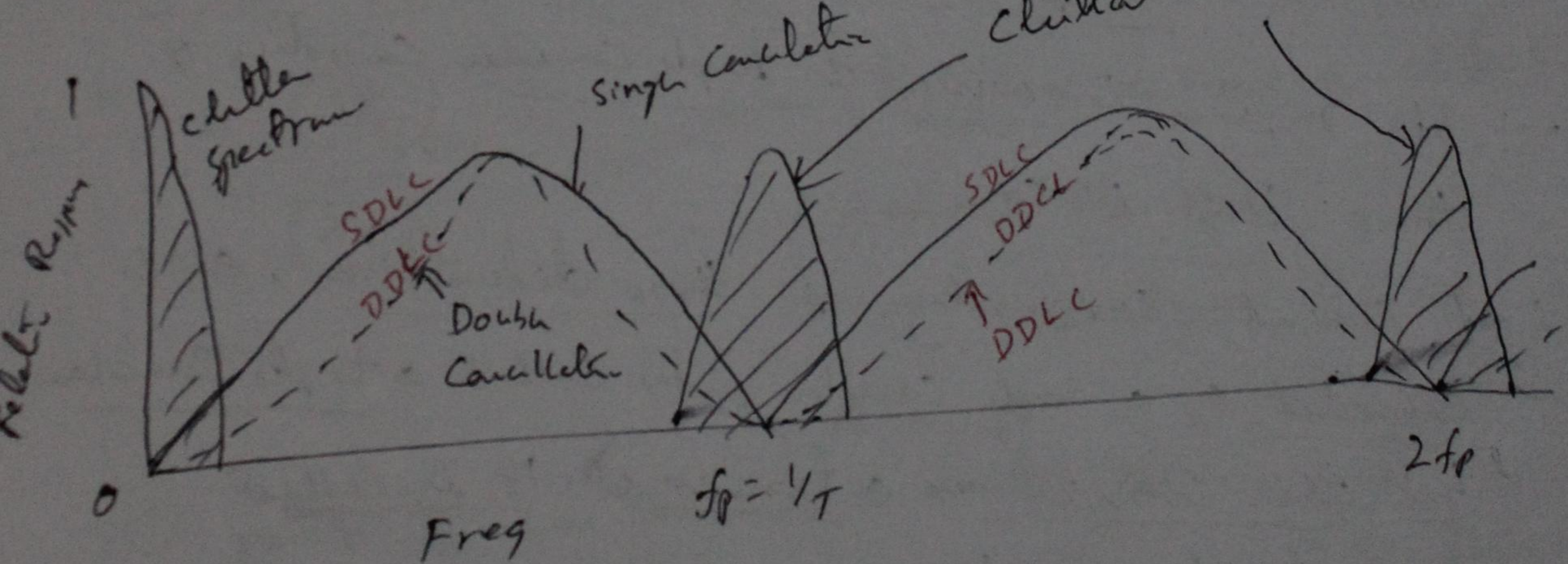


Fig: Relative freq response of the SDL (solid curve) and

TDLC

O/P of adder is $f(t) - 2f(t+T) + f(t+2T)$

Which is the same as the o/p from DDLC

$$f(t) - f(t+T) - f(t+T) + f(t+2T)$$

this configuration is commonly called three-pulse canceller

Transversal filters: three pulse canceller is an example of Transversal.

Its general form with N pulses and N−1 delay lines is shown in below fig.

→ It is also sometimes ~~called~~ known as a feedforward filter, a non-recursive filter, a fine memory filter or tapped delay-line filter

→ The weights w_i for a three pulse canceller utilizes two delay lines arranged as a transversal filter are

1, −2, 1

→ the freq response function is $\propto \sin^2 \pi f_d T$

→ The Transversal filter with three delay lines whose weights are 1, −3, 3, −1 gives a $\sin^3 \pi f_d T$ response.

This is a four pulse canceller.

→ Its response is equivalent to triple canceller consisting of three single DLCs

* → A cascade configuration of three delay lines, each connected as a single canceller, is called a triple canceller, but when connected as a transversal it is called a four pulse canceller.

*

weights

response

$(1-x)^n$

MTI and Pulse Doppler radar

1. Introduction
    1. **CW Radar types, applications**
    2. **MTI Radar types**
2. Delay line cancellers
    1. **SDL,DDLC, Transversal DLC**
3. Moving target detector
4. Pulse Doppler Radar
5. Limitation to MTI performance
6. MTI from moving platform