CHAPTER 3

RADAR

RDF becomes Radar

1. As World War II approached, scientists and the military were keen to find a method of detecting aircraft outside the normal range of eyes and ears. They found one, and at first called it Radio Detection Finding (RDF), then RAdio Detection And Ranging (RADAR). Radar works by firing powerful radio waves towards the target, and collecting the reflected energy. The radar operators can then find the position of the target in terms of its range (i.e. distance) and bearing from the radar installation. Radar equipments can also find another vital fact about a target aircraft – its height. The radar equipment displays the information for the operator on a screen similar to that found in a television.

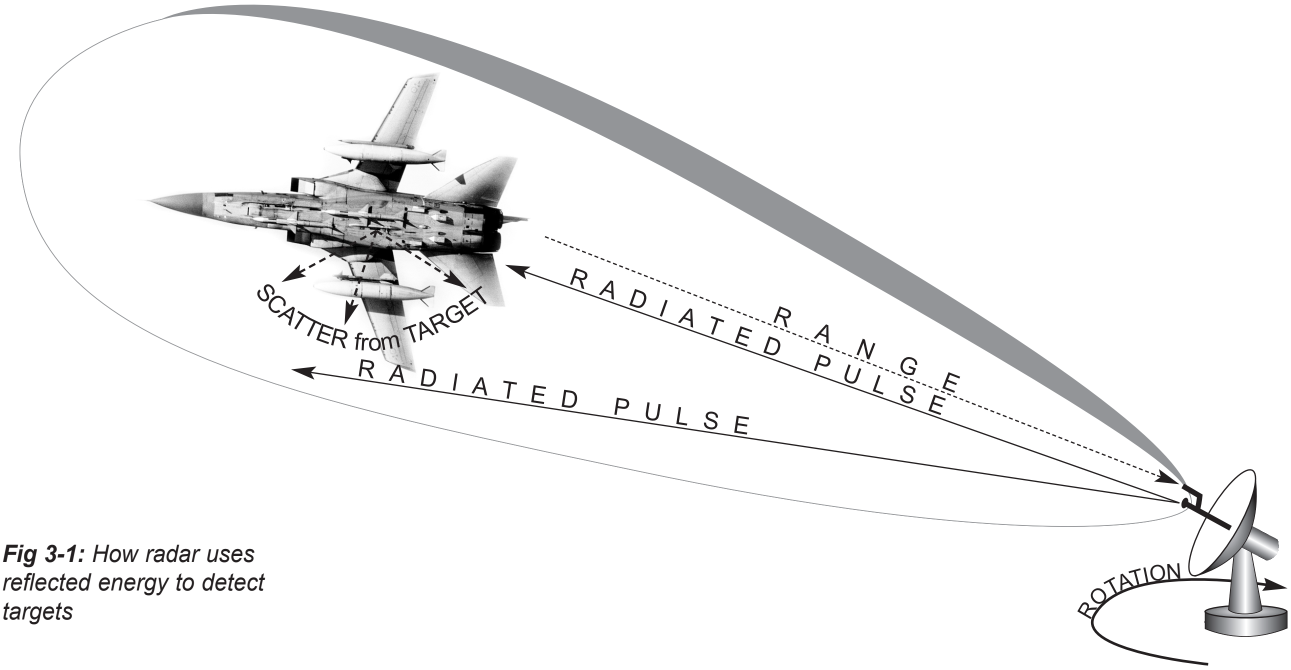


Fig 3-1: *How radar uses reflected energy to detect targets*

Primary and Secondary radar

2. There are basically two different types of radar, namely primary and secondary, and we will look at each in turn. Primary radar relies solely on energy that it has generated and radiated being reflected from the target - i.e. an echo, whereas Secondary radar has some co-operation from the target – the target generates its own 'em' radiation.

Primary Radar

Primary radar uses reflected energy

3. Primary radar systems may be found in ground, air, ship or space platforms and are used in roles such as:

Surveillance (including weather)
Early warning
Navigation
Ground mapping (from space or aircraft)
Guidance control
Target detection and tracking
Terrain following/avoidance
Collision avoidance and altitude measurement
Air Traffic Control

How it Works

Pulsed and CW

4. Radars operate their high-powered radio waves in 2 different modes: pulse-modulated (pulsed) and continuous wave (CW).

Frequency

5. Most radars operate in the Ultra High Frequency (UHF) or Super High Frequency (SHF) bands. The Frequency of operation will depend on the function the radar is to perform, for example, a long range search radar will operate on a relatively low frequency, while a weapons system fire control radar will operate at a very high frequency.

Pulse-Modulated

Radar mile

6. A pulsed radar uses an echo principle. In other words, the transmitter fires a very brief pulse of energy and then "listens" for an echo to return. The speed of radio waves in free space, as we know is 3×10^8 ms^{-1} (186,000 miles per second).
So if we measure the elapsed time between the transmission of the pulse and its reception back at the radar, we can use the formula:

Distance = Speed x Time

To calculate the distance to the target, the time taken for a pulse to travel one mile and return to the radar is known as a "Radar Mile". The following table shows the times for some basic units of distance:

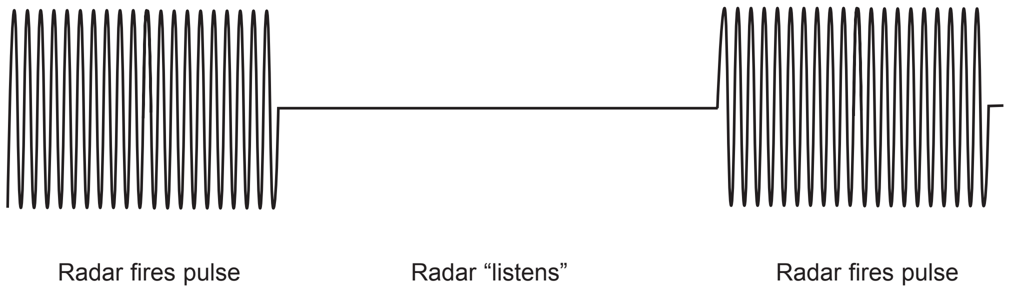
Radar Timetable

Range of Target	Range in metres or feet	Time for Return of Echo	Approximate Time for rough calculations
1 Kilometre	1000 m	6.67 ms	6 ms (6 x 10^{-6})
1 Statute Mile	5280 ft	10.75 ms	10 ms (10 x 10^{-6})
1 Nautical Mile	6080 ft	12.36 ms	12 ms (12 x 10^{-6})

Pulse repetition frequency

7. The pulses from a radar are transmitted at a rate which determines the range of the radar, called the pulse repetition frequency or PRF.

Fig 3-2: *Peak power wave form in a PRF signal*



8. In practice the PRF might range from 250pps for long-range radars to 2000pps for short-range radars. For long-range radar, to get a satisfactory return from a pulse, a massive one million watts (megawatt) of radio frequency (RF) power is required. This high power is used only during the brief transmission of the pulse. The transmitter is then allowed to rest until the next pulse (as shown in Fig 3-2), and the receiver meanwhile is listening for an echo.

Continuous Wave Radar (CW)

9. There are two basic types of CW radar. These are called CW Doppler and frequency-modulated CW (FMCW).

CW Doppler

Radar using Doppler effect

10. Consider the situation where a radar equipment sends out a pulse of radio waves and then "listens" for an echo. If the target is moving towards the transmitter

the reflected waves become bunched up (i.e. they acquire a higher frequency), due to the target's velocity. If the target is moving away, the waves are spread out and their frequency drops slightly. A similar effect can be experienced with sound waves. When a racing car approaches, you hear the pitch of the sound getting higher (sound waves bunching up) until it passes. Then the pitch suddenly drops lower (sound waves spreading out). This is called the Doppler effect. The radar equipment is able to detect these small changes in frequency (or shifts) and so determine the target's velocity with respect to the transmitter. A similar system is used by traffic police with their "speed gun".

11. Of course, a target rarely approaches the radar installation head-on and in the diagram below, the target's track (AC) is at an angle to its bearing from the radar (AB). The velocity in direction AB is less than the true target speed in direction AC. However, by comparing changes in Doppler shift at the radar receiver over a short period, the target's velocity can be calculated.

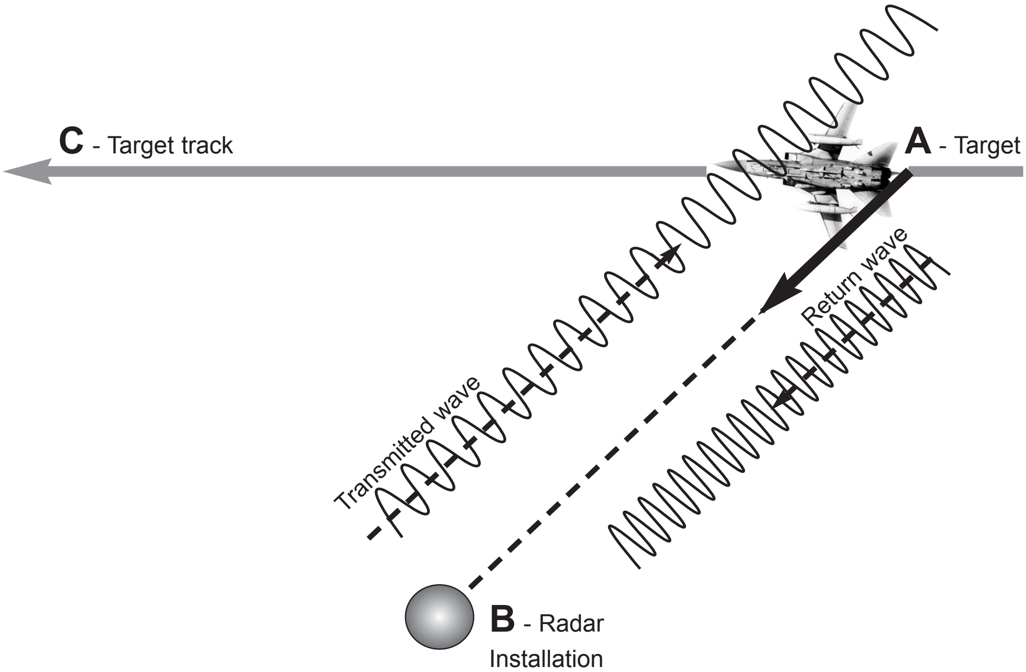


***Fig 3-3:** How Doppler frequency shift is used*

FMCW

12. In the case of FMCW, the transmitters signal is made to vary in frequency in a controlled cyclic manner with respect to time, over a fixed band. By measuring the frequency of the returning echo it is possible to calculate the time interval elapsed since that frequency was transmitted, and thus the target's range.

Secondary Radar

IFF and SSR

13. It is vital to know the identity of an aircraft displayed on an air traffic controller's screen, particularly in a military situation. A method of identifying aircraft was first used in the second World War and called Identification Friend or Foe (IFF). It is still in use today. It works by fitting all friendly aircraft with a transmitter/receiver (called a transponder) which can send a reply signal to an interrogating transmitter/receiver (an interrogator). On the ground the system is co-located with the primary radar, but does not require as much power because the radio waves have only to travel one way – the aircraft replies with its own onboard transmitter. The IFF equipment is specifically for military use, but a civilian version does exist, called Secondary Surveillance Radar (SSR). Both systems are compatible with the ground-based interrogators which use a transmission frequency of 1030 MHz, while aircraft transponders use 1090 MHz.

SSR modes

14. The IFF/SSR systems have been developed so that specific information can be obtained from an aircraft. The aircraft is interrogated on 1030 MHz using coded pulses or modes. Similarly, the aircraft will respond on 1090 MHz using a standard system of codes. There are 3 modes in use and they are:

Mode 1	Military Aircraft Identify	
Mode 2	Military Mission Identify	
Mode 3	A	Common Military/Civilian Aircraft Identify
	B	Civil Identify
	C	Height Encoded Data

15. IFF/SSR system provide ATC authorities with a wealth of information about particular aircraft – far exceeding the amount of information gained by simply using a primary radar. The types of information available are:

Aircraft height (direct from aircraft's altimeter)
Direction
Speed
Type of aircraft

16. The aircraft can also send emergency information such as:

Loss of radio communications (code 7600)

Hijack (code 7500)

SOS (code 7700)

17. The main advantages of IFF/SSR over primary radar are:

Advantages of SSR

a. No clutter problems (i.e. unwanted returns from rain clouds and mountains) since transmitter and receiver operate on different frequencies.

b. Increased range with less transmitted power, as the radio waves only have to travel one way.

c. More information from each target.

d. Ability to use wide bandwidth receivers.

18. SSR has become an indispensable component in Air Traffic and Air Defence systems because an aircraft not using SSR is less easily observed, and presents a potential collision hazard.

Aerials

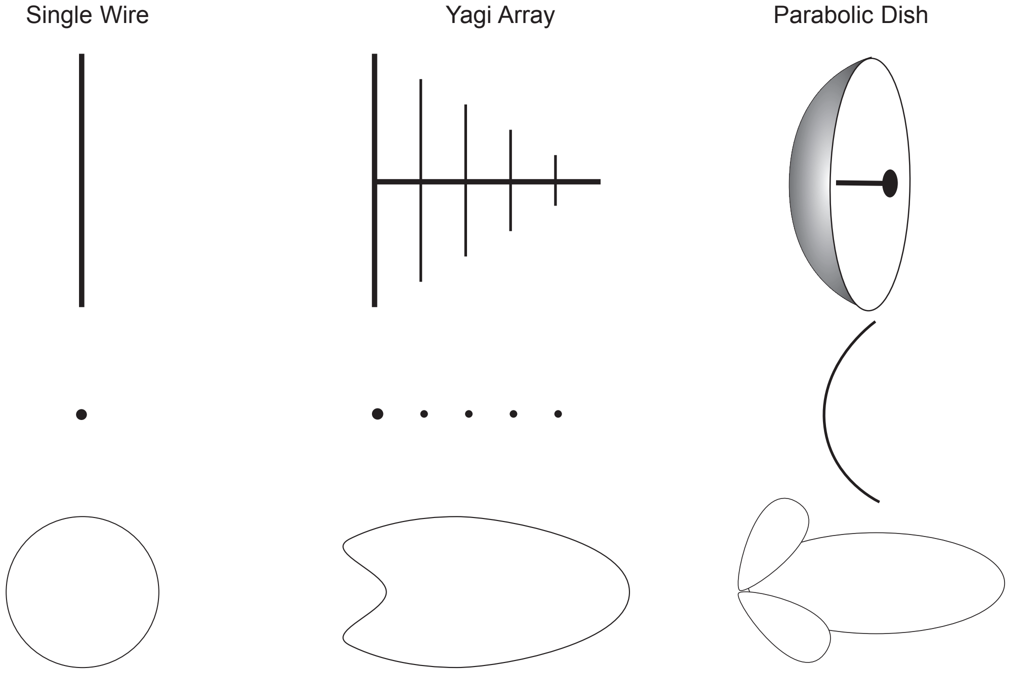
19. As you know, a simple aerial can consist of a piece of wire which, when transmitting, will radiate electromagnetic waves equally in all directions. Similarly, a simple piece of wire will receive signals from all directions. This is of limited use when trying to determine the direction of a particular reflection. Instead, the waves need to be concentrated into a beam so that the radar can be made to "look" and "listen" in one specific direction at a time.

Directing the radiation beam

20. Focusing radio waves into a beam requires a much more complicated aerial system than a simple straight wire. In order to produce a beam of radiation we need

to radiate from a shaped area, and not a single wire. In theory, this means that for long wavelengths great areas of aerial would be needed. To overcome this problem, reflectors are used on the aerial to reflect the radio waves in one direction. The situation is very similar to the reflector in a torch or headlight focusing the light into a narrow beam. To detect accurate bearings of aircraft the aerial is rotated through 360°, sweeping a narrow beam of radiation in a complete circle (called scanning). All reflections can now be plotted around a circle – with the aerial at the centre. To obtain vertical information about the aircraft the aerial is moved up and down through 90° – in a type of nodding movement. From the reflections received, accurate height and range information can be measured.

Fig 3-4: *Beam patterns for differing aerial types*



The Display

CRT display

21. Obtaining a target is only part of the detecting process. The operator needs to "see" the target in visual form. For this we use a cathode ray tube (CRT) which works on a similar principle to a television screen. As the time interval between pulses is short the screen can be calibrated in miles to match the range of the pulse.

22. At Fig 3-5, the instant the pulse is transmitted a spot appears at "A". It then travels towards "B" at a constant speed known as the "base velocity". If a target is detected a "blip" appears; in this case "C". Because the screen is calibrated in miles we know the distance to the target.

For a moving target, the blip would travel along the line "A-B". The important factor here is that the time-base of the CRT is synchronised to the start of the transmission of the radar pulse. Fig 3-6 shows the output from a Type "A" display. From the pips or marks (known as intervals) the operator can estimate the range of the target.

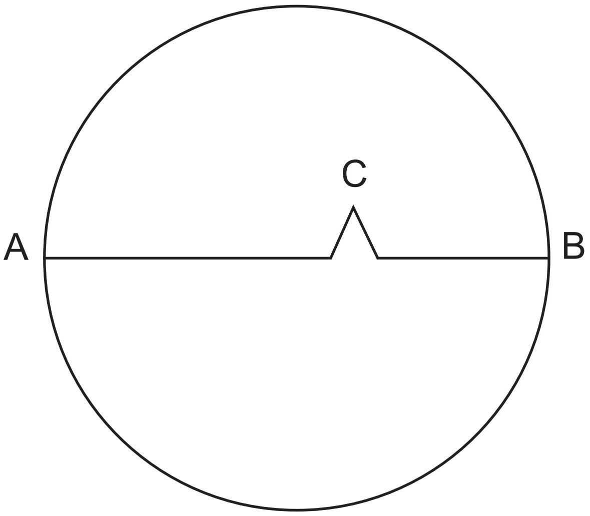


***Fig 3-5:** A CRT display*

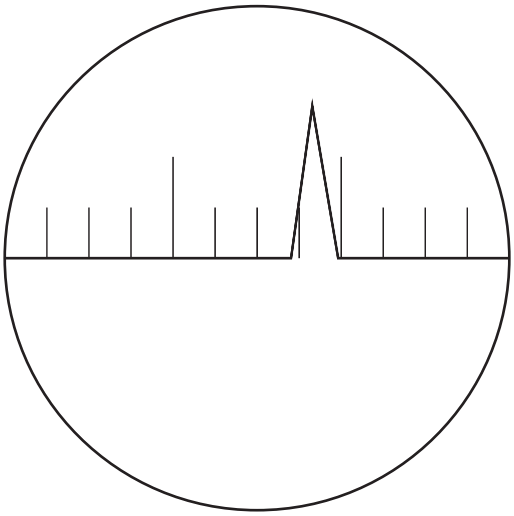


***Fig 3-6:** Type "A" display*

Plan Position Indicator 23. To find the bearing of a target (i.e. its direction) we need to find its azimuth (bearing measured from North). By transmitting a narrow beam of radio waves and rotating it through 360°, the azimuth of any target being illuminated can be calculated. A Type "A" display shows only the range of a target, but it is possible to display both range and bearing on the same CRT by using a plan position indicator (PPI) display. The spot on the PPI displays starts from the centre of the screen and produces a radial trace. This trace moves in time with the rotation of the aerial. Range rings can be added to aid the operator in range finding.

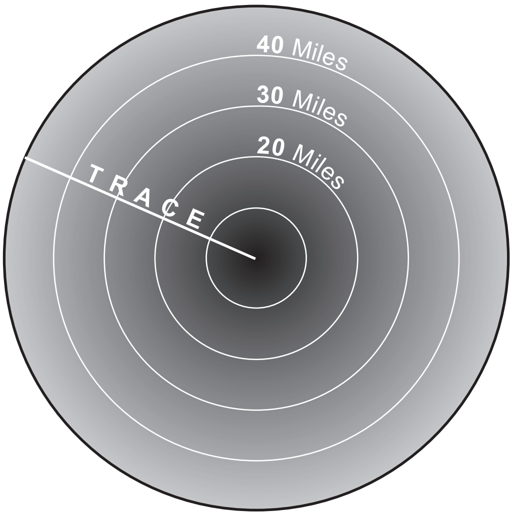


***Fig 3-7:** Range Rings*

Slant ranges and Height

24. The height of a target can be calculated by using the slant range (distance from the radar to the target). This is calculated by using the formula

Height = Slant Range x sin θ

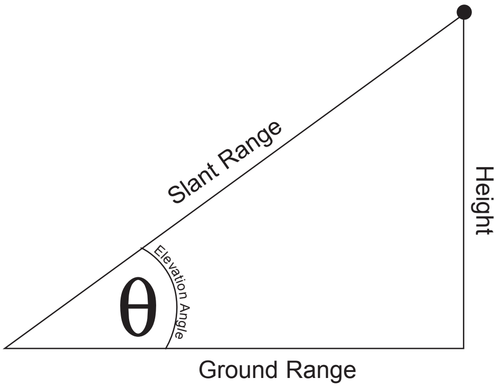


Fig 3-8: *Slant triangle*

Ground range

The target's ground range can be calculated by the formula:

Ground Range = Slant Range x cos θ

3-D radar

25. From what you have just read, to pinpoint a target by both height and bearing requires more than one aerial. However, there is now a radar system that combines both of these facilities into one aerial, known as the 3-D. It works by electronically selecting the various aerial arrays and passing the information to the PPI display.

Factors affecting radar operations

Factors affecting radar performance

26. There are many factors that prevent efficient operation of a radar system, such as:

a. **Noise** – unwanted signals from radio, stars and the atmosphere.

b. **Interference** – unwanted man-made signals such as other radar transmitters, electrical apparatus and electrical machinery. The correct siting of a radar system can reduce the effects of some of these problems.

c. **Clutter** – unwanted echoes from hills, buildings, sea, clouds, hail, rain and snow. These false echoes will weaken real echoes from targets, but fortunately they can be reduced by electronic techniques.

d. **Target characteristics** – a target's shape and composition will have an effect on its echo. Metal, for example, is a better reflector of radio waves than wood or plastic – flat surfaces are better reflectors than curves. The USA’s stealth fighters and bombers make use of the different reflecting capabilities of materials and shapes to effectively "hide" from enemy radars.

Radar Installation

27. This block diagram shows the components of a typical radar installation.

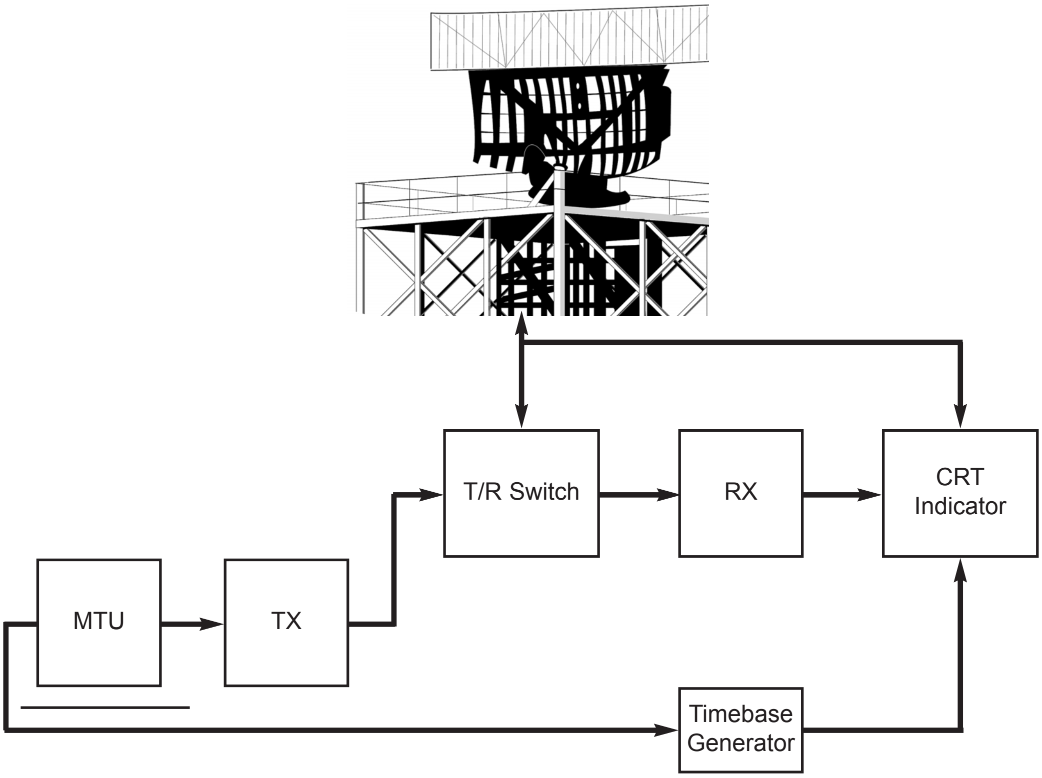


Fig 3-9: *Radar block diagram*

Master Timing Unit (MTU)	This unit produces regular, timed pulses. It controls the number of pulses transmitted per second and the start of the timebase generator, and it synchronises the system.
Transmitter (Tx)	The transmitter produces high energy RF pulses and determines the pulse duration. The range of frequencies used is in the order of 400 MHz to 40 GHz.
Aerial	This is used to launch the RF pulses and collect the returns for processing.

Transmit/Receive (T/R) Switch	
	This is an electronic device that switches both the transmitter and receiver "ON" and "OFF". It is important that the receiver is disconnected with the transmitter is firing pulses (to prevent damage). On the return cycle the transmitter is disconnected while the receiver is on-line to prevent reflections being absorbed by the transmitter.
Receiver (Rx)	The receiver collects and amplifies the returning echoes and then produces the video pulses that are applied to the display.
CRT Indicator	The CRT indicator displays the target echoes to the operator.
Timebase Generator	This unit provides the reference signal for the start of the transmit sequence.

Self Assessment Questions

Do not mark this page in any way! Write your answers on a separate piece of paper

1. What does RADAR stand for?
    a. Radar Detection and Ranging
    b. Radiation Aircraft Ranging
    c. Radio Detection and Ranging
    d. Ranging and Direction Radio

2. How many modes are there in IFF/SSR?
    a. 4
    b. 1
    c. 2
    d. 3

3. What does SSR stand for?
    a. Secondary Surveillance Radar
    b. Service Surveillance Radio
    c. Single Side Radio
    d. Second Sense Radar

4. What does CRT stand for?
    a. Cathode Radio Tube
    b. Cathode Ray Tube
    c. Cathode Radiation Test
    d. Capacitor Resistor Transistor

5. What is the purpose of a timebase generator in a Radar?
    a. Provides the reference signal to start the transmit sequence
    b. Synchronise the T/R switch
    c. Provide a reference signal for the receiver
    d. Used to launch the pulses and collect them on return