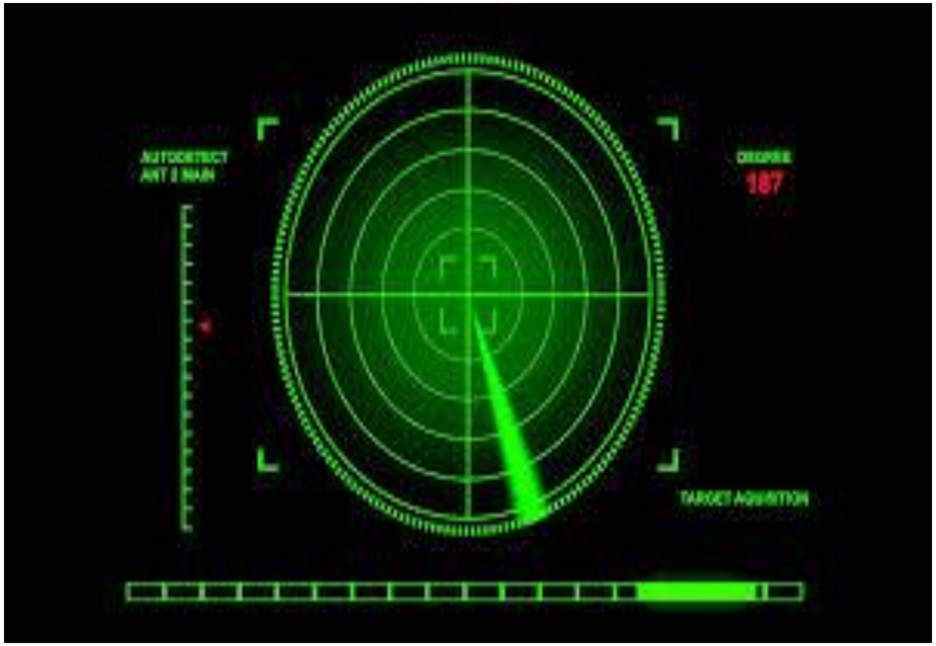
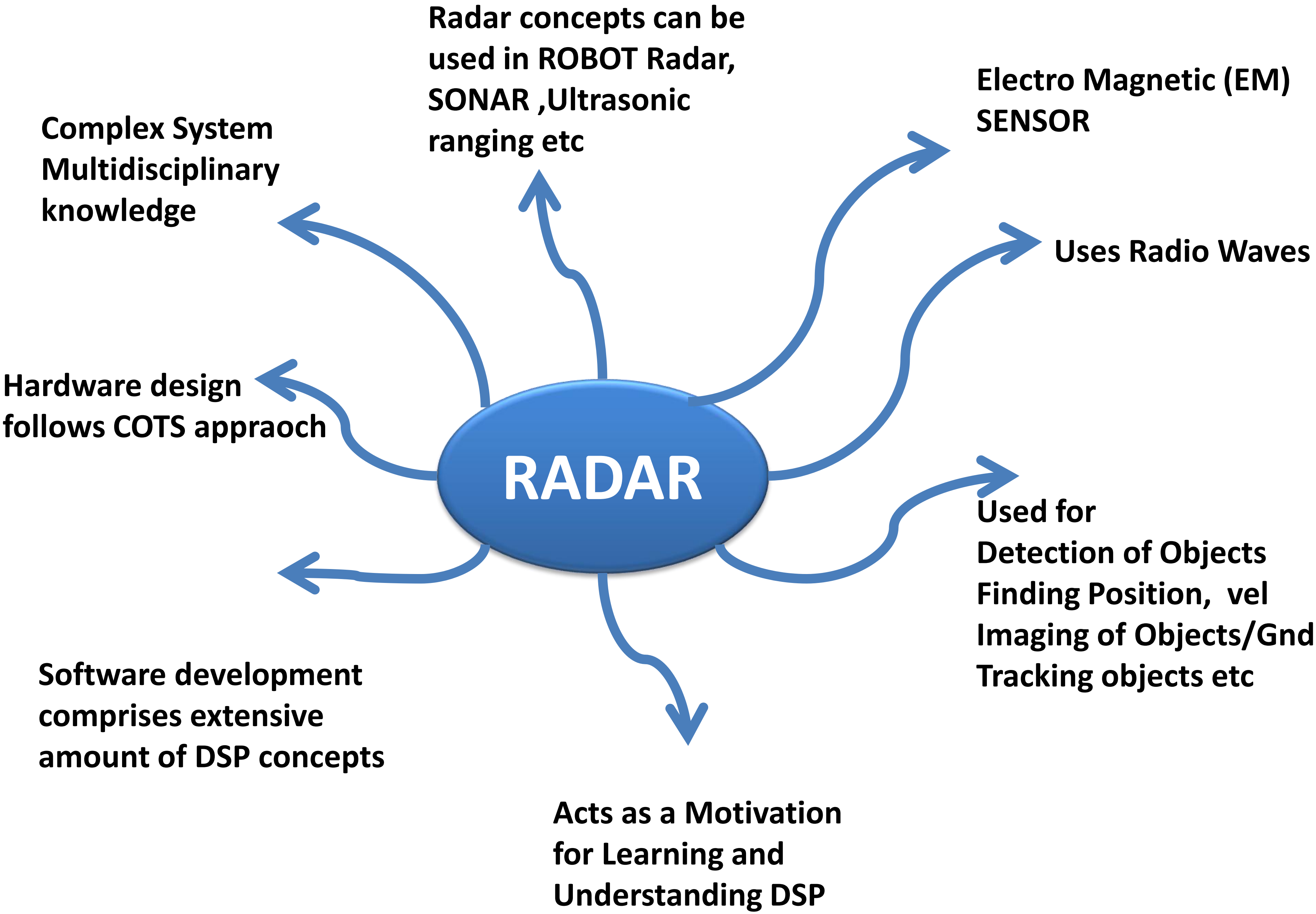
radar




RADAR
Radar concepts can be used in ROBOT Radar, SONAR ,Ultrasonic ranging etc
Electro Magnetic (EM) SENSOR
Complex System Multidisciplinary knowledge
Uses Radio Waves
Hardware design follows COTS appraoch
Used for
Detection of Objects
Finding Position, vel
Imaging of Objects/Gnd
Tracking objects etc
Software development comprises extensive amount of DSP concepts
Acts as a Motivation for Learning and Understanding DSP

INTRODUCTION TO RADAR

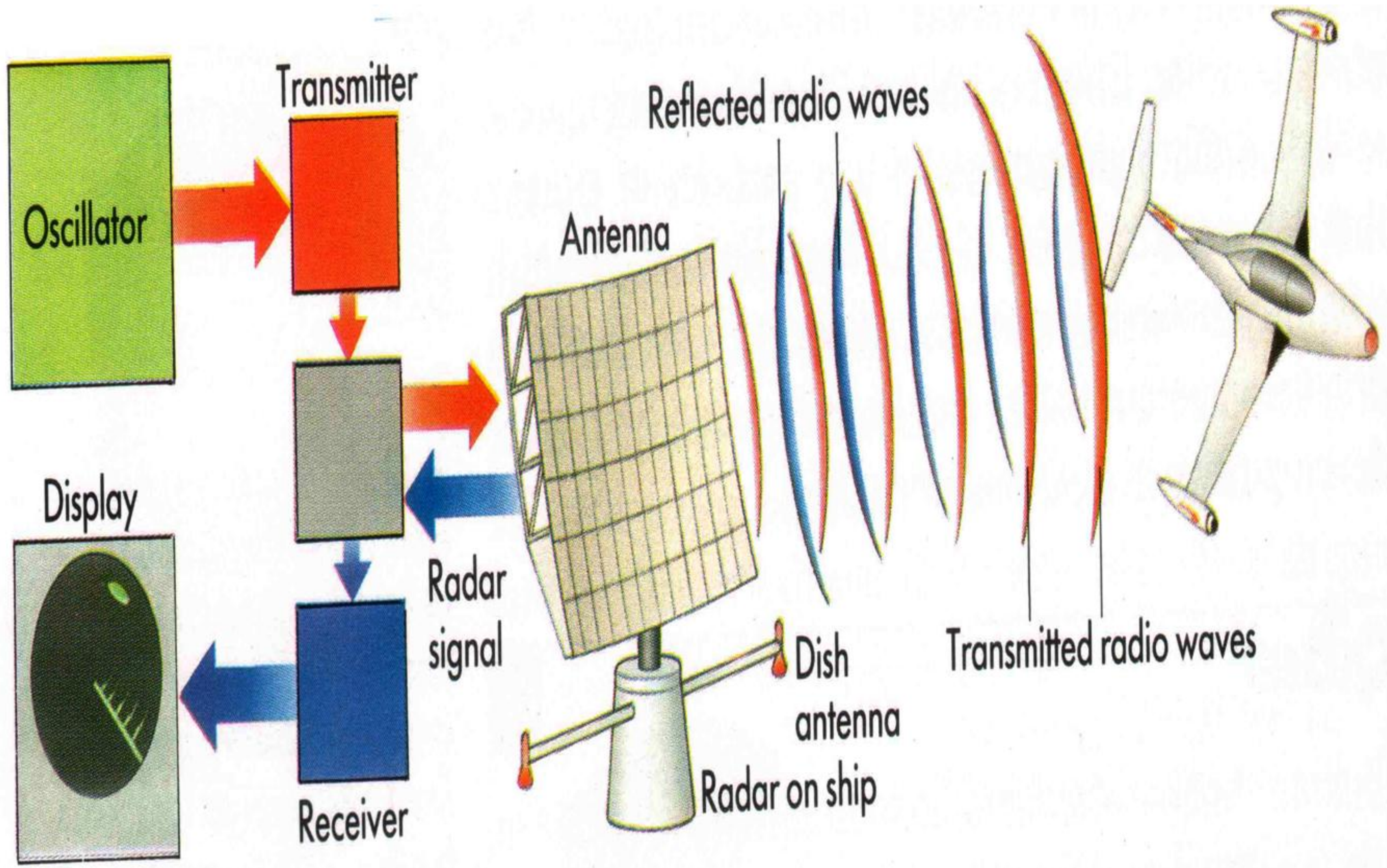
RADAR = Radio Detection and Ranging

- Detects targets by receipt of reflected echoes from transmitted RF pulses

- Measures metric coordinates of detected targets:
  - Range
  - Doppler/velocity of targets
  - Angle (azimuth and/or elevation)

- Special-purpose radars also measure:
  - Target size / shape (target imaging)
  - Target motion spectrum
  - Ground map images (SAR)

RADAR : Working Principle



Radar Measurements

- **Metric Coordinates of Detected Targets**

  – Range: $R = c\tau / 2$; c = speed of light, m/s
  τ = round-trip echo time, s

  – Range Rate: $v_r = \lambda f_d / 2$;
  v_r = target radial velocity, m/s
  λ = wavelength of RF Txmit pulse, m
  f_d = Doppler freq. shift of echo, Hz

  – Azimuth / Elevation Θ, Φ

  – position of antenna beam at time of detection.

Radar Measurements

- **Measurement Resolution of Metric Coordinates**
  - Range: $\Delta R = c/(2\,B)$; B = pulse bandwidth, Hz
  - Range Rate: $\Delta v_r = \lambda/(2\,T_c)$; T_c = coherent integration tim, s
  - Angle: $\Delta\Theta = \lambda/D_\Theta$; D_Θ = antenna aperture, m ($\Delta\Theta$ in radians)

- **Special-Purpose Radar Measurements**
  - Target Motion Spectra; Modulation of Doppler shift by target motion
  - Synthetic Aperture Radar; Conversion of Doppler shift to angle offset

RADAR SIGNAL PROCESSING

Extensive usage of DSP concepts

1. **How to find range of the object/Target ?**

   Time Domain Processing (Band Pass Sampling)

2. **How to find the speed of the object/Target ?**

   Frequency Domain Processing (DFT/FFT)

3. **How to achieve desired range resolution ?**

   Frequency Domain Processing (Fast Convolution, Windowing)

4. **How to suppress Unwanted signal/Clutter ?**

   Frequency Domain Processing (FIR Filters)

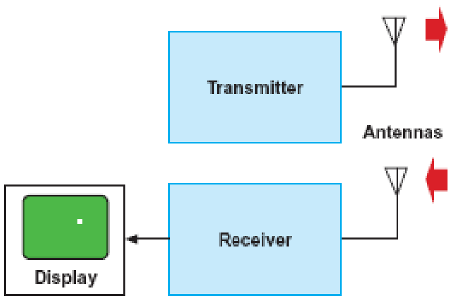
Radar On a Robot

Radar Basics

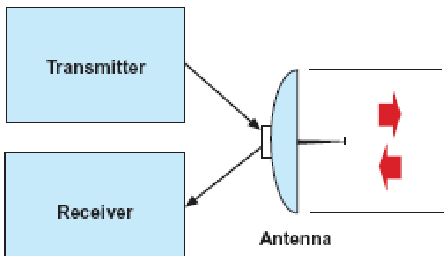
Band Designation	Frequency range (MHz)
HF	3 - 30
VHF	30 - 300
UHF	300 - 1000
L	1000 - 2000
S	2000 - 4000
C	4000 - 8000
X	8000 - 12,000
Ku	12,000 - 18,000
Ka	27,000 - 40,000
mm	40 - 300GHz

Ultrasonic Ranging

RADAR : Basic Types



CW Radar with independent Transmitting and Receiving antenna



Single antenna Time shared by the transmitter and receiver

Continuous Wave Radars(CW)

- Independent Transmitter and Receiver

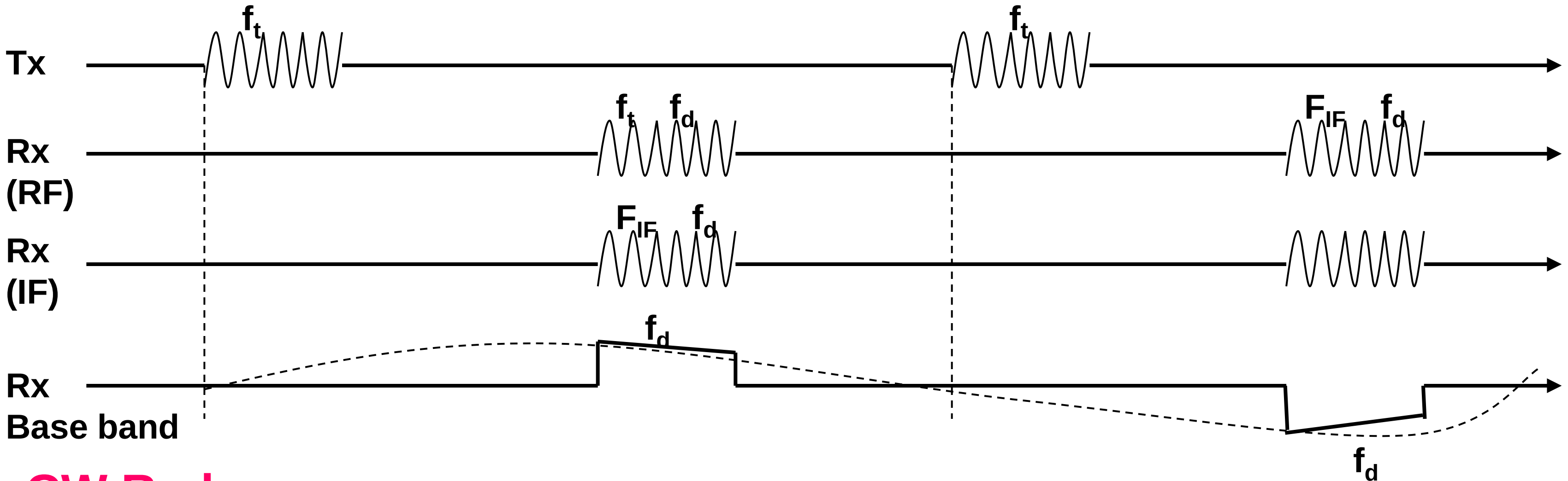
Bistatic Radars

Pulsed Radars

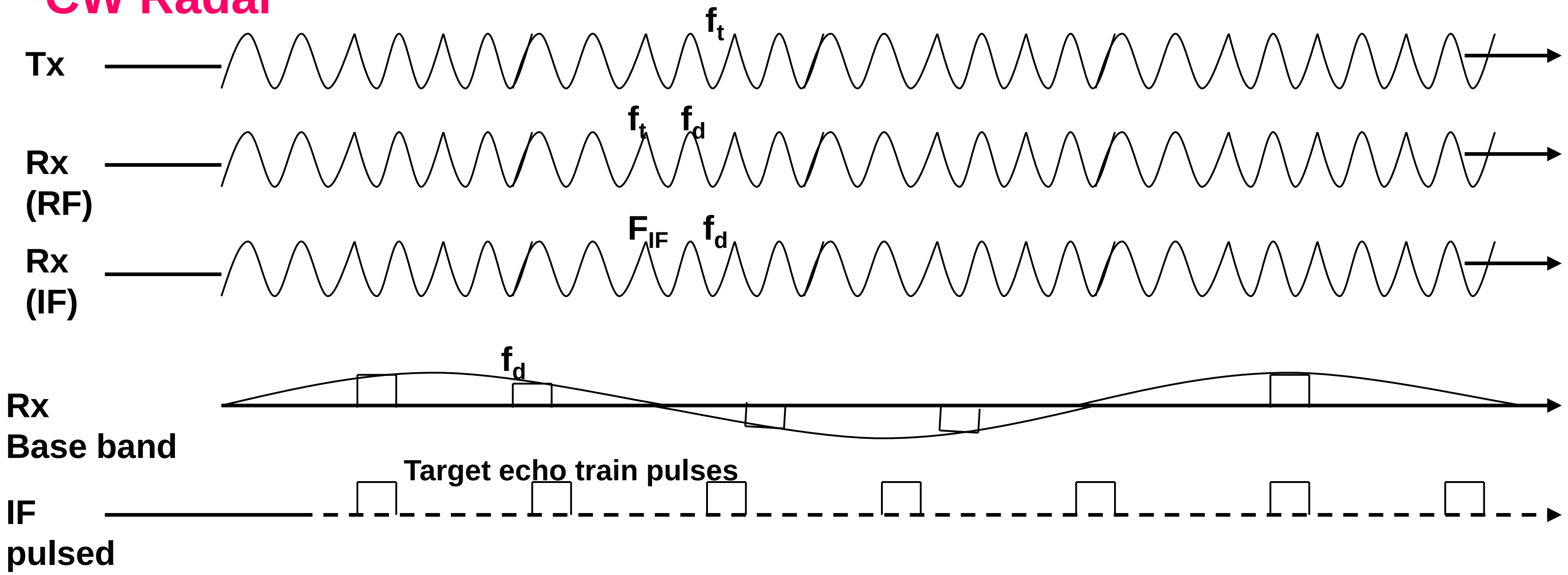
- Co-located transmitter and Receiver with a sharing antenna
- A pulse is transmitted and then the radar listens for the return
- The strength of the signal is proportional to the target distance and its electrical size
- The range is calculated from the time delay

Monostatic Radars

Pulsed Radar



CW Radar



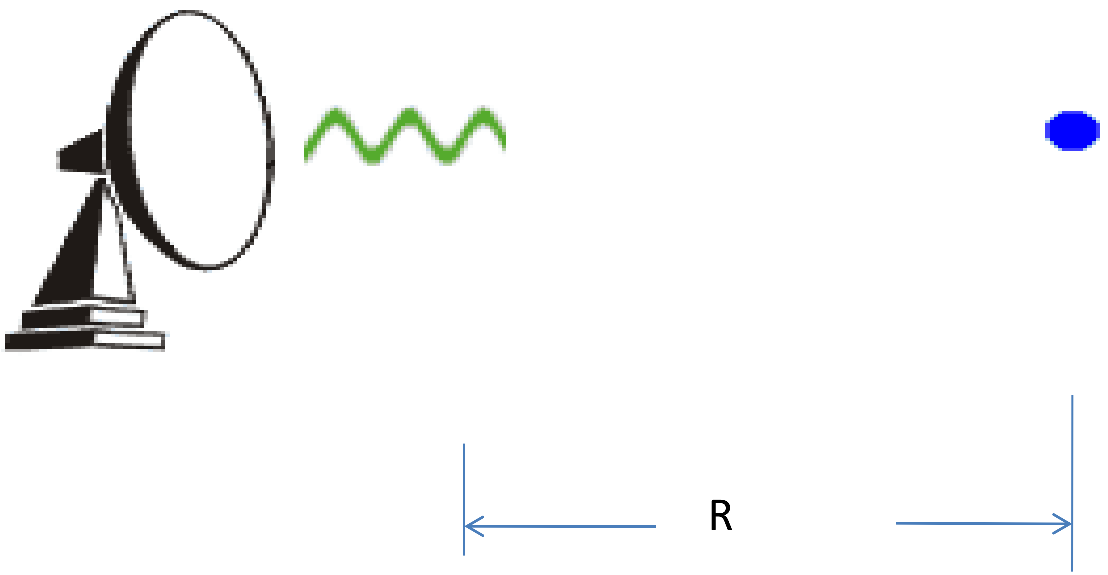
RADAR SIGNAL PROCESSING

Extensive usage of DSP concepts

1. **How to find range of the object/Target ?**

Time Domain Processing (Sampling)

TARGET DETECTION : Detection Range



$R = cT_R/2$

Where

c= velocity of light

T_R= Round Trip Time

For ,

T_R=1us

$R = \frac{1}{2} \times 3 \times 10^8 \times 1 \times 10^{-6}$

=150m.

- **CW : Continuous Wave**
- **FMCW : Freq. Modulated Continuous Wave**
- **Pulsed**
- **Pulsed Coded**

Pulse Width : τ

Pulse Repetition Interval (PRI) : T

Pulse Repetition Frequency (PRF) : $f_r = 1/T$

The PRF is chosen to meet the max. unambiguous Range desired :

Dist = Speed x Time

$$2 \times R_{unamb\ max} = C \times T = C \times 1/f_r$$

$$\therefore\ f_r \leq C / 2.R_{unamb\ max}$$

RADAR RANGE EQUATION

R_{max} proportional to $[P_T G^2 \lambda^2 \sigma / (4\pi)^3) S_{min}]$

P_T = Transmitted power

G = Gain of the antenna

λ = Wave length

σ = Target cross section

S_{min} = Minimum Detection signal

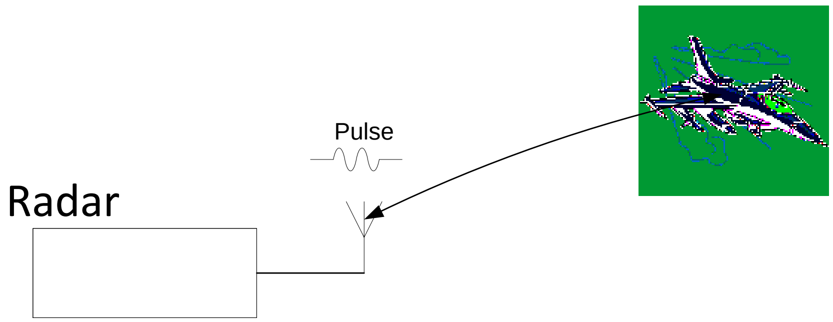
R_{max} = $[P_T A e^2 \sigma / 4\pi\lambda^2 S_{min}]^{1/4}$

Ae = Antenna aperture

RADAR PRINCIPLES: Pulsed Radar

Range measurement

- Radar measures distance by measuring time delay between the transmit and received pulse.
  - 1 us = 150 m
  - 1 ns = 15 cm



$$R = \frac{c\tau}{2}$$

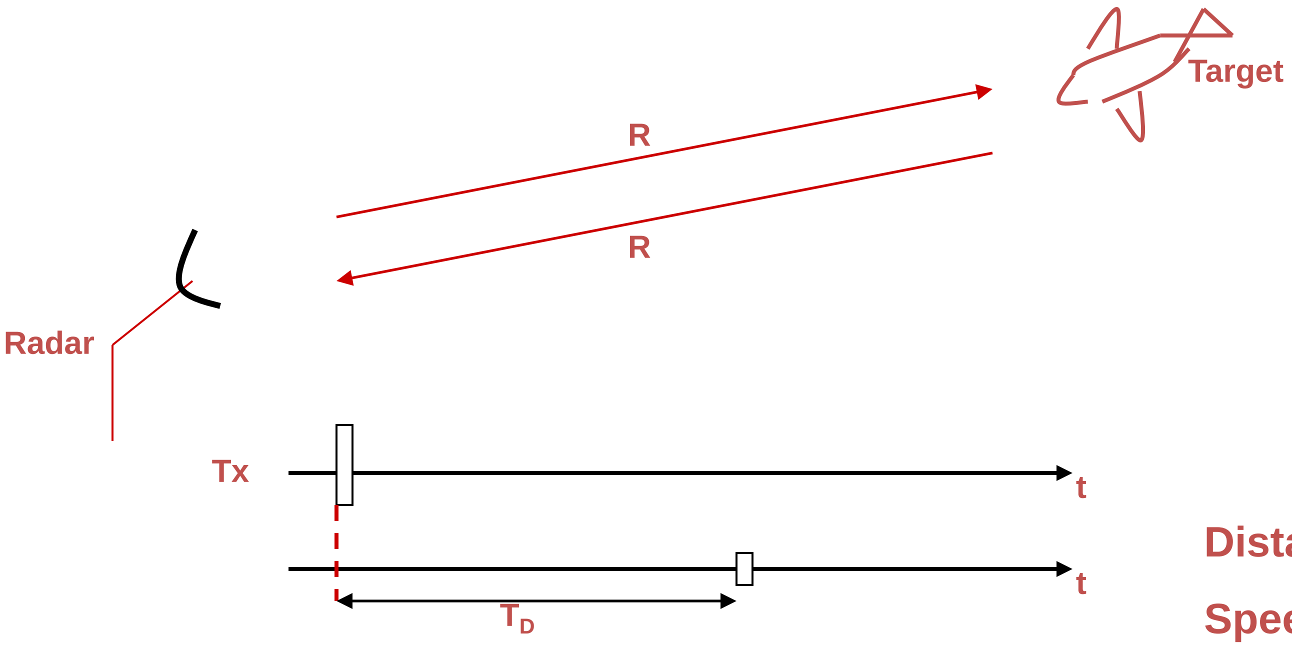
τ = time delay between transmission and reception

c = velocity of propagation

R = Range to the jet.

RADAR

- Radio Detection and Ranging (RADAR)
- Uses Electromagnetic wave



Distance : 2R

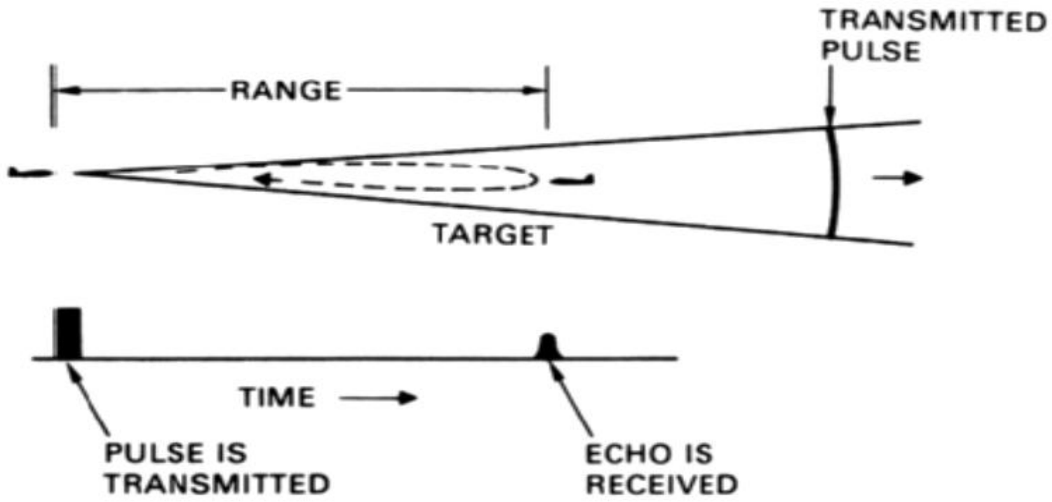
Speed : $3x\ 10^8$ m/s

R = $T_D * 3 \times 10^8$

For 1 Km T_D = 6.666 μsec

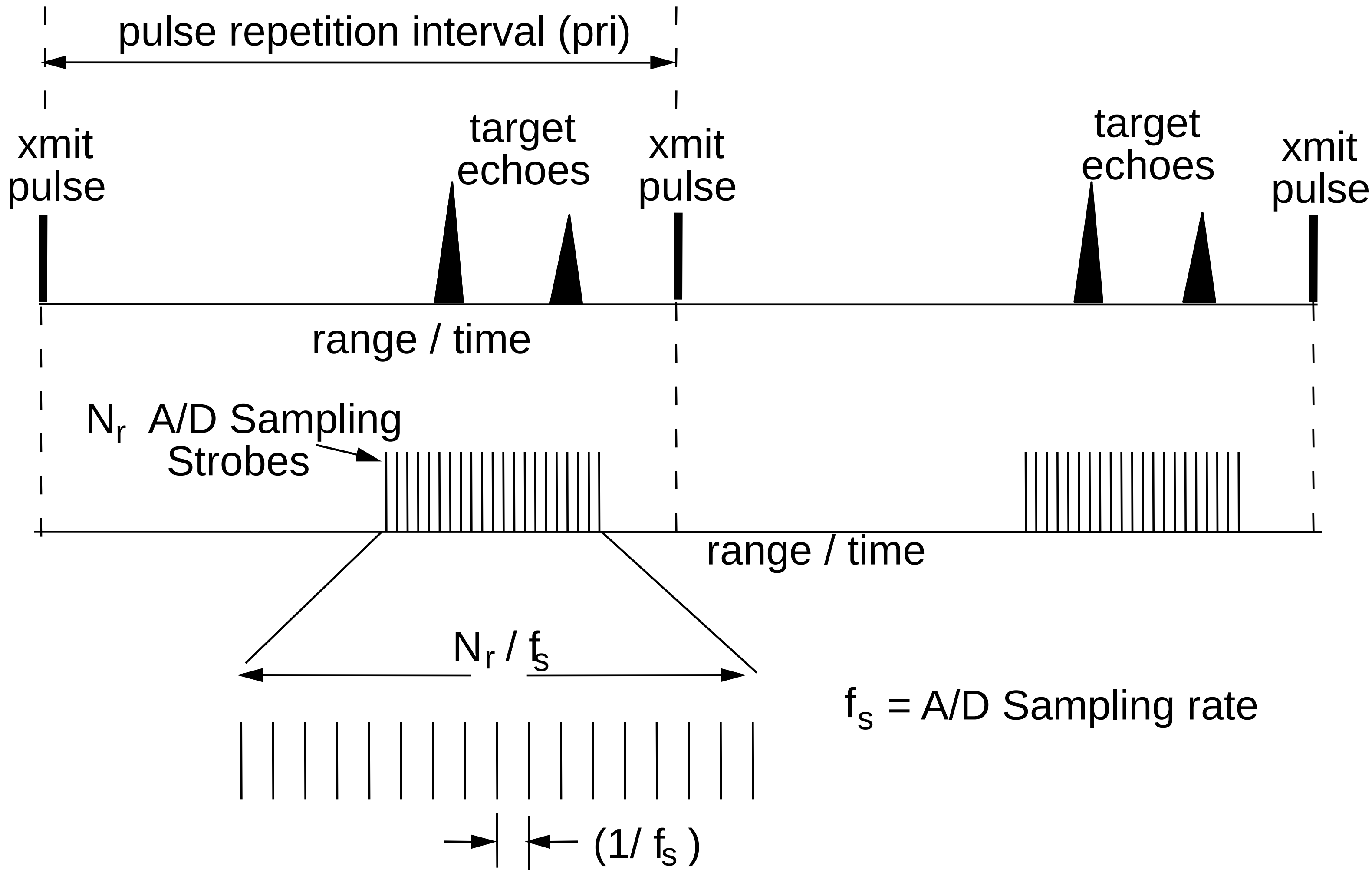
1 μsec delay = 150 m range

How to Find Range?

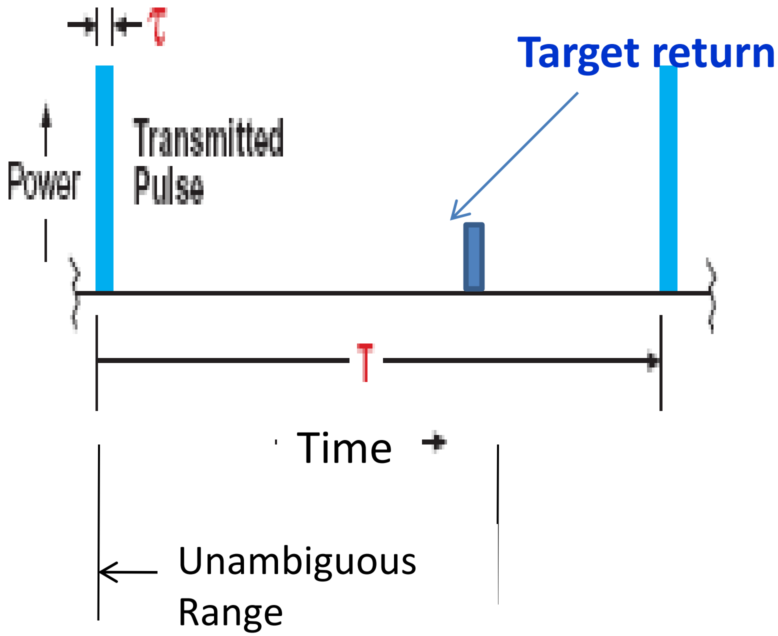


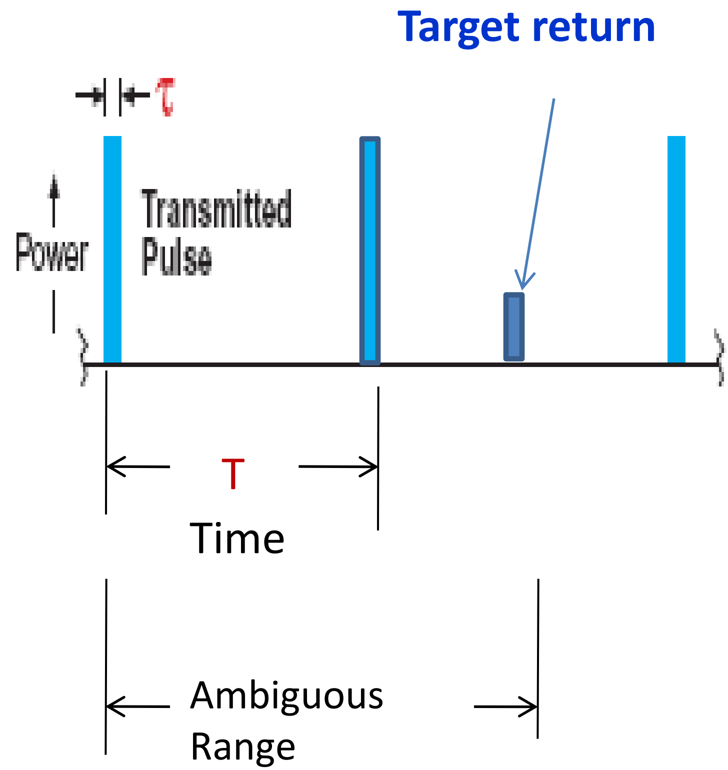
Power : Radar range Equation
Pulse Width : Range Resolution
Pulse Length : Unambiguous Range & Doppler
Number of Pulses : Doppler and Energy
Modulation inside Pulse : Range Resolution

Range (A/D) Sampling Process



TARGET DETECTION : Maximum Range





Maximum unambiguous Range, $R_{un}=cT/2$

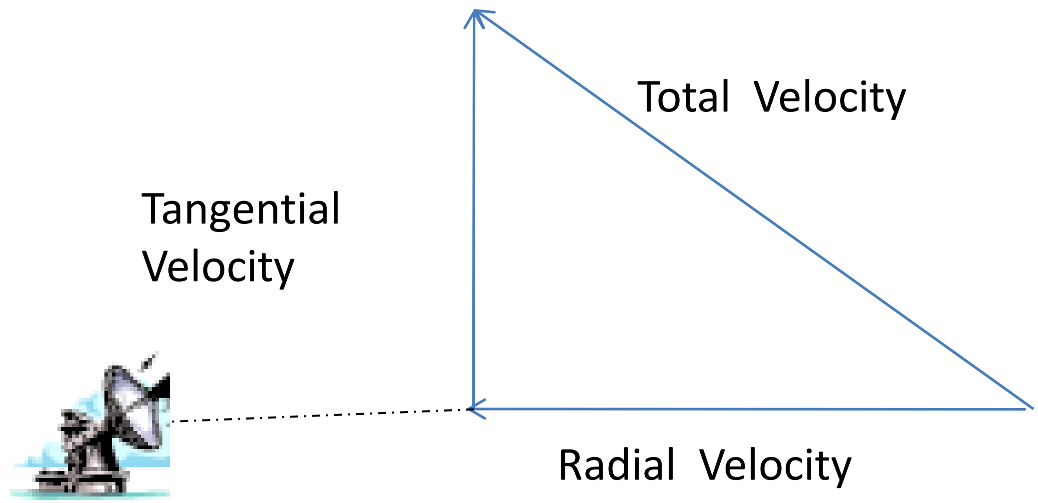
RADAR SIGNAL PROCESSING

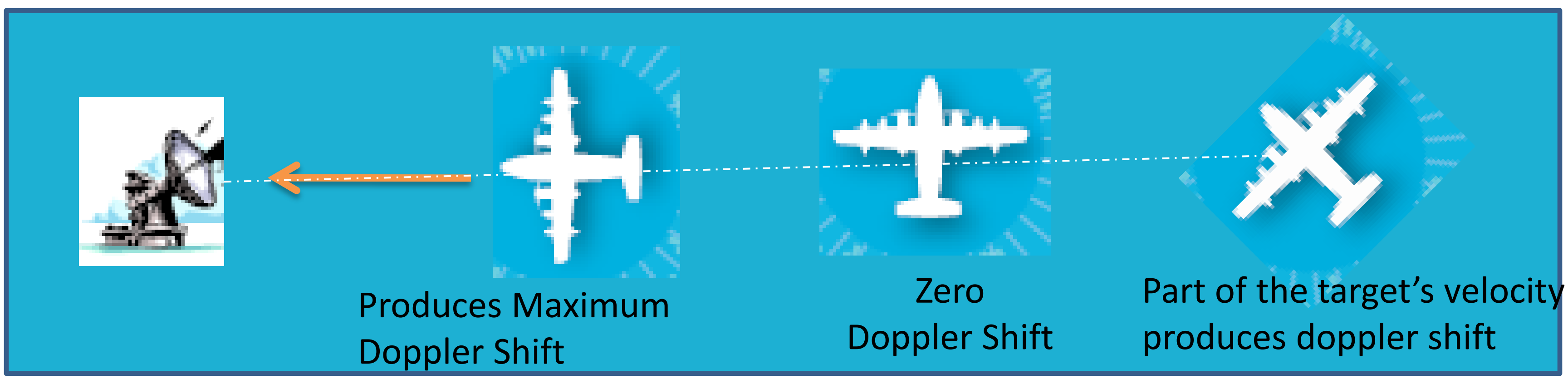
Extensive usage of DSP concepts

1. **How to find the speed of the object/Target ?**

Frequency Domain Processing (DFT/FFT)

TARGET DETECTION : Detect Velocity (Doppler Shift)



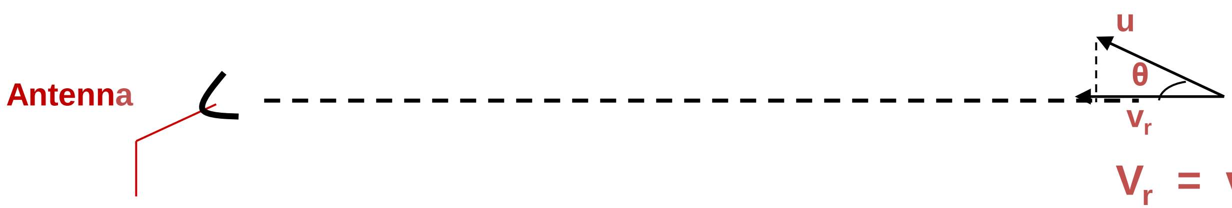


Any echo signal coming from a moving target suffers a change in phase with respect to time

Frequency being rate of change of phase:

$$f = 1/2\pi \, (d\Phi/dt)$$

The echo signal suffers a change or shift in frequency called the DOPPLER FREQUENCY shift, given by : $f_d = 2\, v_r/\lambda = 2\, v.\, \text{Cos}\theta /\, \lambda$



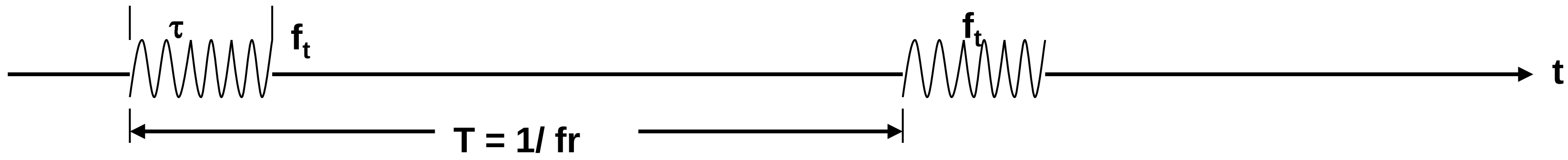
$V_r = v.\, \cos\theta$

Wavelength : λ **is the distance the wave must travel to suffer a 360° phase change or complete one cycle :**

Time for 1 cycle = 1/f

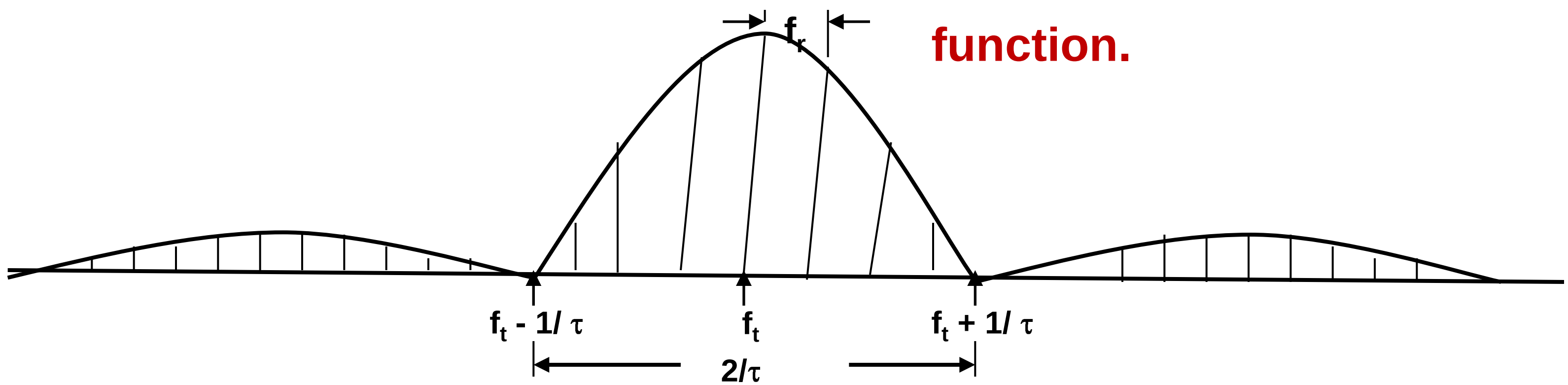
SPECTRUM OF PULSED RADAR SIGNAL

TIME DOMAIN :



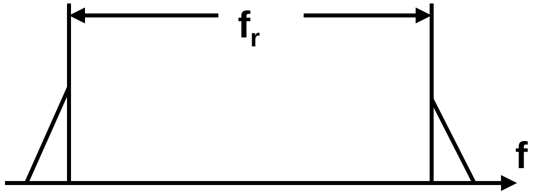
FREQUENCY DOMAIN :

Line spectrum weighted by SINC function.



For target echo : central line will be f_t f_d

Each line has a spread :

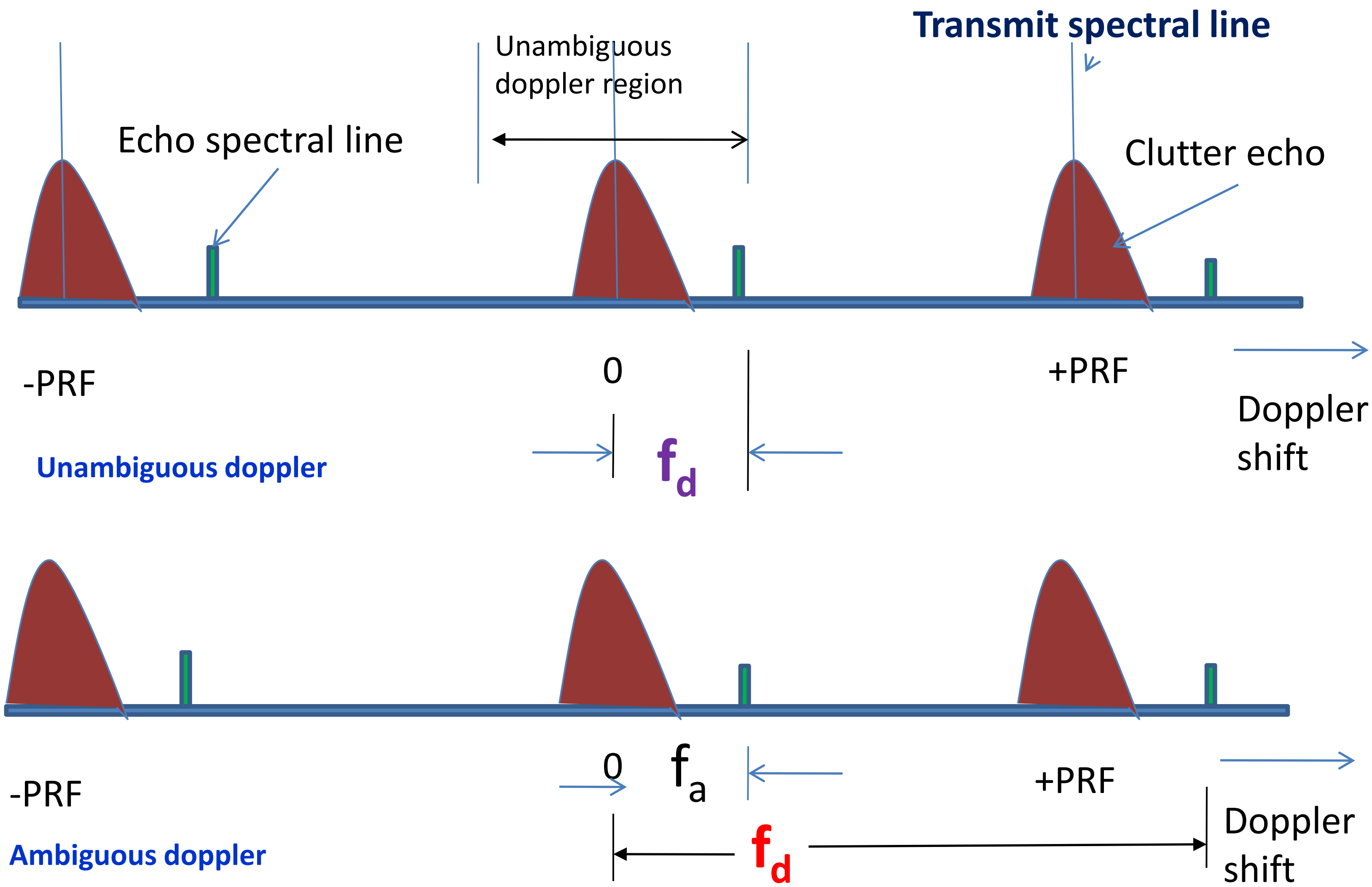


Expanded view

Spread depend on several factors

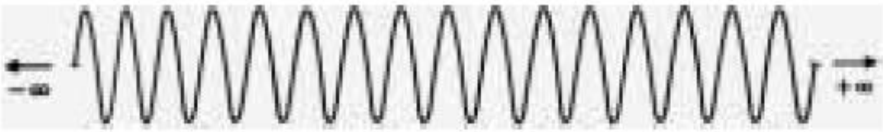
but mainly dominated by inverse of antenna dwell time.

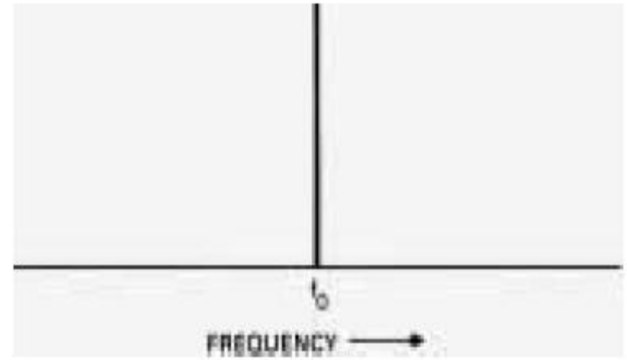
TARGET DETECTION : Doppler Ambiguity

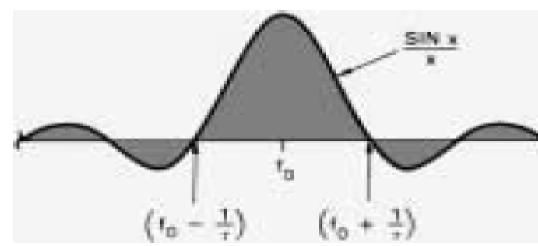


Graphical Analysis of Radar signal Spectrum

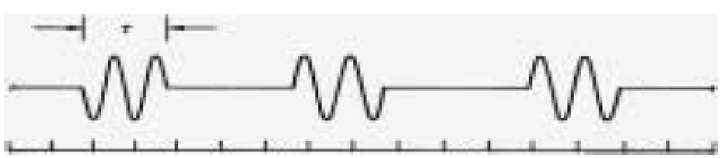
Continuous Wave (CW)
Infinite Length



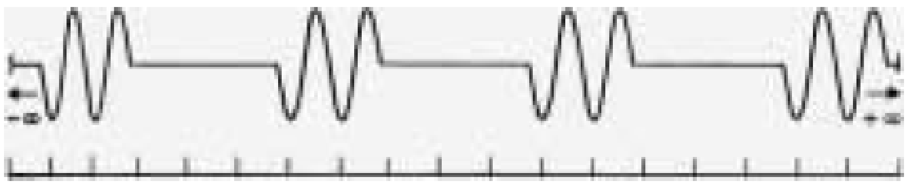


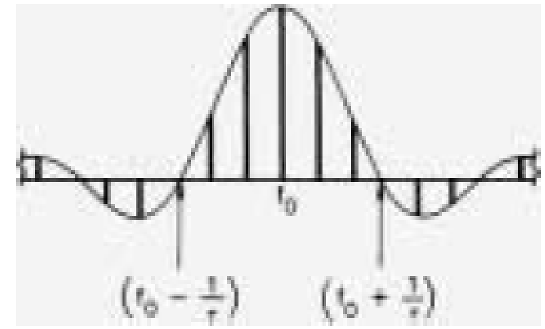


Train of Noncoherent Pulses
(Random starting phases)

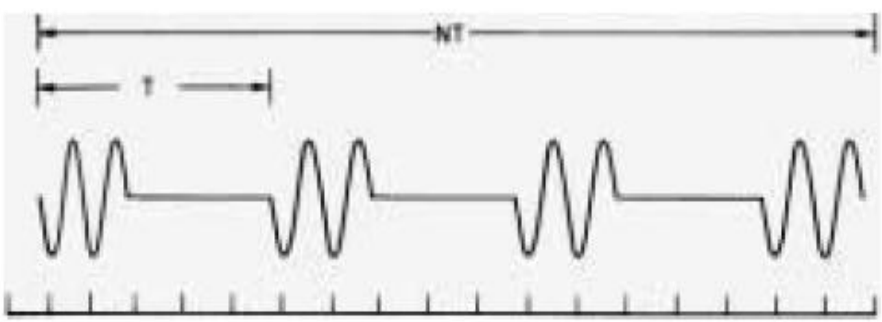


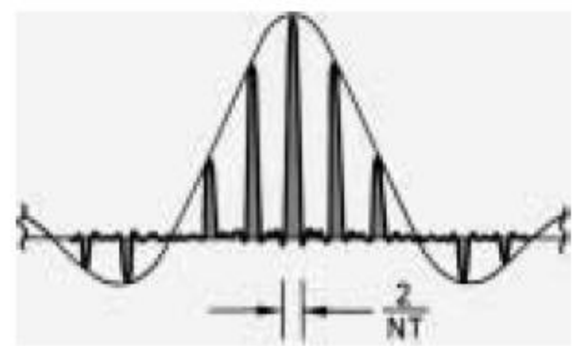
Train of Coherent Pulse
Infinite Length



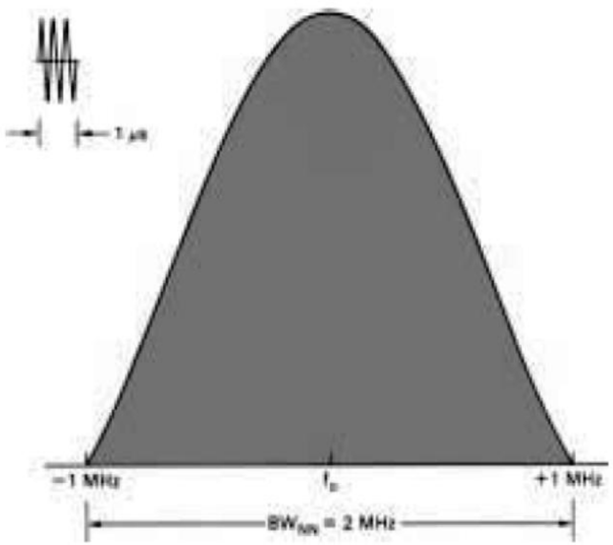


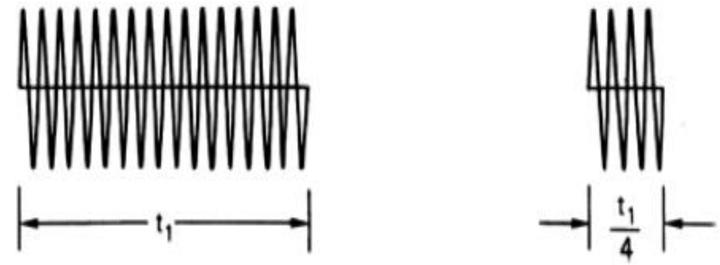
Train of Coherent Pulses
Limited Length

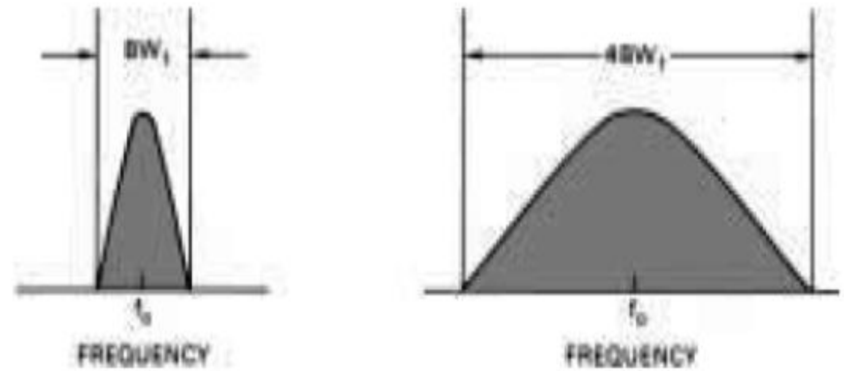


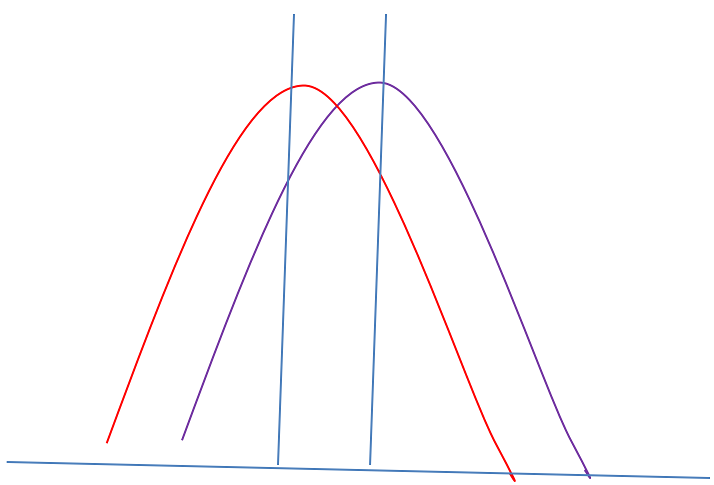


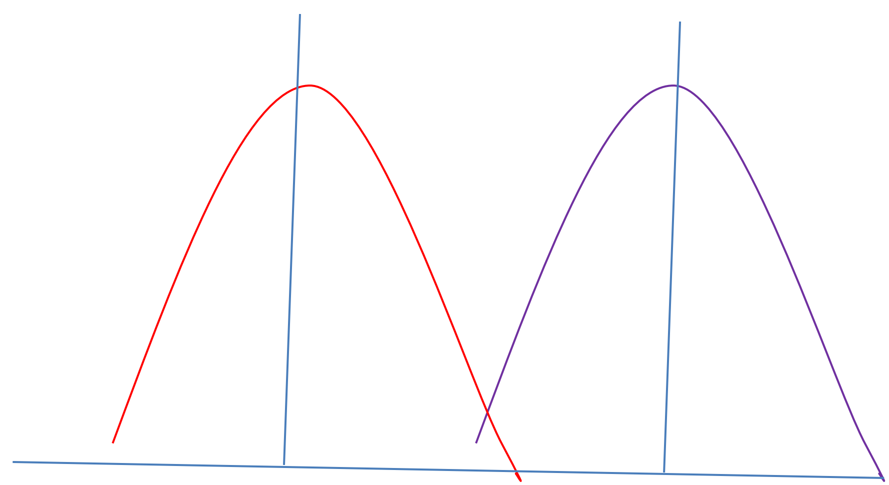
How to Find Velocity?





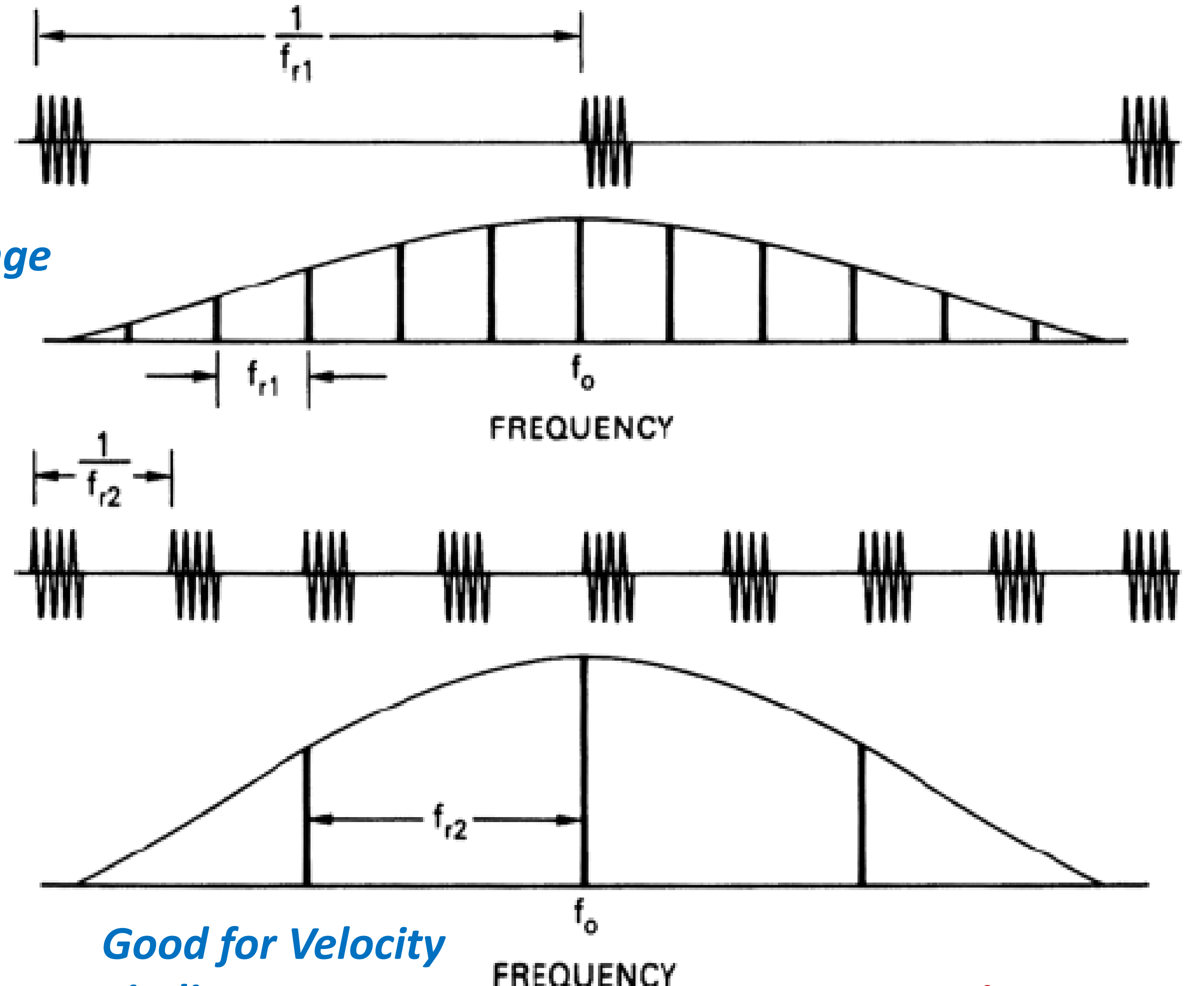






Time & Frequency Trade Off

PRF 1 (low)



repetitive

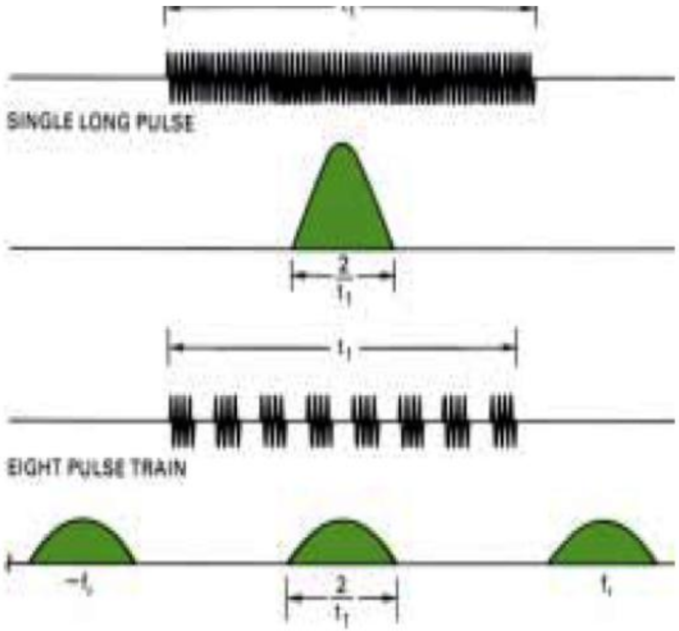
Good for Range Finding

PRF 2 (high)

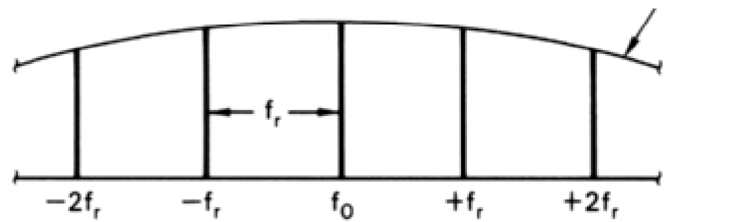
repetitive

Good for Velocity Finding

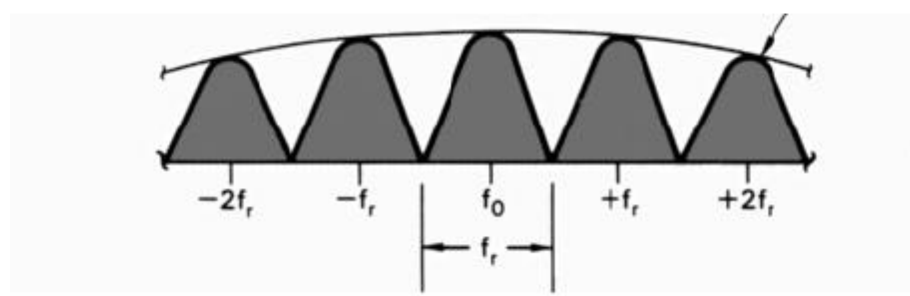
Line spectrum

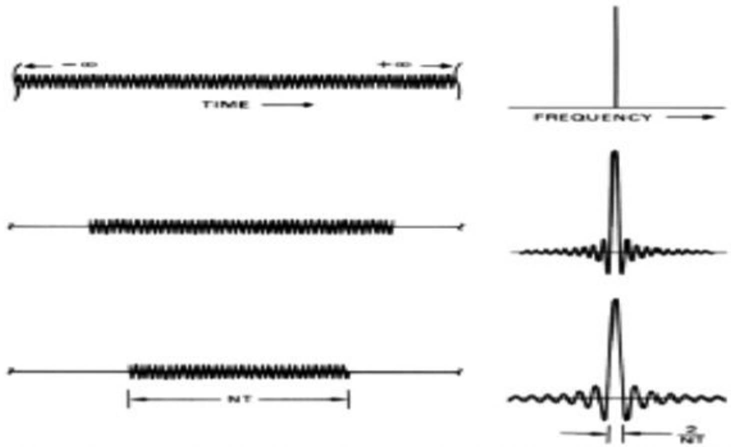


1000 Pulses



2 Pulses

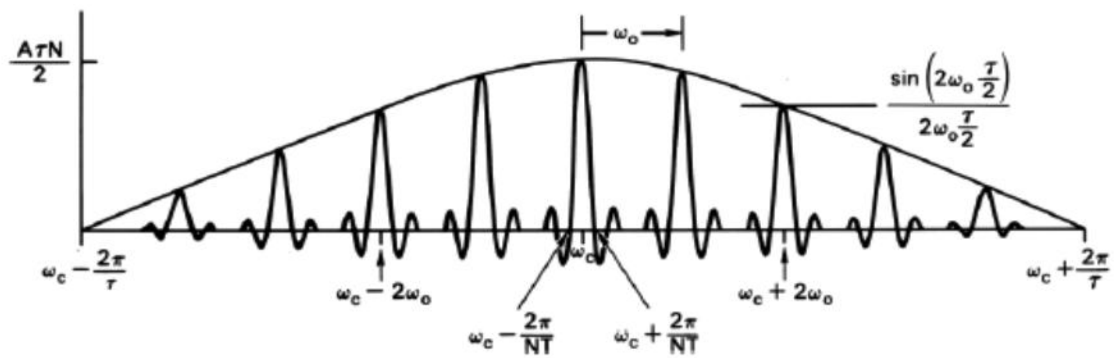




21. CW wave represented by a single line in the spectrum of an infinitely long pulse train. As the length of train is reduced, this wave becomes a single pulse and its spectrum broadens into a sin x/x shape.

CARRIER ENVELOPE LOWER SIDEBANDS UPPER SIDEBANDS

$$F(j\omega) = \frac{A\tau N}{2}\left\{\frac{\sin(\omega-\omega_c)\frac{NT}{2}}{(\omega-\omega_c)\frac{NT}{2}} + \sum_{n=1}^{\infty}\frac{\sin\left(n\omega_o\frac{\tau}{2}\right)}{n\omega_o\frac{\tau}{2}}\left[\frac{\sin(\omega-\omega_c+n\omega_o)\frac{NT}{2}}{(\omega-\omega_c+n\omega_o)\frac{NT}{2}} + \frac{\sin(\omega-\omega_c-n\omega_o)\frac{NT}{2}}{(\omega-\omega_c-n\omega_o)\frac{NT}{2}}\right]\right\}$$



33. Positive-frequency portion of the Fourier transform for a rectangular train of N pulses. The pulses have a width τ, a carrier frequency of ω_c, a PRF of ω_0, and an interpulse period of T.

Reference

INTRODUCTION TO AIRBORNE RADAR

BY GEORGE W. STIMSON

SCITECH PUBLICATIONS


THANK
YOU