Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management Training School

Academic Principles Organisation

FT4

AVIONICS PART 2 PHASE 3
Radar

BOOK 1
Basic Radar Principles

WARNING

These course notes are produced solely for the purpose of training. They are not subject to formal amendment action after issue and they must NOT be used for operating and maintaining the equipment described. Operation and maintenance of equipment is governed by the limitations and procedures laid down in the authorized publications and manuals which must be complied with for these purposes.

BASIC RADAR PRINCIPLES

OBJECTIVES

T.O.s – 42.1, 42.2, 42.3, 42.13

E.O. **S92-01** Describe Aircraft Radar Fundamentals

S92-01-01 Explain the basic theory of radar

S92-01-05 Describe factors affecting Radar performance

CONTENTS :

INTRODUCTION TO RADAR (RECAP)

1. Basic Radar was introduced in an earlier phase of Avionics training. You discovered Radar systems work at higher frequencies than those used in Radio systems. The frequencies used for airborne Radar are generally higher than those for radio systems. Typically they range from the mid UHF band (**C**/**D**) at about 1 GHz (used for secondary radars) into the microwave region, which includes the upper UHF, SHF and into the EHF band (**E/F** to **K**) from about 3 - 35 GHz. Table 1 shows the radar frequency bands including NATO designations.

Wave Length λ	1.2	60	30	15	10	7.5	5.0	3.75	3.0	1.5	7.5	5.0	
NATO Freq Band	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
Freq GHz	0.25	0.5	1	2	3	4	6	8	10	20	40	60	
Freq Band	**HF**	**VHF**	**UHF**			**SHF**						**EHF**	

2. Radar today has many functions depending on the role of the aircraft some are listed below.

a. Search & Surveillance

b. Radar Altimeter

c. Target Acquisition and Tracking (Airborne Interception A.I.)

d. Terrain Following

e. Weather Warning

f. Ground Mapping

g. Proximity Detection (Collision Warning)

h. Identification (IFF/SSR)

i. Navigation (TACAN)

j. Passive Warning (RWR)

Transmission Characteristics

3. Three basic types of radar transmission are:

   a. Pulsed

   b. Continuous Wave (CW)

   c. Frequency Modulated CW (FMCW)

Transmission characteristics and Target Information

4. It is the transmission (or emission) characteristic of a radar system that determines the type of information obtained about the target, which may include any or all of the following:

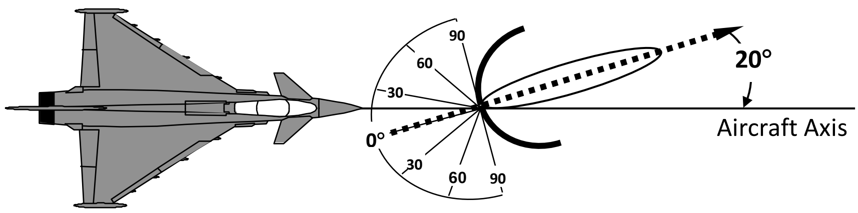
   a. Angular Position (in azimuth and/or elevation).

   b. Slant Range.

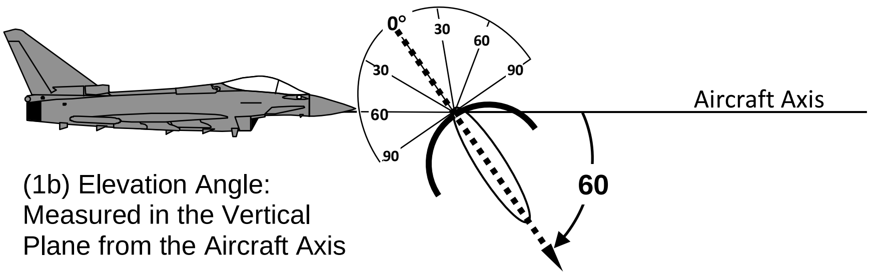
   c. Radial (or relative) Velocity (RV).

5. To achieve this, the transmitted signal is modified in various ways and then analysed or examined in the receiver to see how the target has affected the returning signal or echo (i.e. frequency, phase or timing).

Introduction to Radar (Recap)



(1a) Azimuth or Bearing Angle:
Measured in the Horizontal Plane from a
Reference Direction or Aircraft Axis



(1b) Elevation Angle:
Measured in the Vertical
Plane from the Aircraft Axis

Figure 1 – Angle Position Measurement

6. In a directional radar system:

a. Transmitted RF energy travels in straight lines from TX Aerial.

b. Reflected RF energy from a target also travels in straight lines back to the RX Aerial.

c. The maximum received signal will occur when the RX Aerial is pointing directly at the target.

Measurement of Target Slant Range - Recap

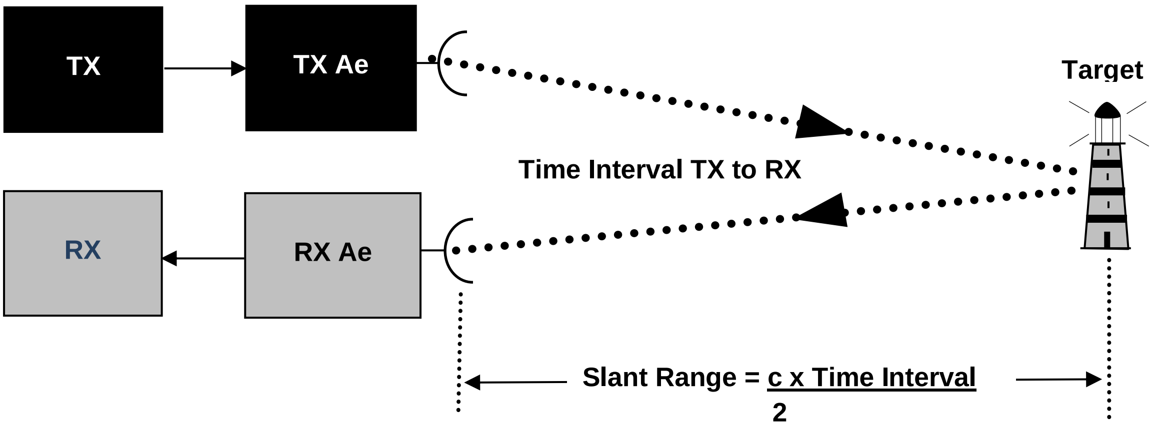


Figure 2 – Slant Range Measurement

Measurement of Slant Range (Refer to Figure 2)

7. To calculate the Slant Range of a target radar systems require:

a. The transmitted RF energy to be coded in some way or have some form of timing mark applied, so that the transmission and echo reception times are known.

b. The time interval between transmission and reception of target echoes to be accurately measured.

i. RF energy travels at the speed of light (c). = 300x10^6 m/sec

ii. Distance = Speed x Time.

iii. Slant range to target is half the distance travelled by the RF energy from the TX and back to the RX.

i.e. $Slant\ range = \frac{speed\ (c) \times echo\ return}{2}$

Worked Example for Slant Range – Pulsed Radar

Given: Speed of Light (c) = 300×10^6 m/sec

Given: The TX – RX Time Interval = 50μsec (50×10^{-6})

Question: Calculate the slant range to a target in km?

Answer: Distance = Speed x Time

$$= (300 \times 10^6) \times (50 \times 10^{-6})$$

$$= 15000\text{m}$$

$$= 15\text{km}$$

(15 Km is the total distance travelled by the RF energy). Slant Range is half the distance the RF energy has travelled out to the target and back.

$$\therefore Slant\ Range\ to\ Target = \frac{15}{2}\ km$$

Slant Range = 7.5km

Methods of Measuring Slant Range

8. For slant range measurement radar uses two main methods to “time code” the RF energy:

a. By transmitting the RF energy in a series of pulses i.e. **Pulse Radar**.

b. By transmitting the RF energy as a CW and varying its frequency in a linear fashion known as **Frequency Modulated Continuous Wave** (FMCW) Radar.

Note: It is **not** possible to measure Slant Range in a pure CW system, as it is not “time coded”. Therefore there is no way of identifying when to measure the TX-RX time interval in CW transmission.

Doppler Effect and Doppler Shift Frequency (Recap)

Doppler Effect

9. In CW (Doppler) radar the transmitted signal consist of a single frequency component (Ft).

10. If there is relative motion between the CW radar and its target, then the frequency of the echo signal reflected from the target will be different to frequency of the transmitted signal. This change in frequency is known as the “Doppler effect”.

Doppler Shift frequency (fd):

11. Doppler Shift frequency (fd) is the actual value of the frequency difference between the continuous wave (CW) transmitted (Ft) and received frequencies (Ft $\pm$fd).

Doppler Shift frequency (fd) is proportional to the radial or relative velocity (RV) of the target

Measurement of Target Radial (or Relative) Velocity (RV)

12. Radial (or Relative) Velocity (RV) is the difference in speed measured along the line-of-sight (LOS) between the aircraft carrying the radar and its target.

a. CW radars measure radial or relative velocity (RV).

b. Although the RV measured could be that of another aircraft, it could also be the aircrafts own RV measured with respect to the ground over which it is flying i.e. its ground speed, as obtained by Doppler Navigation radar.

Examples of Radial or Relative Velocity (RV): (refer Figure 3)

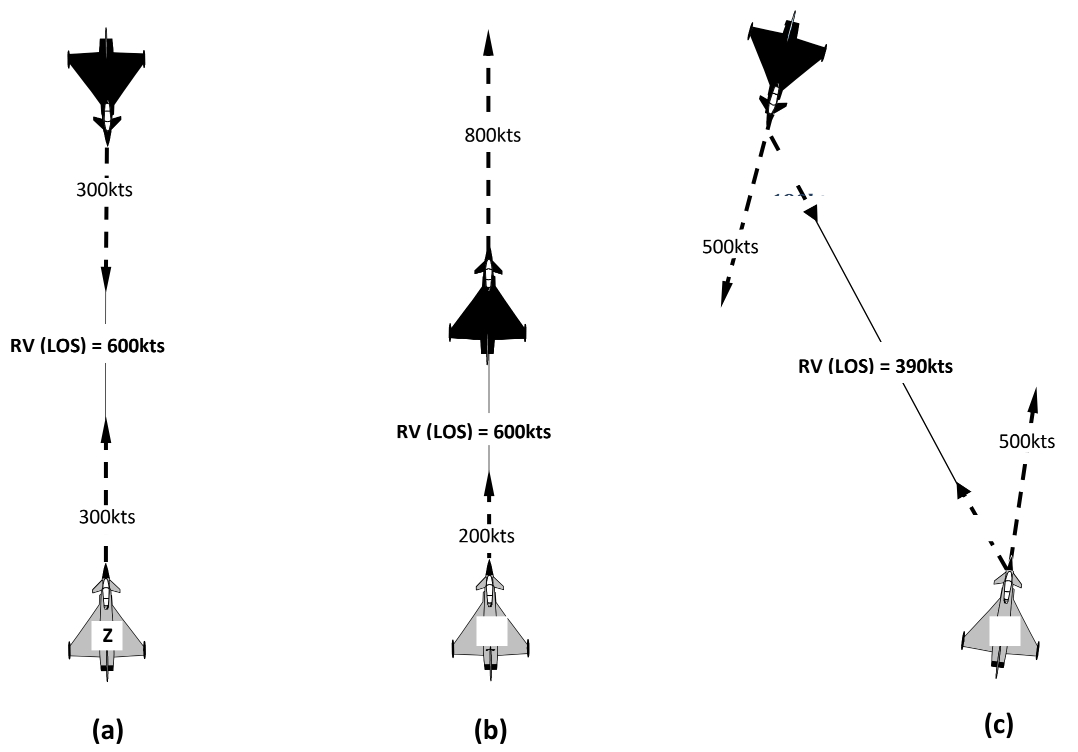


Figure 3 – Radial or Relative Velocity (RV)

13. Refer to “closing” target or velocities in Figure (3a)

a. Aircraft “Y” and “Z” are heading along a line directly between them, called the line-of-sight (LOS); each aircraft is travelling at 300 kts.

b. Because they are heading directly towards each other, their radial velocity will be the sum of their individual velocities. Radial velocity (RV) = 300 + 300 = 600kts.

14. Refer to the “opening” target or velocities in Figure (3b)

a. Both aircraft are now heading along the LOS in the same direction, aircraft “Y” is travelling at 200 kts and aircraft “Z” is travelling at 800 kts.

b. Because aircraft “Y” is moving directly away from “Z” their radial velocity will be the difference of their individual velocities. Radial velocity (RV) = 800 - 200 = 600kts.

15. Refer to the “closing” target or velocities in Figure (3c)

a. Aircraft “Y” and “Z” are both travelling at 500 kts but are now heading at an angle away from each other.

b. Their radial velocity is the sum of their individual velocities along the LOS. Radial velocity (RV) = 210 + 180 = 390kts

16. In CW radar, the Radial or Relative Velocity (RV) of a target is proportional to its measured Doppler Shift frequency.
Velocity measurement is **<u>not</u>** normally possible in a basic pulse radar system as there is no way of determining the Doppler Shift frequency between the transmitted and received signal.

Opening and Closing Target Radial Velocities

17. Whether the frequency of the returning signal at the CW receiver is higher or lower than the transmitted frequency depends upon whether the distance between the CW radar and target is increasing (opening) or decreasing (closing).

18. Refer figure 4a, for closing radial velocities (distance to target decreasing), the received frequency is higher (Ft + fd).

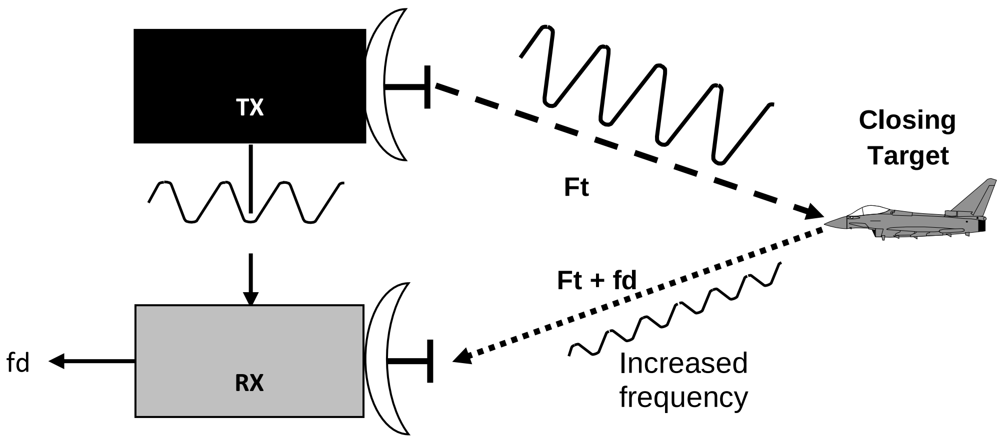


Figure 4a – CW Closing Target Radial Velocities

19. Figure 4b, for opening radial velocities (distance to target increasing), the received frequency is lower (Ft - fd).

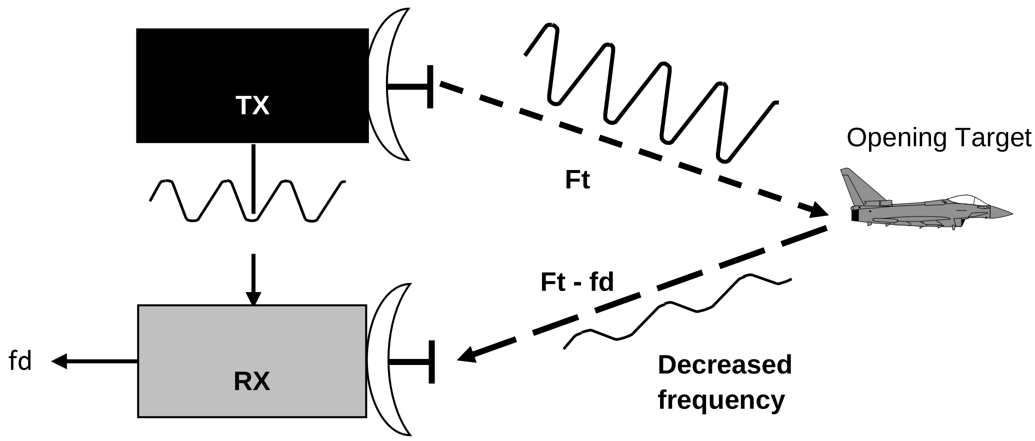


Figure 4b – CW Opening Target Radial Velocities

Radar Classifications

20. Radar systems can also be classified by:

a. Frequency Band e.g. UHF or SHF

b. Wavelength, e.g. metric, centimetric or millimetric

c. Operational function, e.g. navigation radar, airborne interception (AI) radar, identification radar, weather radar, radar altimeters etc.

21. All these different ways of classifying radar systems may be used in the work place. Radar systems could also be classified as being either:

a. Primary Radar Systems

b. Secondary Radar Systems

Primary Radar Systems

22. The basic principle of a Primary Radar System is shown in Figure 5.

23. Main Characteristics of a Primary Radar System:

a. Single independent radar systems.

b. Target co-operation not required.

c. Uses echo return signals reflected from the target.

d. Analyses echoes to obtain target information

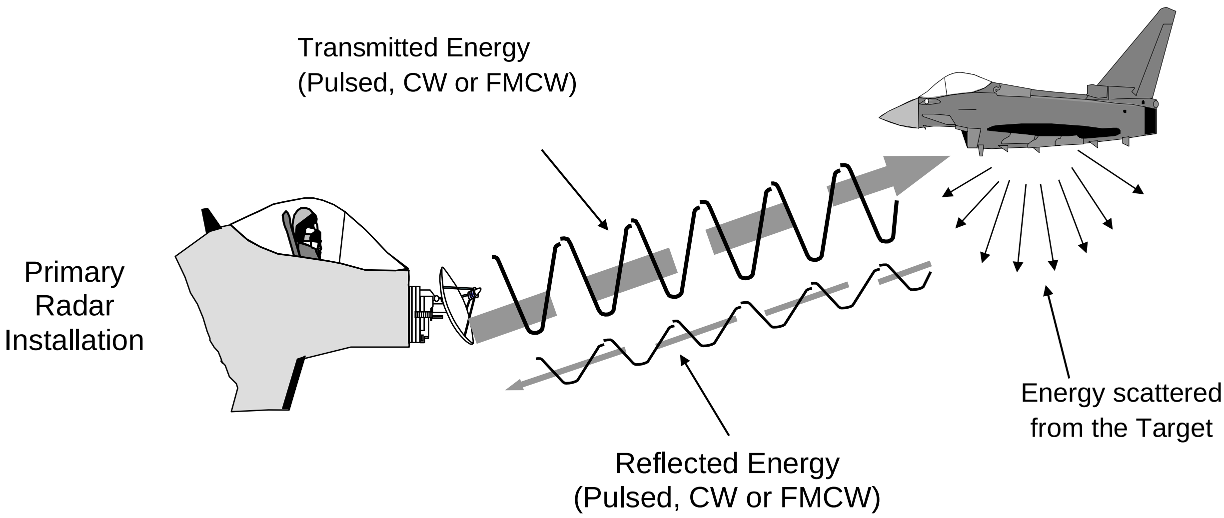


Figure 5 – Primary Radar System

Secondary Radar Systems

24. The basic principle of a Secondary Radar System is shown in Figure 6.

25. Main Characteristics of Secondary Radar System:

a. Secondary radars are co-operative radar systems,

b. Target co-operation takes place with two radars communicating directly with one another.

c. Echo signals reflected from the target are not used.

d. Information is obtained from coded pulses transmitted between the two radars, one interrogating (asking Q's) and the other automatically replying.

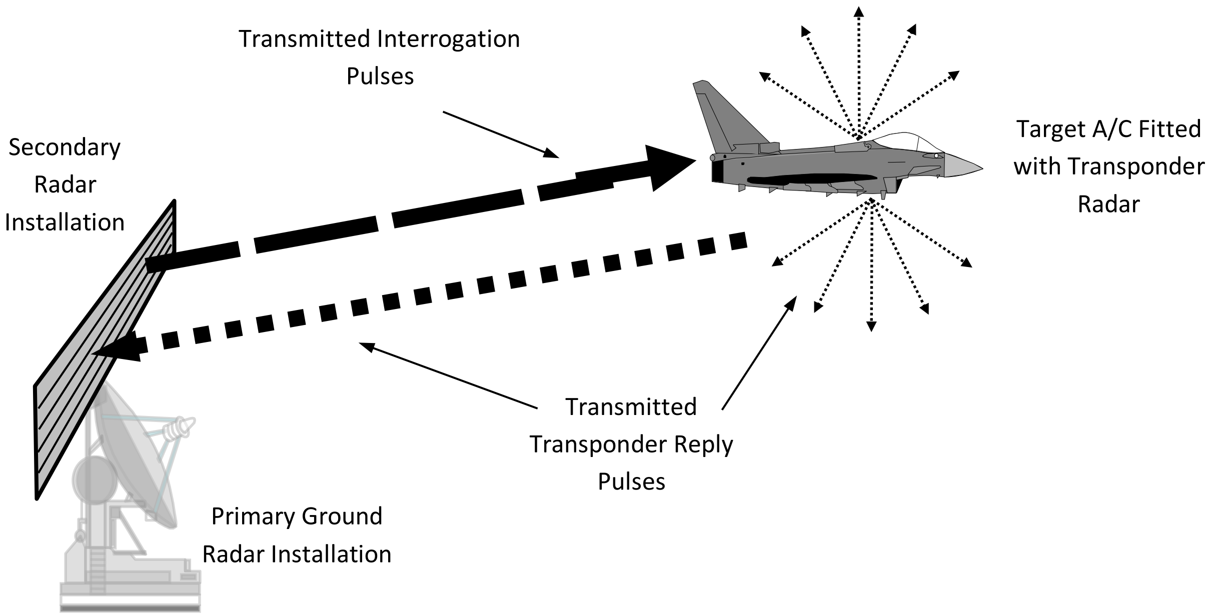


Figure 6 – Secondary Radar System

Main Characteristics of Primary and Secondary Radars

26. Primary and Secondary radar systems possess different characteristics or prop properties due to the way in which they operate. See Characteristics Table 2.

Table 2 - Primary and Secondary Pulse Radar Characteristics

Characteristic	Primary		Secondary
No of radars required	**1**		**2**
Co-operation of Target	**NO**		**YES**
Path of TX Energy	TWO WAY (Out to target and reflected back again)		**ONE WAY** (Radar to Radar)
Type of Transmission	**PULSED**	**CW**	**PULSED**
Tx Power	**HIGH:** (At medium and long ranges)	**LOW** (Compared to pulsed)	**LOW:** **(**Even at long ranges)
Clutter (Unwanted echoes)	**YES** (Target echoes from all objects)	**NO** (Only detects moving targets)	**NO:** (Echoes are Not used)
Type of Target Information	**Bearing, Elevation,** and **Slant Range**	**Relative Velocity Only FMCW gives Slant Range**	**Identity** & **Baro-Height** or Beacon Navigation info **Brg** & **Slant Range**
Information obtained by:	**Echo analysis** and **Aerial position**	**Echo analysis**	**Decoding pulses transmitted between** the two **radars**
Affected by Target Size and Position	**YES** Echoes and Information greatly effected		**NO** Information not effected

27. Identify which of the radars in Table 3 are primary or secondary types.

Radar Function	Primary	Secondary
a. Search and Surveillance		
b. Radar Altimeter		
c. Airborne Interception (AI)		
d. Terrain Following (TFR)		
e. Weather Warning		
f. Ground Mapping (GMR)		
g. Collision Warning		
h. IFF/SSR		
i. TACAN		
j. Doppler Navigation		

Table 3 - Primary and Secondary Radars

Pulse Modulated Radar System

28. The RF energy is transmitted in a series of short pulses that are separated by relatively long inter-pulse receive periods.

a. The choice of pulse width (pulse duration) depends to some extent upon the function of the radar.

b. Long-range early warning or search and surveillance radar uses relatively long pulses typically of 5μs duration, which ensures that they have enough energy.

c. Short-range airborne interception (AI) radar uses very short well-shaped square pulses, (typically of 0.2μs duration.

d. However if a special technique called ‘Pulse Compression “ is applied, much longer pulses of 10 - 15μs may be used, that give the advantages of both long and short range radar, this technique will be looked at later in the phase.

29. During the long inter-pulse periods, the pulse radar is in the receive mode waiting to process any returning echo signals reflected from targets.

30. Target information is obtained by analysis of the direction and timing of the returning echo pulses.

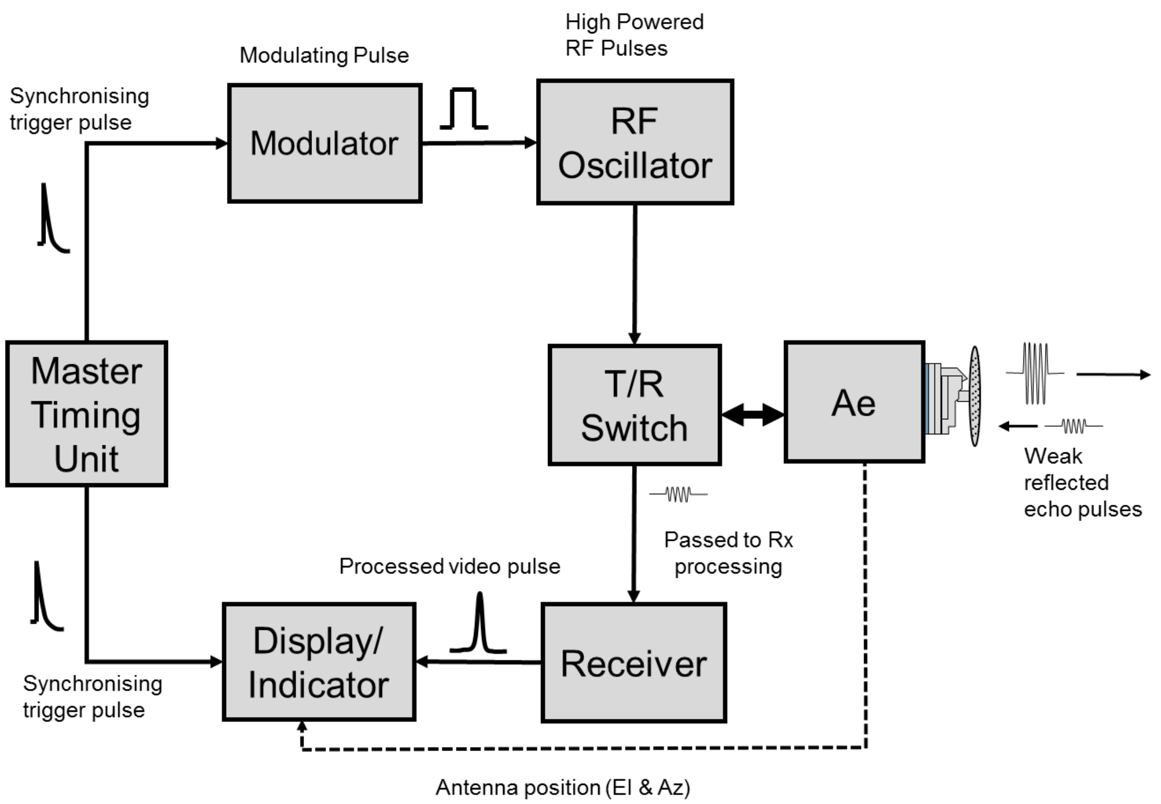


Figure 7 Pulse Modulated Radar System

Pulse Modulated Radar System Block Functions

Pulse Modulated Radar System Block Functions (Refer to Figure 7)

31. **Master Timing Unit (MTU):**

a. The MTU controls the Pulse Repetition Frequency (**PRF)** of the system i.e. the number of timing pulses transmitted every second, which trigger the modulator.

b. The **MTU** also triggers the display to synchronise its information with the target returns from the currently transmitted pulse.

c. **PRF** is an important factor in determining radar performance e.g. maximum range amongst others.

32. **Modulator (Mod):**

a. The Modulator controls the Pulse Width (**PW)** of the system.

b. When triggered by the MTU (at the PRF) the modulator produces a square wave pulse that switches the RF Oscillator “on” for a fixed period of time and then “off”.

c. **PW** is an important factor in determining radar performance e.g. minimum range and target discrimination amongst others.

33. **Tx RF Oscillator:**

a. The RF Oscillator controls the **RF Frequency** of the transmitted pulses.

b. **RF Frequency** is an important factor in determining radar performance e.g. beam width and atmospheric attenuation amongst others.

34. **Transmit/Receive Switch (T/R sw)**

a. Automatically controls the flow of RF pulses to /from the aerial.

b. When transmitting the **T/R sw** protects the receiver by preventing the high power pulses passing to the receiver.

c. When receiving, the **T/R sw** prevents the very low power echo pulses passing to the transmitter.

35. **Aerial (Ae)**

a. Usually a single aerial scanner for both TX and RX that can be steered or directed as needed.

b. During transmission, the aerial focuses and shapes the RF pulses into a beam that can radiate out in the direction that aerial is pointing.

c. During reception the aerial collects some of the reflected signals (echoes), which are then sent to the receiver (RX) for processing.

d. Aerial position information (bearing and elevation angle) can be sent to the display if required.

36. **Receiver (RX)**

a. Usually a superheterodyne type of receiver, which processes the very low power echo pulses through low noise factor circuits, then amplifies, demodulates and presents the signal in a suitable format for display.

37. **Display/Indicator**

a. This shows the processed target echo information in a suitable format as selected by the operator on a variety of display types.

Main Features of a Pulse Modulated Radar System

38. **Path of TX Energy. TWO WAY** – if the transmitted beam of RF pulses hits a target, some of the pulses may be reflected and processed in the RX.

39. **TX Power** (refer to Figure 8)

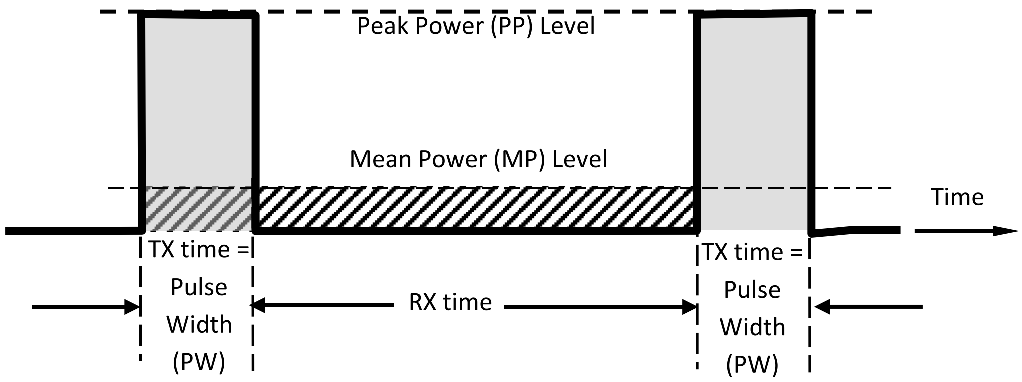


Figure 8 - Peak and Mean Power in Pulse Radar

40. **HIGH** – in peak power terms, to be able to detect a target the returning echo pulses must be big enough to process (i.e. have sufficient energy).

a. The echo or reflected pulse power is generally very low, only a tiny fraction of that transmitted (unless close by), therefore to detect targets at long or even medium ranges requires high power transmitters.

b. The mean or average TX power (spread across the one cycle of pulse TX and RX time) is very much lower than the pulse peak power.

c. The greater the mean power, the more likely it is that target echoes will be received from long ranges.

41. **Clutter: Unwanted target echoes** are called **"Clutter".**

42. Most objects in the radar beam will reflect some energy. Echoes will be returned from; the ground, sea, hills, clouds, built-up areas, ships and aircraft etc. some of which will contribute to clutter. One radar's clutter may be the target for another type of radar i.e. Clouds are AI radar clutter, but targets for Weather radar.

43. **Type of Target Information:**

a. Bearing position (or Azimuth angle / Elevation angle
b. Slant Range

44. **Information sources:**

a. **Target position:** Obtained from the angular position of the radar beam or scanner (in Az and El) when the echoes were received.

b. **Slant range**: to the target is obtained by analysing the transmission and reception times of the radar pulses.

Continuous Wave (CW) Radar Systems

45. In airborne Continuous Wave (CW) radar (also known as Doppler radar):

a. RF energy of a constant frequency and amplitude is continuously transmitted to and received from targets.

b. Target Information is radial or relative velocity (RV) obtained from the **“Doppler Shift”** frequency (**fd**).

c. Airborne CW Doppler radar is mainly used by “**Doppler Navigation”** radar systems to determine the aircrafts ground speed and track or drift angle.

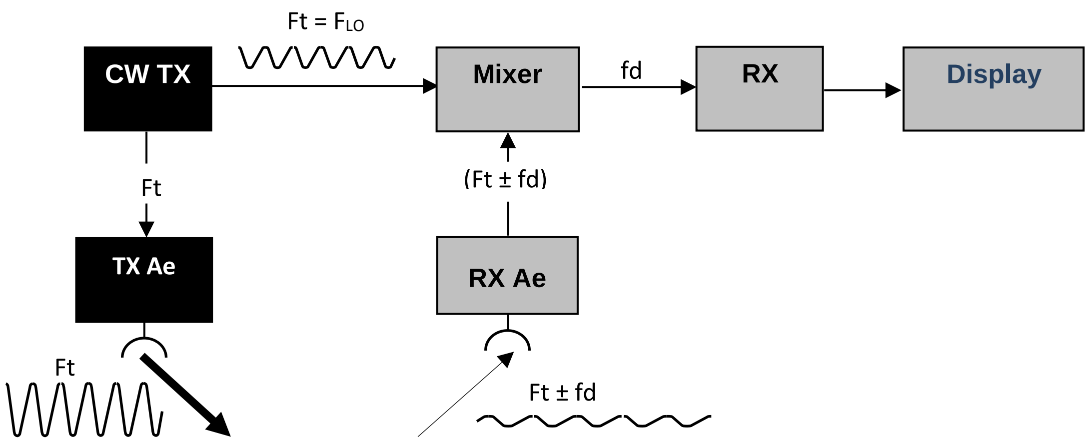


Figure 9 – Airborne CW (Doppler) Radar System

CW (Doppler) Radar System Block Functions

46. **CW Transmitter (TX):** Produces the transmitted CW output signal (Ft) of constant frequency and amplitude. A sample of the transmitted frequency (Ft) is also sent to the mixer as the local oscillator frequency (F_{LO}).

47. **TX Ae:** Transmitter aerial focuses and shapes the CW into a beam that can radiate out in the direction that the aerial is pointing.

48. **RX Ae -** Receiver aerial collects some of the reflected CW echo signal (Ft ± fd), which is then sent to the mixer.

49. **Mixer -** combines the F_{LO} = Ft with the received CW frequency (Ft ± fd) producing the “Doppler” shift frequency (fd) output to the RX.

50. **Receiver (RX) -** amplifies and processes the “Doppler” shift signal (fd) into a suitable format for the display.

51. **Display -** shows the processed target echo information in a suitable format as selected by the operator on a variety of display types.

Main Features of a CW Doppler Radar System

52. Analysis of the Doppler Shift frequency (fd) allows CW radar to determine the relative or radial velocity (RV) of the target.

53. **Path of TX energy. TWO WAY** – if the transmitted beam of CW energy hits a target, then some of that CW energy will be reflected and processed in the RX.

54. **TX Power: Very LOW** –

   a. In airborne Doppler CW radar, the beams are aimed at the ground, giving a large target return at short range (1-6 miles).

   b. Compared with pulse radar over the same range, the energy of a CW beam would be about the same as the average or mean power of a pulse radar. Typically about 100mW for a Doppler Nav system.

55. **Clutter: None –** only detects relative motion to the ground.

56. **Type of Target Information:** The aircrafts radial or Relative Velocity (RV) along and across its heading, which is used to determine its ground speed and track.

57. **Information source:** The transmitted and received CW frequencies are then mixed to obtain the Doppler Shift frequency (fd), which gives the RV.

Frequency Modulated Continuous Wave (FMCW) Radar

58. In airborne Frequency Modulated Continuous Wave (FMCW) radar:

a. The RF energy is continuously transmitted and received if reflected by a target as with CW radar.

b. The transmitted RF energy is frequency modulated in a linear fashion over a fixed range; this effectively applies a timing mark so that the time interval between transmission and echo reception are known.

c. Information on target range is obtained by analysis of the instantaneous modulation frequency difference between the transmitted (FMft) and received signals (FMfr).

d. The modulation frequency difference (Fdiff) should NOT to be confused with Doppler Shift Frequency.

e. Airborne FMCW radar is mainly used in "Radar Altimeter Systems" which determines the height of the aircraft **a**bove **g**round **l**evel (**AGL**).

59. A typical Airborne FMCW Radar System is shown in Figure 10.

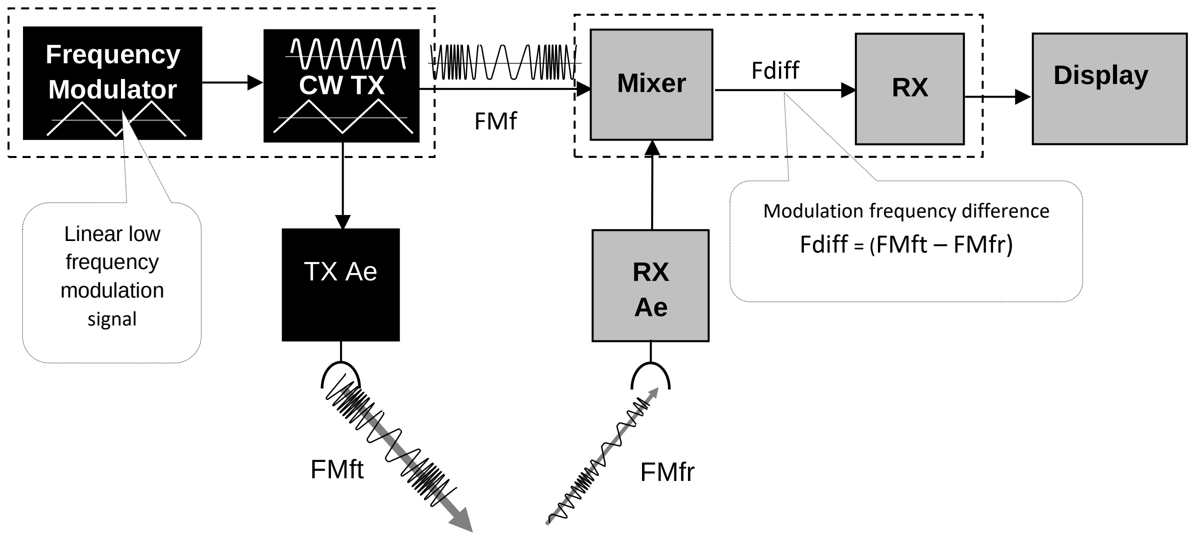


Figure 10 - Frequency Modulated Continuous Wave (FMCW) radar

FMCW Radar System Block Functions

60. **FM Modulator:**

a. Produces a low frequency modulation signal for the CW TX, which varies linearly over a fixed frequency range.

b. The amount of frequency modulation must be significantly greater than the expected Doppler shift or the results will be affected.

61. **CW Transmitter (TX):**

a. Produces an FM modulated CW signal (FMft) of constant amplitude.

b. A sample of the TX CW signal (FMft) is also sent to the mixer.

62. **TX Ae:** Transmitter aerial - focuses the FMCW energy (FMft) into the required beam shape.

63. **RX Ae -** Receiver aerial – detects the reflected FMCW echo signal (FMfr), which is sent to the mixer.

64. **Mixer -** Combines the current transmitted and received FMCW frequencies (FMft **-**FMfr) producing the Modulation frequency difference (Fdiff). (This is <u>NOT</u> the same as Doppler shift frequency)

65. **Receiver (RX) -** amplifies and processes the FM Modulation frequency difference (FMfd) into a suitable format for the display.

66. **Display/Indicator –** shows the processed target echo information in a suitable format as selected by the operator on a variety of display types.

Main Features of a FMCW Radar System

67. **Path of TX Energy. TWO WAY** – if the transmitted beam of FMCW energy hits the ground, then some of that FMCW energy will be reflected and processed in the RX.

68. **TX Power: VERY LOW** - the radar beam is aimed at the ground (Rad Alt), giving a large target at short ranges (0-7 miles). Typically 50mW

69. **Number of Aerials required: TWO**, **–** (as per CW radar).

70. **Clutter:** - **None.**

71. **Type of Target Information:** - **Slant Range** (aircraft height AGL)

72. **Information source: -** Analysis of the difference between the currently transmitted and received modulation frequencies (Fdiff).

FMCW Radar Slant Range Measurement

73. Slant Range in FMCW radar is obtained by analysis of the difference between the currently transmitted and received modulation frequencies (Fdiff).

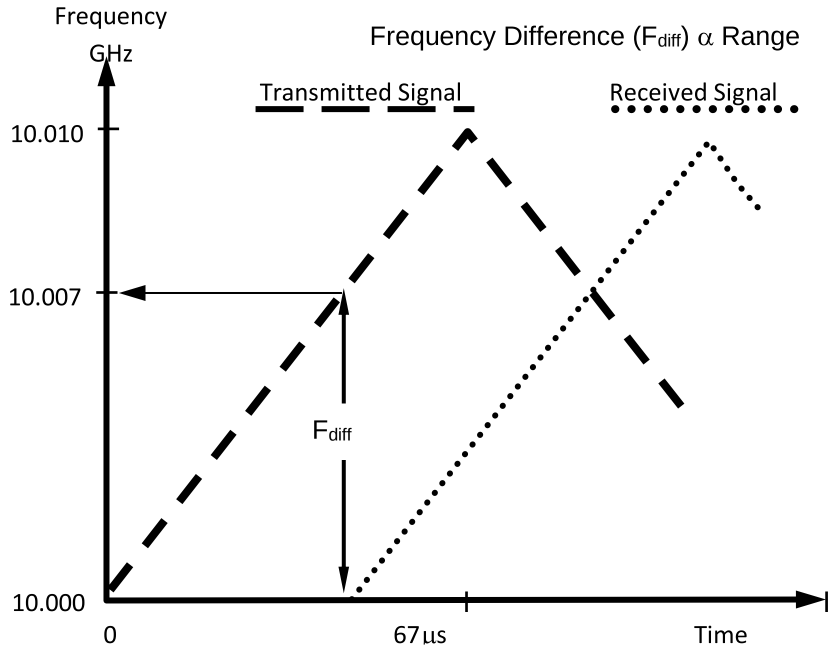


Figure 11 – FMCW Slant Range

Worked Example for Slant Range – FMCW Radar (refer figure 11)

74. **Given:**

Speed of Light (c)	=	300,000km/sec (300x10^3 km/sec)
The Radar Maximum Range	=	10km
Time Interval 10 Km range	=	67μsec (10x6.7μsec)
Frequency Modulation range	=	10GHz to 10. 01GHz
Frequency Modulation rate	=	10MHz in 67μsec = 1MHz in 6.7μsec or 1MHz per km

Question: If the FMCW frequency at the RX = 10GHz and the current FMCW frequency at the TX = 10.007GHz, what is the slant range to the target in km?

Answer: Frequency Difference (F_{diff}) = 10.007GHz – 10.000GHz

= 0.007 GHz (or 7MHz)

Frequency Modulation (FM) rate = 1MHz per km

∴ Slant Range = 7.0km

Comparison of Airborne Radar Features

76. Table 4 compares the three basic radar transmission types looked at so far and shows some of their main features and the information they can provide.

Radar Type / Feature	Pulsed	CW	FMCW
Tx Power	High	Low	Low
Clutter	Yes	No	No
Target El & Az	Yes	No	No
Slant Range	Yes	No	Yes
Relative Velocity	No	Yes	No

Table 4 - Comparison of Radar Features

Note: Some features of a pulsed radar can be combined with those of a CW radar the result being a Pulsed Doppler or Interrupted Continuous Wave (ICW) system that will be covered in a later module.

FACTORS AFFECTING RADAR PERFORMANCE

Introduction

77. In the "Introduction to Radar" it was found that in general airborne radars generate RF energy in the microwave region of the EM spectrum i.e. Upper UHF, SHF and Lower EHF bands Many factors affect the performance and operation of a radar installation.

78. These performance affecting factors can generally be divided into two groups:

a. External factors that affect all radar systems to a greater or lesser extent.

b. Internal or design factors chosen to suit the function of the radar set and optimise its performance.

External Performance Factors (x4)

79. Radar systems have very little control over external factors that limit the performance of radar, four of the main factors are:

a. Clutter.

b. Target Characteristics

c. External noise (including interference).***(covered in Air Comms)***

d. Atmospheric Attenuation. ***(covered in Air Comms)***

Clutter

a. Clutter affects pulse radar and is due to reflections or echoes from unwanted objects.

b. Clutter from clouds and ground returns for example produces fairly constant effects on the radar display unlike noise, which is random.

c. Clutter reduction techniques can be used to improve radar performance and will be covered during Radar Receivers.

Target Characteristics

80. All targets in the path of a radar beam will reflect some energy; however the amount reflected depends upon refer to table 5.

81. **MATERIAL.** Targets made of metal reflect more energy than non-metallic objects e.g. plastics.

82. **SHAPE**. Targets with flat plane-facing surfaces (at 90° to the beam) will reflect more energy back towards the source than will a curved or flat non-plane surfaces; this is due to the scattering of the radar beam energy away from the source.

83. **SIZE.** Large targets will reflect more energy than small targets that are identical in terms of material, shape, distance and position.

84. **DISTANCE.** The greater the distance a target is from the transmitter the smaller will be the energy content of the reflected echoes.

GOOD Reflections from	TARGET CHARACTERISTIC	POOR Reflections from
Metals	Material	Plastics
Flat Plane Surfaces (at 90° to the beam)	Shape	Non- Plane Surfaces (Curved or Angled)
Large	Size	Small
Near	Distance	Far

Table 5 - Target Characteristics.

INTERNAL OR DESIGN FACTORS (X6)

85. Six of the more important factors which can influence pulse radar performance and which can be controlled by design are:

a. Transmitter Peak Power.

b. Receiver sensitivity and Noise Factor.

c. Frequency of operation.

d. Shape of the radar beam and Scanning methods.

e. Pulse Repetition Frequency (PRF).

f. Pulse Width (PW) or Pulse Duration (PD).

Transmitter Peak Power

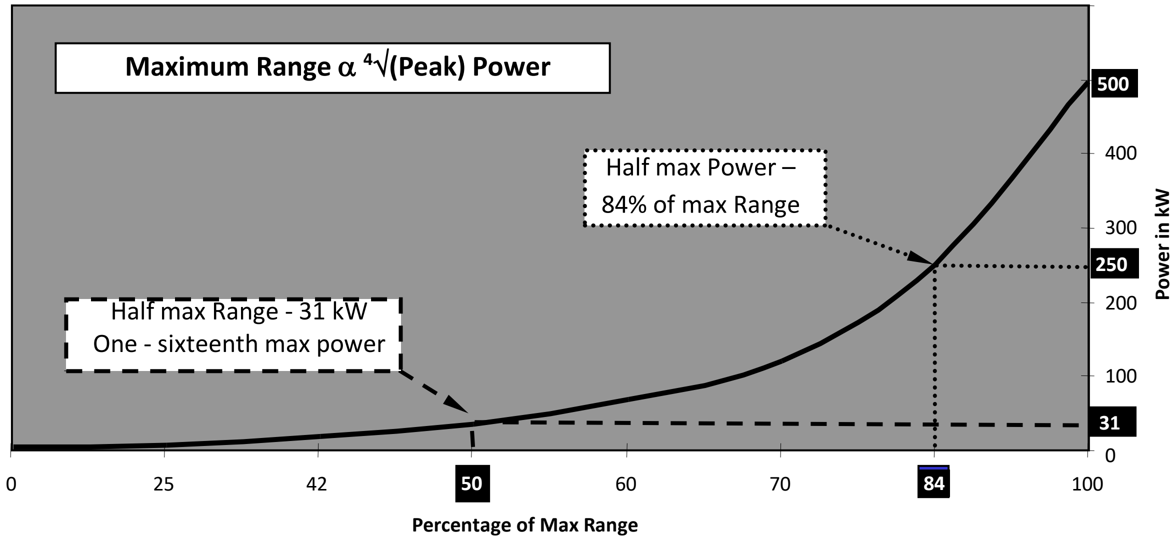


Figure 13 - Relationship between Peak Power and Radar Range

86. Transmitter Peak Power (Refer figure 13)

a. Transmitter power needs to be very high to ensure the returning echoes can be processed because received echoes can be very weak due to range and scattering on reflection from targets, even more so with narrow pulses.

b. The higher the peak power, the greater is the range of the radar.

c. Peak power is not directly proportional to range.

d. To double the range of a system, the peak power has to be increased by approximately 16 times its original value (i.e. from 31 kW to 500 kW).

e. If the peak power is reduced by 50% (i.e. from 500 kW to 250 kW) the maximum range is only reduced by 16% (i.e. from 100nm to 84nm).

Receiver Sensitivity & Noise factor

87. Because the received radar echoes are very weak, the receiver must have high gain to produce a useful output.

88. External noise received with the signal is also amplified in addition to any internally generated receiver noise.

89. Receiver noise is minimised by restricted bandwidth, however video pulses require a very wide bandwidth to preserve the pulse shape. These two requirements conflict and compromise is necessary.

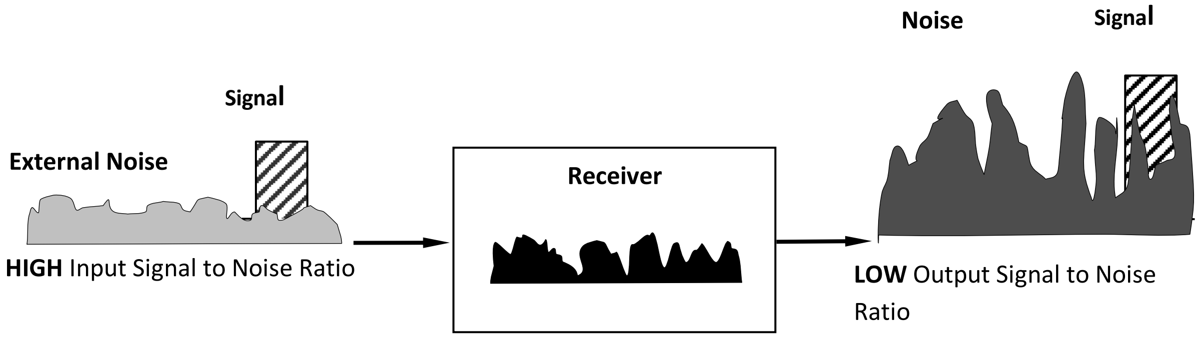


Figure 14 - Receiver Noise Factor

90. (Refer to Figure 14) Noise Factor (N/F) is an indication of the internal noise generated by the receiver itself and is expressed as:

$$N/F = \frac{S/N\ at\ the\ input}{S/N\ at\ the\ output}$$

91. For the “ideal” receiver no internal noise is generated, therefore the Noise Factor is unity (one).

92. For a practical receiver, the Noise Factor is always greater than one and kept as low as is practicable.

93. If the first stage of the RX is an RF Amp that has a low N/F, it gives the overall RX a low N/F.

Transmitter Frequency

94. There are four main factors governing the choice of transmitter frequency:

a. **Size of Target.** To obtain good echoes from small targets, the frequency must be high because the wavelength λ must be less than a quarter of the size of the target.

b. **Beam Width.** For good angular discrimination between targets (in El or Az) that are close together, a very narrow beam width is required. This is more easily achieved in the frequency bands of SHF and above.

c. **Detection Range.**

i. Long-range radar reduces the effects of atmospheric attenuation by transmitting at lower frequencies, which improves the chances of detection.

ii. Short-range radar can transmit higher frequencies as the pulses have less distance to travel through the atmosphere.

d. **Size of Aerial and Waveguides.** As frequency increases the size of aerial scanners and waveguide components get smaller. This could be important where the maximum size of a radar aerial scanner is limited by the space where it has to fit i.e. the forward nose section of an aircraft.

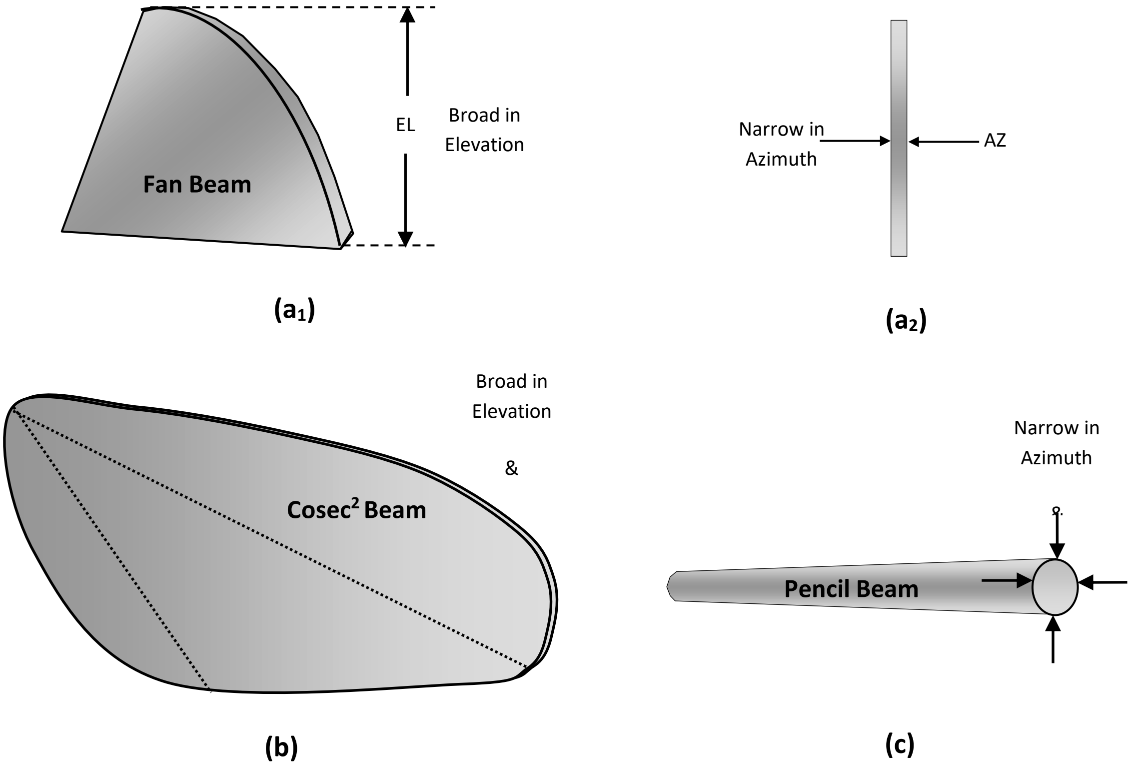
Beam Shape and Scanning Methods

95. (Refer Table 5 & figure 15). Radars with different functions will probably require different beam shapes and different scan patterns as well.

Radar Function	Beam Shape	Beam Features	Tgt Information	Type of Scan
Airborne Interception (AI) Weather & Collision Warning	Pencil beam	Narrow in Az & Narrow in El	Accurate tgt position in Azimuth & Elevation Beam only covers a small volume of space	Race Track. Conical scan. 180°/120° sector scan.
Search & Surveillance	Fan beam	Narrow in Az & Broad in El	Accurate tgt position in Azimuth only. Beam covers a large volume of space	360° continuous rotation or 180°/120° sector scan
Ground Mapping	Cosec^2	Narrow in Az & Broad in El	Uniform display	180°/120° sector scan

Table 6 – Beam Shapes

Typical Beam Shapes



Typical Scan Patterns

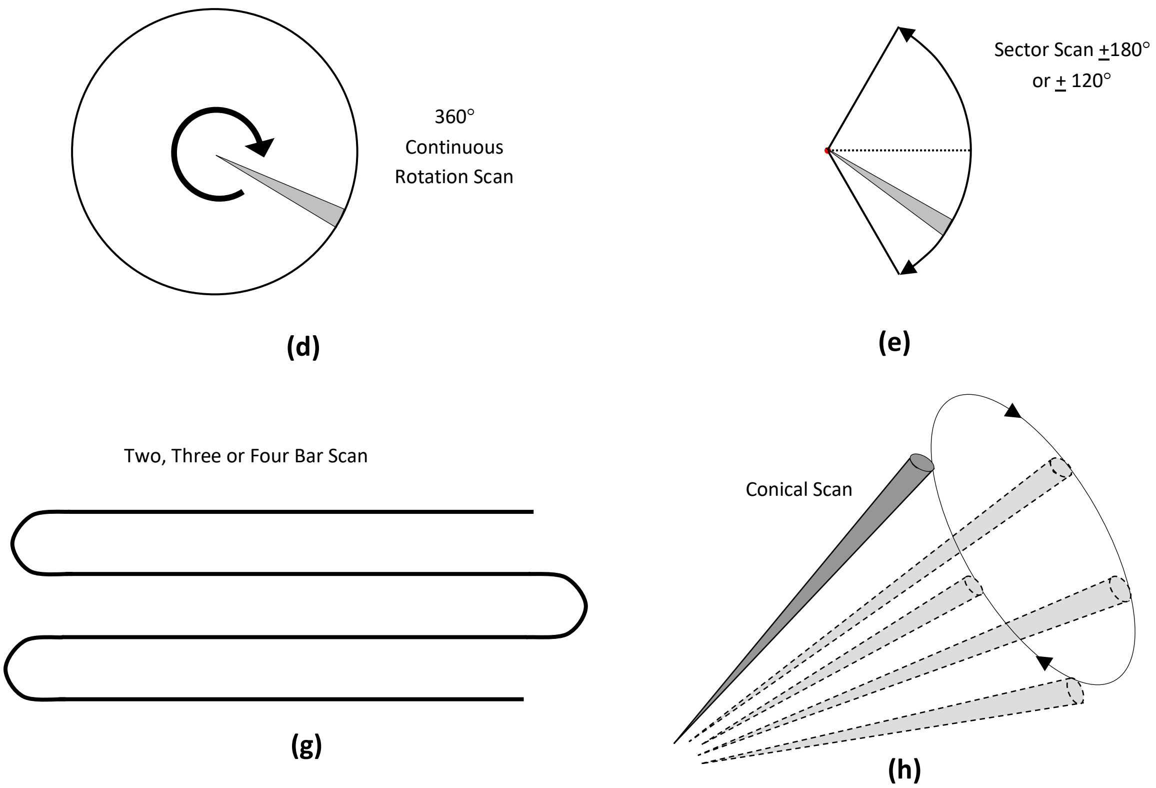


Figure 15 – Beam Shapes and Scanning Methods

Pulse Repetition Frequency (PRF)

96. There are four main factors governing the choice of PRF:

a. Maximum required range.

b. Aerial scanning speed.

c. Improved display definition.

d. Transmitter Mean Power.

Maximum required range.

97. For a selected range, each pulse must be given time to travel to the most distant required target and return before the next pulse is transmitted.

98. Pulse spacing (PS) or the time interval between the leading edges of the pulses therefore represents:

a. The maximum required range time.

b. The periodic time of the PRF (PS = 1 ÷ PRF).

c. Consequently PRF = (1 ÷ PS) pulses per second (pps).

d. If shorter ranges are selected the PS is reduced and the PRF is higher, conversely, if longer ranges are selected the PS is increased and the PRF is lower.

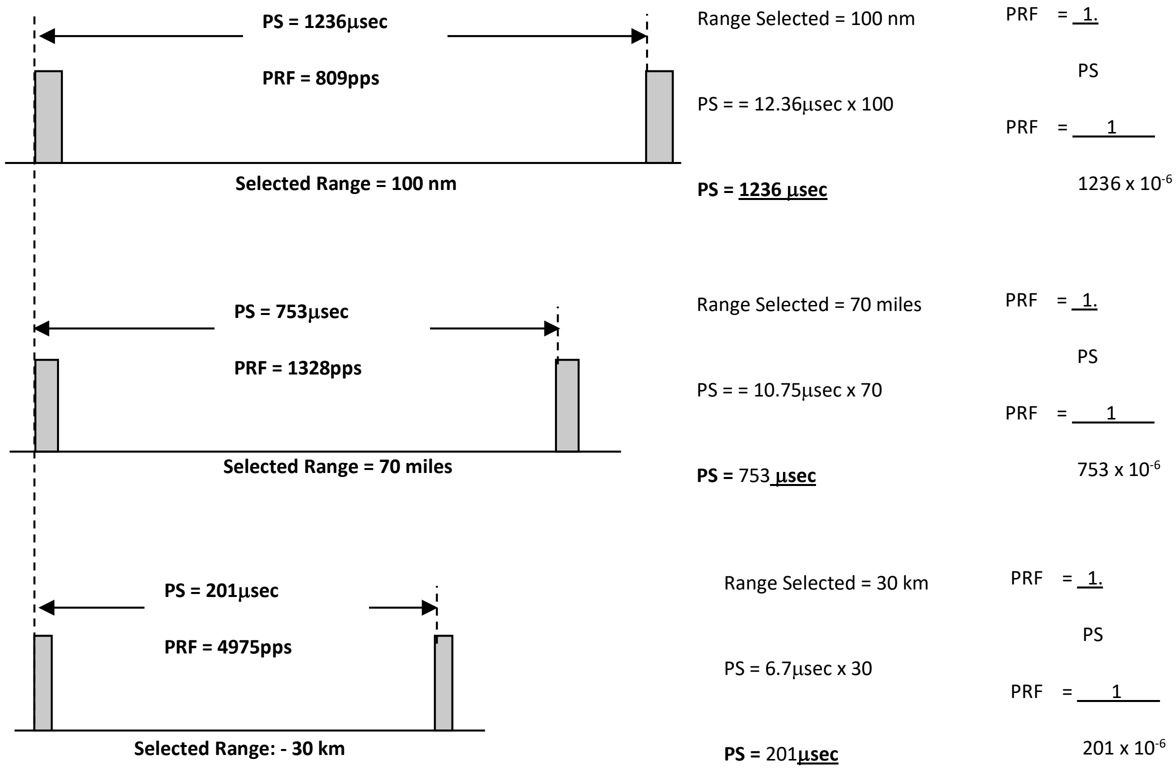


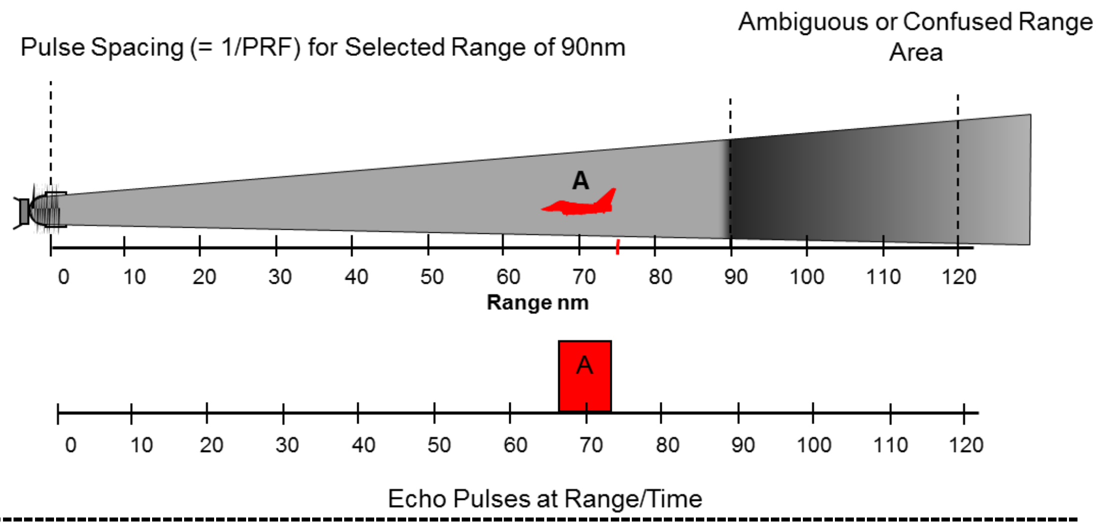
Figure16 – Examples of PS and PRF Values for Different Range Selections

99. Modern radar systems will use several display ranges each having a different PRF and can automatically select the appropriate range/PRF combination based on radar mode and incoming target information.

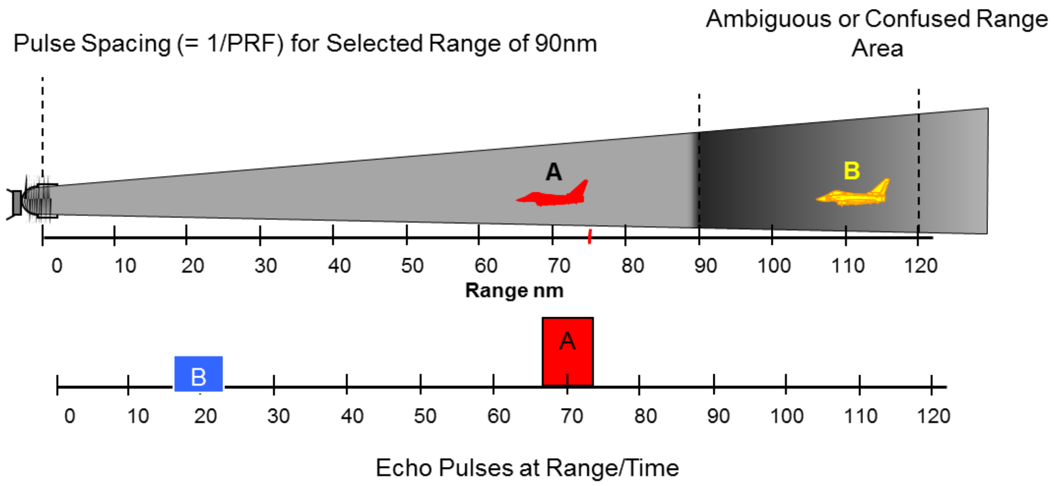
100. There is always a risk of echoes returning from beyond the selected range and appearing in the display time of pulses transmitted later. These 2nd time-around echoes can cause ambiguous or confused target range displays.

101. Figure 17 shows how echoes from beyond the selected range appear as short range targets, giving ambiguous or confused range indications on the display.

102. Jittering (varying) the PRF can help individual radars to identify ambiguous or 2nd time around echoes, which can then be eliminated.



Aircraft A is correctly measured by the current P1 pulse at a range of 70nm from the radar.



Aircraft B echo would not show on the first sweep as it came into range at 120nm but is now seen as a 2nd time around echo from the previous P1 pulse on subsequent sweeps i.e. at range of 20nm (actual range 110nm).

Figure 17 Pulse Radar 2nd time around echoes

Pulse Spacing Worked Example.

103. **Question:** Calculate the Pulse Spacing (PS) and PRF of a radar:

Given:

a. Selected Range = 90km.

b. Time Interval for 1km range = 6.7μs

Answer: (1) Pulse Spacing (PS)

PS = Selected Range x Time Interval for 1km range.

= 90 x 6.7μs

= $90 \times 6.7 \times 10^{-6}$

Pulse Spacing (PS) = 603μsec

Answer: (2) Pulse Repetition Frequency (PRF)

PRF = 1 ÷ Pulse Spacing (PS)

= 1 ÷ 603μsec

= $1 \div 603 \times 10^{-6}$

PRF ≈ 1660 pps

Aerial Scanning Speed - PRF b (Refer figure18)

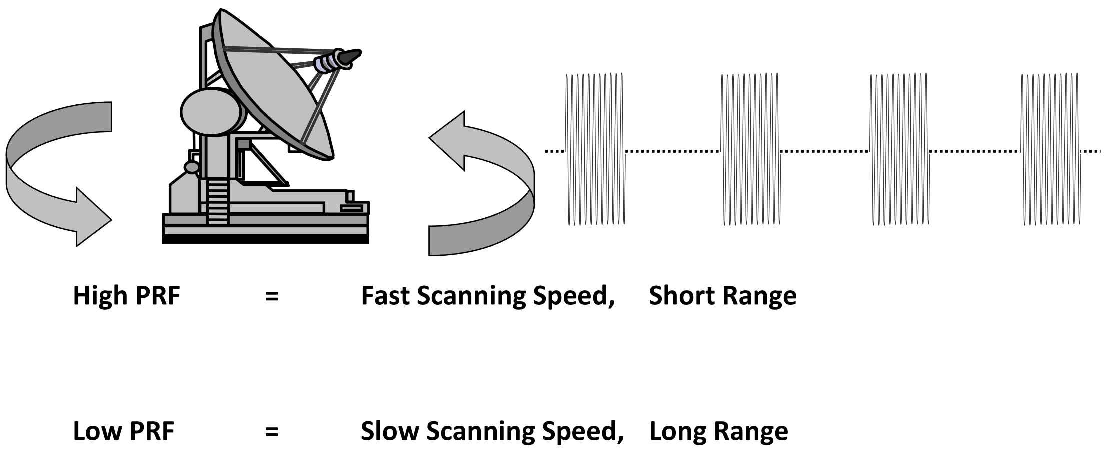


Figure 18 - Scanning Speed

104. If the aerial scanning speed was fast and the pulse repetition frequency low, targets may be missed. This is because, in the relatively long time interval between pulses, the aerial may have turned away from the returning echoes

105. Therefore the higher the PRF, the faster must be the scanning speed.

Display Definition - PRF c (Refer figure 19)

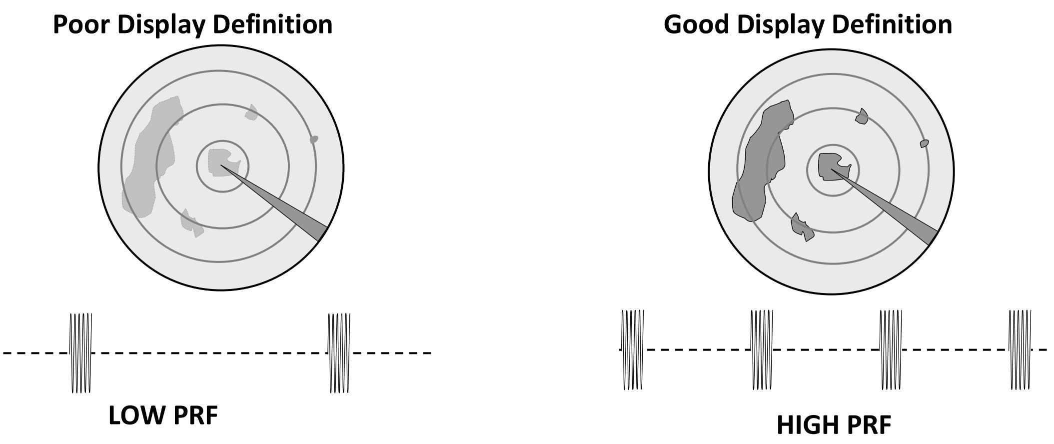


Figure 19 - Display Definition

106. The more pulses that are transmitted per second, the brighter and clearer is the resulting display, (Refer figure 19).

107. That the choice of pulse repetition frequency for specific radar systems must be a compromise between conflicting requirements.

108. Modern radar systems use more than one value of PRF for different ranges and the ability to vary the PRF adds to the overall efficiency of the radar system to detect a target.

Transmitter Mean Power - PRF d (Refer figure 20)

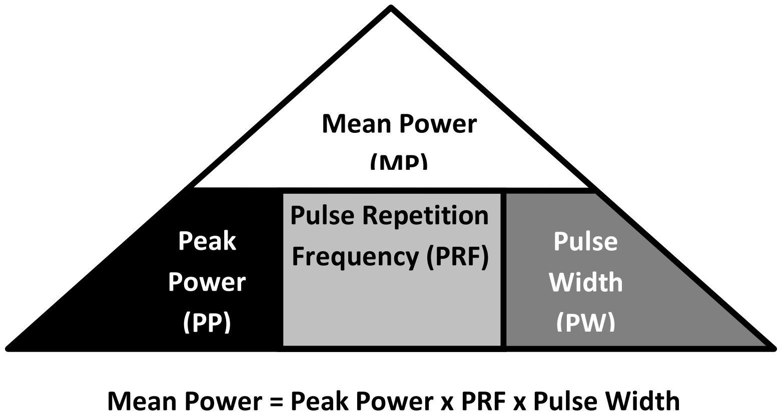


Figure 20 – Mean Power Triangle

109. The mean power (MP) of radar is the transmitter peak power spread across the pulse spacing (PS), i.e. one pulse cycle from leading edge to leading edge. Therefore mean power is very much lower than the pulse peak power.

110. The mean power is a key factor in determining radar range. This is because it is energy not power that does work and the energy in a train of pulses equals the Mean Power (MP) x length of the pulse train.

111. If a radar to give its best operating performance for a given mean power (MP) and pulse width (PW), then the PRF may have to be adjusted to produce an acceptable peak power output.

Worked Example

112. **Question:** Calculate the radar Mean power (MP) (Refer figure 9)

Given:

a. Peak Power (PP) = 100 kW

b. Pulse Width (PW) = 5 μs

c. PRF = 2,000 pps (pulses per second).

Answer: Mean Power MP = PP x PRF x PW

$\therefore$ MP $= 100 \times 10^3 \times 5 \times 10^{-6} \times 2 \times 10^3$

$= 100 \times 5 \times 2$

$= 1000$

MP = 1kW

113. (Refer Figure 20). It was found that one way to improve radar range was to increase the transmitter peak power (PP), which will also increase the mean power (MP) however:

a. There are physical limits to the amount of peak power (PP) a waveguide will accept before arcing occurs.

b. From the mean power triangle it can be seen that mean power (MP) can also be increased by increasing either the pulse width (PW) or the PRF or both.

c. Therefore if the radar needed a larger peak power (PP) the same mean power (MP) and pulse width (PW) values, then the PRF must be reduced.

d. Changes to the PRF will would cause changes to the radar maximum range.

Worked Example

114. **Question:** Calculate the PRF of the radar if the peak power is increased but the mean power and pulse width remain the same as in example 2

Given:

a. Peak Power (PP) = 1 MW

b. Mean Power (MP) = 1 kW

c. Pulse Width (PW) = 5 μs

Answer:

$$PRF = \frac{MP}{PP \times PW}$$

$$\therefore PRF = \frac{1 \times 10^3}{1 \times 10^6 \times 5 \times 10^{-6}}$$

$$= \frac{1 \times 10^3}{5}$$

$$= \frac{1000}{5}$$

PRF = 200pps

Pulse Width (Pw)

115. There are four main factors governing the choice of PW:

a. Minimum Detection Range.

b. Target Discrimination.

c. Transmitter Mean Power.

d. Receiver Bandwidth.

Minimum Detection Range - PW a (Refer figure 21)

116. The pulse width (PW) for single aerial systems determines the minimum detection range of the system.

117. The period for which the transmitter is on and propagating E.M. energy is the duration or width of the pulse as determined by the modulator

118. Whilst the radar is transmitting, echo pulses cannot be received.

119. For any given pulse of known width, the pulse length can be determined by multiplying PW by the speed of propagation of E.M. energy (speed of light).

120. If during transmission the leading edge of the pulse hits a target, reflection will occur and an echo will be sent back to the aerial.

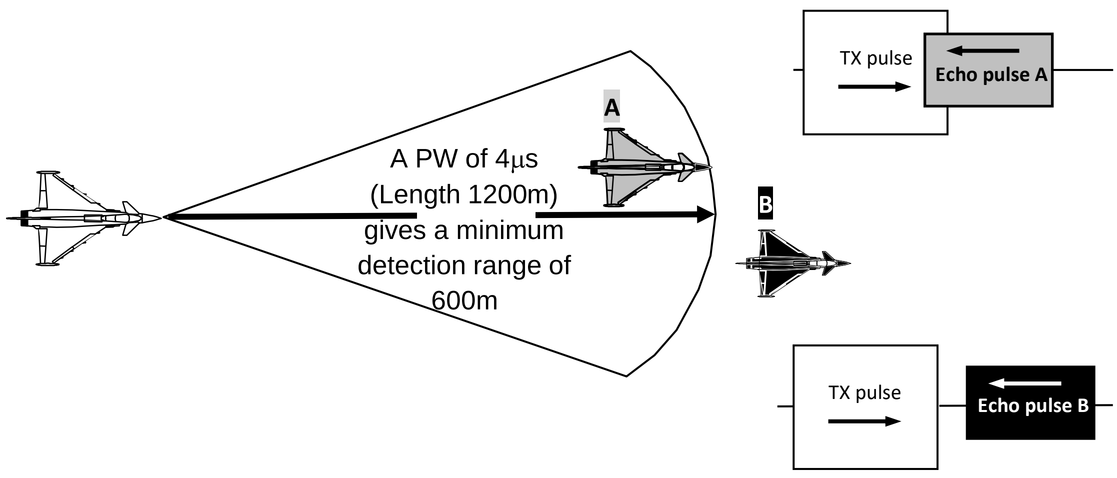
121. If the pulse is still being transmitted the echo will not be received or the target detected.

122. The minimum detection range for pulsed radar is therefore equal to half the length of the pulse.

123. For example. Pulse Length (m) = c x PW, therefore a PW of 4μs has a length of $300 \times 10^{6} \times 4 \times 10^{-6}$ = 1200m and a minimum range of 600m.

Reflected echo pulse **A** has returned whilst the pulse is still being transmitted

Therefore the range of aircraft "A" <u>cannot</u> be measured



Reflected echo pulse **B** has returned after the pulse has finished being transmitted

Figure 21 – Minimum Detection Range

Worked Example

124. **Question:** Calculate the minimum detection range

Given:

a. Pulse Width (PW) = 5 μs

b. Speed of EM transmission (c) = 300 x 10^6 m/sec

Answer: Pulse Length = PW x (c)

$= (5 \times 10^{-6}) \times (300 \times 10^6)$

$= 5 \times 300$

= 1500m

Minimum detection range = Pulse Length ÷ 2

$= \frac{1500}{2}$

= **750m**

125. Refer Worked Example

a. Targets any closer than 750m to the radar aerial will not be detected.

b. If shorter detection ranges are required, then pulses of shorter width or duration are required.

c. The effect of using long duration pulses on short-range targets is seen in figure 10.

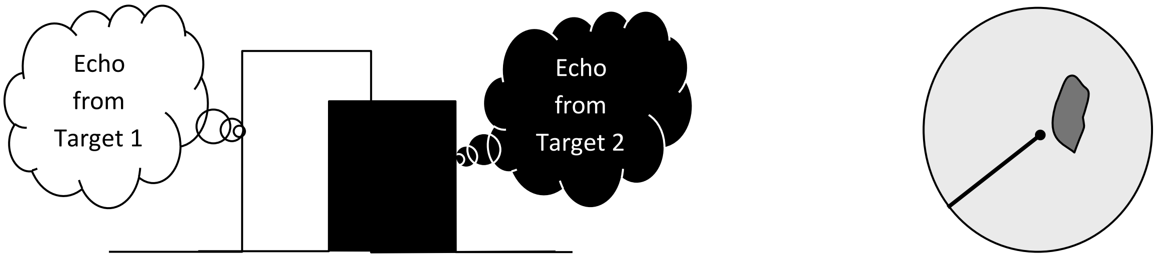
Target Discrimination - PW b (Refer figure 22)

126. The ability of a radar system to detect targets that are close together as separate echoes is known as **TARGET DISCRIMINATION** and the value is found in the same way as minimum range.

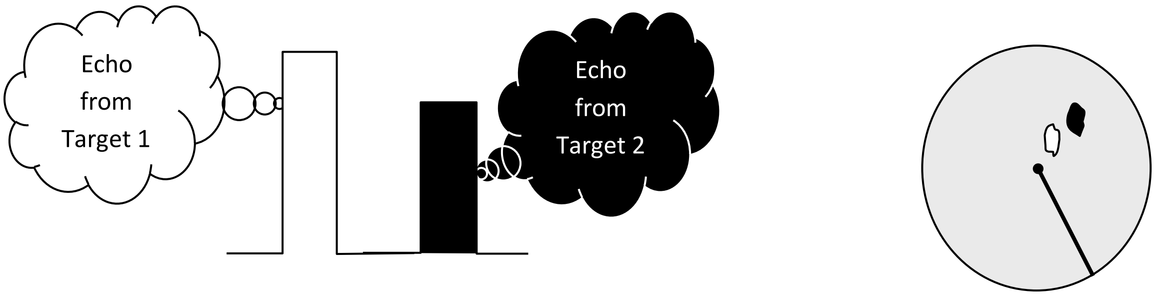
127. Target Discrimination distance is obtained from the pulse width converted into pulse length. (PW x c)

128. To be seen as separate targets, the minimum distance between targets must be greater than half the pulse length.

129. For radar to have good target discrimination requires the use of narrow width (short duration) pulses.



Wide pulses poor target discrimination– returns appear as a single echo



Narrow pulses good target discrimination– returns appear as two separate echoes

Figure 22 – Target Discrimination

Worked Example

130. **Question:** Calculate Target Discrimination Distance.

Given:

a. Pulse Width (PW) = 1 μs

b. Speed of EM transmission (c)= 300 x 10^6 m/sec

Answer: Pulse Length = PW x (c)

= $(1 \times 10^{-6}) \times (300 \times 10^6)$

= 1 x 300

= 300m

Target Discrimination Distance = Pulse Length ÷ 2

$$= \frac{300}{2}$$

= **150m**

131. Targets any closer together than half the pulse length e.g. 150m will be as a single target echo return.

Mean Power (MP) - PW c (Refer figure 9 and design factor **PRF d –** covered earlier), also:

132. For long-range radar the transmission of pulses with high-energy (high mean power) could be obtained from either:

a. Very narrow pulses at high peak power and high PRF.

Or

b. Very wide pulses at low peak power and low PRF.

133. However very wide pulses do not give good target discrimination.

a. Ideally what is required is a technique that produces very wide (long duration) high energy (high mean power) pulses on transmission. But then processes these pulses on reception as if they were narrow (short duration) pulses giving good target discrimination.

b. A technique commonly used in radar to achieve this ideal combination is called **Pulse Compression** and will be covered later in the phase.

Receiver Bandwidth (B/W) - PW d

134. The bandwidth (B/W) of pulsed radar receivers (MHz) is very much greater than those used in analogue communication systems (kHz).

135. The bandwidth (B/W) required by a radar receiver is determined by the choice of pulse width (duration) and pulse shape.

136. Generally as the pulse width (PW) becomes narrower the receiver bandwidth (B/W) becomes wider.

137. A wide bandwidth (B/W) receiver is needed to preserve the steep leading edges and square shape of the received pulses that are required for accurate range measurement.

138. Typically, if the narrowest pulse width (PW) of a radar system is 1μs the receiver would need a bandwidth (B/W) of 5MHz to avoid distortion and for a pulse width (PW) of 0.5μs a bandwidth (B/W) of 10MHz would be needed.

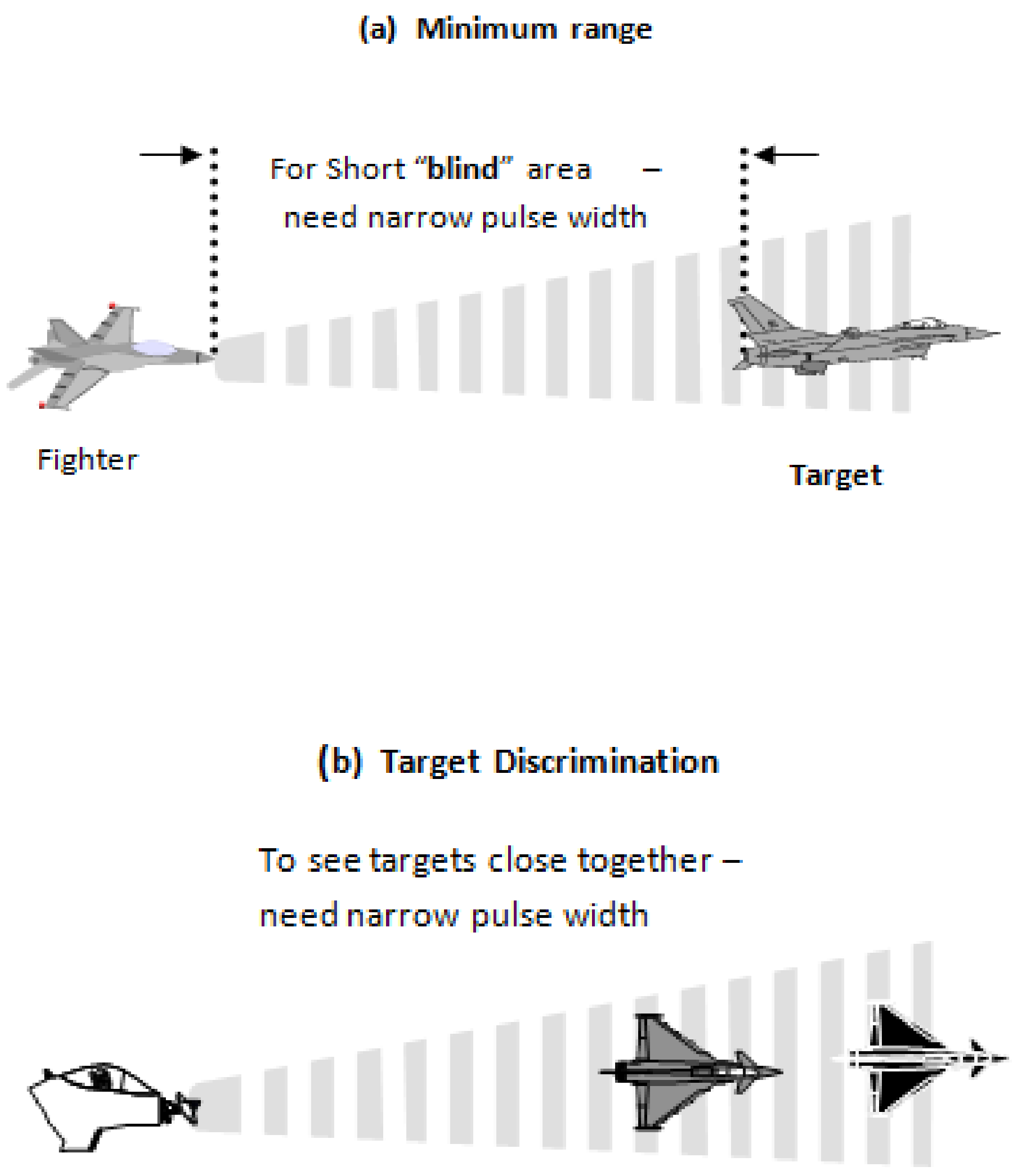


Figure 23 – Summary of Factors Determining Pulse Width

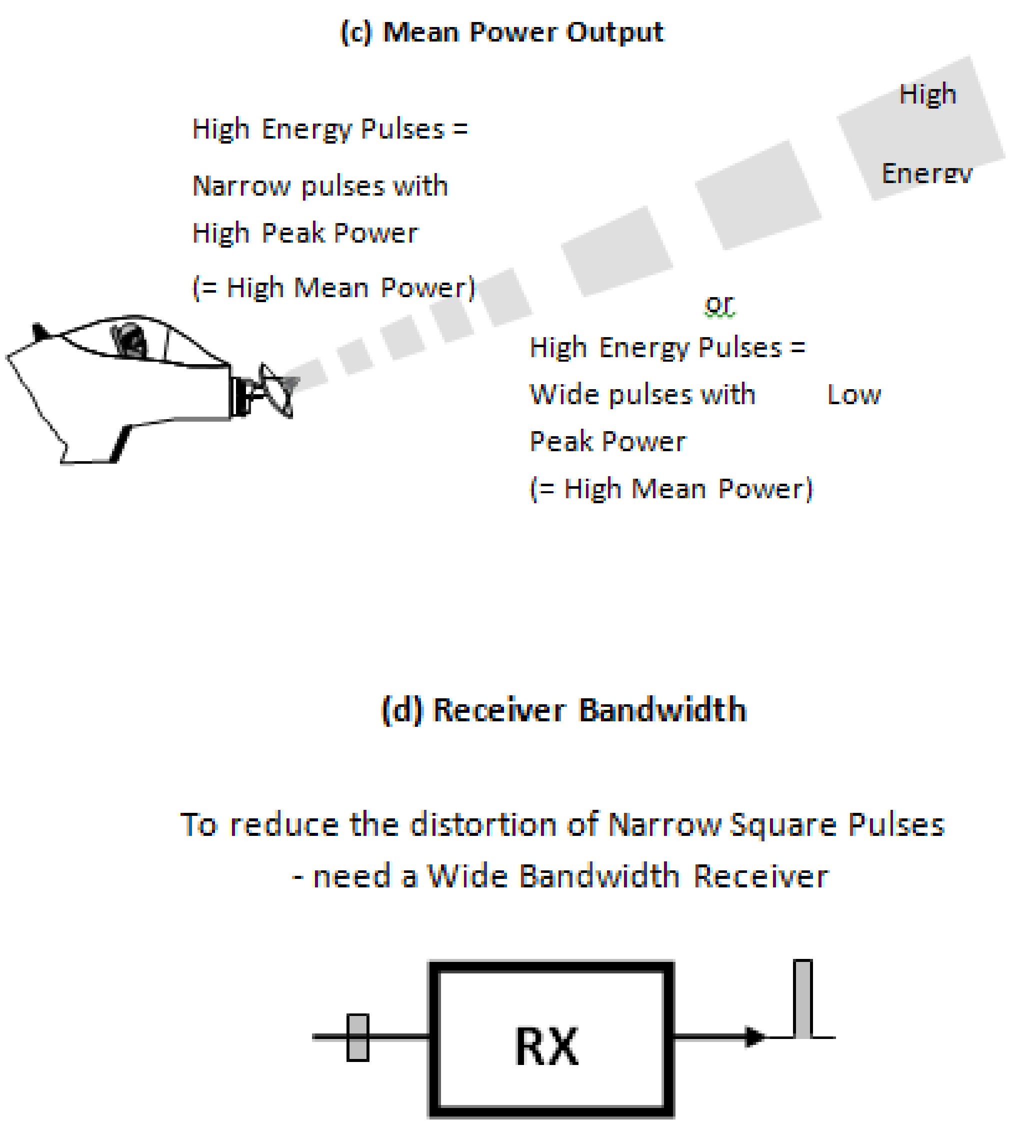
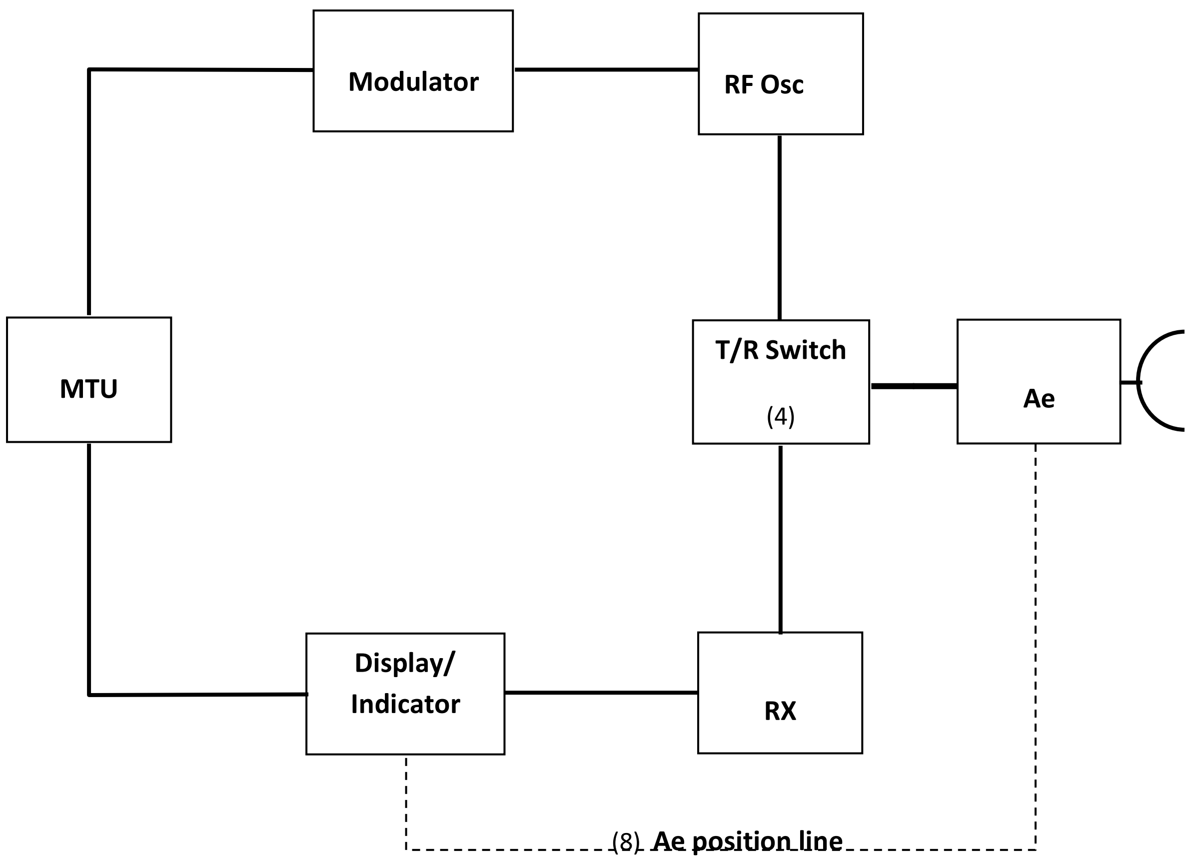


Figure 23 – Summary of Factors Determining Pulse Width

SIMULATOR PRACTICAL EXERCISE FOR BASIC PULSED RADAR

INTRO:-

a. Draw the **input/output** waveforms for each of the blocks in the diagram below.



Basic Pulsed Radar Diagram

b. Explain the purpose of each block or line on the Basic Pulsed Radar diagram.

1	**MTU**	
2	**Modulator**	
3	**RF Osc**	
4	**T/R switch**	
5	**Aerial (Ae)**	
6	**Receiver (RX)**	
7	**Display**	
8	**Ae pos'n Line**	

c. List the four main factors governing the choice of each of the following:

i. Pulse Repetition Frequency **(PRF)**.
ii. Pulse Width **(PW)**.
iii. Transmitter Frequency **(TX RF)**.

i. PRF 1	
2	
3	
4	
ii. PW 1	
2	
3	
4	
iii. Freq 1	
2	
3	
4	

Task 1:

Radar Simulator set-up

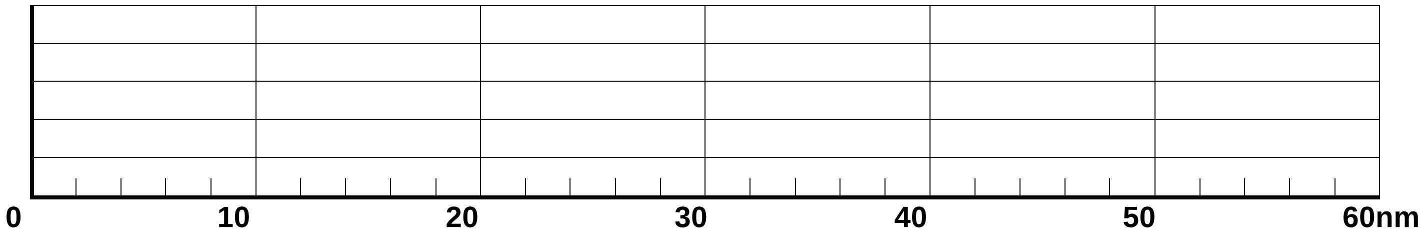
a. Switch **Unit power ON** (on rear of unit)

b. Set **PRF** to **3** (Low)

c. Set **Pulse Width** to **1** (Short)

d. Set **Display Range** to **3** (Long)

e. Draw the targets as seen on the Radar Display; label the Range of each target.

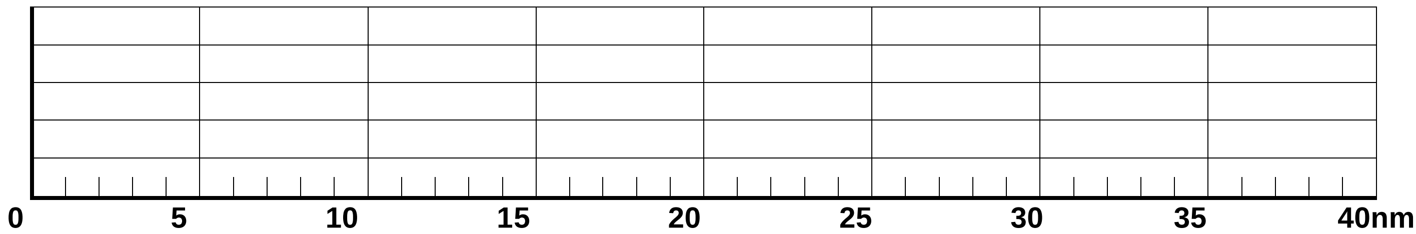


Task 2:

Radar Simulator

a. Set **PRF** to **2** (Medium)

b. Draw the targets as seen on the Radar Display; label the Range of each target.



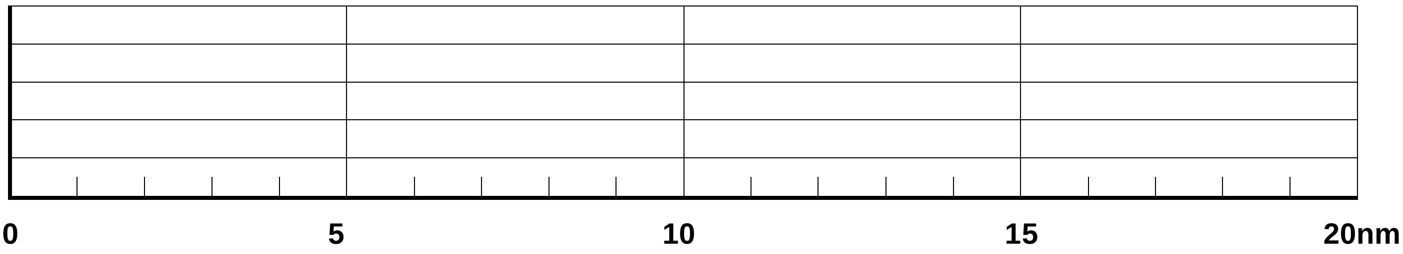
c. Explain any changes to the displayed targets & ranges compared to those in **Task 1.**

Task 3:

Radar Simulator

a. Set **PRF** to **1**. (High)

b. Draw the targets as seen on the Radar Display; label the Range of each target.



c. Explain any changes to the displayed targets & ranges compared to those in **Task 2.**

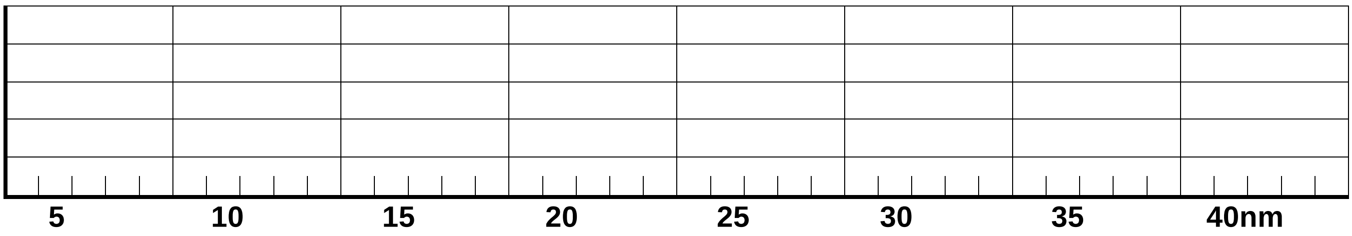
Task 4:

Radar Simulator

a. Set **PRF** to **2** (Medium)

b. Set **Pulse Width** to **2** (Long)

c. Draw the targets as seen on the Radar Display; label the Range of each target.



d. Explain any changes to the displayed targets & ranges compared to those in **Task 3**

Task 5:

Oscilloscope set-up

a. Switch **Power ON** and allow to warm-up.

b. **Channel 1** set to **ON**

c. Connect oscilloscope **Channel 1** to **MTU Output** - **TP1**.

d. **Channel 1** set to **2V per cm**

e. **Channel 2** set to **ON**

f. Connect oscilloscope **Channel 2** to **Modulator Output** - **TP2**.

g. **Channel 2** set to **2V per cm**

h. **Main Time Base** (MTB) set to **0.1 ms**

i. **Channel 4** set to **TRIGGER** and connect to **Scope Trigger Point** on Radar Simulator.

Radar Simulator

a. Set **PRF** to **3** (Low)

b. Set **Pulse Width** to **2**. (Long)

c. Draw the relationship between the various radar module waveforms in **Table 1** below.

d. Change **Ch 1 to TP3** repeat c), then **Ch 2 to TP4** repeat c) finally **Ch 1 to TP5** repeat c).

Test Point TP	Pulsed Radar Module	Pulsed Primary Radar Waveforms
TP1	M.T.U o/p	
TP2	PULSE MODULATOR o/p	
TP3	RF OSC o/p	
TP4	RX i/p	
		2 10 12 26
TP5	RX o/p	

Table 1

Notes