RADAR THEORY and OPERATION

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Subject Page

RADAR THEORY and OPERATION

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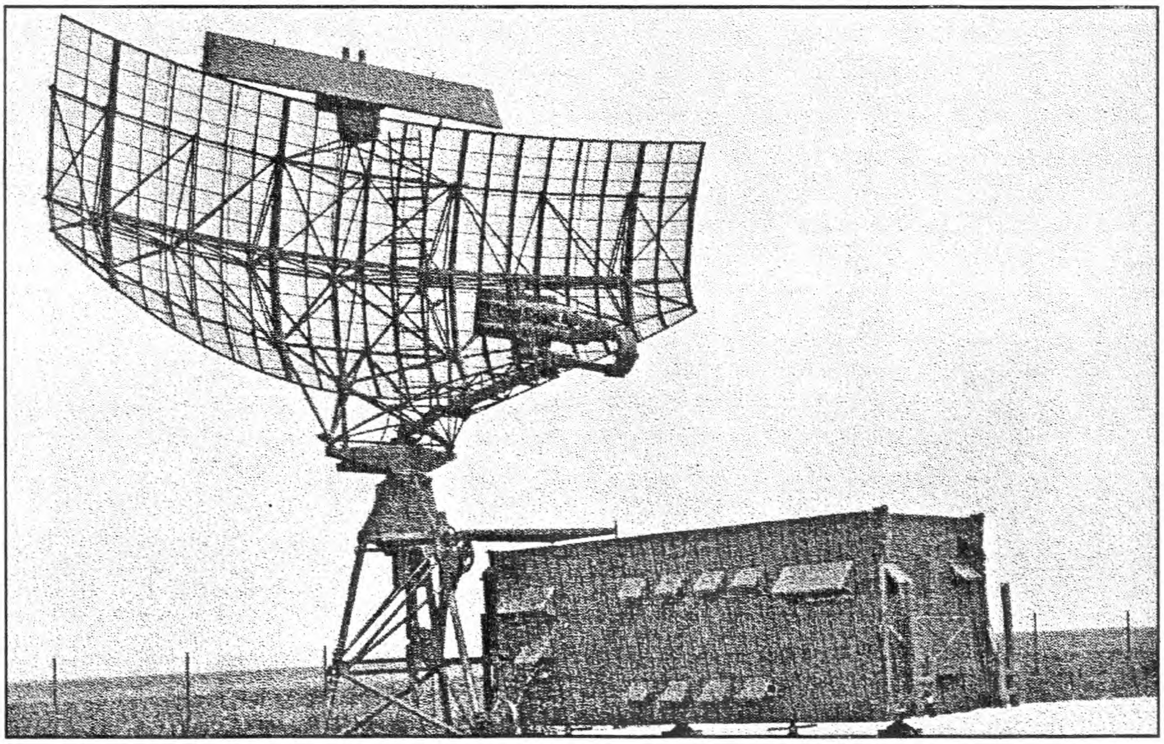
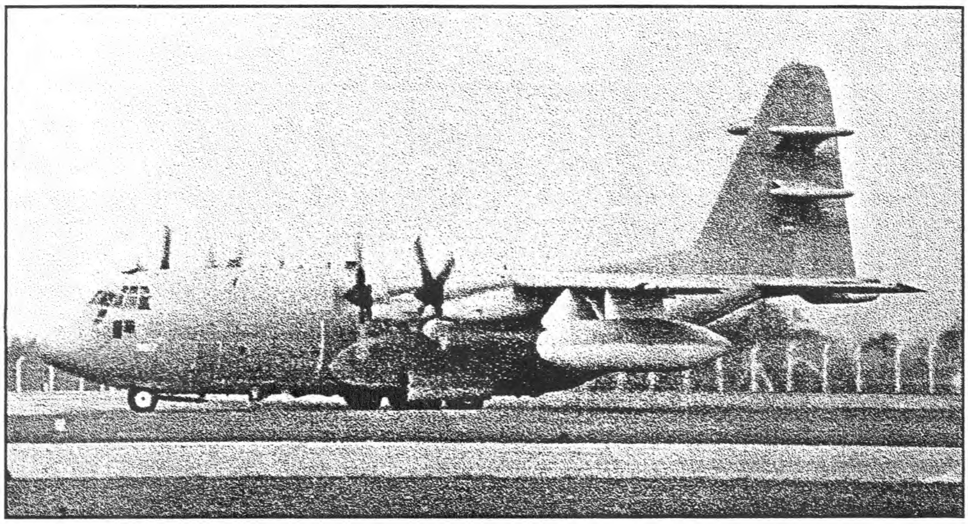


Shown above is the French Thomson-CSF D-band early warning radar, designated TRS 2056 'Centaure'. Typical of many radar systems, this was designed around a 'core' transmitter/receiver module, variations in antenna and processing capability meet the need of individual customers.



Specialised C-130 HERCULES transport aircraft, an EC-130E, adapted to operate in the psychological warfare role under the 'Rivet Rider' programme. This particular aircraft is assigned to the 193rd Special Operations Group (SOG) based with the Pennsylvania Air National Guard (ANG) at Harrisburg International Airport.

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1. BRIEF HISTORY OF RADAR

Radar (**RA**dio **D**etection **A**nd **R**anging) as a branch of technology really started at the beginning of World War 2. The basic principles however have been known almost since electromagnetism was discovered. In 1886 Hertz, while testing the theories of Maxwell, showed that radio and light waves were similar and went on to demonstrate that metallic bodies reflected radio waves.

In 1904, Hulsmeyer, a German engineer, was granted British patent No. 13170 titled 'Hertzian Wave Projection and Receiving Apparatus Adapted to Indicate or Give Warning of the Presence of a Metallic Body such as a Ship or Train in the Line of Projection of such Waves'.

In 1922, Marconi in a speech to the Institution of Radio Engineers, suggested that it was possible to project a beam in any desired direction and reflect it from any metallic object in its path. Reception of reflected wave would therefore indicate the presence and direction of the object in fog or bad weather. Most of these experiments were carried out at modest frequencies by today's standard, usually below 50 Megahertz.

Though it was realised that pulsed techniques had much to offer in terms of obtaining positional information, many difficulties were experienced. The British were first to demonstrate the pulse technique in June 1935 and, by September of that year, were capable of detecting a bomber at 40 miles distance. March of 1936 saw detection at 90 plus miles and the first example of height finding.

In 1937 a number of 'Chain Home' radar stations were built around the south coast of Britain. Operating on a frequency of 25 Megahertz, they tracked Chamberlain's aircraft returning from Munich in 1938. By then the stations were manned 24 hours a day and watch was kept until the end of the war. It was realised the 'Chain Home' system was not accurate enough to vector fighters to their targets, so work on the first Air Intercept (AI) radar was put in hand, this operating on 200 Megahertz.

Both Britain and Germany continued development of airborne radar throughout the war for use in intercept, bombing and navigational roles. Until the middle of 1940, British and American efforts were carried out independently, but in September of that year a British technical mission was sent to the United States suggesting that they develop an AI radar using microwave frequencies (above 1,000 MHz). The British had realised that advantages in determining angular resolution required by AI and Anti-Aircraft Fire Control radars could be achieved by using these much higher frequencies. The same mission also demonstrated a device called the 'Cavity Magnetron' which had been developed by Randall & Boot at Birmingham University. This technology was given to the U.S. to aid the development of Air Intercept radars and proved to be one of the most important factors microwave radar development.

The success of microwave radar was not certain, and the U.S. Service Laboratories concentrated their efforts on VHF (Very High Frequency) equipment where the technology was already established. Further development of microwave equipment was carried out by the Radiation Laboratory of the Massachusetts Institute of Technology (M.I.T). In addition to the United States and Britain, Germany, France, Italy, the USSR and Japan were all independently developing radar systems.

2. PROPAGATION

Above 30 MHz radio waves tend to travel by line of sight (LOS). The range is restricted therefore by the curvature of the earth's surface to the **OPTICAL HORIZON** - how far it is possible to see.

OPTICAL HORIZON governed by, RANGE = $3.57\sqrt{h_\circ}$
(where $h_\circ$ = observer height in metres)

If a distant object is also at a height, then range is given

by $3.57\,(\sqrt{h_\circ} + \sqrt{ht})$ (where ht = target height)

There are factors which extend radio range at frequencies above 30 MHz, the main one being **ATMOSPHERIC REFRACTION.** Due to the greater atmospheric density nearer the earth's surface waves are refracted towards it beyond the normal LOS, this extending radar range by some 15%. There is also greater absorption nearer the surface which tends to slow the lower portion of the wavefront.

The **REFRACTIVE INDEX** (bending effect), referred to as the *'K' factor*, differs throughout the world depending on prevailing air density, mainly due to climatic conditions. For the purposes of this document the 'K' factor has been given a value of 4.1.

LOS RADAR RANGE (km) = 'K' factor (4.1) $\times \sqrt{h_\circ}$
(where h° is the height of the radar antenna, the 'head')

The above formula will produce the estimated LOS range to a target at the radar horizon. As it is derived by multiplying the 'K' factor by the height of the radar 'head', the greater the height of the head, the greater the radar LOS range. Where either the target or the radar head is situated well above ground level, airborne for example, then this must be taken into consideration. Under these circumstances, the following formula is used in determining LOS radar range.

= 'K' factor (4.1) $\times (\sqrt{h_\circ} + \sqrt{h^t})$
(where h^t is the height of the target)

Example, Radar head at 25 metres, target aircraft flying at 2,500 metres

CALCULATED RANGE = $4.1\,(\sqrt{25}\ (h^\circ) + \sqrt{2{,}500}\ (h^t))$

= $4.1\,(5 + 50)$

= **225.5 km**

2.1 - Anomalous propagation (super-refraction)

In normal atmospheric conditions temperature falls with increased height. In fine, hot weather, evaporation takes place over the sea which, if prolonged, can create a condition where the upper atmosphere becomes warmer than the lower atmosphere and the resulting **TEMPERATURE INVERSION** forms a **DUCT.** This duct acts as a waveguide for radio waves and produces a dramatic extension in reception range. The initial duct is called a **SURFACE DUCT,** normally occurring between 10 - 30 metres above the surface.

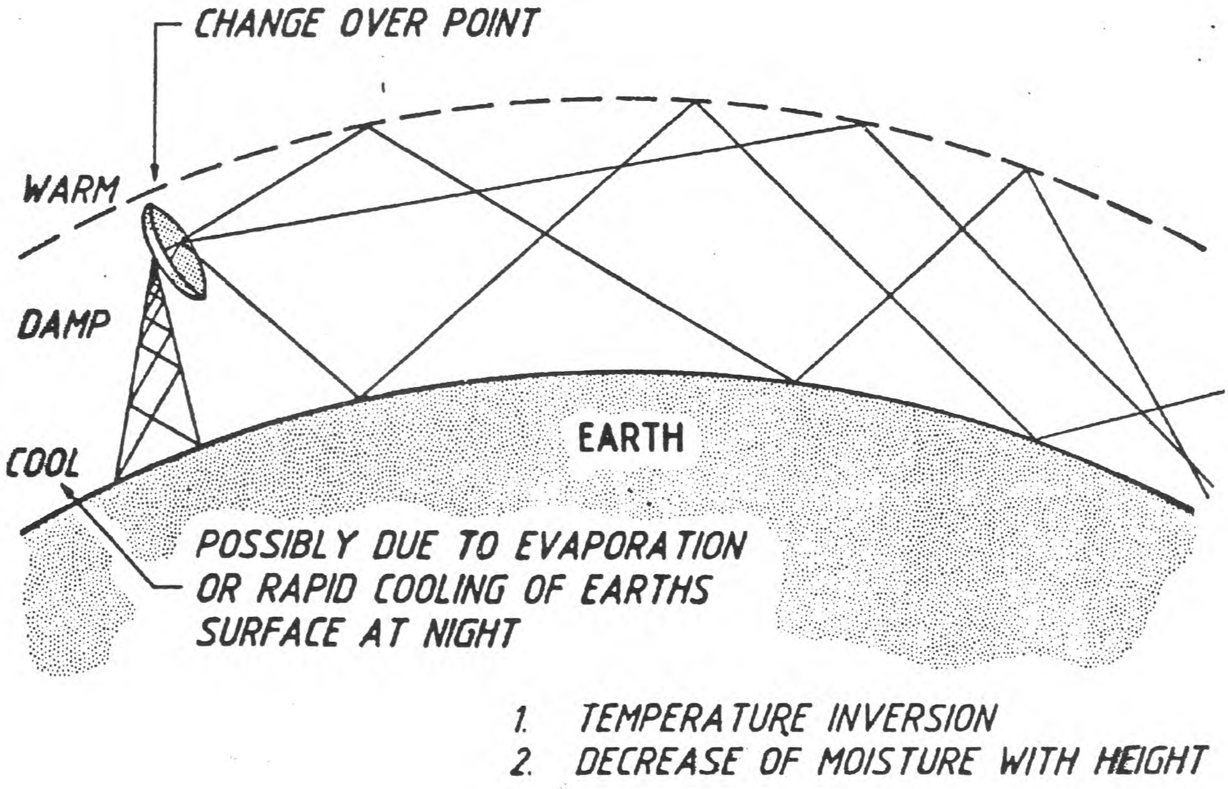


fig. 2.1:1

SURFACE DUCT

Ducts can be formed in layers, with the more common **ELEVATED DUCTS,** increasing range even further and are found at heights varying between 15 and about 300 metres and occur when a layer of cool, moist air is trapped between layers of denser warm air, these forcing the cooler air upwards. .

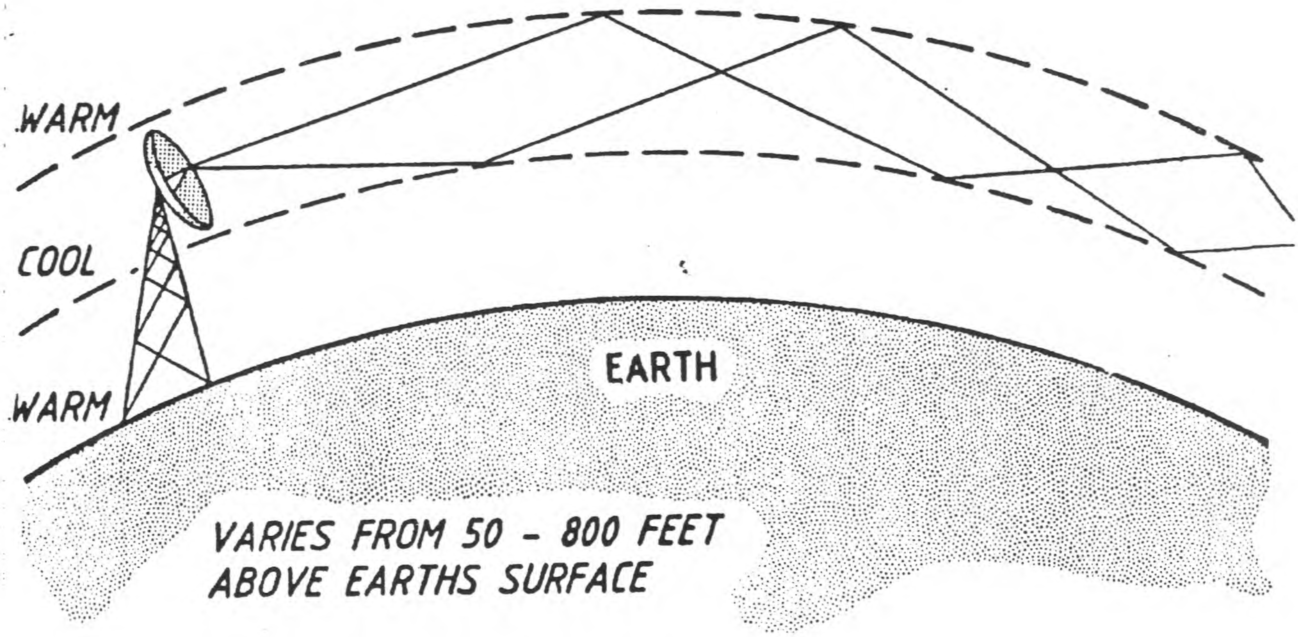


fig. 2.1:2 *ELEVATED DUCT*

Such effects are to be found around inland seas where evaporation forming over the sea at night is detached from the surface by air from the land moving out as it warms through the day.

Ducting is essentially a fine weather phenomenon and the most intensive ducting occurs over tropical regions. In temperate climates, it is most predominant in summer. Most prevalent over water, seas etc., where they can last for long periods. Can also occur locally around thunderstorms where downdraught of cool air spreading out from its base causes the necessary temperature inversion. Phenomenon rarely lasts longer than the storm front and can be rapidly moving.

Conditions which favour the formation of ducting:-

a) *Fine, calm anticyclonic weather.*

b) *Evaporation of inland water in hot weather (inland seas, lakes etc.)*

c) *Rapid cooling of the lower atmosphere at night after a hot day with clear night sky's.*

Ducting can occur in spring and winter as well as summer, ducts occur because of ***relative*** temperature changes - not actual high temperature.

Strong winds or precipitation will destroy existing ducts and reception then reverts to line-of-sight.

It is important to realise that reception will not be limited to radar line-of-sight.

3. BASIC PRINCIPLES OF RADAR

The principle of RADAR (**RA**dio **D**etection **A**nd **R**anging) involves measuring the time delay between transmission of a signal and the reception of the reflected energy from an intended target. As the signal is transmitted at a Radio Frequency, it applies to both basic types of Radar, **PULSED** and **CONTINUOUS WAVE (CW).** Radio waves travel at the velocity of light waves which, for the puroses of this course, is taken as being 300,000 kilometres per second (km/sec) or 300 metres per microsecond (m/μs), that is a wave travels 1 kilometre in 3.33μs.

Of the two basic types of Radar mentioned, Pulsed radar still forms about 90% of our interest and will be concentrated on here, Continuous Wave techniques being discussed later.

BASIC PULSED RADAR

A pulse is simply a very brief burst of Radio Frequency (RF) energy. To cause this the Radar transmitter is activated to provide a very short burst of energy, normally no more than a few, or even parts, of a microsecond (μs). In practice, not just one pulse is transmitted but a stream of pulses to form what can be called a pulse train. The *length of time occupied by the pulse* is known as the **PULSE DURATION,** and the *number of pulses that are fired per second*, the **PULSE REPETITION FREQUENCY** as shown below in figure 1.

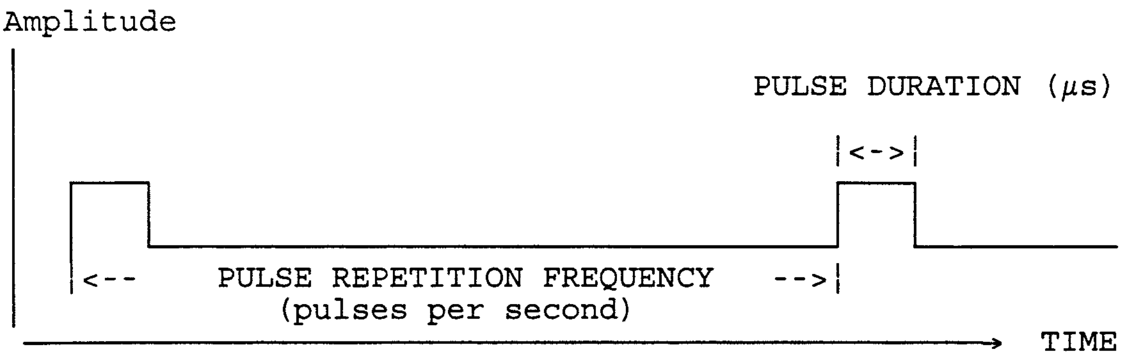


fig. 3.0:1

THESE ARE SOME OF THE IMPORTANT CHARACTERISTICS OF ANY PULSED RADAR SYSTEM. THEY CAN BE MEASURED AND THIS COLLECTED DATA CAN BE USED TO DETERMINE ITS FUNCTION AND OPERATION.

3.1 - Production of a pulse

A pulse starts life as a sine wave generated by an oscillator within the *timing circuit* to the desired pulse repetition frequency.

Still within the timing circuit, the pulse is then shaped by a waveform generator to produce a rectified output of DC 'spikes' which are *used to 'trigger' the radar transmitter via a modulator.* The duration of the 'spike' controls the pulse duration, their timing sets the pulse repetition frequency.

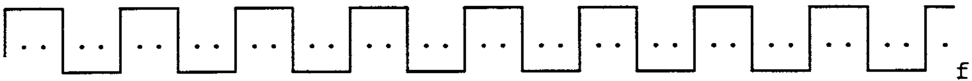


fig. 3.1:1

Sine wave severely limited then passed to differentiating circuits.

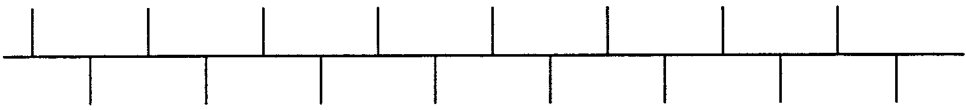


fig. 3.1:2

Alternating DC 'spikes' produced by circuits, finally offered to rectification stage which removes negative spikes.

fig. 3.1:3

These are passed through the MODULATOR which converts the low power spike into an output of the necessary voltage and time duration to drive the TRANSMITTER thereby producing the required modulated high power radio frequency signal.

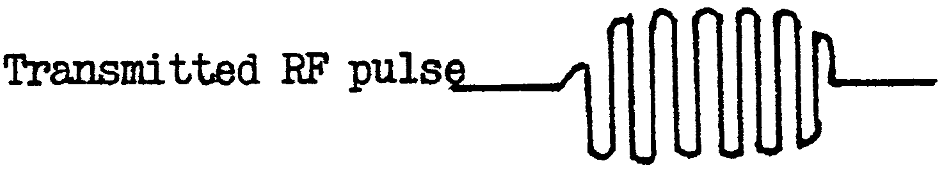


fig. 3.1:4

A common antenna is normally used for both transmission and reception so a **DUPLEXER** (TX / RX SWITCH).The reflected RF energy collected by the receiver is converted to an **INTERMEDIATE FREQUENCY** as near the antenna as practical to minimise any system losses as received echoes are very weak. This is then amplified before being presented in whatever manner required, commonly as a **PLAN POSITION INDICATOR (P.P.I.)**.

3.2 - Basic Primary Radar, block schematic diagram

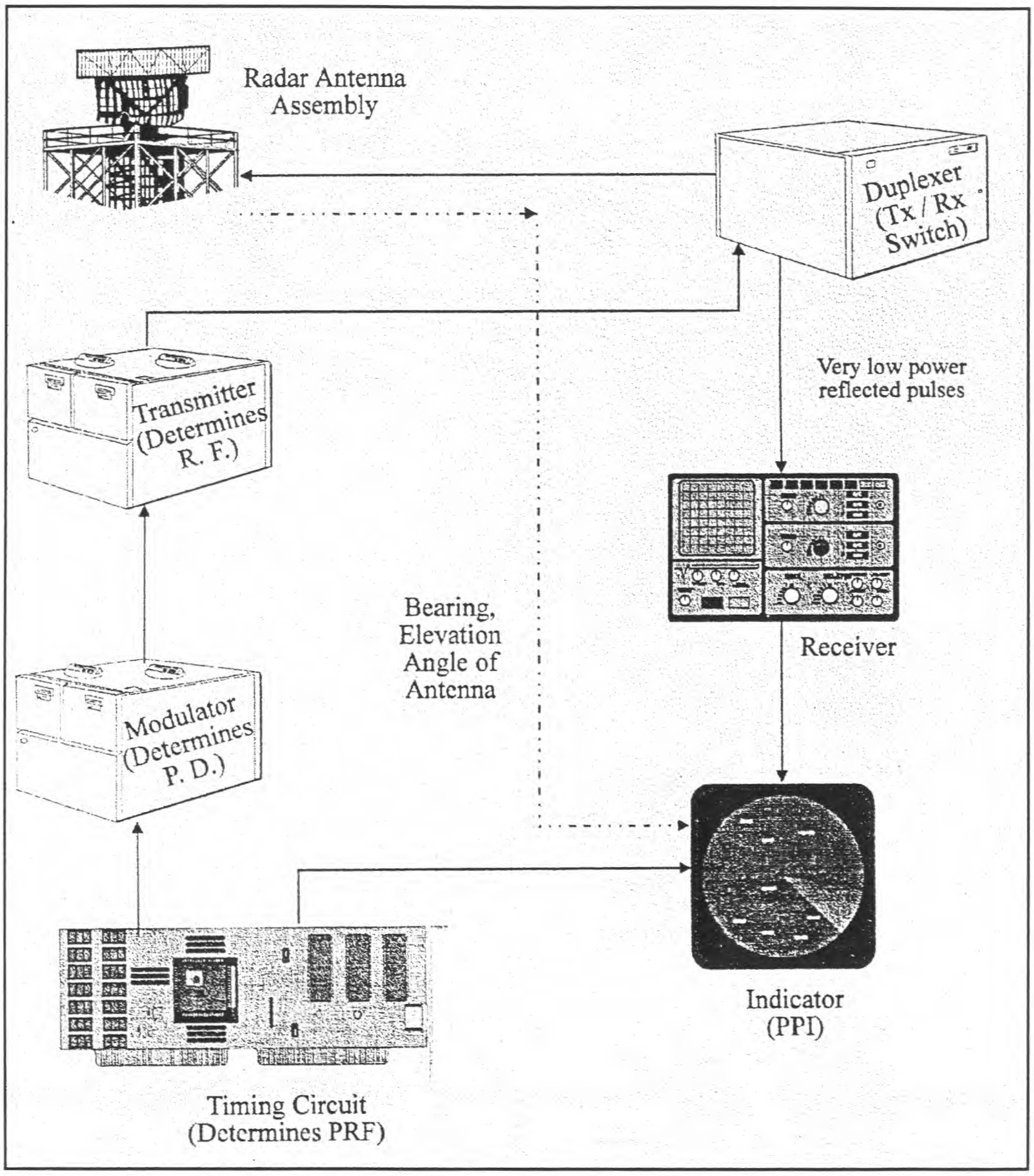
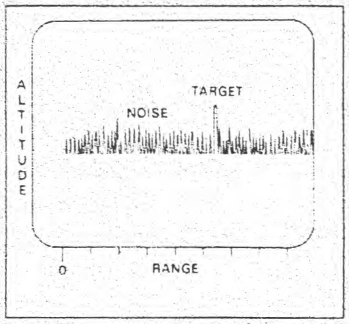


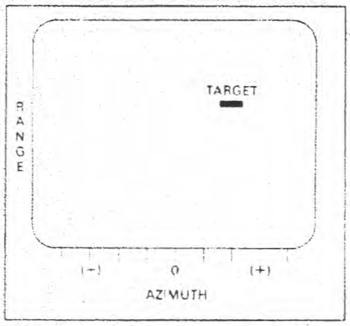
fig. 3.2:1

Simplified block diagram of a pulsed radar system. The Timing Circuit provides 'trigger' pulse for both the Modulator and the radar Indicator ensuring that both the radar signal and the indicato trace of the returning 'echoes' synchronised to the same intended pulse repetition frequency. O the Transmit side, the outgoing signal path is via the Modulator which produces the low powe timing 'spikes'. These are converted into much higher power bursts of radio frequency energy b the Transmitter. In many cases both transmitted pulses and the much lower power level retur echoes share the same antenna. To ensure that none of the high power energy can damage th sensitive receiver, a Duplexer is fitted. This is basically a Transmit/Receive switching device whic blocks the input to the receiver signal path while transmitting and likewise blocks the transmitte while the antenna is being used to listen for weak return echoes. Should the radar be using scanning antenna, then information regarding its position in Azimuth (bearing) or any other require angular data is fed to the radar display.

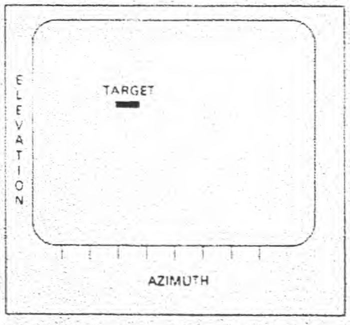
3.3 - Presentation of typical radar displays



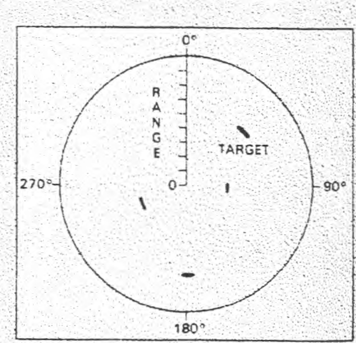
"A" Display. Plots amplitude of receiver output versus range on horizontal line, called a range trace. Simplest of all displays, but little used because it does not indicate azimuth.



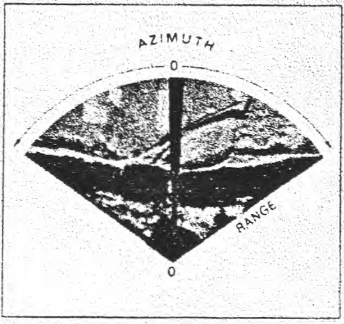
"B" Display. Targets displayed as blips on a rectangular plot of range versus azimuth. Widely used in fighter applications, where horizontal distortion near zero range is of little concern.



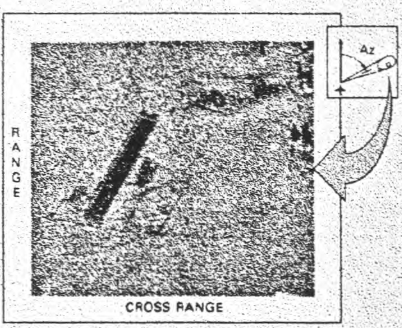
"C" Display. Shows target position on plot of elevation angle versus azimuth. Useful in pursuit attacks since display corresponds to pilot's view through windshield. Commonly projected on windshield as Head-Up Display.



PPI (Plan Position Indicator) Display. Targets displayed in polar plot centered on radar's position. Ideal for radars that provide 360 degree azimuth coverage.



Sector PPI Display. Gives undistorted picture of region being scanned in azimuth. Commonly used for sector ground mappi



Patch Map. In high resolution (SAR) ground mapping, a rectangular patch map is commonly displayed. This is a detail map of a specific area of interest at a given range and azimut angle. The range dimension of the patch is displayed vertically the cross range dimension (i.e., dimension normal to the line sight to the patch), horizontally.

fig. 3.3:1

Computer assisted radar displays

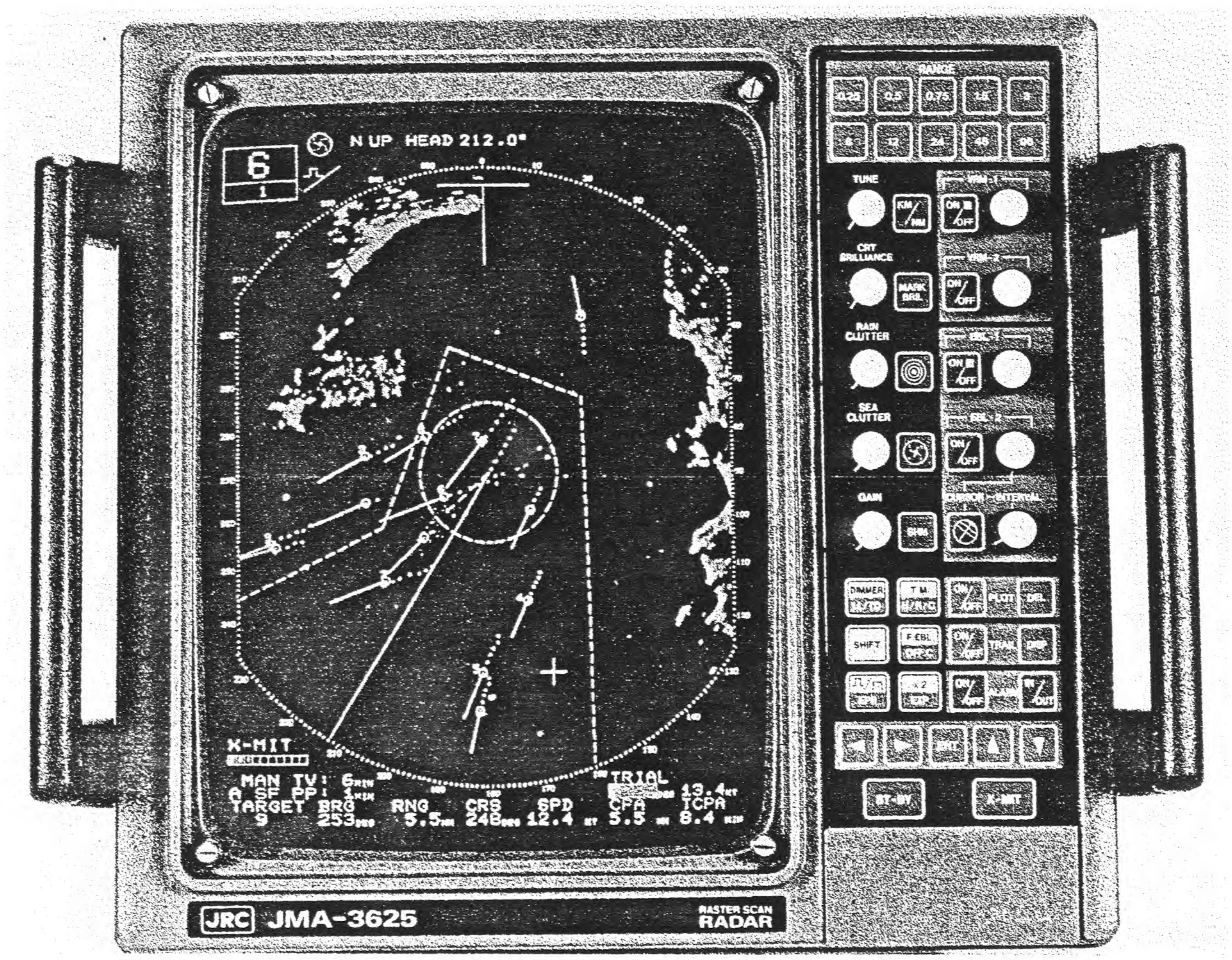


fig. 3.3:2

With the increasing use of computer assistance within the field of radar, many of todays displays do not use the '*raw*' video output from the receiver to display returns on the screen but have them processed by suitable computer software to provide what is called a '*synthetic*' picture. Such techniques not only produce a flicker free screen image but by using what is known as Automatic Radar Plotting Aids (ARPA), can show additional information, ie. target heading, in a more readily discernible form. Shown above is the screen of a commercial maritime radar with '*touch*' controls for range and clutter rejection circuitry selection to the right. Within the display shore returns can be seen to the left and right. Not only the present position of other shipping is indicated (small number tagged circles) but their current heading (solid lines extending out from each plot). This allows the master/navigator to have a better appreciation of shipping activity around his/her own vessel.

4. CHARACTERISTICS OF PULSED RADAR

Pulsed radar transmissions are comprised of certain characteristics to enable target detection. These include the radar's frequency, the duration and number of times per second each pulse is transmitted and the beamwidth created by the antenna. The performance of the radar will be dictated by the actual values of each characteristic selected by the designer.

To the collector, the precise parameter of each measurable radar characteristic can lead to a correct analysis of the systems intended function and performance. Contained in the subject matter that follows are insights into the effect and inter-relationship of these characteristics within a radar system

MEASURABLE CHARACTERISTICS :-

RADIO FREQUENCY

FREQUENCY SPECTRUM

PULSE REPETITION FREQUENCY / INTERVAL

PULSE DURATION

(DUTY CYCLE)

RADIATED BEAMWIDTH

POLARISATION

SCAN TYPE

SCAN PERIOD OR RATE

SIGNAL STRENGTH

(Characteristic shown in brackets is not of immediate concern to the collector)

PARAMETRIC STUDY OF THESE COLLECTED CHARACTERISTICS WILL ALLOW THE FUNCTION AND OPERATIONAL PERFORMANCE OF THE RADAR TO BE DETERMINED.

FREQUENCY SPECTRUM

<table>
<tr><th colspan="2">Hertz (Hz)</th><th colspan="3">Kilohertz (KHz)</th><th colspan="3">Megahertz (MHz)</th><th colspan="12">Gigahertz (GHz)</th></tr>
<tr><td>10</td><td>10^2</td><td>1</td><td>10</td><td>10^2</td><td>1</td><td>10</td><td>10^2</td><td>1</td><td>10</td><td>10^2</td><td>10^3</td><td>10^4</td><td>10^5</td><td>10^6</td><td>10^7</td><td>10^8</td><td>10^9</td><td>10^{10}</td><td>10^{11}</td></tr>
<tr><th colspan="9">Wavelength in Metres</th><th colspan="3">Millimetres (mm)</th><th colspan="8">Micrometres (μm)</th></tr>
<tr><td>$3x10^7$</td><td>$3x10^6$</td><td>$3x10^5$</td><td>$3x10^4$</td><td>$3x10^3$</td><td>$3x10^2$</td><td>30</td><td>3</td><td>0.3</td><td>30</td><td>3</td><td>0.3</td><td>30</td><td>3</td><td>0.3</td><td>$3x10^{-2}$</td><td>$3x10^{-3}$</td><td>$3x10^{-4}$</td><td>$3x10^{-5}$</td><td>$3x10^{-6}$</td></tr>
<tr><td colspan="4">ACOUSTIC</td><td colspan="16">▨</td></tr>
<tr><td colspan="3">▨</td><td colspan="8">RADIO and RADAR</td><td colspan="9">▨</td></tr>
<tr><td colspan="11">▨</td><td colspan="3"><i>INFRA-RED</i></td><td><i>LIGHT</i></td><td colspan="5"><i>ULTRA-VIOLET, X-RAYS and GAMMA RAYS</i></td></tr>
</table>

(Fig 4.0:1)

4.1 - Radio Frequency

In ELINT it is the radar's transmitted pulse which we receive for parametric measurement and analysis in order to determine its function(s) and capability as well as its location and platform. There are a number of measurements we can make which will tell us about the radar. The characteristic values which we measure are known as the **PARAMETERS.** We will look at these individually to determine which govern each part of the radar's overall capability.

Radio Frequency - As in the HF spectrum, the longer the wavelength (lower the frequency), the greater the distance the wave will travel. However, higher in the RF band additional absorption factors effect specific wavelengths. Certain gases found in the atmosphere will absorb enough energy to degrade the normal range of a radio wave within a specific frequency range. Water, for example, causes enough attenuation at around 22 GHz and, for this reason, the range 18 to 27 GHz is generally not used.

Generally speaking, atmospheric absorption decreases with frequency to a point where, below 1 GHz, it is virtually negligible.

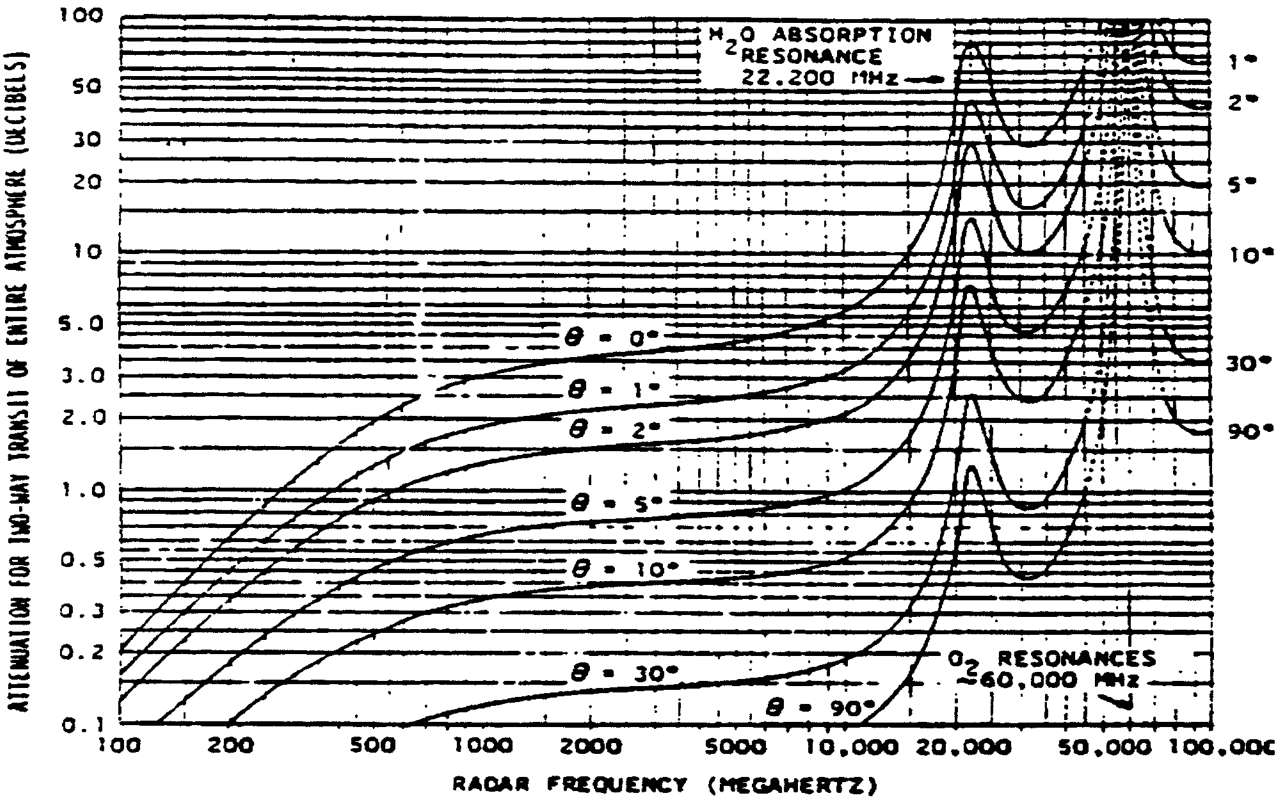


fig. 4.1:1

There are other factors which can degrade the designed performance of a radar, some listed below:

Cosmic Noise	'Stellar' noise in the RF band is caused by activity within the 'Milky Way' and other galaxies. Decreases with increasing frequency, virtually nil above 1 GHz.
Solar Noise	Caused by sun spots etc., and other sun related activity. Increases as frequency increases.
Urban Noise	Noise from car ignition, X-Ray machines, microwave ovens (normally around 2.5 GHz) etc. Decreases as frequency increases.
System Noise	The most serious source of noise occurs within the radar system itself, especially receiver circuitry. The selection of less than perfect components or connection methods can create random electron flow, this introducing noise into the system. Often referred to as '***Thermal Noise***', many systems deliberately cool the RF amplification stages to increase conductivity keeping this random flow as low as possible.

To summarise, at frequencies *below 1 GHz, Cosmic Noise is more prevalent. Above 1 GHz, Atmospheric Absorption becomes the major deciding factor.*

So in general, the ***GREATER THE DISTANCE*** the radar is required to operate over, the ***LOWER THE RADIO FREQUENCY*** must be. There are other factors which enhance the use of a low RF, these will be dealt with shortly.

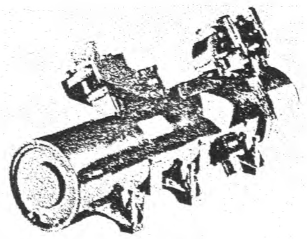


fig. 4.1:2

Many of today's radar systems use a device known as a Travelling Wave Tube (TWT) to generate their operating radio frequencies (RF).

This high power amplification device is capable of producing a 'coherent' frequency source, and is well suited to provide the stable RFs required by present pulse-doppler radars.

Due to the limitations placed on radar antenna design by the relationship between wavelength and required beamwidth, generally speaking, for a given beamwidth, the lower the frequency (longer the wavelength), the larger the antenna. Long range (low RF) requires a large physical structure which limits the movement (scan) of the antenna, so most radars are a compromise which hinges on the function the radar is required to perform. It is difficult to achieve fast scan rates at low RF's due to the problems of moving the array at speed although this can be overcome by scanning the beam electronically.

THE RADAR'S INTENDED FUNCTION/ROLE WILL DETERMINE THE RADIO FREQUENCY IT WILL OPERATE ON.

FREQUENCY / WAVELENGTH CONVERSION

$$\text{WAVELENGTH} = \frac{\text{C}}{\text{FREQUENCY}} \qquad \text{FREQUENCY} = \frac{\text{C}}{\text{WAVELENGTH}}$$

(where C is taken as the speed of light, 300,000,000 m/sec)

CONVERSION

Where **frequency** given in **MHz**, take **'C'** as **300** and divide by frequency value, answer in metres / parts of a metre.

WHERE POSSIBLE, ALWAYS LEAVE WAVELENGTH IN METRE UNITS.

Example: convert 3,000 MHz to wavelength

so formula is C ÷ Frequency = 300 ÷ 3,000 = 0.1 m (10 cm)

Similarly, converting **WAVELENGTH TO FREQUENCY,**

Example: convert 30 cm to frequency

Express 30 cm as parts of a metre, 0.3 m

then F = C ÷ Wavelength = 300 ÷ 0.3 = 1,000 MHz

SO BY TAKING 'C' AS 300, ANSWER WILL BE DIRECTLY INTO MHZ.

4.2 - Radio Frequency Spectrum of a Pulsed Signal

Radio frequency spectrum of an **UNMODULATED CONTINUOUS WAVE** transmission.

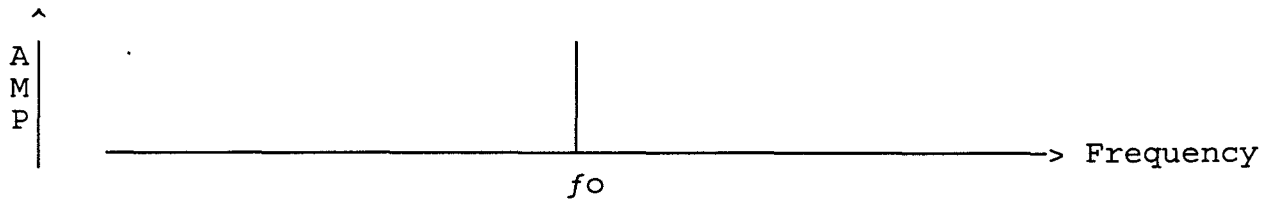
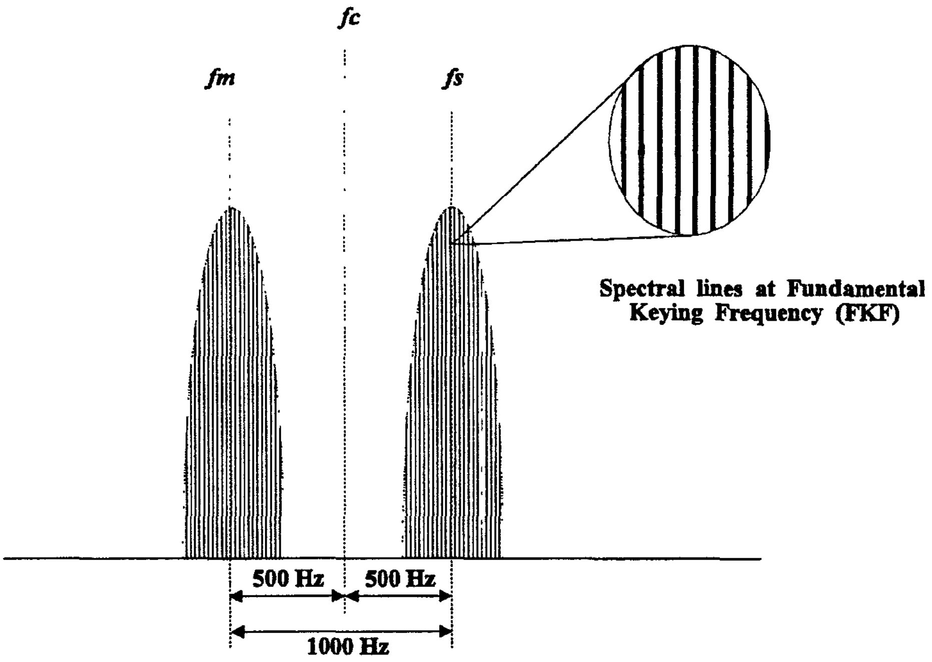


fig. 4.2:1

As we can see, this will only produce an amplitude increase at the operating (transmission) frequency, *f*o. No other sidebands will be present.

Should we **modulate the signal in ANY way**, by Phase, Frequency or Amplitude, then **SIDEBANDS WILL OCCUR** at the rate of modulation and direct harmonics of it.



Above is fig. 4.2:2 a representation of a carrier Frequency Shift Keyed at 500 Hertz, that is the carrier shifted 500 Hertz above and below the centre frequency to create the '*Mark*' (*f*m) and '*Space*' (*f*s) frequencies. Spectral lines will be created by the *Fundamental Keying Frequency* (*f*k) or the modulation rate. If the transmission is ON/OFF Keyed (OOK), these will occur at *f*m ±*f*k, ±3*f*k, ±5*f*k etc, and similarly *f*s ±*f*k, ±3*f*k etc.

To accommodate such a signal we would normally open the receiver bandwidth to take in the overall frequency shift plus 3 times the fundamental keying frequency.

In a pulsed transmission however, the harmonic frequency offset is at the reciprocal of the Pulse Duration (1 ÷ Time), the pulse repetition frequency being the modulation rate. The bandwidth of the signal is now dictated by the pulse duration with spectral lines occurring within the envelope at the PRF. The resultant spectrum produced by a 1μs pulse with pulse repetition frequency of 1,000 pps shown below.

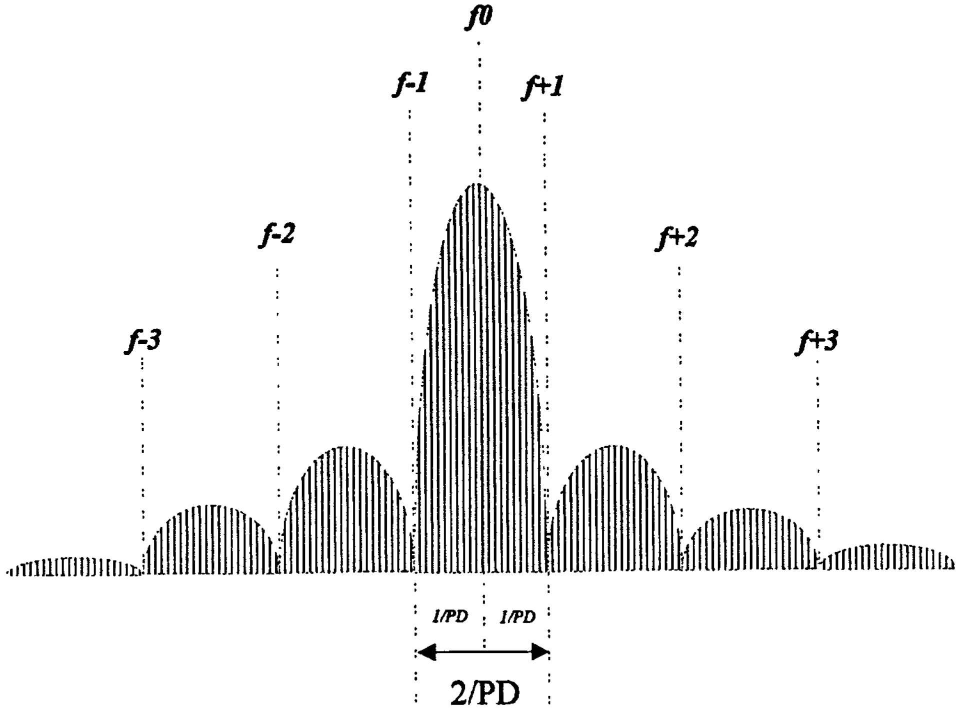


fig. 4.2:3

The carrier frequency is now shifted by the frequency value of the Pulse Duration (1μs = 1 MHz). For faithful reproduction, the receiver bandwidth must be sufficient to take in f-1 to $f+1$ then both the PRF and overall pulse presentation will be satisfactorily accommodated. We can therefore state that the bandwidth of a pulsed transmission will be :

$$\mathit{BANDWIDTH\ (Hertz)} = \frac{2}{\mathit{PULSE\ DURATION}}$$

As pulse durations are normally transmitted in μs, by dividing 2 by the PD (μs), the bandwidth will be directly in Megahertz ie.: a PD of 0.5μs will produce a bandwidth of (2 ÷ 0.5) = 4 MHz. The bandwidth relates not only to optimum receiver setting but to that required by any recording media to ensure true retention of the signal for off-line processing.

It should be remembered from this formula that:

SHORTER THE PULSE DURATION THE WIDER THE BANDWIDTH,
LONGER THE PULSE NARROWER THE BANDWIDTH.

4.3 - Radio Frequency Bands

In the field of Electronic Warfare, by international agreement,the RF spectrum has been divided into bands, each band denoted by a letter commencing from the lowest frequency as follows:-

EW BAND	FREQUENCY RANGE	INTERNATIONAL DESIGNATION	WAVELENGTH
A	0 to 250 MHz	LF/MF/HF/VHF	0 to 120 cm
B	250 to 500 MHz	VHF/UHF	120 to 60 cm
C	500 to 1,000 MHz	UHF	60 to 30 cm
D	1 to 2 GHz	L	30 to 15 cm
E	2 to 3 GHz	S	15 to 10 cm
F	3 to 4 GHz	S	10 to 7.5 cm
G	4 to 6 GHz	C	7.5 to 5 cm
H	6 to 8 GHz	C	5 to 3.75 cm
I	8 to 10 GHz	X	3.75 to 3 cm
J	10 to 20 GHz	X (10 to 15 GHz) Ku (15 to 18 GHz)	3 to 1.5 cm
K	20 to 40 GHz	K (18 to 26.5 GHz) Ka (26.5 to 40 GHz)	15 to 7.5 mm
L	40 to 60 GHz	V	7.5 to 5 mm
M	60 to 100 GHz	W	5 to 3 mm

4.4 - Pulse Repetition Frequency

The Pulse Repetition Frequency (PRF) is the rate at which each pulse in a repetitive pulse train is transmitted and is expressed in pulses per second (pps).

Since, at maximum range, ***EACH INDIVIDUAL PULSE MUST HAVE TIME TO REACH THE TARGET AND RETURN BEFORE THE NEXT PULSE IS TRANSMITTED, IT IS THIS RATE (PRF) THAT GOVERNS THE MAXIMUM THEORETICAL UNAMBIGUOUS RANGE (MTUR).***

The MTUR can be derived from the formula :

$$\text{MTUR} = \frac{C}{2 \times \text{PRF}} \text{ km.} \quad (\text{where } C = 300{,}000 \text{ km/sec})$$

So, for a PRF of 1250 pps, the MTUR would be found by:

$$\frac{C}{2 \times \text{PRF}} = \frac{300{,}000}{2 \times 1250} = 300{,}000 \div 2500 = 120 \text{ km}$$

Simplified further, MTUR = 150,000 ÷ PRF, Answer will be in Kilometres.

Conversely, $$\text{PRF } (Hz) = \frac{150{,}000}{\text{MTUR } (km)}$$

INCREASING THE PRF DECREASES THE MTUR

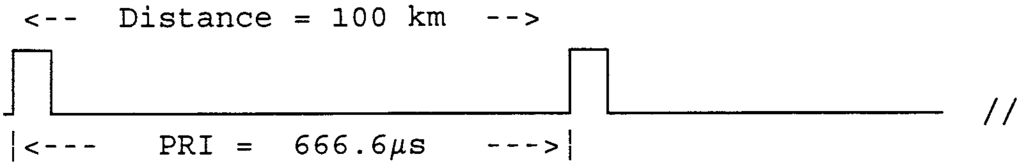
DECREASING THE PRF INCREASES THE MTUR.

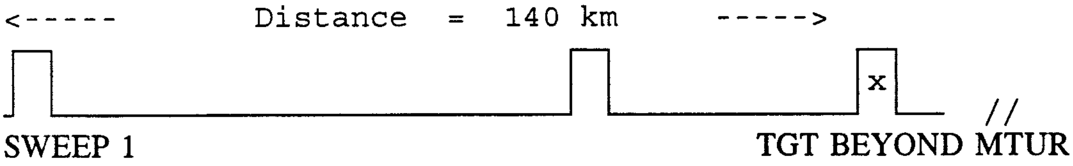
Calculate MTUR from PRF,	1,000 pps	=	150 km
	1,500	=	100 km
	2,500	=	60 km
Calculate PRF from MTUR,	300 km	=	500 pps
	500	=	300 pps
	1,500	=	100 pps

A transmitted pulse does not, of course, stop at the maximum intended range of the radar. It will continue on and may strike a target beyond the MTUR. Although the target will cause an echo, the range information is no longer true, it is ambiguous. Radar equipment is obviously designed to correctly display target range, so there must be no doubt that the information presented is correct.

In practice range ambiguities can be eliminated by using only a portion of the MTUR, it is not uncommon for only 50 to 75% utilisation. Other methods such as **PULSE STAGGER** can be used and these will be fully discussed later in the course.

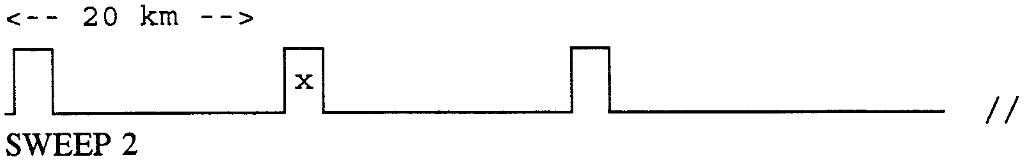
Consider the following:





A target is present beyond the MTUR and returns an echo at the PRI plus its distance in time, that is $666.6 + 266.6\mu s$, $933\mu s$ AFTER the trigger pulse.

Imagine then what would result if the timebase (MTUR) of our radar was set at 800 μs.



The next sweep of the radar timebase will show the target as if it were only $133\mu s$ away, or 133 ÷ 6.66 (Radar Km), giving an **AMBIGUOUS RANGE** of 20 km on the target which is in fact **beyond our MTUR.** The radar is now showing two targets, one with an unambiguous (true) range of 100 km and the other false target at an ambiguous range of 20 km. This false target is referred to as the '***Second Time Round Echo***'.

Pulse Repetition Interval

Consider a pulse stream emitted by a simple, pulsed radar. The **PULSE REPETITION INTERVAL (PRI)** is the **TIME BETWEEN SUCCESSIVE PULSES** and is **inversely proportional to the pulse repetition frequency (PRF).** Normally measured as the time lapse between the leading edges of consecutive pulses in microseconds.

<---------------------- **P R I** ------------------------->

$$\mathbf{PRI} = \frac{1}{\mathbf{PRF}} \qquad\qquad \mathbf{PRF} = \frac{1}{\mathbf{PRI}}$$

To calculate PRF from the PRI, substitute 1,000,000 for the numerator as we normally deal in microseconds (μs).

So a PRI of 1250μs = 1,000,000 ÷ 1250 = 800 pps

Distance may be quoted using a time measurement based on the speed of radio waves (300,000,000 m/sec). Since, in order to provide range information a pulse must strike the target and then return to the radar receiver,

a **RADAR KILOMETRE** will be **TWICE THE TIME** taken for the wave to travel one kilometre, and is **6.666μs.**

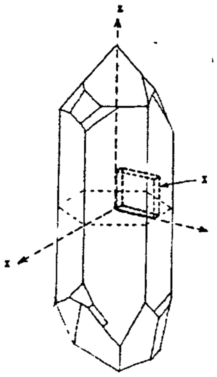
What PRI is required for 100 km ? 100 x 6.666 = 666.6μs

What PRF " " " " ? 1,000,000 ÷ 666.6 = 1,500 pps

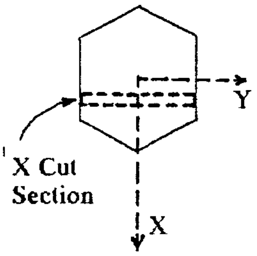
4.5 - Crystal Oscillators

The stability of any radar's parameters is reliant upon the generating source whether it be to produce the radio frequency, the pulse repetition frequency or the scan rate.

In the case of the **Pulse Repetition Frequency**, a highly stable timing source can be used to produce a pulse train with little or no variation between intervals on a pulse-to-pulse basis. The most common source used today is based on a **QUARTZ CRYSTAL OSCILLATOR** where the crystal is cut to resonate at the desired frequency when mounted in a suitably engineered circuit, the thickness of the crystal determining the resonant frequency. Applying a current across the crystal 'slice' causes the it to oscillate at its resonant frequency, this being produced by the '***Piezo-Electric Effect***'. To further ensure stability, the encapsulated crystal oscillator is mounted in a thermostatically controlled oven. This eliminates any expansion or contraction of the crystal which, by effecting the electrical characteristics of the oscillating circuit, would cause the frequency to vary in sympathy.



A complete quartz crystal is shown on the left. Slices cut from it for various purposes are described in terms of the angles between them and the three axis, X = Electrical, Y = Mechanical, Z = Optical as notated. For instance a slice cut with its face perpendicular to the 'X' axis is called an 'X-Cut Crystal' and is used in radio frequency filters and oscillators.



As well as the PRF, the oscillator is also widely used to generate the range markers on a Plan Position Indicator (PPI) and, in this case, the crystal value used is said to be '*range related*'.

Since the radar kilometre is 6.66 μs, this will equate to a frequency of:-

$$\frac{1,000,000}{6.666} = 150,000 \text{ Hz} \quad \text{or} \quad 150 \text{ kHz}$$

So if each pulse were used to generate a marker on the PPI they would be every kilometre. Similarly if we wanted markers every 2 kilometres, we would need an oscillator generating half this frequency (twice the distance), that is 75 kHz.

The value used to denote the velocity of a radio wave so far, 300,000 km/sec, is just an approximation. A more accurate figure would be 299,708 km/sec giving a more exact frequency of 149,854 Hz for the radar kilometre.

It will be apparent that, due to their high value, direct crystal frequencies will not normally be used as the actual PRF. This is produced by circuitry which, by virtually counting each waveform and then taking say every tenth one to trigger the modulator, can translate the crystal frequency to a much lower usable frequency. The actual number of waves required to produce this is called the **COUNTDOWN.** So for example the 100th. countdown of a 2 km (74,927 Hz) crystal would be 74,927 ÷ 100 = 749.927 Hz.

THE CRYSTAL VALUE USED WILL DEPEND ON THE FUNCTION OF THE RADAR and how accurate it wishes range measured. Landbased radars which are used in the Early Warning role would probably be quite happy with a 2 km crystal whereas shipborne Fire Control radars would need very precise range information and usually use a value of 2,000 yards, or 81,932 Hz.

COMMON CRYSTAL VALUES : 2 km = 74,927 1 nM = 80,906
(Hz) 1 km = 149,854 2,000 yds = 81,932
HALF km = 299,708

Further discussion into the use and exploitation of radar systems using crystal oscillators will appear later in the course.

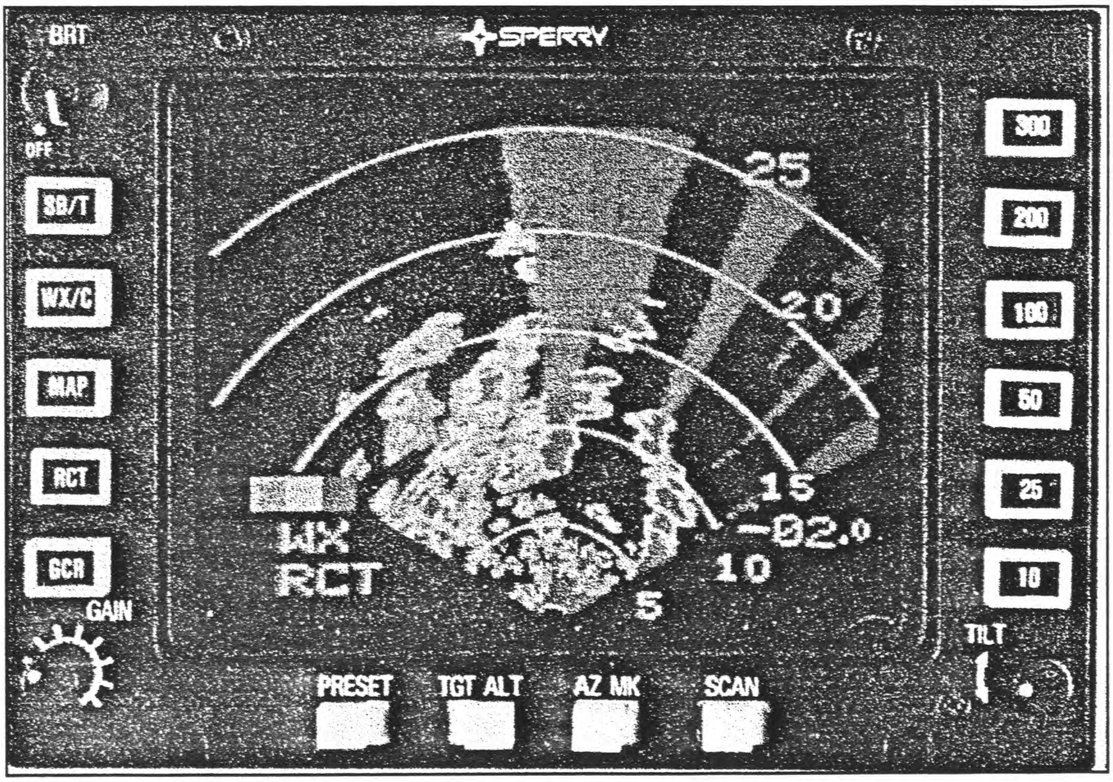


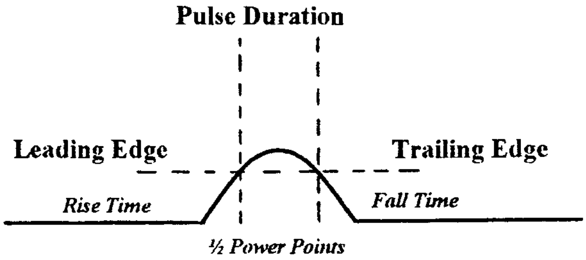
fig. 4.5:1

Typical display from an airborne weather radar showing range markers with values of 5, 10, 15, 20 and 25 nM indicated on the right.

4.6 - Pulse Duration

In a radar system, the time duration that energy is radiated as a pulse at the radio frequency is known as the **PULSE DURATION (PD)** or pulse width and is **NORMALLY MEASURED IN MICROSECONDS** (μs).

The transmitted pulse can be seen as a form of on/off keyed, that is square wave modulation. Here there is an near-instantaneous rise to full power during the pulse's leading edge 'rise time', a period at full power, then a rapid fall at the trailing edge, 'fall time', as transmission ends. Being a square wave, true measurement of the pulse's duration is taken as the duration between the rise/fall time ½ power points (3db or 0.707 RMS). On analogue analysis equipment generally taken visually from between 50% of the rise/fall time.



The PD governs two factors, the **MINIMUM RANGE** and the **RANGE RESOLUTION** of the radar.

MINIMUM RANGE - *THE MINIMUM RANGE FROM A RADAR THAT A TARGET CAN BE DETECTED*

To detect the return echo from a target, the receive part of the system must be listening, therefore the transmitter must be **OFF.** Since the time of transmission is set by the pulse duration, any target closer to the radar than the distance covered by each transmitted pulse will not be detected as the receiver will not be listening. In the case where a target **IS** that close, *it is said to be 'eclipsed' by the pulse,* this condition known as **MAIN BANG ECLIPSING** but can be eliminated by varying the PRI/PD relationship described later. Since the speed of the transmitted radio wave is known, the radar range equation can be simplified to show distance per microsec.

So a **2μs** pulse would have a minimum range of :- **2 x 150m = 300m.**

To decrease the minimum range, in other words to be able to continue detecting targets when they are close to our radar, the pulse duration must be decreased accordingly.

A **0.5μs** pulse has a minimum range of :- **0.5 x 150m = 75m**

Remember that in the range equations so far, the distances resolved allow for the whole of the pulse to strike the target and be returned. Once the pulse has been transmitted and the transmit/receive switch is on 'receive', it is then ready to measure target range.

However *THE INITIAL RANGING REFERENCE MARK RECEIVED FROM THE TARGET WILL BE THE RETURNING LEADING EDGE OF THE TRANSMITTED PULSE, NOT THE ENTIRE PULSE.* For minimum range, *THE DISTANCE INVOLVED WILL BE RELATED TO THE TIME TAKEN FOR THE LEADING EDGE OF THE PULSE TO STRIKE THE TARGET AND BE DETECTED RETURNING.* THIS WILL EQUATE TO HALF THE ACTUAL DISTANCE IN SPACE THE PULSE OCCUPIES.

THE ABILITY OF A RADAR TO DETECT MULTIPLE TARGETS ON THE SAME BEARING BUT SEPARATED IN RANGE.

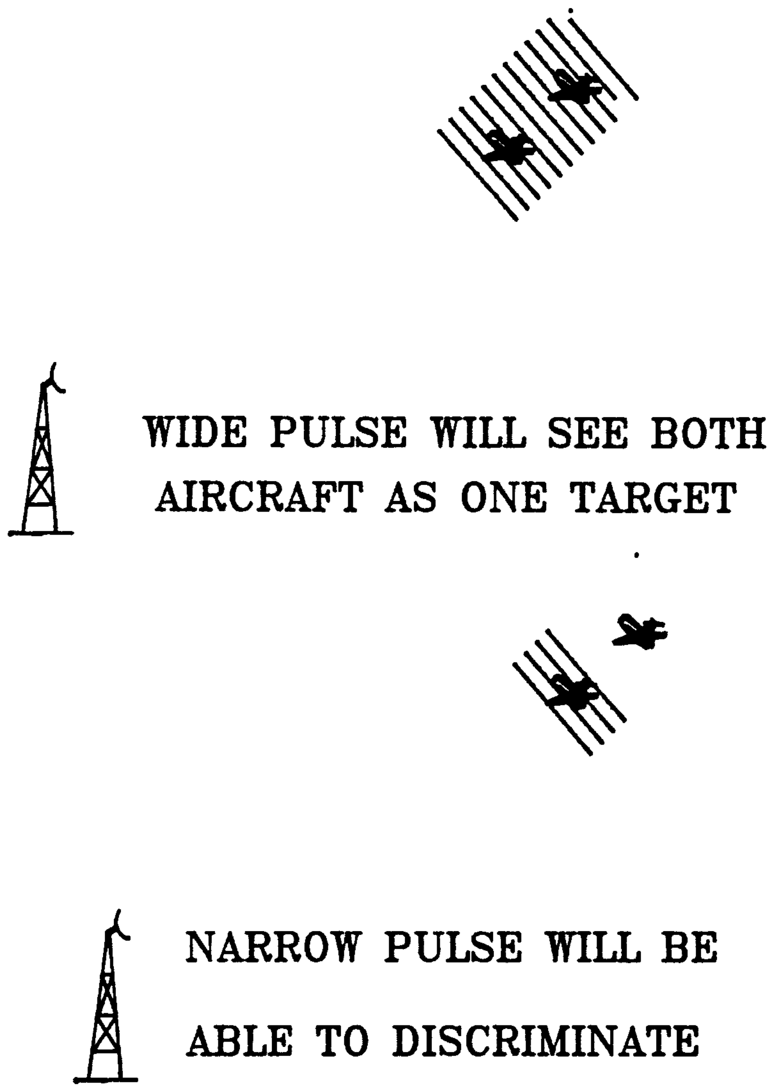


fig. 4.6:1

THIS IS AGAIN GOVERNED BY THE PULSE DURATION.

To measure range, either of single or multiple targets, any pulsed radar measures the time difference between the transmitted and received pulse. What must be considered is that the timing 'mark' used will be that moment in time when the leading edge of the pulse was formed, not the entire pulse duration. However any return 'echo' will be at the full pulse duration. This means that should there be *any additional targets separated in range of less than the half the pulse duration, its returning 'timing mark' will be contained within the time envelope of the first returning pulse and be obscured.*

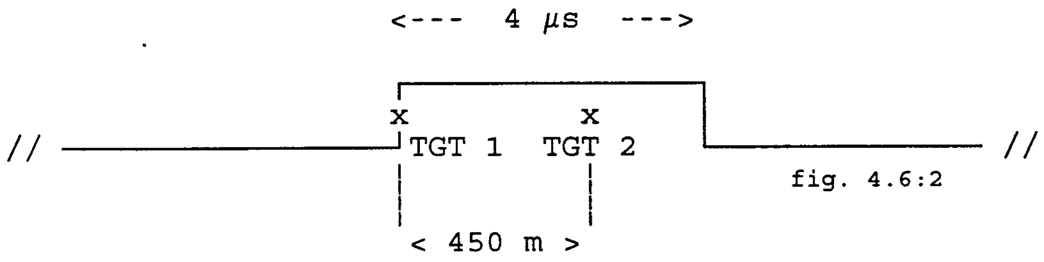


fig. 4.6:2

In the above there are two targets on the same bearing but separated in distance by 450 metres. The radar has a 4μs pulse. In radar, the minimum range this pulse duration would be able to detect would be:

$$\text{PD} \times 150\ \text{m}/\mu\text{s} = 4 \times 150 = \mathbf{600\ metres}$$

So both targets would be seen as just ONE RETURN ECHO, the radar would be unable to resolve that there were two.

If **the PD is now shortened** to say **2μs,** then the pulse now occupies only :

$$\text{PD} \times 150\ \text{m}/\mu\text{s} = 2 \times 150 = \mathbf{300\ metres}$$

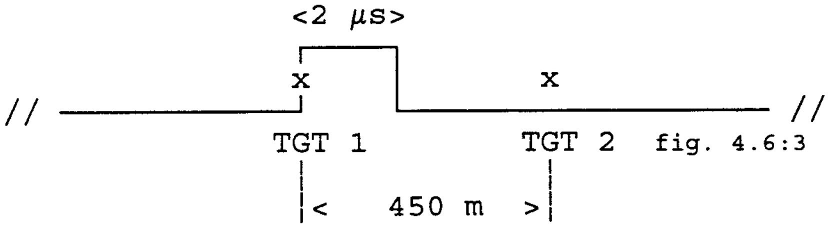


fig. 4.6:3

We can see that the radar receiver would have time to detect the first returning 'echo' fully before the second 'echo' pulse arrived. So it would detect TWO DISTINCT RETURN ECHOES, it has resolved the range difference between Target 1 and Target 2.

THE SMALLER THE PD,
THE LOWER THE MINIMUM RANGE AND THE BETTER THE RANGE RESOLUTION.

HOWEVER, NOTE THAT THE SMALLER THE PD,
THE HIGHER THE PRF (TO MAINTAIN DUTY CYCLE)
THEREFORE THE LOWER THE MTUR.

4.7 - Pulse Power and the Duty Cycle

DEFINITION

THE DUTY CYCLE IS THE RATIO OF THE PULSE DURATION (TRANSMITTER ON) TO THE PULSE REPETITION INTERVAL (TRANSMITTER OFF)

In any radar design, the pulse must contain sufficient energy to detect the smallest target at the maximum range. Consider however, the structure of a pulsed radar signal.

The transmitter is only switched on for a very short period of time, the pulse duration, then switched off as the receiver listens for the target echo before being switched back on at the rate determined by the designed maximum range, this rate of course being the PRF.

ONLY FOR THAT PORTION OF TIME THAT THE TRANSMITTER IS ON CAN MAXIMUM ENERGY, PEAK POWER, BE DIRECTED TOWARDS THE TARGET.

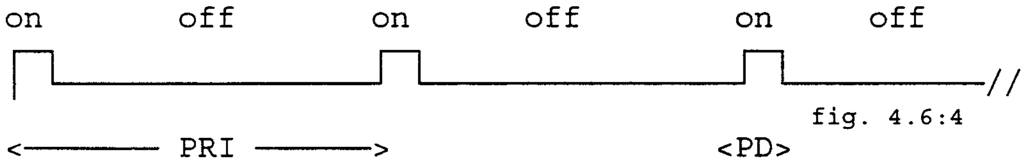


fig. 4.6:4

During the time until the next pulse is transmitted, no power is used. So the **AVERAGE POWER** that can be directed towards a target is the peak power times the ratio between power on (PD), and the length of time the transmitter is switched off (PRI). This ratio is known as the **DUTY CYCLE.** In common radar design, a ratio of 1 : 1,000 (0.001) on/off times is normal.

The duty cycle is important in radar design as components used are rated to cope with the average power, even domestic appliances can handle the power spike that occurs when switched on as it is present for only an extremely short time. To ensure this remains as constant as possible, any change in transmitted parameters (PD or PRF) must be compensated by changing the other. So if the PRF is halved, to increase range say, the PD must be doubled to preserve duty cycle and operators should be prepared for this if the PRF changes.

$$\textbf{AVERAGE POWER} = \textbf{PEAK POWER} \times \textbf{DUTY CYCLE}$$

conversely,

$$\textbf{PEAK POWER} = \frac{\textbf{AVERAGE POWER}}{\textbf{DUTY CYCLE}} \text{ (Watts)}$$

$$\underset{\text{(Ratio)}}{\textbf{DUTY CYCLE}} = \frac{\textbf{PD}}{\textbf{PRI}} \quad \text{however, since} \quad \frac{1}{\textbf{PRI}} = \text{PRF},$$

$$\text{then DC also} = \textbf{PD} \times \textbf{PRF}$$

Note that some modern radars don't change PD when PRF changes but they compensate by altering the output power or employing FMICW (Frequency Modulated Interrupted Carrier Wave) techniques where the duty cycle can be as high as 0.5. (i.e. 50% of time transmitting, 50% of time receiving)

Should **POWER NEED TO BE INCREASED**, say **TO INCREASE RANGE**, then to maintain the duty cycle PD / PRI relationship will have to be changed as follows :-

INCREASE PD - DECREASE PRF

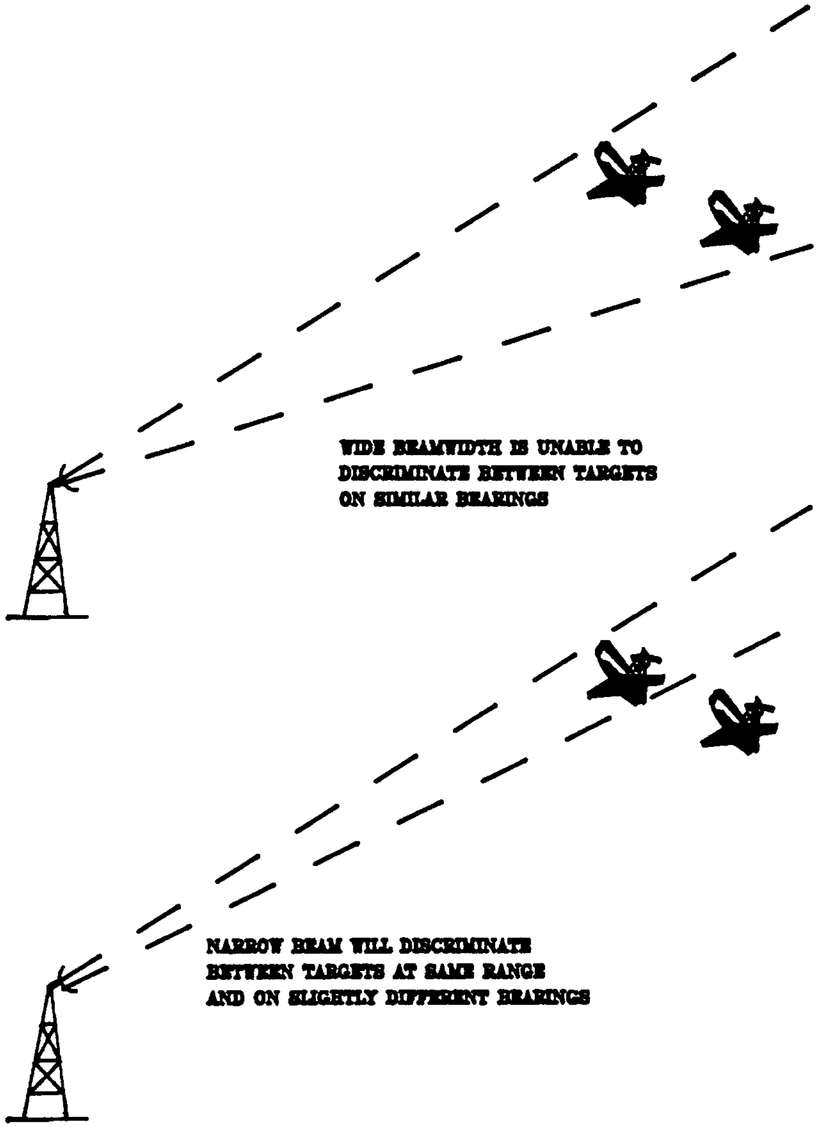
Where **LOWER POWER** is required, ie. short range, then

DECREASE PD - INCREASE PRF

Note that **AN INCREASE IN POWER WILL NOT INCREASE RANGE BY THE SAME MAGNITUDE,** ie. doubling the power output will not double the range, as the full engineering radar range equation shows that power **WILL ONLY INCREASE TO THE FOURTH ROOT.** So a doubling of power, $2 \times Pt$, will result in a range increase of only some 18% ($\sqrt[4]{2} \times Pt$). A costly process better achieved in other ways as we shall see.

4.8 - Beamwidth

BEAMWIDTH GOVERNS THE ABILITY OF A RADAR TO RESOLVE BETWEEN TARGETS AT THE SAME RANGE BUT CLOSE IN BEARING.



WIDE BEAMWIDTH IS UNABLE TO DISCRIMINATE BETWEEN TARGETS ON SIMILAR BEARINGS

NARROW BEAM WILL DISCRIMINATE BETWEEN TARGETS AT SAME RANGE AND ON SLIGHTLY DIFFERENT BEARINGS

fig. 4.8:1

The beamwidth of an antenna is determined by two factors, its **SIZE** and operating **WAVELENGTH** (FREQUENCY).

As stated previously, the radar antenna's beamwidth governs its ability to resolve between targets at the same range but close in bearing. For instance, a radar antenna with a beamwidth of say 4° would see two targets only 2° apart as one strong echo as they would both be within the beam at the same time. A narrower beamwidth, say 1°, would be able to resolve the fact that there were two targets as only one would be within the beam at any one time.

Can be calculated, for full parabolic dish, by the following formula:-

$$\text{BEAMWIDTH} = \frac{67 \times \lambda}{\text{DISH DIAMETER}}$$

(Note that the constant will vary as depends on how well power distributed over antenna. For calculation purposes within this document, taken as 67)

Take a radar operating on 3,000 MHz with a 6.7 m dish.

$$\text{Beamwidth} = \frac{67 \times 0.1 \text{ m}}{6.7 \text{ m}} = 1^\circ$$

If we make the dish smaller, say down to 3.35 m then

$$\text{Beamwidth} = \frac{67 \times 0.1 \text{ m}}{3.35 \text{ m}} = 2^\circ$$

THE **SMALLER THE ANTENNA**, THE **BROADER THE BEAMWIDTH** CONVERSELY THE **LARGER THE ANTENNA**, THE **NARROWER THE BEAMWIDTH**.

ALSO NOTE

THE HIGHER THE FREQUENCY (SHORTER THE WAVELENGTH) THE SMALLER THE ANTENNA REQUIRED FOR A GIVEN BEAMWIDTH.

LOWER THE FREQUENCY (LONGER THE WAVELENGTH), THE LARGER THE ANTENNA REQUIRED FOR A GIVEN BEAMWIDTH.

Pulse Paint

DEFINITION

THE NUMBER OF PULSES ABLE TO STRIKE THE TARGET DURING THE TIME PERIOD THAT IT IS WITHIN THE RADAR BEAM.

To ensure a satisfactory display on CRT, more than one reflected pulse is necessary. It has been found that; on average, up to 15 pulses are required. The greater the number of pulses striking the target, greater the 'paint', the more return echoes available which combine to give a stronger display response.

Pulse paint can be calculated by the formula :-

$$\frac{\textbf{PRF} \times \textbf{BEAMWIDTH (DEGREES)}}{\textbf{SCAN RATE (DEGREES PER SECOND)}}$$

For example: PRF 540, SCAN CIRCULAR @ 10 SECS/REV, BEAMWIDTH 2°

So PRF (540) × BEAMWIDTH (2°) ÷ SCAN RATE in °/sec (360° ÷ 10 = 36°) = **30 PULSES**

If we NARROW THE BEAMWIDTH TO 1°,

then 540 × 1 ÷ 36 (°/sec) = **15 PULSES**

Other formula transpositions:

$$\frac{\text{BW (DEGS)}}{\text{SCAN (DEGS)}} \times \text{SCAN TIME} \times \text{PRF} \qquad {}^{\circ}\text{/sec} = \frac{\text{SCAN}^{\circ}}{\text{SECS/REV}} \quad \text{or} \quad \frac{\text{BW x PRF}}{n}$$

NARROW BEAMWIDTH, FEWER PULSES ON TARGET
WIDE BEAMWIDTH, MORE PULSES ON TARGET

HIGHER THE PRF, GREATER THE PULSE PAINT. HOWEVER, FASTER THE SCAN RATE, LESS TIME ON TARGET, LOWER THE PULSE PAINT.

Although not required as part of the course syllabus, it should be noted that increasing the pulse paint allows more returned pulses to be integrated for processing by the radar system and can increase Maximum Unambiguous Range.

INTEGRATION FACTOR = $\sqrt{n}$ (where n = number of pulses)
embodied as IMPROVEMENT INDEX = $\sqrt[4]{}$ Integration Factor

4.9 - Polarisation

An electromagnetic wave is composed of moving fields containing electric and magnetic energy. These are at right angles to each other, the illustration showing the electrical component vertical with the magnetic horizontal. The polarisation of any received wave can be taken as the plane in which the electrical component is measured at maximum signal strength.

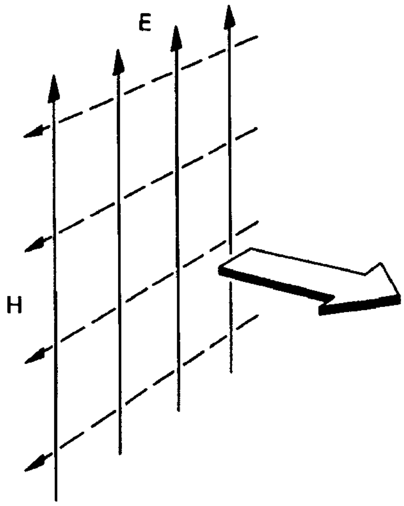


fig. 4.9:1 In free space, a wave's magnetic field is always perpendicular to its electric field. Direction of travel is perpendicular to both.

For maximum signal we need to match our antenna feeds to the correct plane. However, due to possible distortion in the signal from multipath reception say, the received polarisation may not equate to the transmitted one, we can only report what we actually receive.

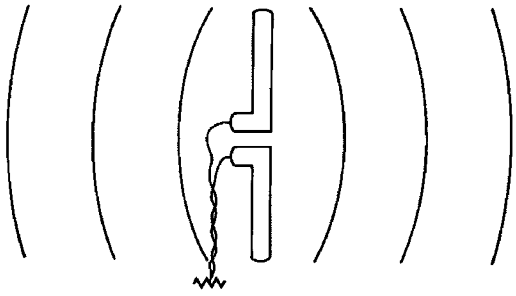


fig. 4.9:2 If a wave's electric field is vertical, the wave is said to be vertically polarised.

Circular Polarisation

Not all signals are transmitted using linear polarisation. It is known that ***RAIN DROPLETS WILL 'TWIST' THE SIGNAL** and the **ORIENTATION OF THE ELECTRICAL COMPONENT IN THE RETURN ECHO WILL BE 90° OUT OF PHASE COMPARED TO THAT TRANSMITTED***. If we drive an RF from two different transmitters whose horizontal and vertical linear polarisations are 90° out of phase with each other, it will PRODUCE A SIGNAL WHOSE PHASE CHANGES THROUGH 360° AT THE RF RATE.

This can be used to **ELIMINATE CLUTTER CAUSED BY RAIN**.

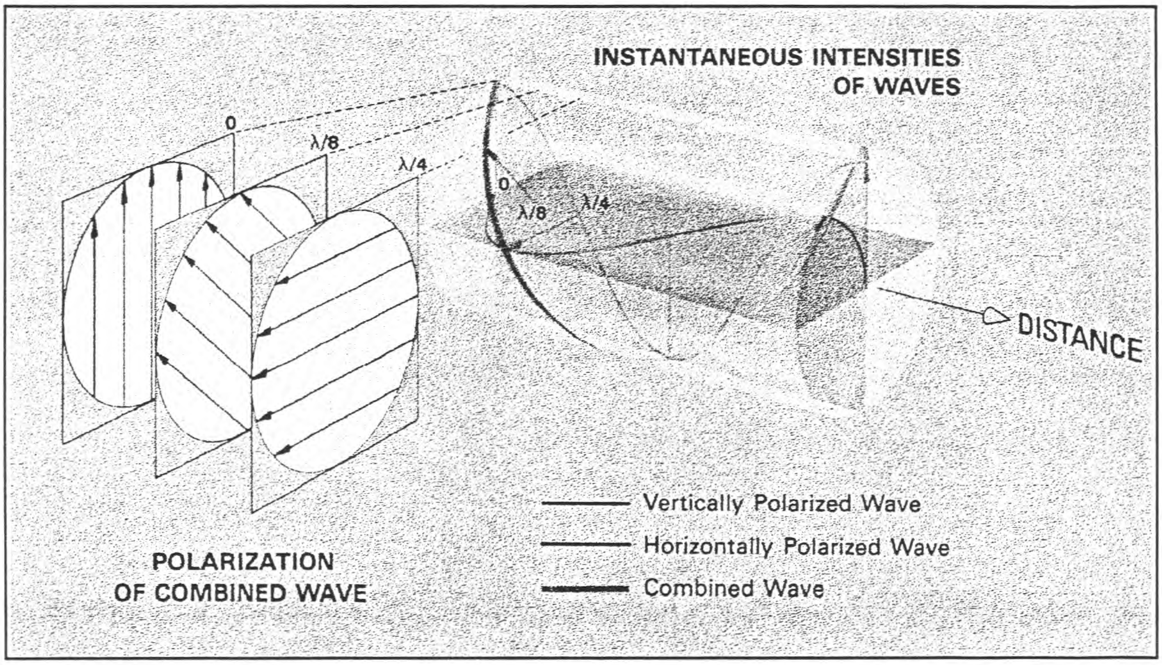


fig. 4.9:3

If a radar signal is transmitted using circular polarisation with a LEFT HAND sense, any rain droplets encountered will '*twist*' the signal and cause reflections to be in the RIGHT HAND sense

However a normal target has a variety of differently angled reflective surfaces and will return 'echoes' in both the LEFT HAND and RIGHT HAND senses. So if the radar receiver uses LEFT HAND sense returns only, the rain clutter will be eliminated.

5. SCANNING TECHNIQUES (Electromechanical)

In order to increase a radar's capability for detection or surveillance, most antenna and/or the feed, are moved physically in such a way as to encompass a desired area of space depending on its intended function.

Scan types are divided into two broad categories, those having a

SLOW SCAN RATE (measured in **seconds** per revolution),

and those with a

FAST SCAN RATE (measured in **hertz**).

5.1 - Search Scans (Slow Scans)

CIRCULAR

The most common, covers a search arc of 360 degrees at a constant rate from 1 to 100 seconds per revolution. This scan type is used by **EARLY WARNING, NAVIGATIONAL, GROUND CONTROLLED INTERCEPT AND TARGET ACQUISITION** RADARS as well as performing other functions where a full 360 degree scan is required.

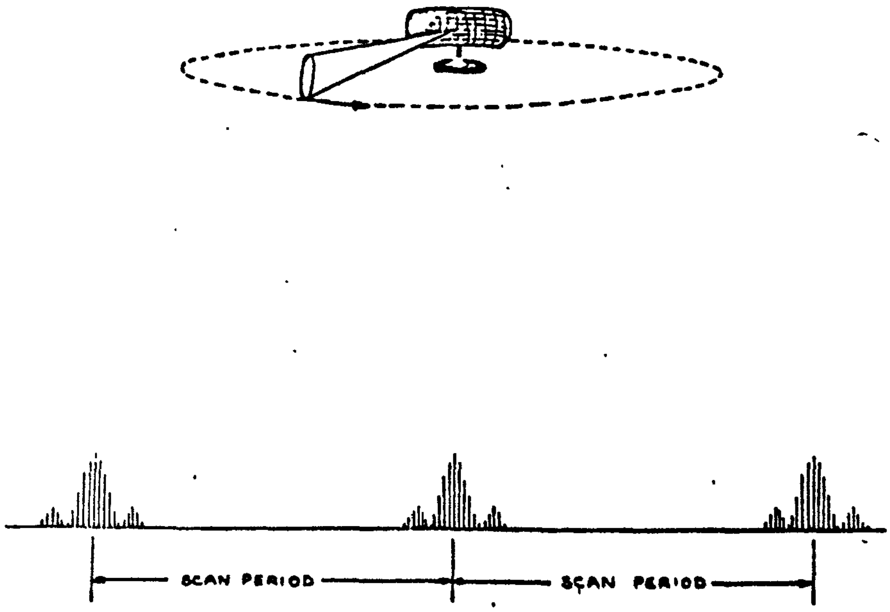


fig. 5.1:1

By scanning the beam within a 360° arc, the radar will not only be able to determine the range of the target but also its bearing (azimuth). A radar which has the ability to determine the position of a target in both **range and bearing**, ie. in **two dimensions**, is commonly referred to as a '***2-D Radar***'. An increasing number of modern radars are not only able to determine the range and azimuth of the target but its height as well. Such radars have the capability of measuring the angle of elevation between itself and the target. Having measured its range, simple trigonometry can be applied to calculate the targets height (altitude). Since we now have **range, azimuth and height** information, that is target data in **three dimensions**, this technique produces a '***3-D Radar***'.

In practise there are various methods used to obtain the target angle from a circularly scanning radar. One method, shown below, involves creating a number of beams, each one produced being at a slightly different angle in the vertical plane. The strongest return echo from the target will be received in the appropriate beam whose angle of elevation corresponds to that of the target.

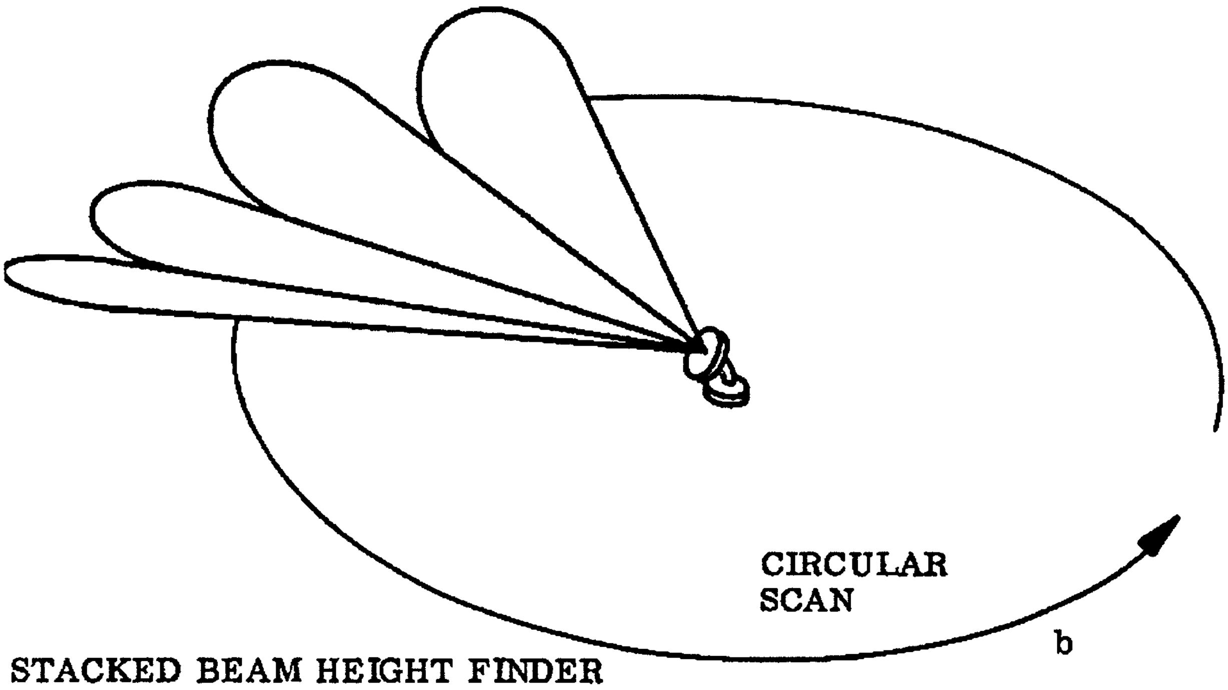


fig. 5.1:2

Common Operating Modes of Circular Scanning Radars

The most widely used search scan type, its 360° coverage suiting itself to radar systems providing the following functions.

EARLY WARNING

Alerts other systems to the approach of possible targets giving as much warning as possible to allow defence systems to react to oncoming threat.

TARGET ACQUISITION

Provides missile systems with dedicated target information, can be from either fixed or mobile platforms.

GROUND CONTROLLED INTERCEPT (GCI)

Similar to the Early Warning role but provides information direct to air defence sources. Allows friendly fighters to be vectored towards incoming enemy attacking force via ground-to-air voice or data links.

AIRFIELD SURVEILLANCE RADAR (ASR)

Virtually the civilian equivalent of GCI, controls aircraft movements around airfields. Some other civil air radar terminology includes '*Terminal Marshalling Area* (TMA)', '*Air Route Surveillance* Radar (ARSR)' and '*Airfield Surface Detection Equpment* (ASDE)', the latter being able to detect aircraft and vehicle movement on and around airfield runways and terminal buildings.

SURFACE SEARCH

Shipborne role enabling surrounding area to be monitored for other ship movement.

GROUND MAPPING

Airborne role used by tactical/strategic bomber aircraft to provide high definition map of the ground beneath and ahead to verify terrain during bombing missions. Similar techniques are used in the specialised '*Anti-Submarine Warfare* (ASW)' radars which can detect a submarines periscope/snorkel amongst sea clutter.

NAVIGATION

Used by both ships and aircraft. In the shipborne role, provides coastal profile information to allow 'blind' navigation of coasts, waterways etc. When used by aircraft, can be especially useful in maritime patrol to monitor shipping movements around the immediate aircraft plot.

Other roles that can use this type of scan include harbour and battlefield surveillance as well as dedicated weather radars.

V-Beam

A form of circular scanning radar which uses two antenna, one producing a vertical beam, the other slanted at 45 degs. The system measures the time difference between the received echo from each to determine target altitude, the lower the target, the less the time difference. Never found favour in service as more accurate height information given by dedicated height finders and more sophisticated FRESCAN techniques.

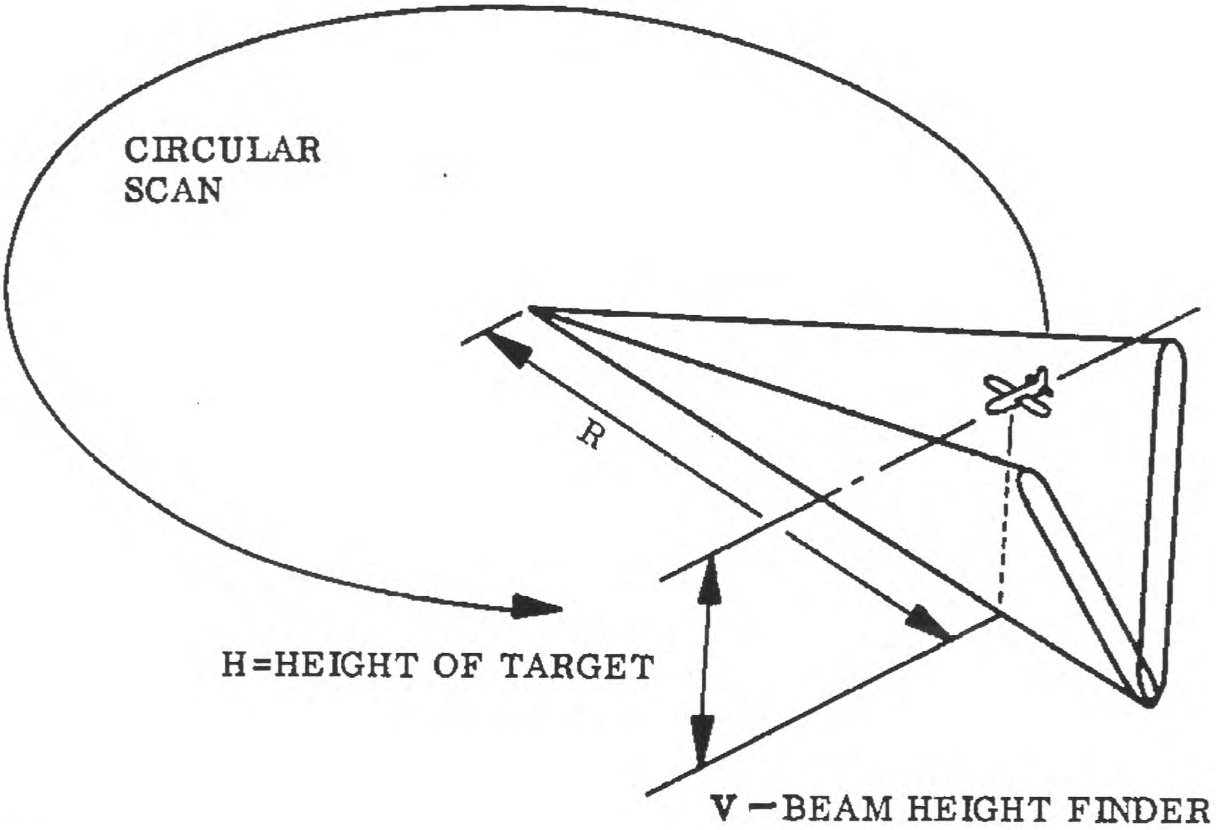


fig 5.1:3

AN/CPS-6B 'V-Beam' radar showing both horizontal and 45° antenna. This was one of the first '3-D' radars to enter service and used five transmitters, each producing a different radio frequency. The horizontal antenna created three stacked beams in elevation while the remaining two transmitters produced beam from the slanted antenna.

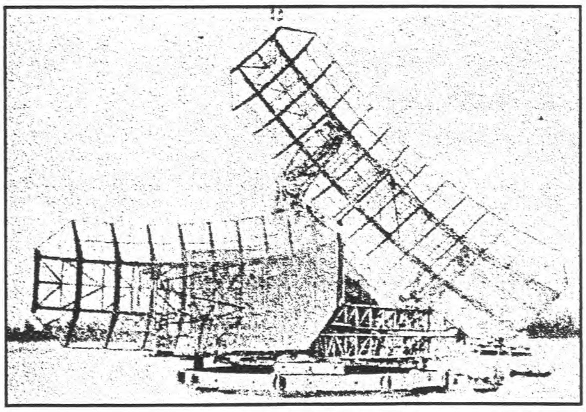


fig 5.1:4

Bi-Directional Sector

Where the radar covers only a sector of space, either in the **HORIZONTAL** or **VERTICAL** plane by moving the beam backwards and forwards within the sector. This produces a characteristic beam pattern which enables us to differentiate between a genuine sector and a psuedo circular. Vertical sectors are normally associated with **HEIGHT FINDERS** while horizontal can be used for **GROUND MAPPING** by aircraft.

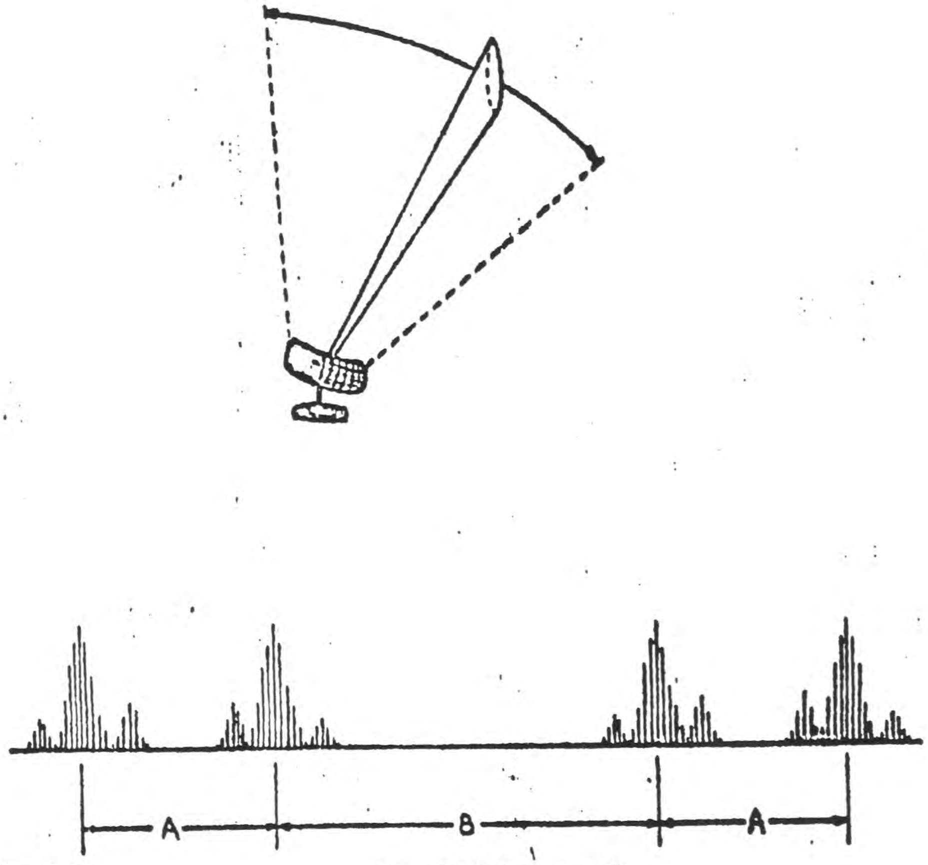
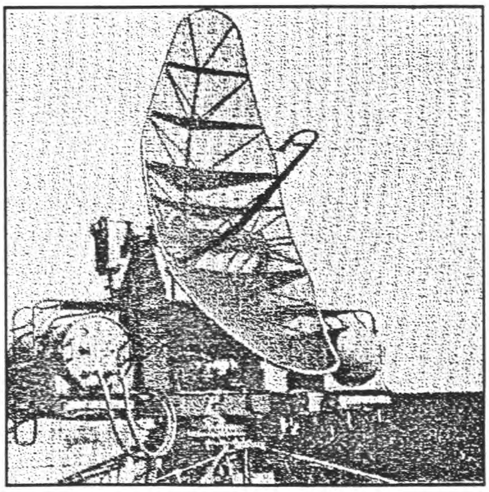


fig. 5.1:5

Scan Period = A + B



AN/TPS-10D Height-Finding Radar displaying typical mechanical '*nodding*' antenna. This produces a narrow beam in the vertical plane but wide in the horizontal. The narrowness of the vertical beam allows accurate angle of elevation measurements to be made of the target. Once this has been electronically correlated with the target's range, its true altitude can be calculated.

fig. 5.1:6

Precision Approach Radar (P.A.R)

PARs are used to guide aircraft along two beams, one in the horizontal plane the other in the vertical, to assist in landing during adverse weather conditions, ie. fog. To achieve this, commonly two bi-directional sector beams are used in these planes, either alternately or with them interleaved. The advantage of the latter, despite being more complex in practice, being a higher data rate as the aircraft will be illuminated more often. Each sector is normally displayed on a separate 'scope showing range and any horizontal deviation from the prescribed glidepath or vertical deviation from the glideslope to the airfield.

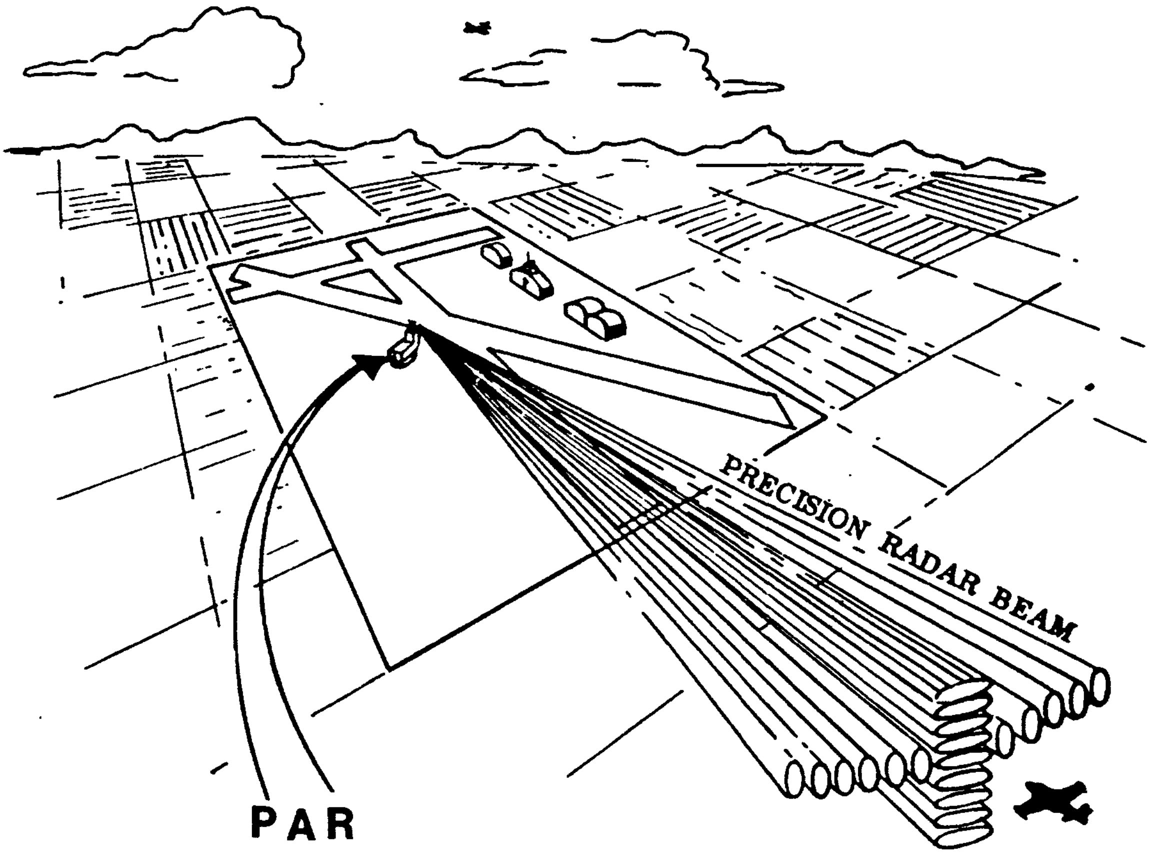


fig. 5.1:7

Precision Approach Radars

As described overleaf, some Precision Approach Radars have separate displays for the Vertical (Glideslope) and Horizontal (Glidepath) beams. These can be seen below with the Glideslope in the upper display, and the lower displaying the Glidepath.

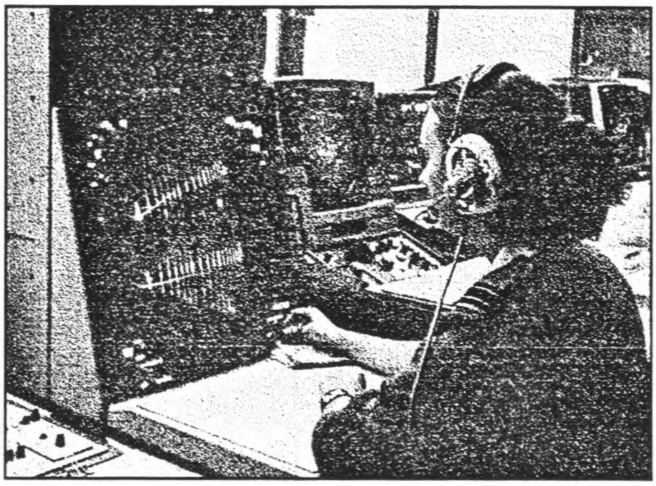


fig. 5.1:8

The vertical and horizontal sector beams can be scanned mechanically, as shown below on the left, or electronically, shown by the AN/FPN-62 on the right.

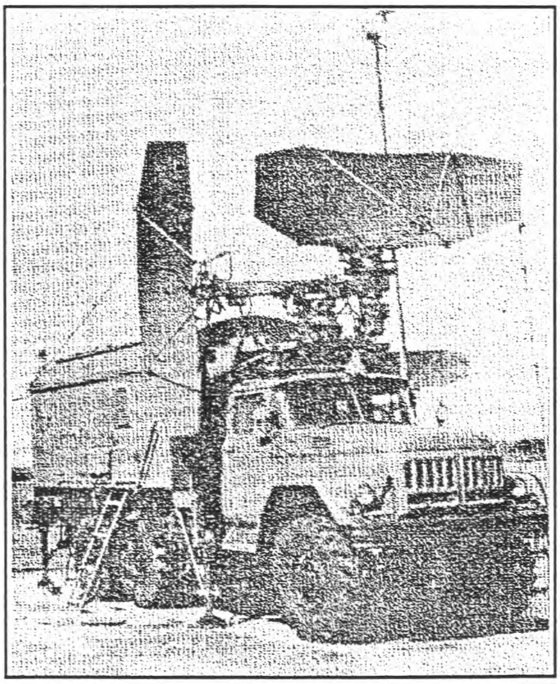


fig. 5.1:9

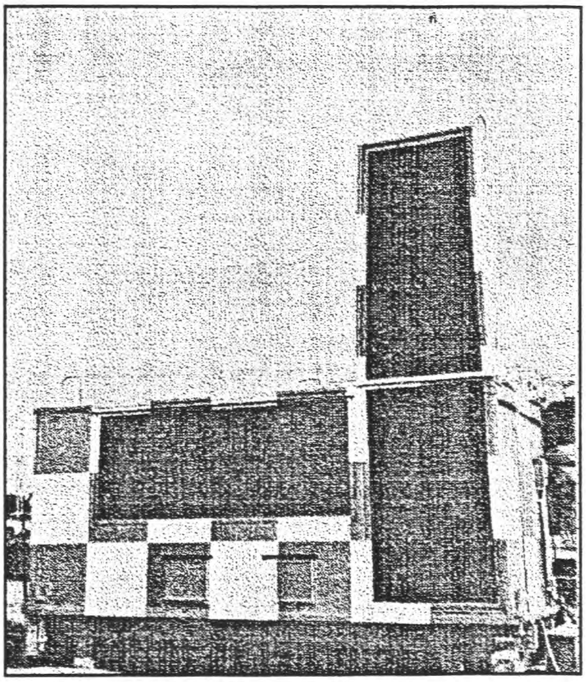


fig. 5.1:10

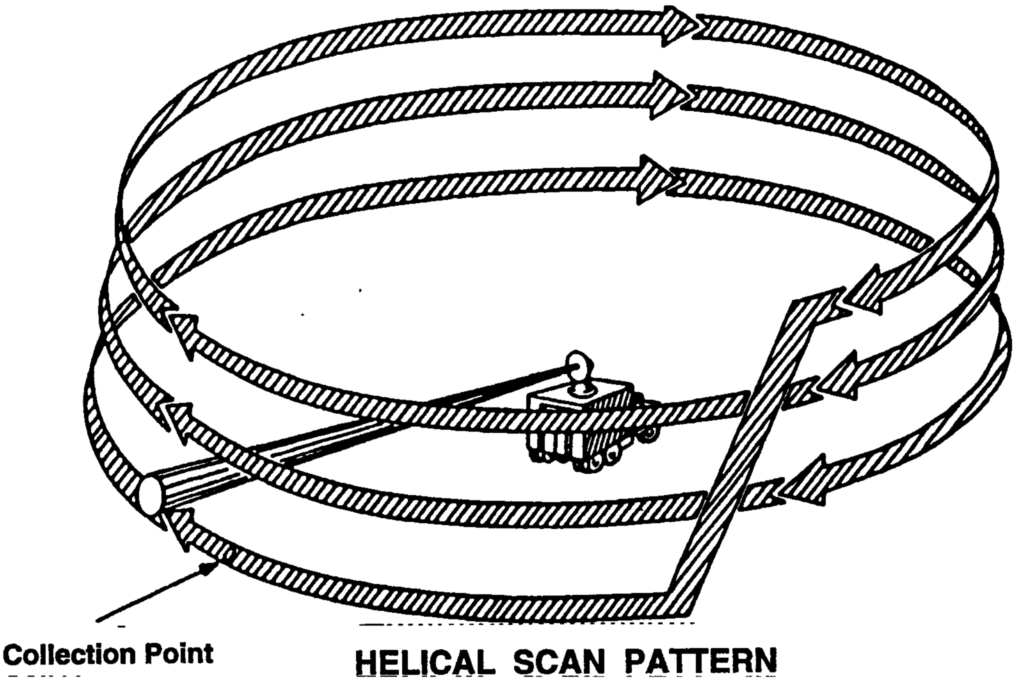
HELICAL

With a Helical scan, the beam is made to scan in azimuth through 360° but it steps in elevation to discrete levels, referred to as bars, in a **'corkscrew'** pattern.

Two measurements can be made, the **FRAME TIME** and a **BAR RATE.**

Frame Time	*The total time taken, in seconds, for the complete scan cycle*
Bar Rate	*The number of times per second, in Hertz, each bar is illuminated*

Scanning technique utilised in Meterological and Fire-Control Radars.



HELICAL SCAN PATTERN

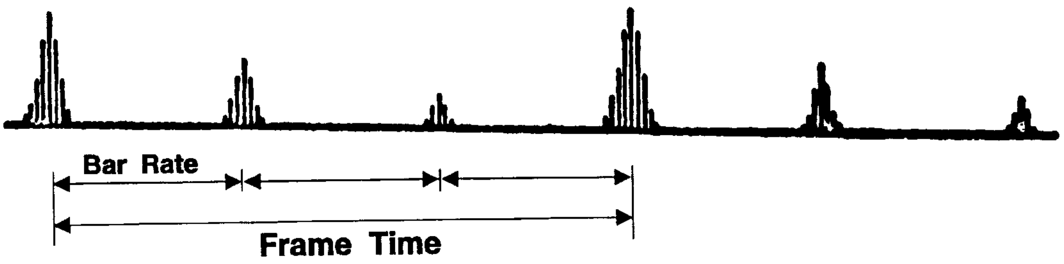


fig.5.1:11

SPIRAL

A centre to circumference spiral, **'Swiss Roll'** effect, may spiral back or have fast fly-back with FRAME TIME and BAR RATE.

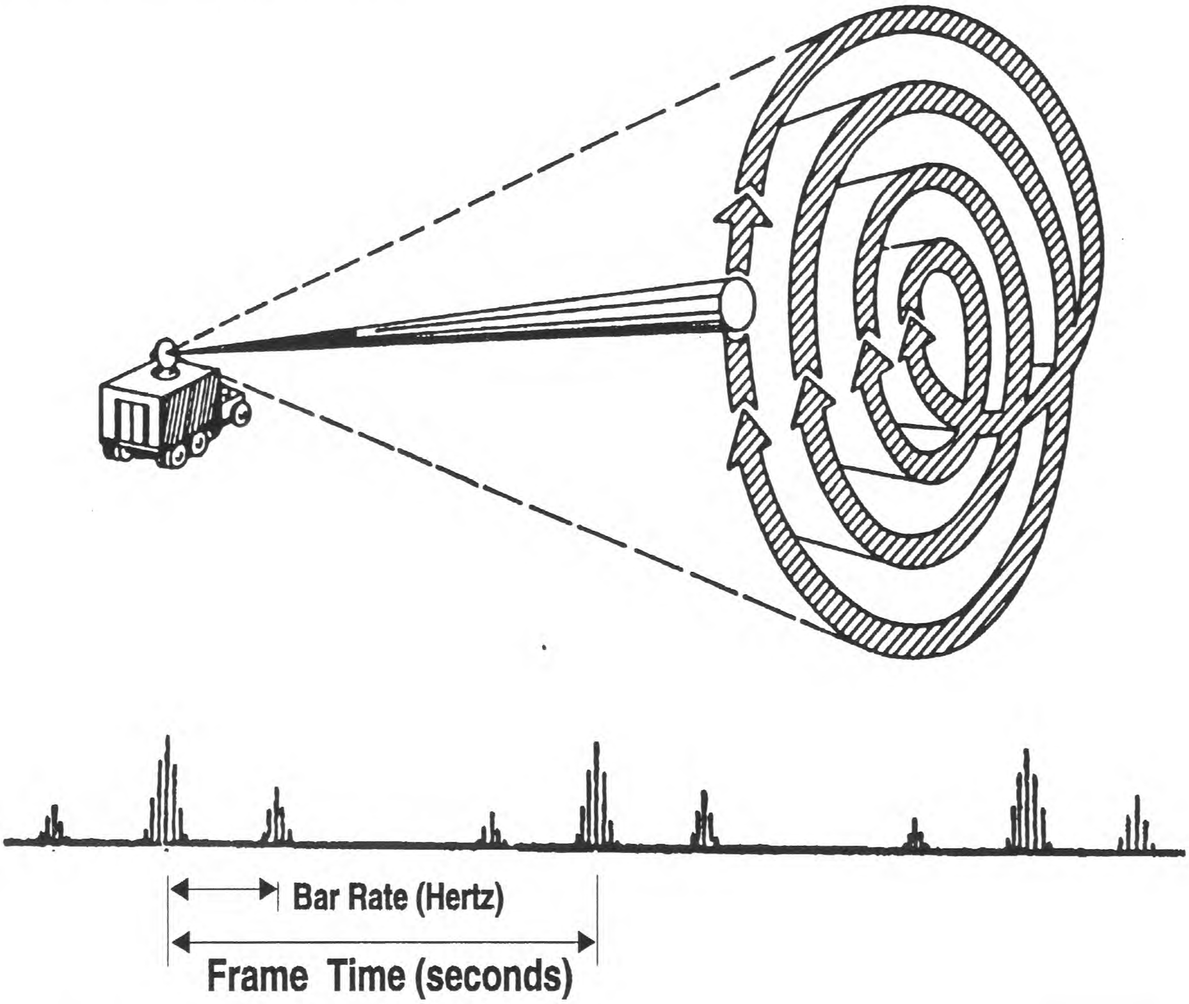


fig. 5.1:12

Normally associated with gunnery fire-control radars on land and fitted as '*tail defence*' radars on some military aircraft.

One of the few aircraft equipped with such a radar, the Russian Tupolev TU-22 BLINDER medium bomber, is shown on the right. This controls the single barrelled 30mm cannon which is believed to fire a mixture of chaff and incendiary rounds as ECM/IRCM (Electronic/Infra-Red CounterMeasures) against attacking fighters.

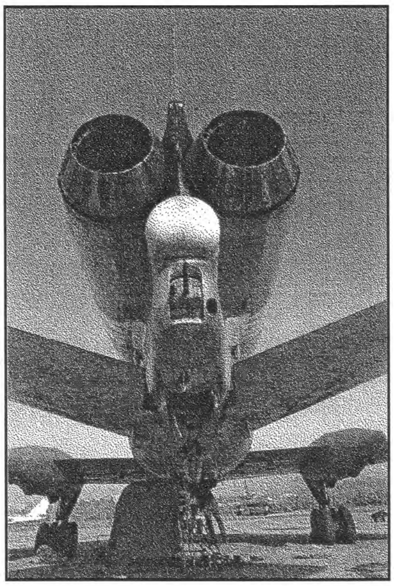


fig. 5.1:13

RASTER

Where volume of space covered by a series of sweeps over any number of levels, typically 2 - 8. One complete operation of the raster gives a **FRAME TIME** and the individual sweep being the **BAR RATE**. Unless number of bars known or very evident, usually only the overall frame time measurable. Used commonly by Air Intercept (A.I.) radars.

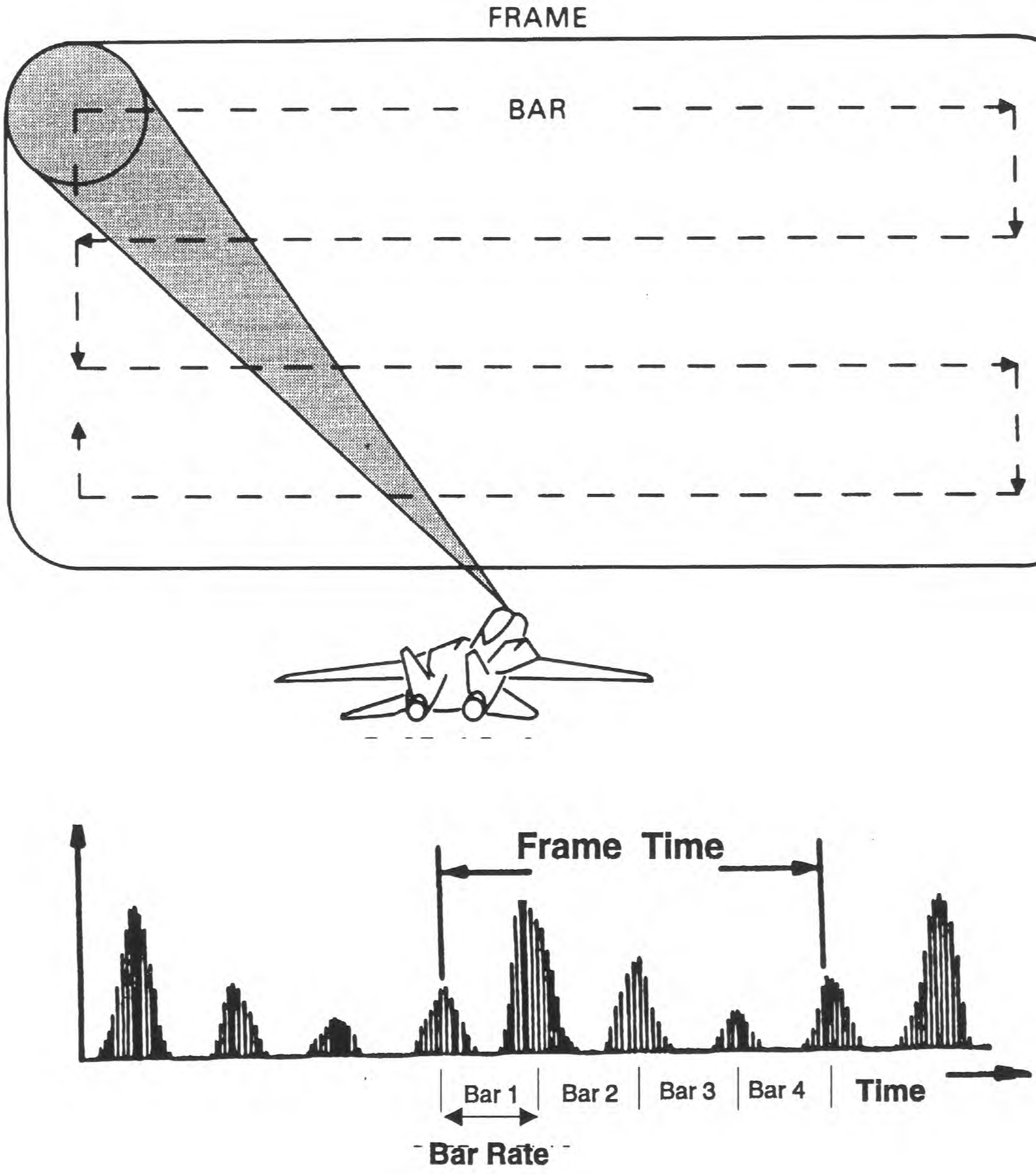


fig. 5.1:14

$$\text{Bar Rate (Hz)} = \frac{\text{Number of Bars}}{\text{Frame Time (secs)}}$$

Manual / Irregular

Most radars, especially landbased, can stop their normal scan period and be manually moved as in a height-finder being turned to commence scanning another portion of space. Where the radar scanner is being moved in a random manner with no apparent rate, then the scan is deemed to be **IRREGULAR.**

Steady

A steady, or non-scanning, signal can either be an intentional mode or unintentional, where radar just stops scanning. Most radars are therefore capable of producing a steady scan.

Sector Blanking

Although not a scan, this technique is sometimes used on circular scans whereby the transmitter is switched off for part of the scan, even though the antenna may continue on its scan path. This prevents the radar from transmitting while pointing towards objects that may either be interfered with by the transmission (other radar / electronic equipment) or may be close enough to cause damage to the radars receiver by reflecting sufficient energy back. Is also used to blank out portions of scanned area not required, ie. nearby hills etc. In practice may be detected by sharp cut off in received beam instead of normal gradual drop in amplitude as main beam passes.

5.2 - FAST SCANS

Radars that employ fast scan types, that is where the time taken to complete one scanning revolution is less than 1 second/rev, are used generally for **TRACKING** purposes.

These are employed when a target(s) has been acquired by an *EARLY WARNING, SURVEILLANCE* or *TARGET ACQUISITION* radar and its position is therefore known. To enable say **FIRE CONTROL** or **MISSILE ASSOCIATED** systems more accurate target information, a **TARGET TRACKING** radar will be employed. Generally a pencil beam is rapidly moved around the target area allowing a far higher data update of the targets movement enabling it to be tracked with far greater precision. Some radars employing fast scans are also capable of observing and following the movements of a target while continuing to scan in a search or acquisition mode. This is known as **TRACK-WHILE-SCAN (TWS)**.

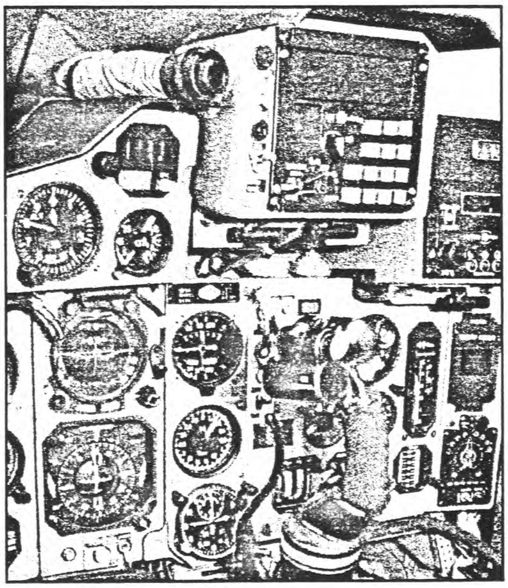
Tracking radars can employ two scanning techniques.

ACTIVE where the transmitted signal is modulated by the scan rate

PASSIVE where the radar transmits a steady, non-scanning beam with the antenna determining target location by scanning the received echoes only.

Common forms of passive scans are:
LORO (**L**obe-**O**n-**R**eceive-**O**nly) and
COSRO (**CO**nical-**S**can-On-**R**eceive-**O**nly).

Some radars are capable of switching from active to passive scanning as a form of **DECM** (**D**eceptive **E**lectronic **C**ounter**M**easure), the non-scanning signal disguising the fact from the target that the radar is now in track mode and is therefore a high priority threat.



Shown left, fig.5.2:1, is the cockpit of a Russian Mikoyan MiG-29 FULCRUM 'A' single seat fighter. Near the bottom right hand corner is the Radar Warning Receiver display. When the aircraft is illuminated by a radar emitter deemed to have a high threat priority, such as an Air Intercept (AI) or Surface-to-Air Missile (SAM) radar, the pilot is alerted and the direction of the emitter is displayed in the appropriate 'attack zone'.

fig. 5.2:1

LOBE SWITCHING

One of the earliest tracking techniques, Lobe Switching employs a number, normally four, of feeds directed towards the radar reflector, each one producing a pencil beam off-set from the others but slightly overlapping its neighbours. The signal is then transmitted sequentially from each feed. Target range is deduced by the normal method but target movement can be tracked as the amplitude return will be determined by its position within the lobing structure. This can be used as an ***ERROR SIGNAL*** to enable automatic tracking, **AUTOTRACK,** of the target. The error signal can be fed to servo motors controlling the azimuth and elevation angles of the antenna. If an error signal is produced, the target must be in whichever lobe quadrant produced it. By using this to actuate the appropriate servos, the antenna is moved until the return from all quadrants is equal, ie **NO ERROR SIGNAL,** the target must then be within the boresight. This is virtually the basis of all automatic tracking techniques.

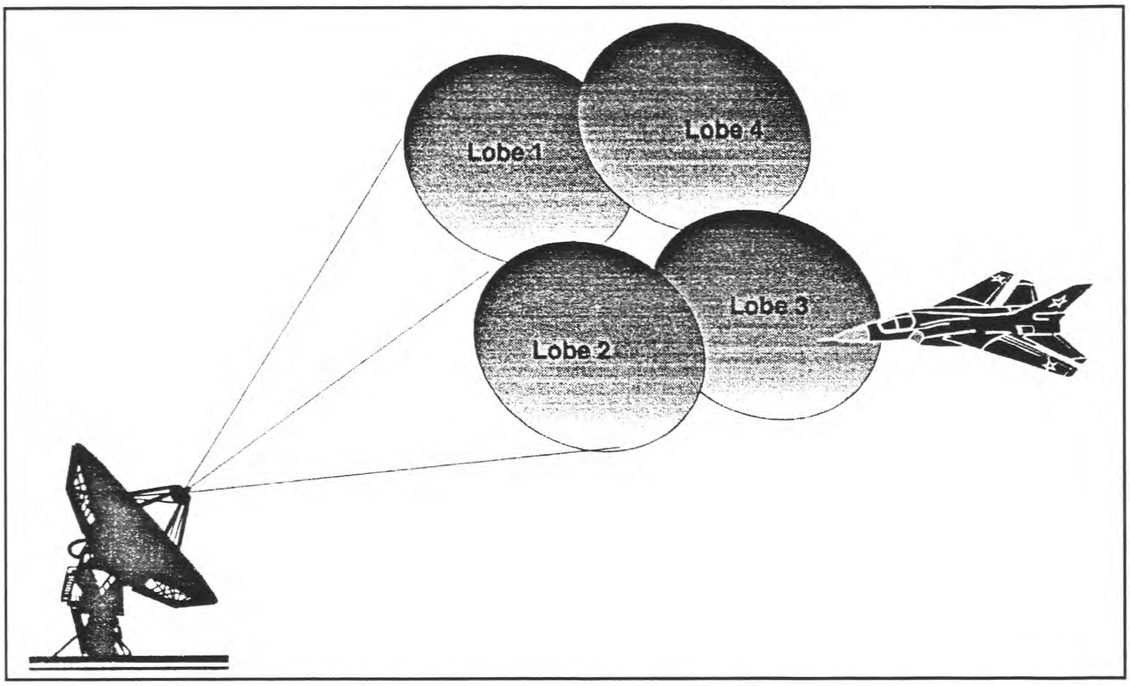


fig. 5.2:2

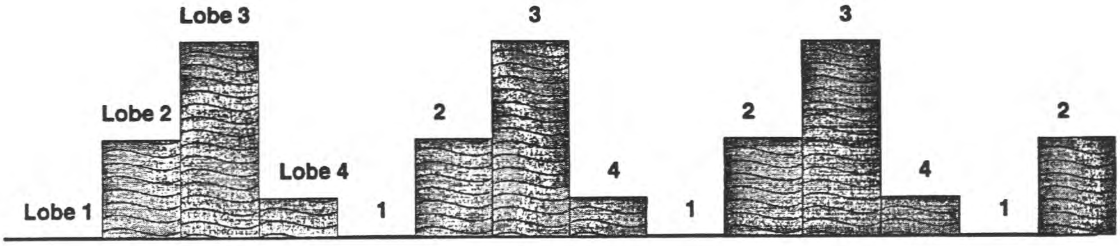


fig. 5.2:3 - Return echo amplitude versus sequential lobing scan time

In the above diagram maximum error signal is being produced from lobe 3 and none from lobe 1, the radar processor will cause the antenna to be moved towards the direction of maximum error signal. No error signal will be created when the echo return amplitude output from all lobes is equal.

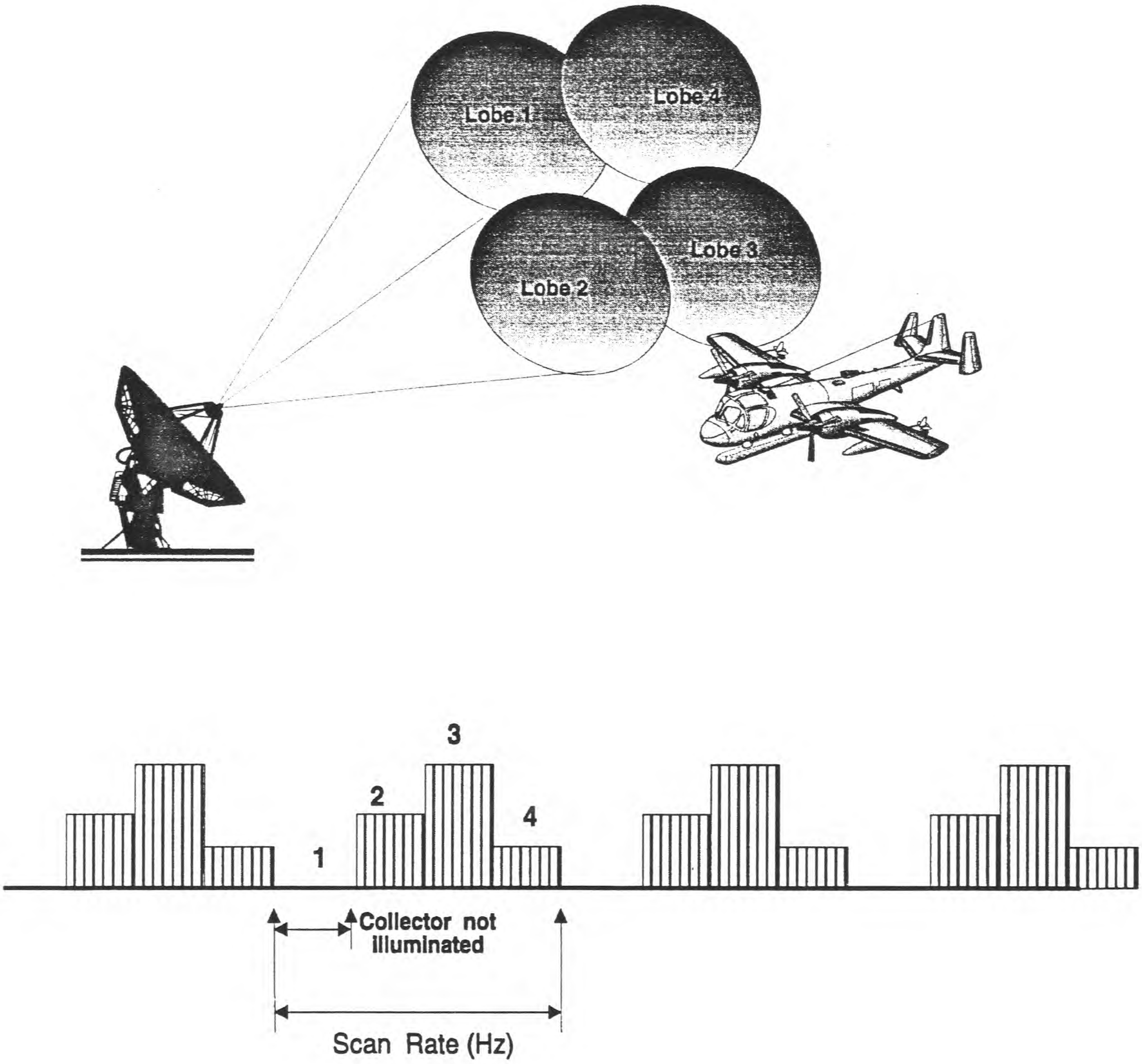


fig. 5.2:4

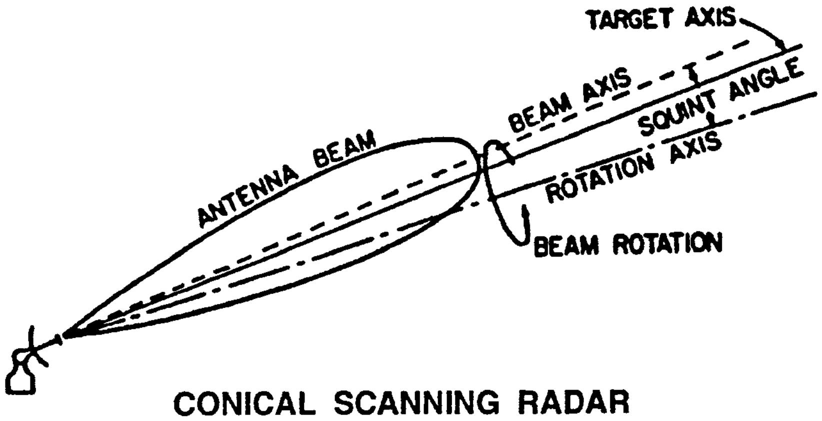
Shown above is a representation of a four lobe switching antenna system described previously.

Depending on the position of the collector relative to the transmitted beams, received signal amplitude will vary. The time versus amplitude plot shown indicates that one of the beams was illuminating an area outside the collectors coverage by the 'missing' portion in the total scan pattern.

CONICAL

A logical extension of sequential lobing, this technique employs an off-set feed. This is rotated continuously rather than stepped sequentially through the beams. The radiated beam formed is cone shaped, hence Conical Scan. As long as the target is off-centre, returned echoes will contain modulation at the scanning rate, an '*error signal*'. Returns will continue to display this until the target is within the radar boresight when the error signal will be zero and the emitter will be '*locked on*' the target.

Two methods of producing the conical scan mechanically are by either rotating the off-set feed, this causing the signal to display rotating polarisation **(ROTPOL)** or spinning the reflector. Here the feed remains in only one plane and the signal will therefore display that polarisation, this being referred to as nutating polarisation **(NUTPOL)**. Due to the inertia caused by spinning a dish in say the nose of an aircraft, in practice it is normal to rotate only the subreflector.



CONICAL SCANNING RADAR

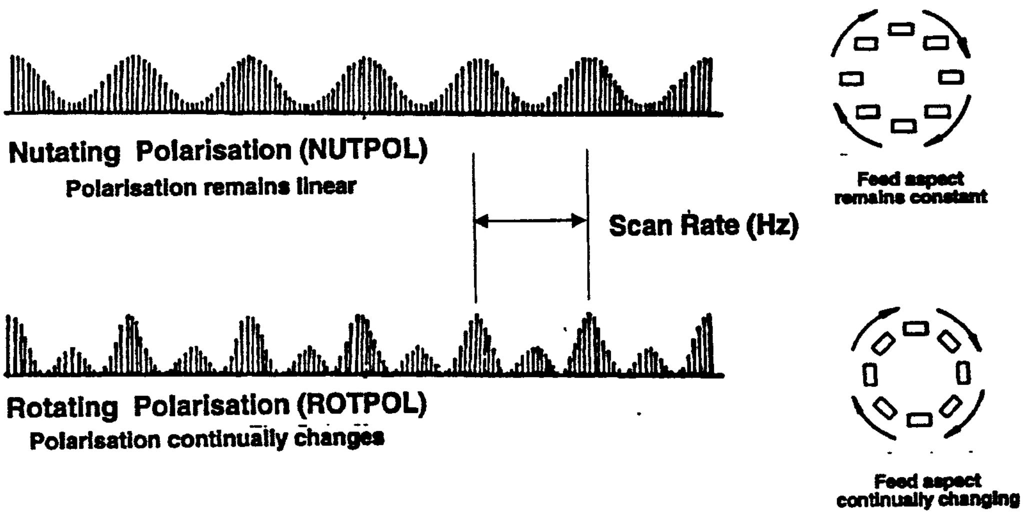


fig. 5.2:5

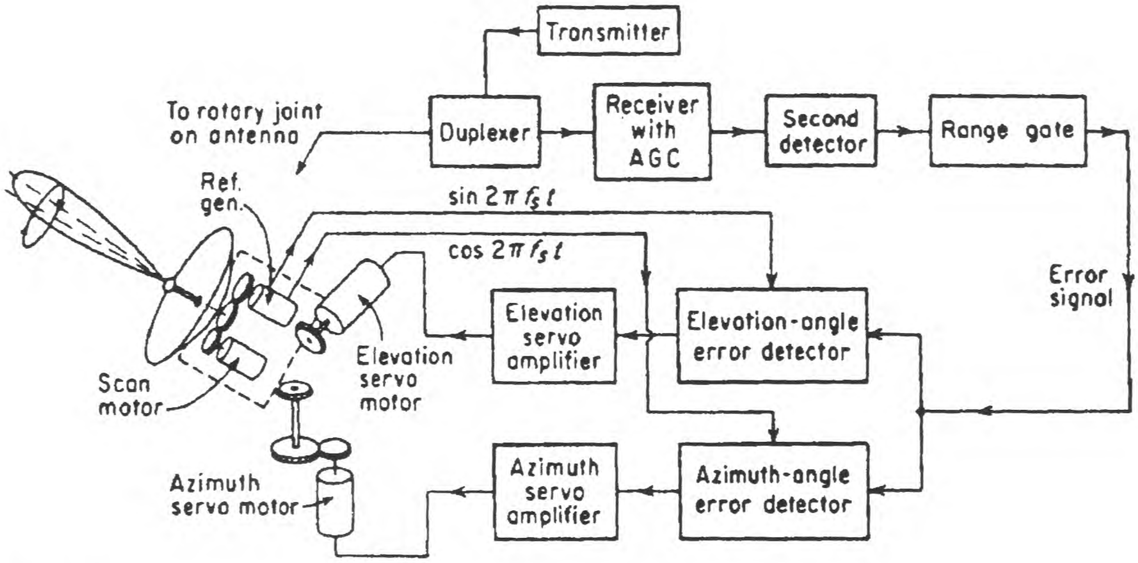


fig. 5.2:6

Diagram showing how '*error signals*' are fed to both the elevation and azimuth servo motors to enable the antenna to be continually '*locked on*' to the target boresight.

Typical use of a conical scanning radar is in directing Anti-Aircraft Artillery (AAA) fire. The rapid processing of target returns allows almost instantaneous 'fall-of-shot' correction

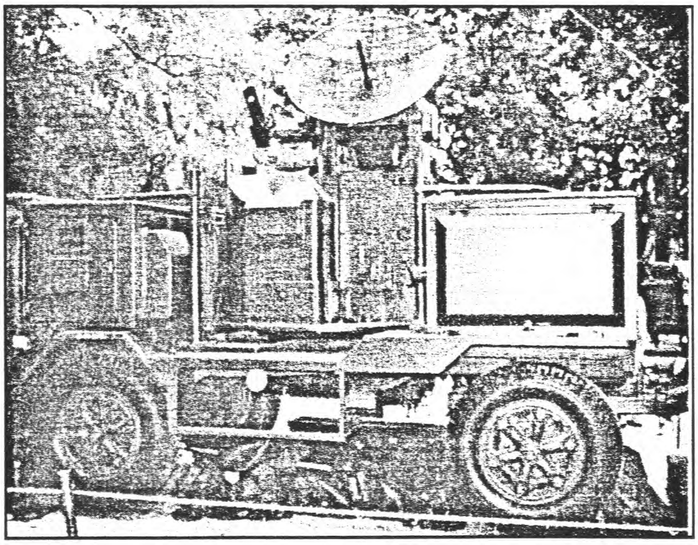


fig. 5.2:7

Some mobile AAA systems are provided with their own tracking radar, while others serve more than one gun battery. The trailer mounted radar shown on the left is an example of the latter. Built by Contraves AG of Switzerland, this particular system known as SUPER-FLEDERMAUS is widely exported throughout the world and serves medium calibre weapons. An optical tracker is mounted to the left of the radar scanner to augment radar tracking.

LOBE-ON-RECIEVE-ONLY (LORO)

Lobe-on-receive-only **(LORO)** utilises a fifth feed, normally at the focal point, which transmits the non-scanning signal. The beam produced by the feed encompasses the individual beams of the four normal feeds which now just sequentially scan in the receive mode only. Error signal produced is processed to provide 'autotrack' in the normal manner. This technique, as well as being capable of providing a DECM capability, is also simpler as only one high-power transmit/receive switch is require compared to four, one per beam, using normal lobe switching.

CONICAL-SCAN-ON-RECEIVE-ONLY (COSRO)

As in LORO, only the received beam is scanned. Under certain reception criteria, the COSRO rate can be detected superimposed on the steady signal. Effect can be simulated by emitting a steady tone from a loudspeaker and placing an electric fan between the speaker and listener.

Illustrated on the right is one of the versions of the FAN SONG target tracking radar for the Russian SA-2 GUIDELINE surface-to-air missile system. This normally uses Horizontal and Vertical Uni-Directional Sectors radiated from the 'trough' type antenna.

However in the '*Passive Scan*' mode, a non-scanning signal is transmitted from the top two parabolic dishes and the *return echoes only* are then scanned by the trough antenna. This can deny to aircraft Radar Warning Receivers (RWRs) the easily recognised apparent on/off keyed signal produced when the troughs radiate.

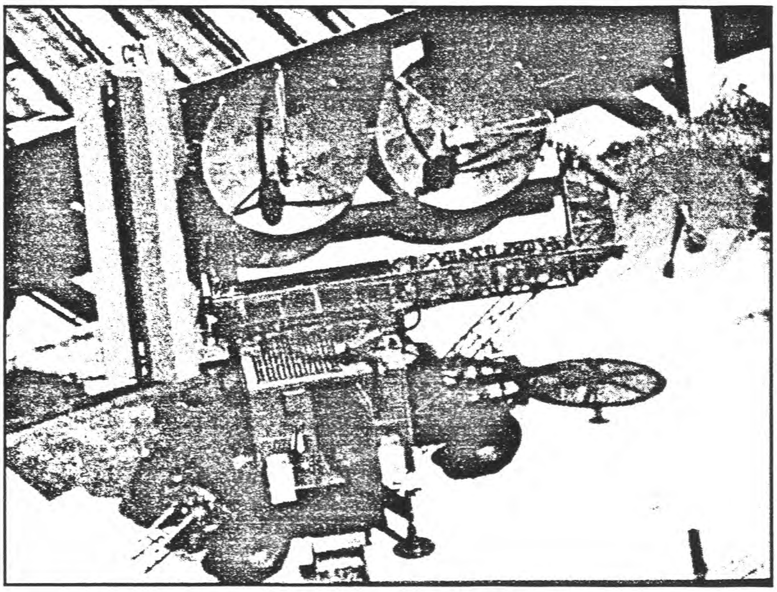


fig. 5.2:8 - FAN SONG target tracking radar complex. Missile guidance signal is transmitted from parabolic dish on the right.

MONOPULSE

One of the drawbacks inherent with both Lobe Switching and Conical scans is that tracking errors occur when returns from the target fluctuate causing scintillation or '*glint*' at or near the actual scan rate on a pulse to pulse basis. To elimanate this, a technique where, by utilising a pair of beams, the phase or amplitude difference present on **EVERY** received pulse is processed to provide '***error signal***' detection as described below.

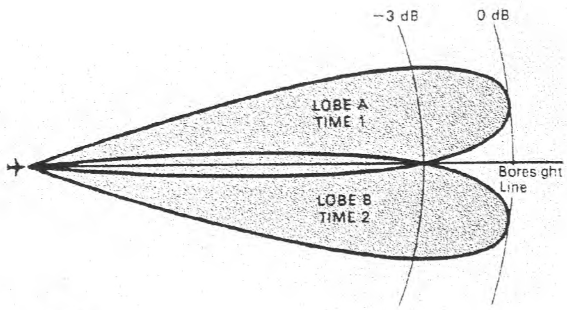


fig. 5.2:9

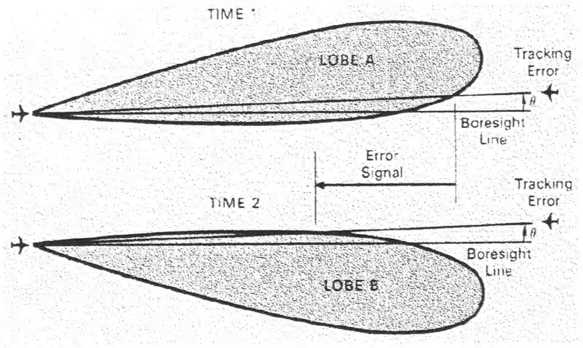


fig. 5.2:10

With sequential lobing, during reception the tracking error is determined by alternately placing mainlobe on one side and then the other of antenna boresight line.

If the target is off the boresight, return received through one lobe will be stronger than that received through the other. Magnitude of this difference corresponds to magnitude of tracking error with the sign of the difference equating to the direction of the error.

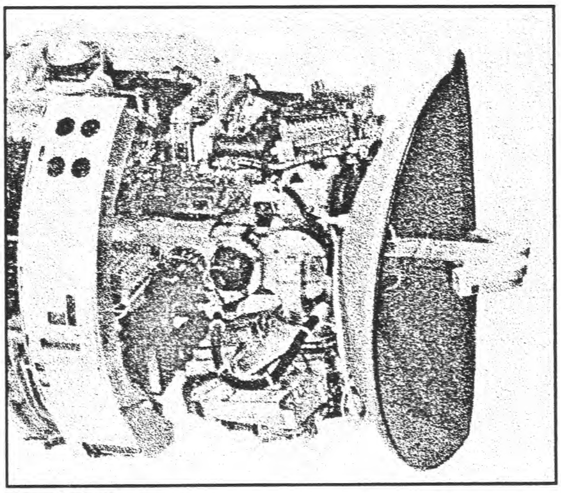


fig. 5.2:11

Shown on the left is one of the first automatic tracking radars which used monopulse techniques. Manufactured by Ferranti, the AIRPASS (AI Mk.23) airborne radar was fitted to one of the British Royal Air Force's specialised interceptor aircraft, the LIGHTNING. Designed to be fitted within the nose cone of the aircraft, mechanical separation of the required individual vertical antenna lobes was accomplished by the construction of a bifracted waveguide. Horizontally displaced beams were achieved, again mechanically, by having a complex reflector. Modern radars electronically construct the desired offset beams to achieve amplitude/phase comparison.

Phase and Amplitude Comparison Monopulse

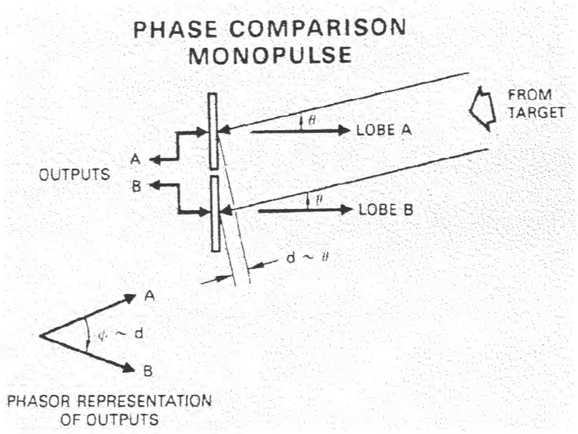


fig. 5.2:12

In **phase comparison monopulse** as the lobes of the two antenna halves point in the same direction there will be **no phase difference when the target is in the antenna boresight**. In all other cases a phase difference will be present, its value being related to the degree the target is off-set from the boresight.

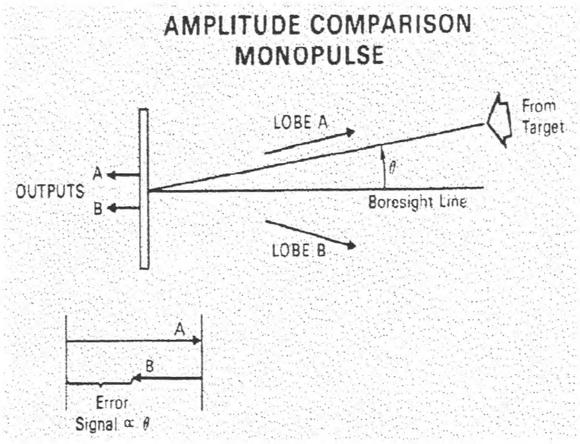


fig. 5.2:13

In essence, **amplitude comparison monopulse** duplicates sequential lobing in every respect except that return is received simultaneously through both lobes. Error signal is difference between outputs A and B.

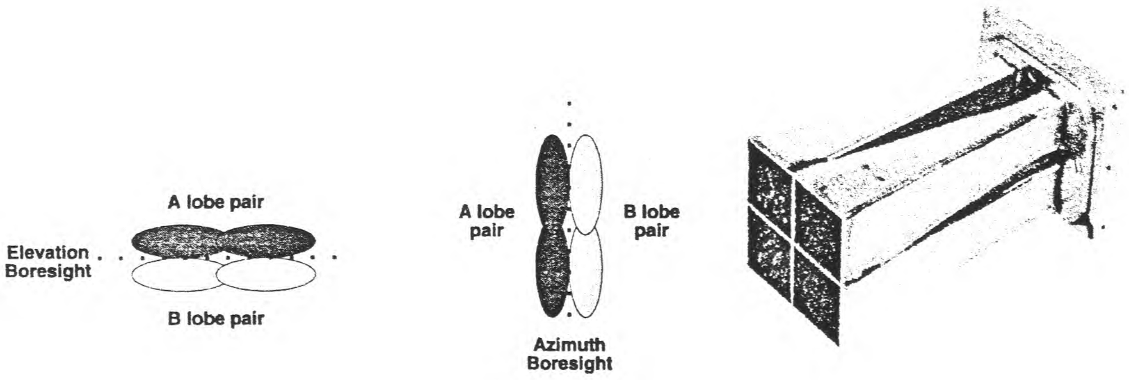


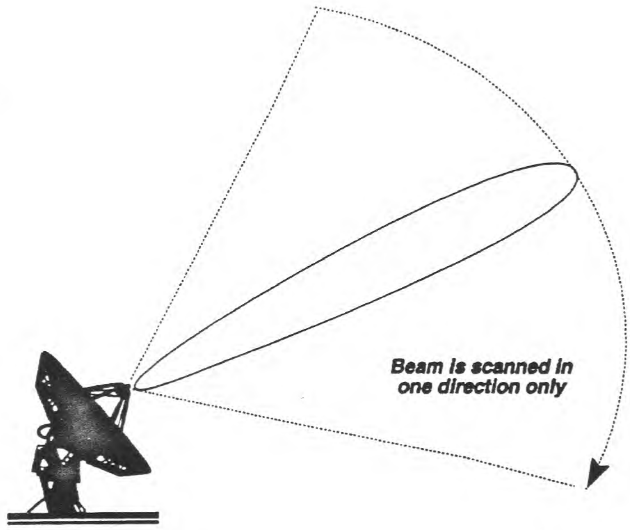
fig. 5.2:14

Monopulse antenna feed provides sum signal for range tracking, difference signals for angle tracking
Difference signals for azimuth and elevation tracking may be processed on a time-sharing basis.

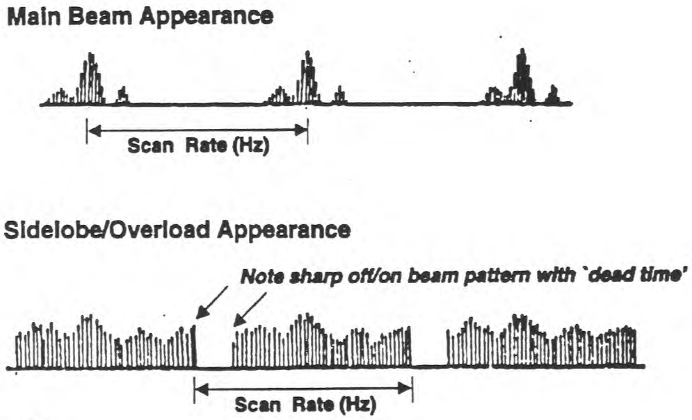
UNI-DIRECTIONAL SECTOR (UDS)

In this scanning method a narrow beam is made to rapidly scan, in either azimuth or elevation, a narrow sector of space IN **ONE DIRECTION ONLY.** A mechanical method of producing a UDS would normally employ a multiple feed system spun in front of a fixed antenna to avoid wasted scan time.

Electronic methods such as ***FRESCAN***, where position of beam determined by frequency switching, are now commonly employed to produce this scan type. Where both azimuth and elevation beams are transmitted simultaneously, a **TRACK-WHILE-SCAN** capability exists and has also been noted used in passive mode.



UNI-DIRECTIONAL SECTOR (UDS)


Main Beam Appearance

Sidelobe/Overload Appearance

Note sharp off/on beam pattern with 'dead time'

fig. 5.2:13

COMBINATION SCANS

Combinations of slow and fast scans are encountered. They include :-

PALMER : Circular with conical superimposed

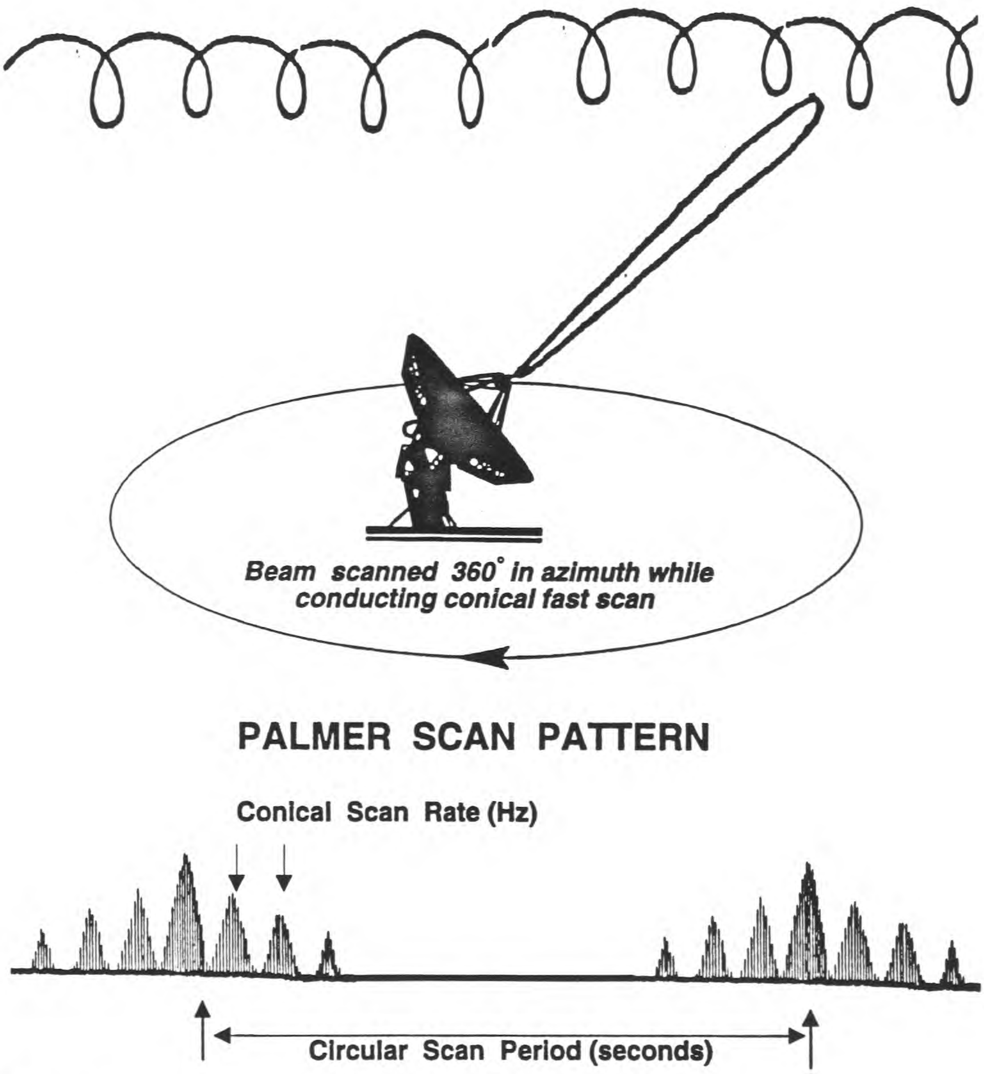
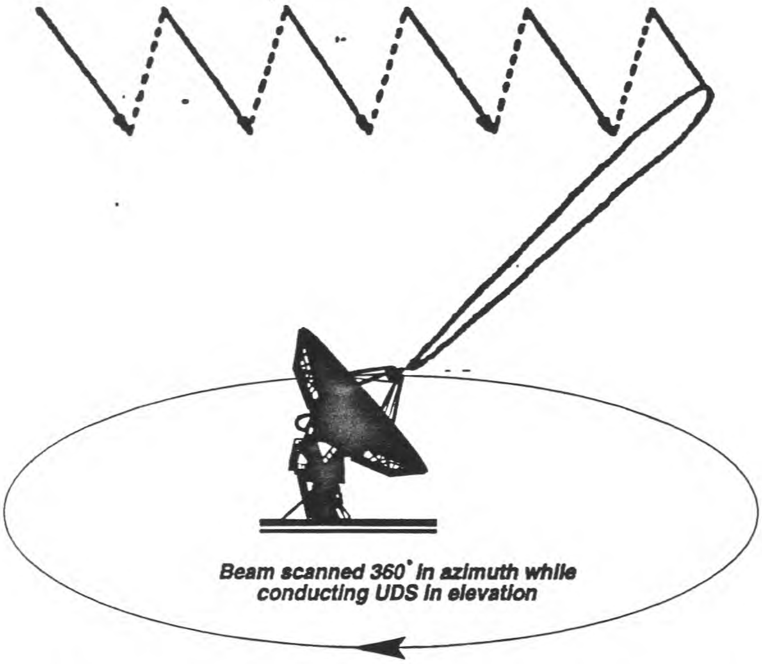


fig. 5.2:14

The conically scanning component can be either rotating or nutating polarisation (ROTPOL or NUTPOL).

Other scan combinations include:

Palmer Raster	Raster search scan with conical tracking scan supermimposed. Enables rapid switch from search to target tracking.
Circular and UDS	Circular scan with uni-directional sector superimposed. May have more than one level of sector scan. Some shipborne fire-control radars use this type.



CIRCULAR and UDS SCAN PATTERN

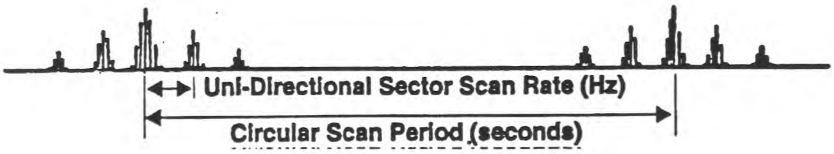


fig. 5.2:15

Modern radars can form their scan patterns electronically creating what is known as an **AGILE BEAM** system. This will be dealt with in later subject matter.

6. ANTENNA and RECEIVER SYSTEMS

Requirements of an ELINT antenna

a. **HIGH GAIN** - We are not the intended recipients of the signal.

b. **WIDE BEAMWIDTH** - For effective search (widen 'look' angle).

c. **NARROW BEAMWIDTH** - For accurate 'pinpointing' of target (DF).

d. **WIDE FREQUENCY RANGE** - Desired signals may be spread over a number of different frequencies or even frequency bands.

e. **VARIABLE POLARISATION** - So that receive antenna can match the plane of the incoming signal for maximum response.

To meet these requirements as closely as possible it is necessary to have more than one antenna in order to cover wide radio frequency range.

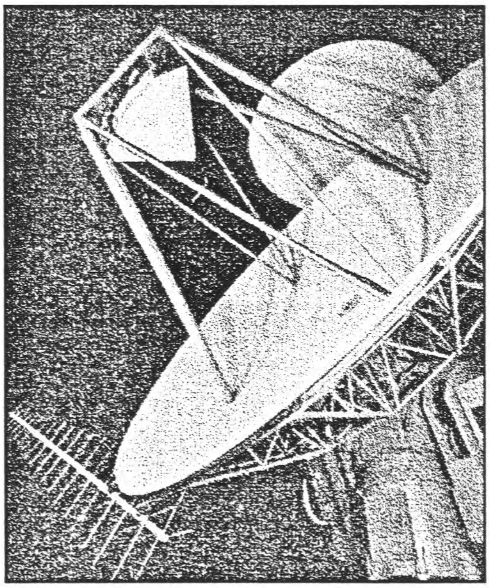


fig. 5.0:1

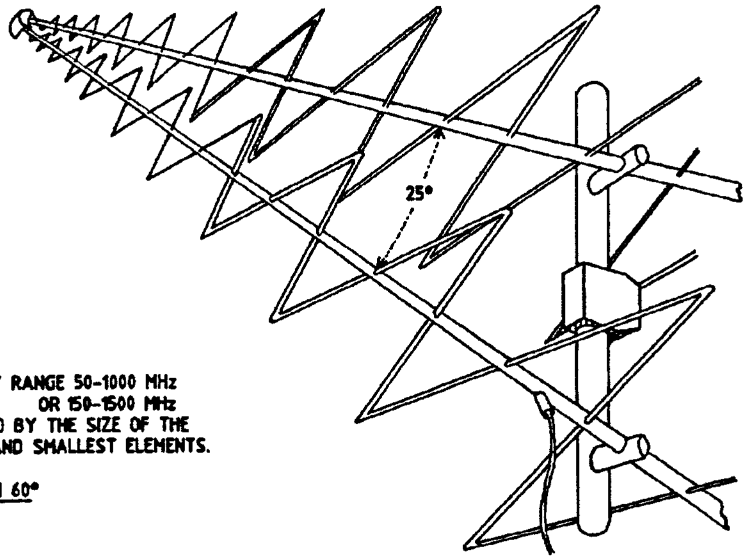
Typical multi-band ELINT antenna system combining, on the left, a Log Periodic Array for low frequency coverage with the main antenna being the Parabolic dish. Although not evident, the feed for the dish will probably be an encapsulated Log Periodic Structure to cover the higher frequency ranges.

Types of antenna

DIPOLE	- Simplest form with 'wire' cut and formed to desired wavelength.
YAGI	- Basically dipole with reflector and directors added to improve beamwidth.
LOG PERIODIC DIPOLES (L.P.D)	- Dipole array of varying dimensions enabling wide band coverage. Can be used as antenna feed.
LOG PERIODIC STRUCTURE (L.P.S)	- Similar to LPD but each element is 'active'.

The main drawback of all the antennae listed above is their very broad beamwidth, this undesirable where good DF is required. An LPS for instance has beamwidths of 60° in the horizontal plane and 100° in the vertical.

Any of the above antenna may be used as the feed element of a more sophisticated system, say in front of a **parabolic reflector**, to dramatically decrease (improve) the beamwidth produced.



L.P.S

FREQUENCY RANGE 50-1000 MHz
OR 150-1500 MHz
DETERMINED BY THE SIZE OF THE
LARGEST AND SMALLEST ELEMENTS.

BEAMWIDTH 60°

GAIN 10db

COAX FEED GOES THROUGH HOLLOW
SUPPORT ARM TO POINT.
THE BRAID BEING CONNECTED TO ONE
STRUCTURE & THE CENTRE CONDUCTOR
TO THE OTHER

fig. 6.0:2

6.1 - ELINT/ESM Receivers

In order to detect radar emissions for collection or identification, any ELINT/ESM electronics suite must have receivers capable of covering the frequency range of the emissions. Some tactical scenarios may require only a relatively narrow band of frequencies to be scanned for target emissions while specialised surveillance missions may have to view either all or most of the spectrum from 30 MHz up to 40 GHz and beyond. Observing such a large frequency range presents a major challenge as there will be many unwanted emissions present. The advent of modern computer systems has helped greatly by providing a rapid ability to discern between target and non-target emissions and is essential within ESM equipment to provide accurate threat analysis.

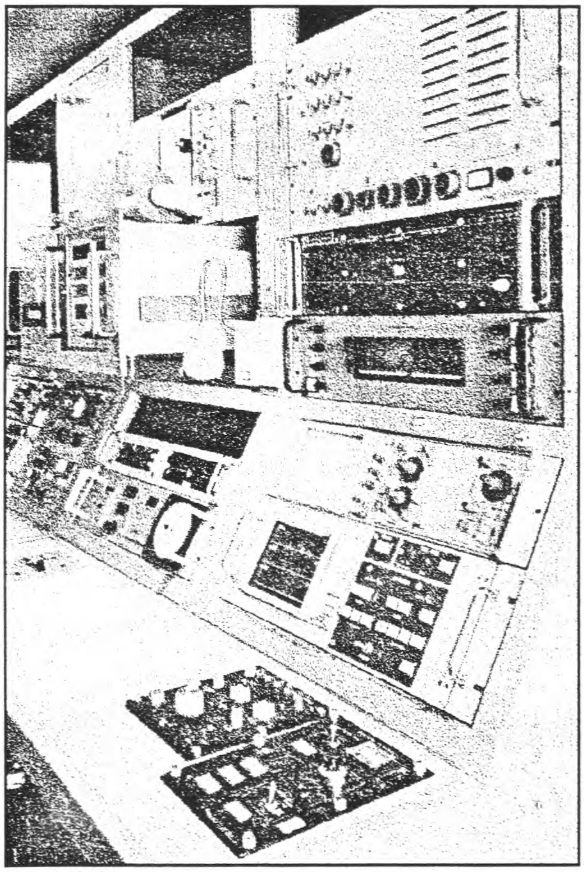


fig. 6.1:1

Where a large radio frequency range has to be covered, it is normal practice to 'split' this into manageable frequency bands. When presented on a multi-trace panoramic display, the operator can see active emitters and in many cases be able to tune a sensitive analysis receiver to the desired frequency. Such receivers are able to provide a number of differently processed outputs so that the operator can determine the parameters of the emission. The Israeli built CR-2740 ELINT system shown on the left can cover from 500 MHz to 18 GHz. Designed for landbased use, the electronics suite includes the necessary receivers and various oscilloscopes to assist tuning and analysing the desired emission. Much of the target emitter search and acquisition functions can be performed automatically with initial computer derived parametric analysis presented to the operator on a graphics display. A special fibre-optic recording device, commonly referred to as a 'Visicorder', is also provided for detailed scan and modulation analysis. Audio and video recording facilities are presumably available.

For use in more confined areas, some receivers combine both signal acquisition and analysis features within the same unit. The Thorn MS3360 Microwave Surveillance Receiver shown on the right is just such a system. Covering 1 to 18 GHz, the range is split in to three user definable bands. Once detected, the signal can be fine tuned and the screen divided to allow various signal demodulation and parameter measurements to be made and displayed.

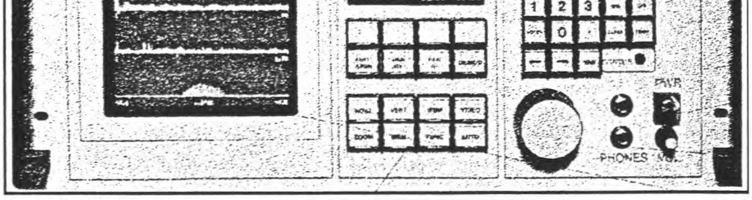


fig. 6.1:2

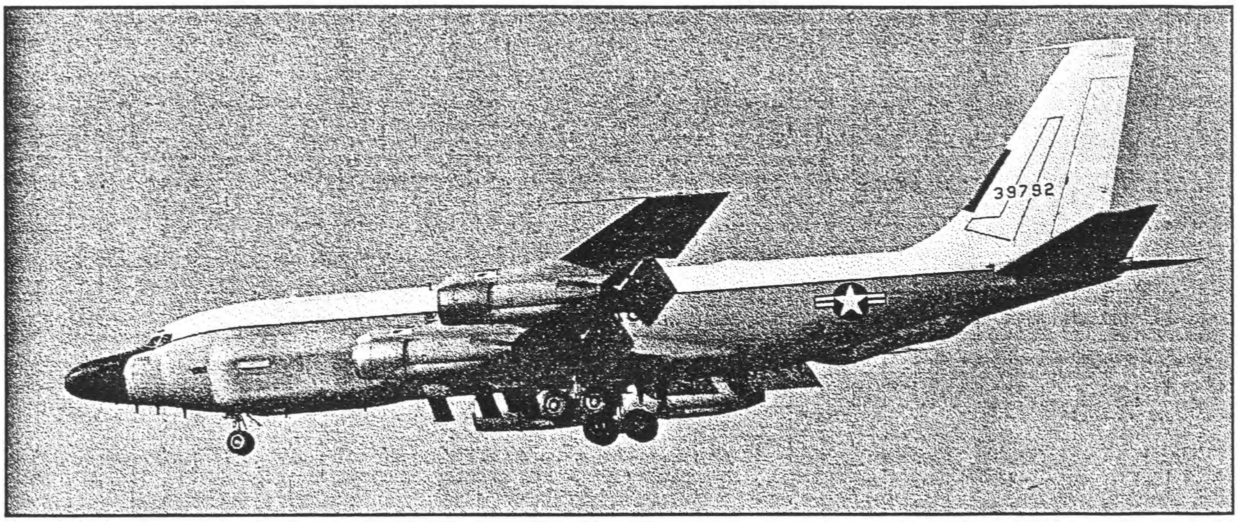


fig. 6.1:3

For long range airborne missions, modified transport or bomber aircraft are often used as the basis for conversion. One of the most utilised airframes is the Boeing 707 which is not only used in the reconnaissance role but, in the E-3 SENTRY, as an Airborne Warning And Command System (AWACS). Shown above is an RC-135V derived from the KC-135B STRATOTANKER which itself is based on the military version of the Boeing 707, the C-135. Belonging to the 55th. Strategic Reconnaissance Wing (SRW) based at Offutt AFB, Nebraska, the aircraft is powered by four Pratt & Whitney TF33 turbofan engines. With a maximum take-off weight of some 135 metric tonnes, including almost 60,000 litres of fuel, it has a maximum unrefuelled range of around 9,000 km.

On the right is reproduced a rare photograph of an ELINT console aboard an RC-135. The operator is furnished with suitable receivers and oscilloscopes for initial signal identification. Further more detailed analysis can be performed on dedicated pulse and waveform measurement equipment on the extreme right. Not only can on-board magnetic recordings be made of desired emitters, but many aircraft used in such missions are capable of transmitting to ground stations via secure data links.

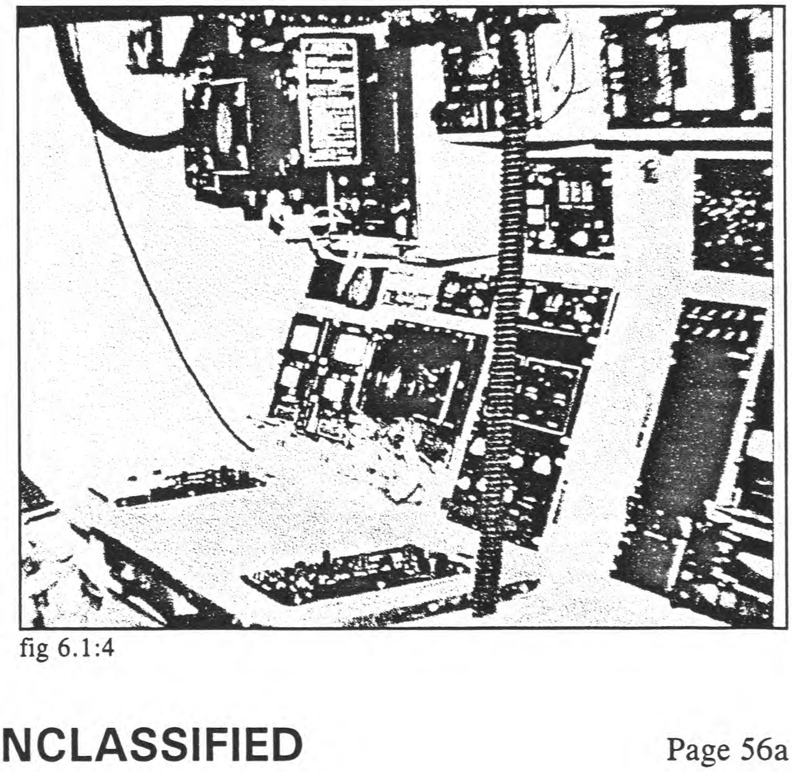


fig 6.1:4

7. SPURIOUS SIGNALS

Genuine unidentified signals are rare but when the do appear it is vital to collect as much information as possible. This can be a high cost, intensive effort with resources being deployed especially. In order to ensure that this effort is not wasted, unwanted or spurious signals must be recognised and eliminated as quickly as possible. Knowing the main types that can occur and being able to recognise such signals will allow full dedication to valid signal collection.

Types of spurious signals - Direct Harmonics

These can occur at direct multiples of the genuine transmission frequency. Can sometimes be easily recognised by the signal displaying a wider bandwidth than the modulation would indicate. This is due to the fact that a signal radiating at twice the fundamental frequency, the 2nd harmonic, it will display a bandwidth twice the intended modulation rate. For instance a signal transmitting on a frequency of 2,300 MHz with a bandwidth of 750 kHz can produce a harmonic at 4,600 MHz but the bandwidth will appear to be 1,500 kHz.

Image Reception

Image Reception occurs in superhetrodyning receivers where sum and difference frequencies are present before final filtering. One of these is the wanted signal, f_w, to which the receiver is tuned, and the other is an unwanted signal called the Image Signal.

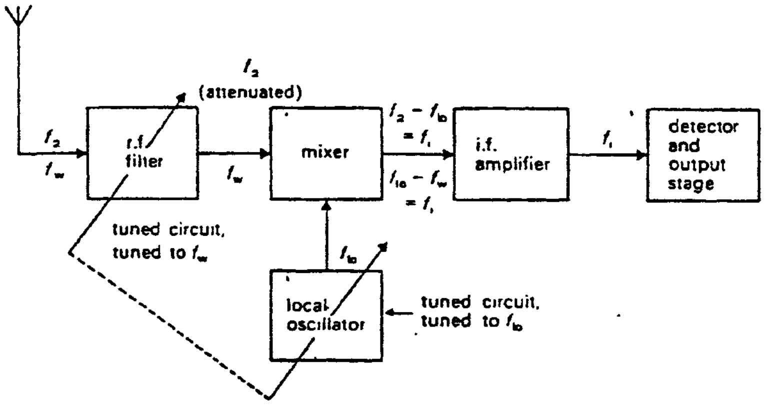


fig. 7.0:1

The case shown above illustrates when the receiver is designed so that the wanted signal's carrier frequency, f_w, is below the local oscillator frequency, f_{lo}. In this case the local oscillator is said to be 'tracking high', in other words its frequency value will always be above that of the mixer input signal, f_w.

This will produce a state within the receiver that, should any bandpass filtering following the mixer stage be insufficiently narrow, both the wanted and spurious Image Signal will be present at the output stage.

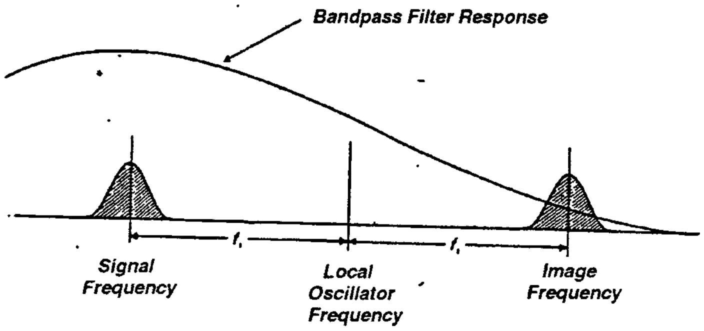


fig. 7.0:1

This is the case illustrated above where the wanted signal is being tuned on the left but the Image Signal is still present within the frequency range of the bandpass filter. It is important to note that the Image signal appears twice the Intermediate Frequency (f_i) value, typically 160 MHz in microwave receivers, away from Signal Frequency in the same direction that the LO tracks.

Points to note are :-

- As, in the case above, the Image Signal will be the sum signal not the difference, it will be seen to track in the opposite direction to 'true' signals on an RF panoramic display.
- Assuming an 160 MHz IF with LO tracking high, an image signal could be present twice the IF value (320 MHz) above the wanted signal.
- Compared to the Image, the wanted signal will be twice the IF value away from the image in the opposite direction of LO tracking. For example, image on 2320 MHz, true signal 320 MHz below, on 2000 MHz.

Other sources of spurious signals :

- Strong signals close in frequency to the wanted signal can cause cross-modulation within the receiver circuitry to give a falsely modulated output. This may not allow true representation of the wanted signal's waveform. Referred to as Adjacent Channel Interference.
- Unscreened equipment, be especially suspicious of anything on receive equipment IF or harmonics.
- Other microwave sources, test equipment, auto-ignition etc.
- Any signal displaying modulation rates of 50 or 60 Hz. (European/US mains).

8. MULTI - PULSING

So far we have been dealing only with single pulse transmissions, that is one pulse per PRI. Now we want to look at signals where **MORE THAN ONE PULSE IS TRANSMITTED WITHIN EACH PRI.** The PRI is now constant but two or more pulses are being transmitted instead of just one.

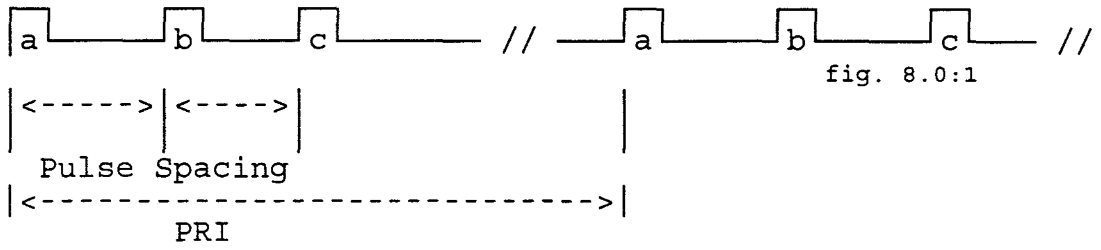


fig. 8.0:1

There should be no confusion between pulse stagger and multi-pulsing where the signal is checked on a digital or analogue oscilloscope in the following manner:

a) Display the first pulse then adjust the timebase **SLOWLY** (smallest increments).

b) Be aware that pulses per group can be different from PRI to PRI, so use whatever means available on your pulse analysis equipment, strobing for example, to analyse successive pulse groups if this looks likely ie. on analogue 'scopes, some of the pulses **won't** break the timebase.

fig. 8.0:2

The above example shows successive PRIs with 3 pulses per group (ppg) and an additional pulse inserted each alternate PRI. This would be reported as an alternating 3 pulse group and 4 pulse group each at **HALF THE PRF RATE** (every second PRI).

Presentation on expanded timebase:

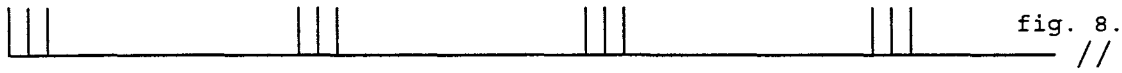


fig. 8.0:3

Multi-pulsing, each pulse would break timebase and pulse group will be present at beginning of trace.

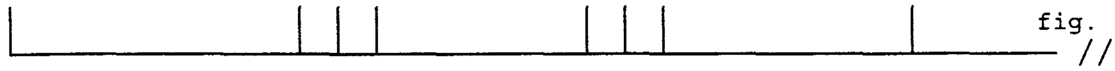


fig. 8.0:4

Pulse stagger, timebase not broken on all displayed PRI's and no apparent pulse group at beginning of trace.

MEASURING PULSE DURATIONS AND INTERVALS IN A MULTI-PULSE GROUP CAN BE VERY STRAIGHTFORWARD.

a) Display **ALL** pulses in the group.

b) Measurement of first pulse (pulse A) is as normal, ie from leading to trailing edge.

c) The pulse spacing between each pulse is taken as the time difference from the leading edge of one pulse to the leading edge of the next.

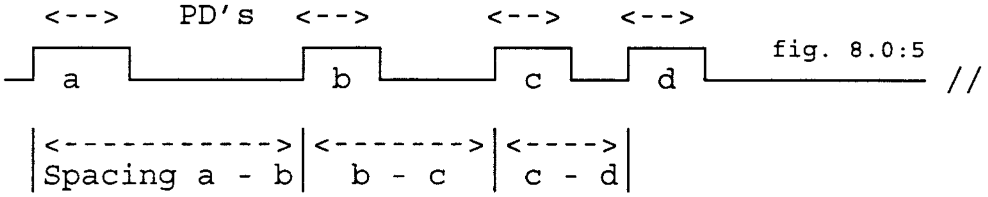
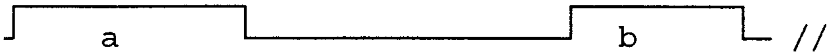


fig. 8.0:5

As can be seen from the above example, **ALL PULSE SPACINGS ARE TAKEN AS THE TIME FROM THE LEADING EDGE OF ONE PULSE TO THE LEADING EDGE OF THE NEXT.**

BE AWARE THAT AN INCORRECTLY SET TIMEBASE CAN GIVE YOU A FALSE PRESENTATION OF THE PULSE GROUP, ESPECIALLY ON ANALOGUE OSCILLOSCOPES. ONLY BY ADJUSTING THE TIME-BASE SLOWLY CAN YOU SATISFY YOURSELF THAT THE TRUE MAKE UP OF THE PULSE GROUP IS SHOWN. SEE EXAMPLE BELOW.

True grouping



With timebase too short, only two pulses will trigger

Pulse c triggers next sweep of timebase

fig. 8.0:6

On analyser, trigger pulse will appear brighter as being triggered by **BOTH** pulses *a* and *c*. On an analogue oscilloscope, pulse *b* will not break the timebase on this setting.

Two of the most common forms of multi-pulsing are:

PULSE POSITION MODULATION (PPM)

All pulses in the format **are sent whether conveying data or not** and it is their change of position within the format that conveys the data.

PULSE CODED MODULATION (PCM)

Only those pulses that are intended to convey information within the format **are transmitted**.

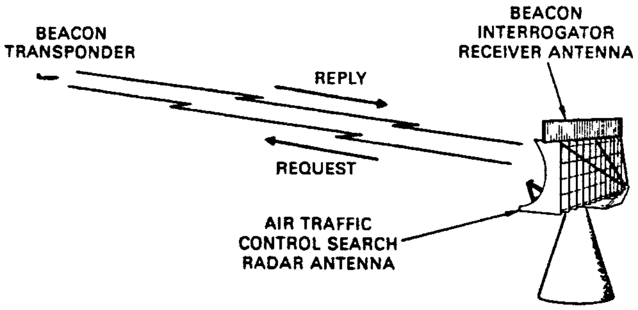
MULTI-PULSE APPLICATIONS

IDENTIFICATION - FRIEND - OR - FOE (I.F.F.)

IFF System comprises of **INTERROGATORS**, normally co-located with a PARENT RADAR, to illicit a coded reply from remote **TRANSPONDERS**.

AIR TRAFFIC CONTROL TRANSPONDERS

Similar to I.F.F. but the response contains information derived from onboard equipment such as Flight Number, aircraft altitude etc.



10. By transmitting coded interrogations and coded replies, the air traffic control beacon system provides a traffic controller with the identities and altitudes of all aircraft.

fig. 8.0:7

Note that in IFF/ATC operation, transponder will reflect PRF of interrogating radar.

Beacon Interrogation

Used to illicit response from targets such as missiles and satellites to enhance their radar 'echo' so that they can be accurately tracked. Typical installation of a missile beacon is shown here. The photograph on the right shows the rear of a Russian SA-N-3 GOBLET shipborne surface-to-air missile. Sited at the end of two of the fins are pods, each containing beacon antenna. With many systems of this type, circuitry within the missile will transmit back a transponder signal when illuminated by say either the target / dedicated missile tracker or the guidance component. This provides the weapons system with a '*synthetic return echo*', greatly enhancing its ability to track the small radar cross-sectional area target the outgoing missile would otherwise represent.

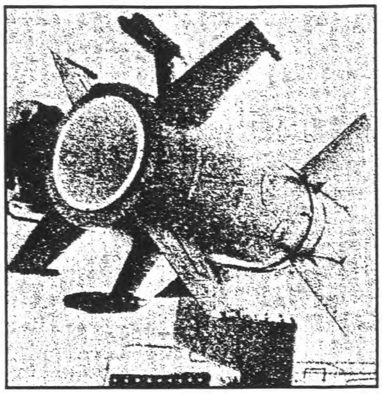


fig. 8.0:8

Navigational Systems

Provides feedback between transmitter and remote, mobile equipment to enable determination of position.

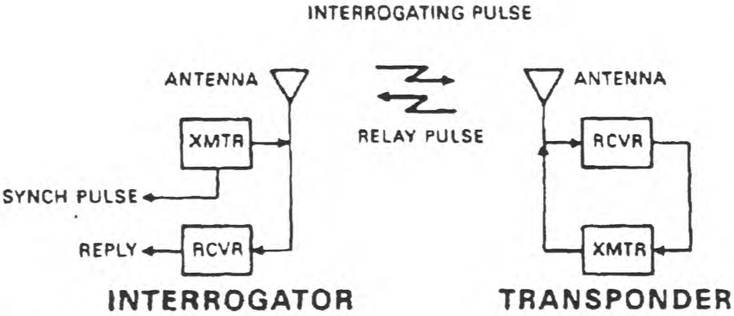


fig. 8.0:9

Basic elements of a radar beacon system. Interrogator transmits interrogating pulses which are received and replied to by a transponder. Replies may be displayed on a primary radar's display or compared with time of interrogator's synchronising pulses to determine range to beacon.

Data Information

Formatted systems such as missile guidance and telemetry.

8.1 - Secondary Radars

A SECONDARY RADAR IS USED TO PROMPT A RESPONSE FROM ANOTHER RADAR OR ONBOARD EQUIPMENT AND **DOES NOT** ITSELF **RELY ON RETURN ECHOES FOR RANGE INFORMATION.** IT IS NOT CAPABLE OF PRODUCING ITS OWN INTERNALLY DERIVED PRF BUT MUST RELY ON ANOTHER SOURCE.

Nearly all secondary radars rely on the primary or parent radar using multi-pulse techniques to illicit the necessary response. A typical system can be based on three components, two co-located, *PARENT RADAR* and *INTERROGATOR*, and one remote, the *TRANSPONDER*. All three components can operate on entirely different RF ranges.

In operation, the Parent Radar provides the timing source (the PRF) to trigger the Interrogator which will transmit a coded pulse group at this rate to prompt a response from its intended target. The equipment onboard the target can reply to this basically in two different ways. It can transmit a time delayed simple pulse code, or it can send a more sophisticated pulse group containing onboard derived information such as identity, height, fuel status etc. Such a device is called a **TRANSPONDER.** This information can then be fed back to the parent radar enhancing the raw azimuth and range data available.

ADVANTAGES

- As not relying on weak return echo, received signal from target much stronger and can contain much more detailed information than just normal return.
- Size of target now irrelevant, not relying on surface area of target to reflect radiated energy.
- Total elimination of ground clutter, only signal received is the response from target.
- By using different interrogation codes or modulation, switching PRI's, we can ask for specific information from the target.

DISADVANTAGE

- Can only operate with co-operating targets, those unable to respond to interrogation will not reply.

USES OF SECONDARY RADAR

Most of the uses of secondary radars have been covered previously. One addition is in the field of meteorology.

The measurement of upper air temperature and pressure are important not just for weather prediction but, for military applications, vital to enable the correct trajectory calculation required for firing ballistic missiles. In practise the method used to derive the necessary information differs slightly from normal transponder use.

Two main components comprise this upper air data gathering system. These are the parent radar and a device known as a Radiosonde which transmits coded information containing air pressure and temperature information. The radiosonde is suspended beneath a meteorological balloon which is also fitted with a device known as a '*corner reflector*'. This presents the tracking radar with a much larger radar cross-sectional area than the lighter-than-air balloon/radiosonde combination would present.

By utilising precision tracking techniques (fast scanning), the parent radar can determine accurate target movement. In this way the radar can measure wind speed at differing heights by noting changing range and elevation angle. Information from the radiosonde is cross referenced to radar data allowing temperature/pressure/height gradients to be measured.

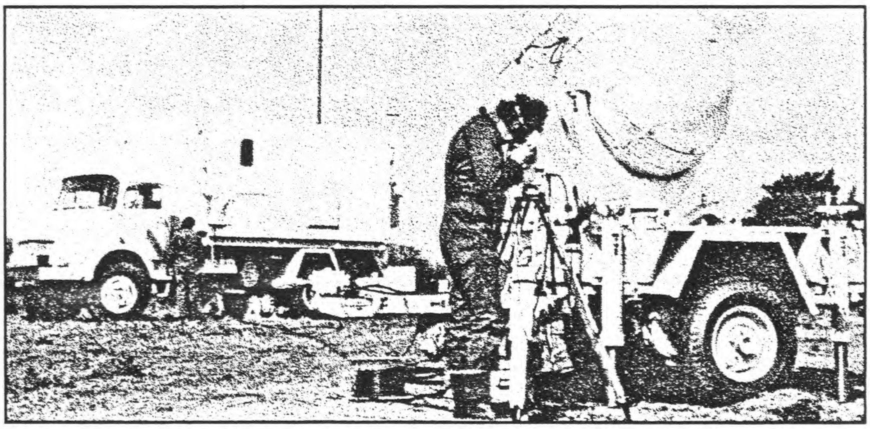


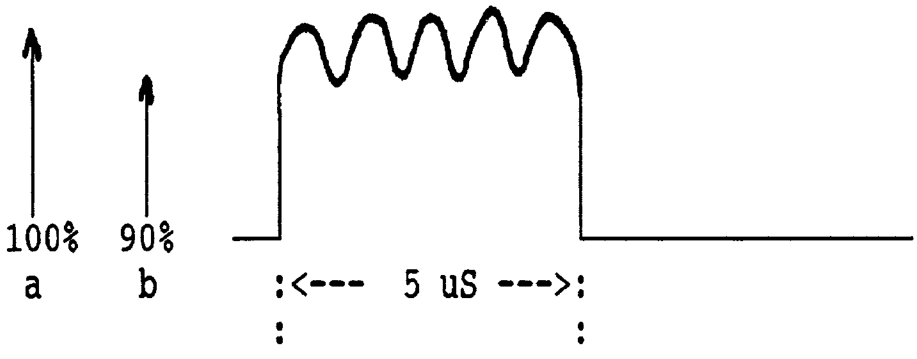
fig. 8.1:1

Shown on the left is the Plessey WF3M mobile wind finding radar incorporated in to the Artillery Meteorological System (AMETS). The radar itself is mounted on a single axle trailer and towed behind a vehicle equipped with all necessary instrumentation. This enable wind speed and direction data to be computer processed for rapid dissemination to artillery assets.

The hydrogen filled balloon carries a simple radiosonde which transmits air temperature data. This is received via the Yagi antenna fixed to the radar housing. Additionally surface pressure and humidity information can be included. Balloons and their hydrogen gas containers are carried in support vehicles which would normally include a command post to co-ordinate information flow between this and other information inputs required to accurately direct artillery fire.

Amplitude Modulation On the Pulse (AMOP)

An **INTRAPULSE MODULATION** technique where an additional modulation frequency, usually in the order of Megahertz, is superimposed on the pulse causing it to display an amplitude ripple. The frequency of the ripple is determined by the modulation frequency and the amount of modulation, or depth of modulation, is expressed as a percentage relative to the amplitude value of the pulse. Can be used to allow individual pulse coding such as found in IFF systems.



Depth of modulation = a - b = 10%

fig. 8.1:2

Above diagram shows a 5μs pulse displaying 1 MHz AMOP (1 cycle per μs) modulating the pulse by 10%.

Note. To measure modulation rate, display one cycle in oscilloscope graticule and note time base. Where value is known to be in MHz, set time base to 1μs/cm and count number of cycles within 1 cm, this will equate to rate in MHz.

8.2 - Sidelobe Suppression (SLS)

A serious problem in I.F.F. / A.T.C. transponder systems is that aircraft close to the interrogator will receive sufficient energy to cause the replies from the transponder when in the beam's side lobes. The resulting presentation is of multiple incorrect bearing indications and can even cause a system overload in busy terminal areas. This can be prevented by electronically suppressing the side lobes by transmitting a delayed pulse triggered by the main interrogation format and radiated by an omni-directional antenna.

The power of the delayed pulse is arranged to be above that of the main antenna side and back lobes but below that of the main beam. In this way the aircraft transponder will be literally receiving a continuous low power single pulse which effectively blanks the transponder from receiving the interrogation format when close to the transmitter. It will now only trigger a response when the higher power interrogation contained in the main beam passes through.

Another sidelobe suppression (SLS) technique used is to incorporate a '***Guard Horn Receiver***' within the radar system. The main antenna is fitted with an additional horn feed whose beamwidth is greater than the main antenna sidelobes. This guard horn antenna is coupled to a receiver whose output level is fixed. The radar processor then compares the output from both the main and guard receivers. Where an echo is present in one of the sidelobes but not the main lobe, the guard receiver will produce an output but the main antenna receiver won't and the processor will disregard it. When a return echo is present in **both** the guard receiver and the main receiver, the signal must be in the main lobe and will be processed, registering on the radar display. In this way echoes from the sidelobes are suppressed.

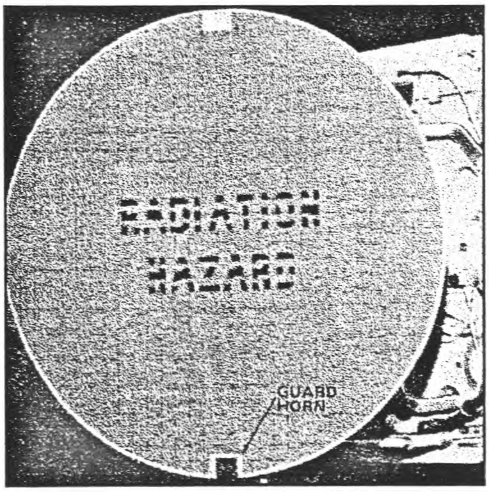


fig. 8.2:1

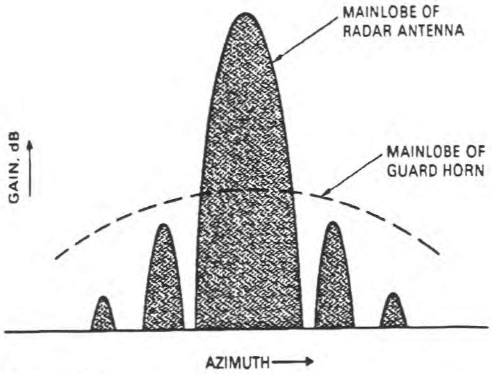


fig. 8.2:2

Guard Horn Receiver and output response

9. CONTINUOUS WAVE RADAR

Basically a Continuous Wave Radar transmits an unmodulated radio frequency signal. A portion of this signal is allowed to '*leak*' into the receiver circuit to provide a reference signal. Reflected energy from the target is collected by the common transmit / receive antenna and compared with this reference. Should the target be moving, a frequency difference, the ***DOPPLER SHIFT***, will occur between the transmitted and received frequency. The amount of the difference and its direction, higher or lower, will indicate radial velocity and whether approaching or moving away from the radar.

AN UNMODULATED CW RADAR IS UNABLE TO MEASURE RANGE BUT CAN RESOLVE RADIAL VELOCITY BETWEEN RADAR AND TARGET.

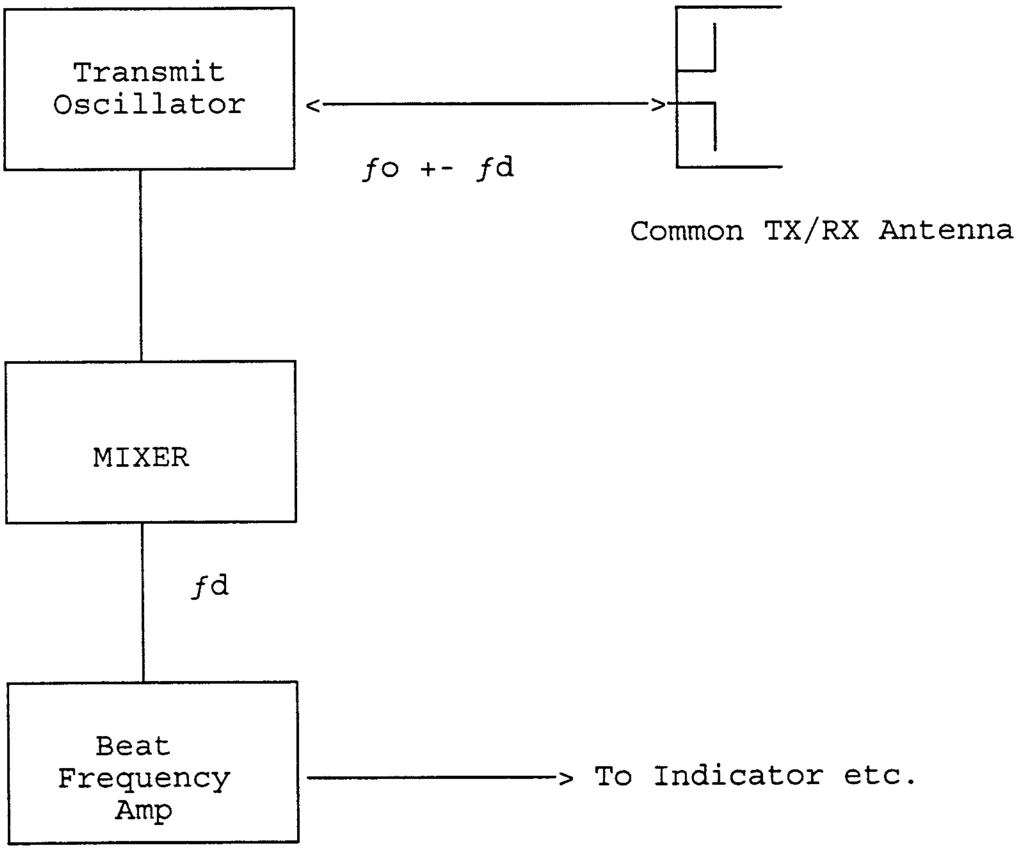


fig. 9.0:1

To measure DOPPLER FREQUENCY SHIFT,

$$f\text{d (Hz)} = \frac{2 \times \text{RF} \times \text{Vr}}{\text{C}}$$

(where ƒd = Frequency difference and Vr = Velocity, radial)

or, for calculation purposes,

18.5 Hz (fd) per 100 MHz (RF) per 100 kph (Vr)

ADVANTAGES

- Simple design, no complex TX / RX switches required
- Narrow transmitted RF causes less adjacent interference, increases sensitivity of receiver
- Low power outputs, many transmit only milliwatts of power.
- Can handle targets down to zero range (no eclipsing) and at any velocity with no ambiguities

DISADVANTAGES

- *CANNOT MEASURE RANGE*
- Leakage of transmitter power limits output, increase may require separate antenna
- Increasing power also increases input noise to receiver
- Due to low power, has only short range

USES

- Velocity measurement, for instance Police speed traps
- When modulated, radar altimeters in aircraft
- Missile target illuminators

Probability Of Detection

Detection of unmodulated CW radars is deemed to be generally very low due to the following :

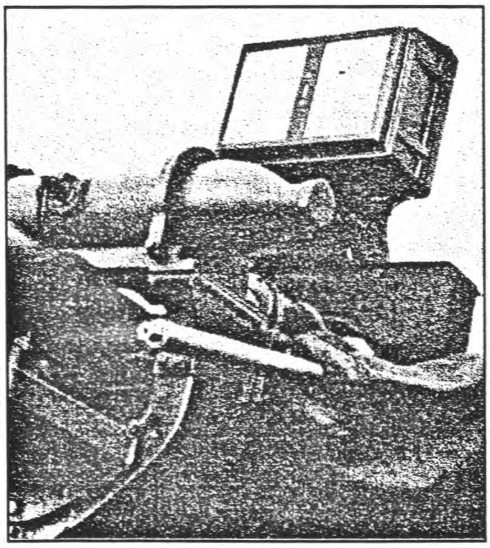
a. Use low power, not designed to be capable of long ranges

b. As unmodulated, no audible response from '*guard*' (wideband) receivers or visual display. May be able to detect lowering of background noise level in receiver when tuned to frequency or when emitter scans through.

c. In MODULATED CW, **may** be able to hear signal and it **may** give visual display on superhetrodyne receiver panoramic display.

On the right, a typical hand-held radar '*gun*' used by police forces to determine speed of motor vehicles through measurement of the '*Doppler Shift*'. Such devices can also be vehicle mounted and be used to indicate speed difference between police vehicle and speeding offender.

fig. 9.0:2



Displayed on the left is a Continuous Wave radar device mounted on top of a howitzer to measure the velocity of shells leaving the gun barrel after firing. Such information is essential to ensure accurate ranging on distant targets.

fig. 9.0:3

9.1 - Frequency Modulated Continuous Wave Radar (FMCW)

The inability of basic Continuous Wave radar to measure range is related to the unchanging nature of the transmitted waveform. Some form of reference mark must be used to permit measurement of the time elapsed before the return echo is received. Sharper or more distinct marks result in more accurate measurement of two-way path time between transmitter and target. A widely used technique to introduce time marks onto a CW is by **FREQUENCY MODULATING** the carrier, **FMCW**. The constant change in frequency serves as the timing reference with path time proportional to the difference in frequency.

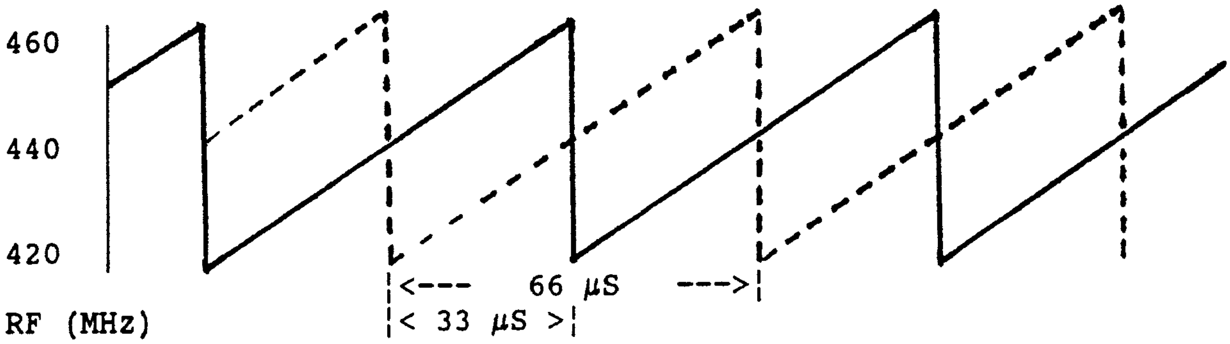


fig. 9.1:1

In the above diagram, the transmitter is radiating a CW signal at 420 MHz and linearly changing frequency by 40 MHz every 66μs.

The echo arrives back some 33μs later when the transmitter frequency is on 440 MHz, a frequency difference of 20 MHz or **HALF THE SWEEP TIME PERIOD OF 66μs.**

Range between the transmitter and the ground is easily calculated by dividing the time difference, 33μs, by 6.66 (the radar kilometre), the result being 5 kilometres (5,000 metres).

This type of modulation overcomes one of the disadvantages of pulsed radar, minimum range. Because no pulse is transmitted and range is found by determining frequency difference, range can be measured down to virtually zero. Such radar techniques are commonly found in use as **RADAR ALTIMETERS** and missile associated precision **RANGING ONLY** radars

Typical examples of radar altimeter equipment

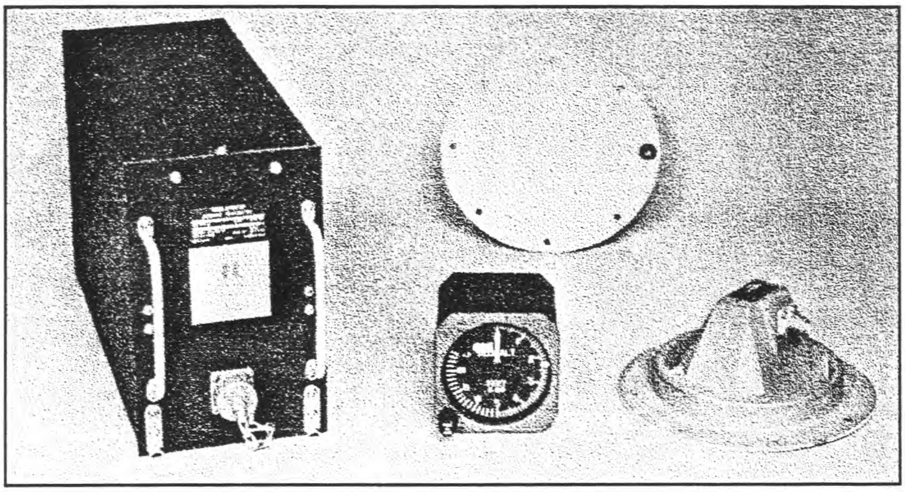


fig. 9.1:2

Above is example of radar altimeter operating in the 4.3 GHz range showing, from left to right, the Modulator, Altitude Indicator and the Transmit/Receive antenna.

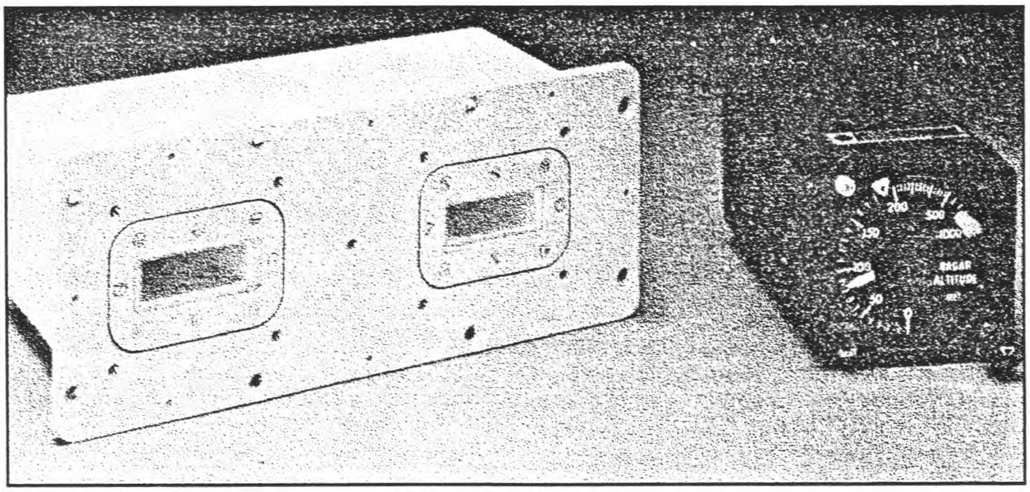


fig. 9.1:3

Compact J-band altimeter showing TX/RX antenna co-located in same machined block making it ideal for mounting on smaller aircraft.

10. MOVING TARGET INDICATOR (MTI) TECHNIQUES

DEFINITION

A MOVING TARGET INDICATOR (MTI) TECHNIQUE ALLOWS A RADAR TO IDENTIFY MOVING TARGETS FROM WITHIN THE RECEIVED ECHO RETURNS.

Some pulsed radars have the capability to determine Doppler frequency shifts on the returned target echoes. This may be used to obtain radial velocity information or improve the radar's detection capability in tracking targets in heavy ground clutter. Sampled systems such as pulsed radar can create ambiguities in both the Doppler frequency (relative velocity) and the echo time delay (range measurement). Velocity ambiguities can be avoided by using very high PRF's while a low PRF would eliminate range ambiguities (MTUR). It is not always possible to achieve both simultaneously and, as a consequence, these radars fall into one of two categories described below.

Moving Target Indicator (MTI) Radar

Such a radar uses a PRF which is low enough to avoid ambiguities in range, no 2nd time around echoes, but with the consequence that the Doppler frequency measurement is ambiguous and results in MTI BLIND SPEEDS at the PRF OR MULTIPLES OF THE PRF. In practice, these radars are designed to :

DETECT LOW-FLYING AIRCRAFT AMIDST GROUND CLUTTER FROM HILLS, BUILDINGS ETC.

DETECT MOVING TARGETS AT GROUND LEVEL, SAY A BATTLEFIELD, AGAIN FROM CLUTTER RETURNS CAUSED BY THE TOPOGRAPHY.

ELIMINATE GROUND CLUTTER TO SHOW JUST THE MOVING TARGET(S)

As, compared to the transmitted RF, the Doppler shift frequency will be very small, detection and measurement requires a high degree of RF and / or PRF stability.

MTI radars can generally be split into two operating types,

COHERENT -	Where the PHASE OF THE TRANSMITTED SIGNAL IS COMPARED TO THAT OF THE RETURN ECHO, A CHANGE IN PHASE DENOTING A MOVING TARGET.
NON-COHERENT -	In this a DELAY LINE CANCELLER is used to detect AMPLITUDE VARIATIONS CAUSED BY A MOVING TARGET and ELIMINATE FIXED TARGET ECHOES. Also known as '*Clutter Reference*' MTI.

10.1 - Coherent MTI Radar

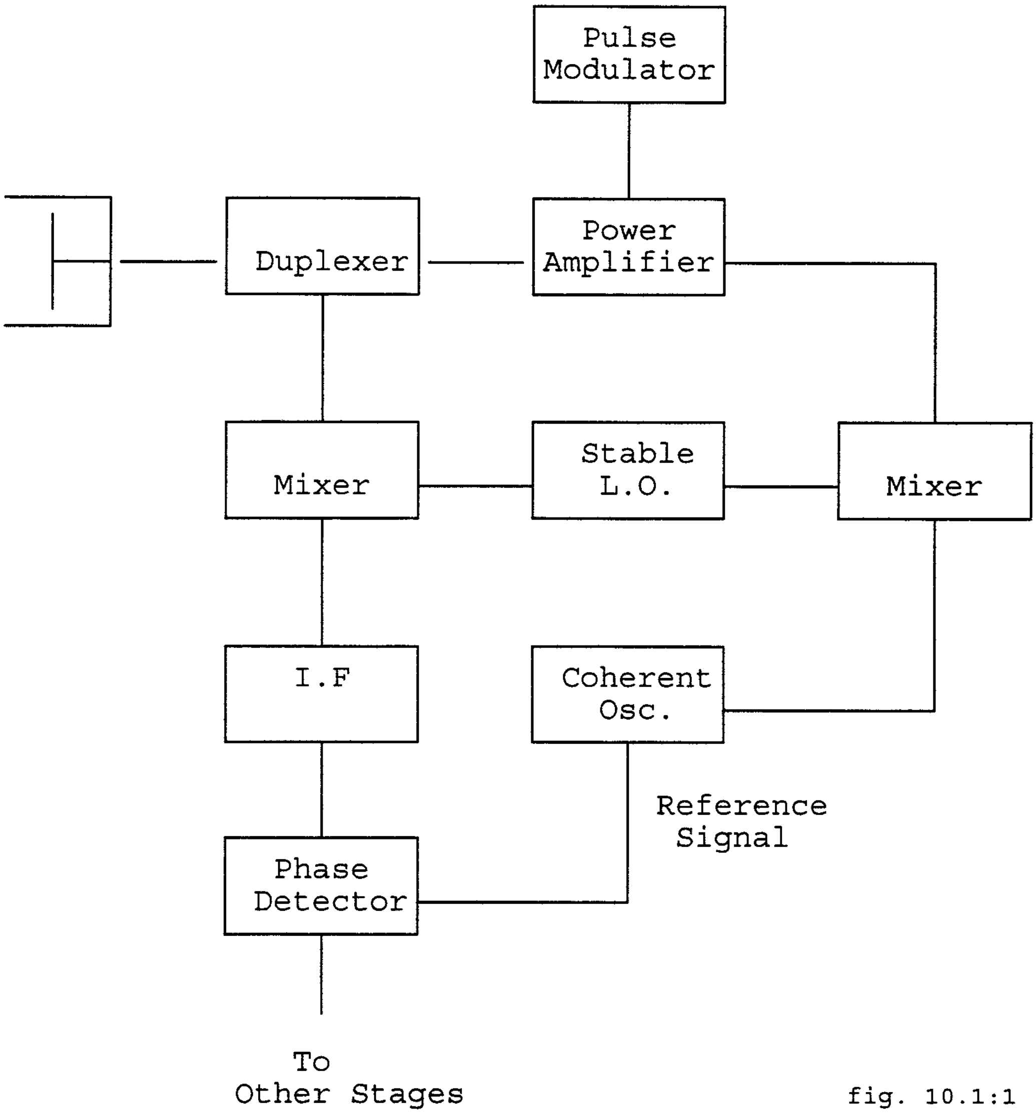


fig. 10.1:1

A very stable Local Oscillator (STALO) is used to trigger the Coherent Oscillator (COHO) which produces a pulsed reference signal directly in phase with the transmitted pulse. This is then stored and compared to the return pulse on a pulse-to- pulse basis by the Phase Detector. Any return from a fixed target will still display the same phase whereas those from moving targets will show a phase shift as its distance relative to the radar will be changing.

10.2 - Non - Coherent MTI Radar

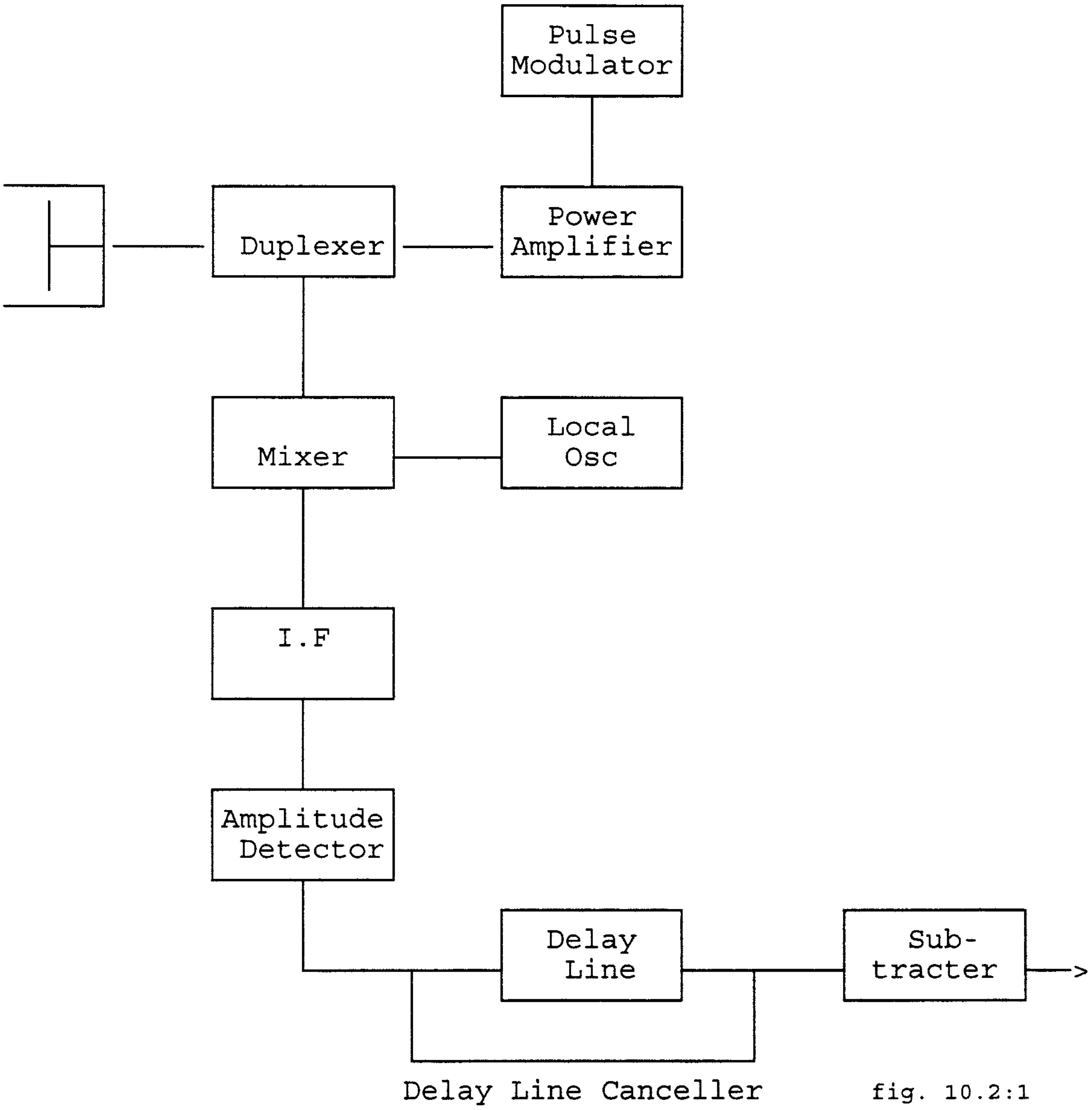


fig. 10.2:1

In the **NON-COHERENT RADAR** the return echoes are processed via a delay line which **DELAYS THE RECEIVED PULSE BY ONE PRI.** The subtracter circuit then compares the amplitude of both current and delayed pulses. Returns from fixed targets will cause no difference therefore no output. Compared to that, the echo from a moving target will, due to its changing distance, display an amplitude difference which will produce an output and be detected. The amplitude difference will fluctuate at the Doppler shift frequency. Note that the variation in amplitude is caused by differing pulse-to-pulse phase relationship but it is not a function of the non-coherent system to have the ability to resolve this only the resultant amplitude difference.

Moving Targets

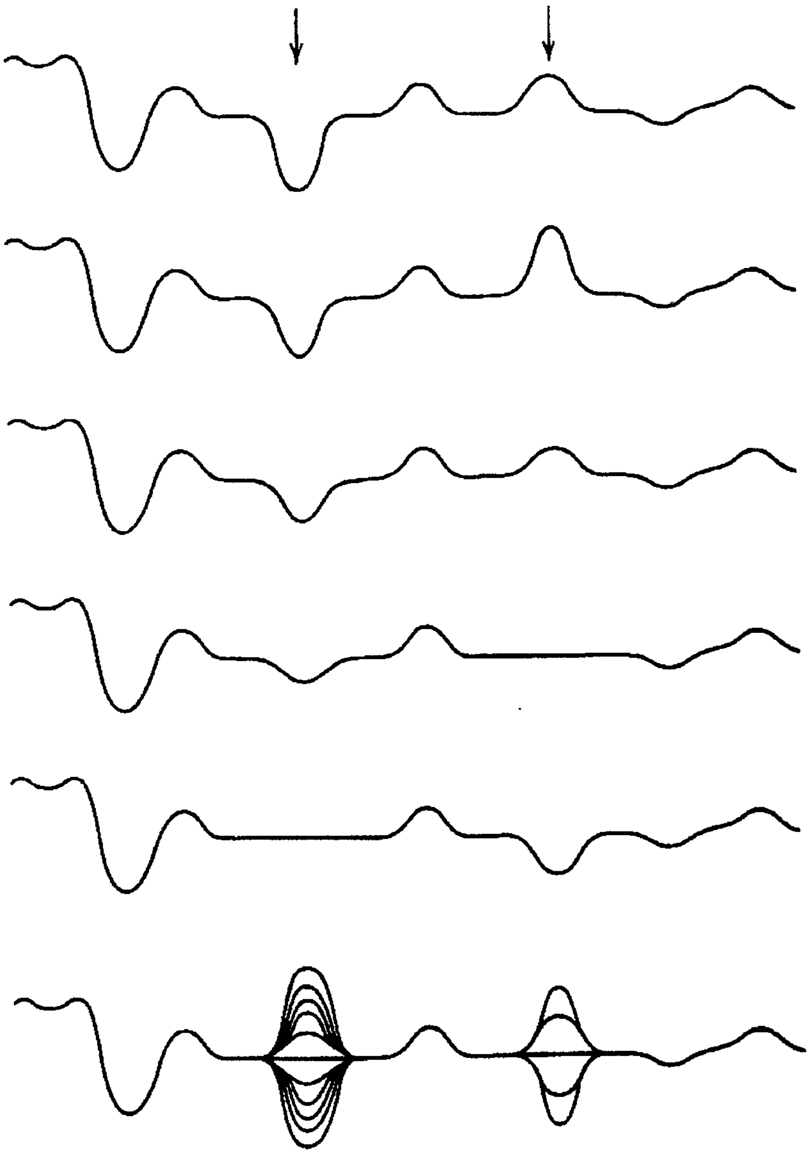


fig. 10.2:2

Above figure shows successive return echoes from moving target displaying amplitude differences. These differences will fluctuate at the Doppler shift frequency. Note that the variation in amplitude is caused by differing pulse-to-pulse phase relationship but it is not a function of the non-coherent system to have the ability to resolve this, only the resultant amplitude difference.

The limitation of this type of system is that clutter is necessary to provide a 'reference' threshold. If no clutter is present, no MTI can be made. However this facility can be switched out and the system will switch back to normal operations. The main advantage of the **Non-Coherent system** is that it is **simpler and therefore cheaper** than the more sophisticated 'phase' systems.

10.3 - MTI Blind Speeds

The main disadvantage of MTI radars is that, should a target be travelling at a **VELOCITY OF HALF THE WAVELENGTH** during one PRI OR A MULTIPLE, due to the two - way radar path the echo will exhibit a 360° phase shift. The comparator will obviously process this as NO PHASE SHIFT and cancel the echo the same as if it were a fixed target.

THIS IS KNOWN AS THE MTI BLIND SPEED

Assume a target is approaching a radar which is operating on an RF of 3000 MHz with
a PRF of 1,000 pps.

From this we can calculate that the wavelength of the radar will be 10 cm and the PRI is 1,000μs

An approaching target is travelling at ½ our transmitted wavelength (5 cm) in 1,000μs

So the distance travelled in 1 hour will be:

5 cm × 1,000 (to convert to cm/sec) = 5,000 cm/sec or 50 m/sec

In kilometres per hour (kph), multiply the distance covered in one second (50m) by the number of seconds in one hour, 3,600.

This will produce 50 × 3,600 = 180,000 m/hour or **180 kilometres per hour (kph)**

This is the ***first blind speed, Vb*** (Velocity, blind)

$$Vb = \frac{C \times PRF}{2 \times Frequency} \text{ m/sec} \quad \text{or} \quad \frac{.54 \times PRF}{RF\ (GHz)} \text{ kph}$$

To prove the Doppler frequency for 180 kph (Vr)

$$fd = \frac{2 \times RF\ (MHz) \times V\ (kph)}{1078.95} = \frac{2 \times 3000 \times 180}{1078.95} = 1,000$$

It can be seen that, as stated, the first MTI blind speed does occur when the relative velocity (Vr) is such that the Doppler shift is equal to the PRF. The second and subsequent blind speeds will occur when fd = PRF x n (number of PRF's). Using this we can plot the necessary MTI RESPONSE CURVES for individual RF/PRF combination.

11. INTERPULSE MODULATION TECHNIQUES

11.1 - Pulse Stagger

Interpulse modulation is created by altering the transmitted PRI, the pulse itself is not altered. One form of interpulse modulation is *PULSE STAGGER where the interval between successive pulses is altered in a deliberate and programmed manner.*

Why do radars employ Pulse Stagger ?

1) To identify 2nd time round echoes from targets located beyond the MTUR

2) Alleviates interaction between adjacent radars using the same PRF

3) Eliminate MTI blind speeds

4) As an Electronic Protection Measure (EPM) technique

5) To increase unambiguous range

To illustrate 1), let us assume we have a radar with a desired effective range of 15 km and not using pulse stagger It would require a PRF of 10,000 pps, PRI being 100µs. There are two targets in our area, one at 13 km, the other at 20 km.

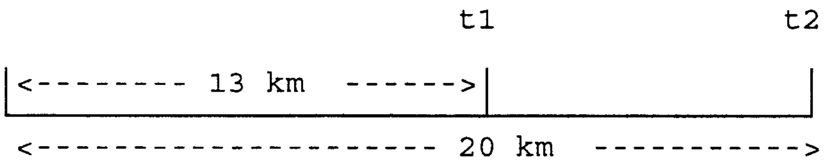
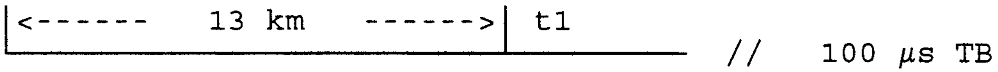


fig. 11.1:1

t1 = 13 x 6.66µs, 86.6µs t2 = 20 x 6.66µs, 133µs

What happens when we have a succession of pulses fired ?



1st sweep, return from t1 only

fig. 11.1:2

fig. 11.1:3

Target t2 which is 20 km beyond the selected MTUR will now appear at 'false' (ambiguous) range derived from the difference between the timebase of our display (100µs) and the target (133 µs), this being 33µs which equates to 5 km.

2nd and successive sweeps, t1 and 2nd time echo from t2

fig. 11.1:4

Now let us see what happens when we send a second PRI say 10μs less than t1 so we are firing PRI's of 90 then 100μs alternately.

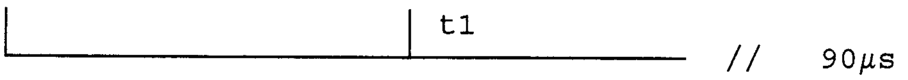


fig. 11.1:5

Only the target within the MTUR will show on the first sweep, successive sweeps will show both targets.

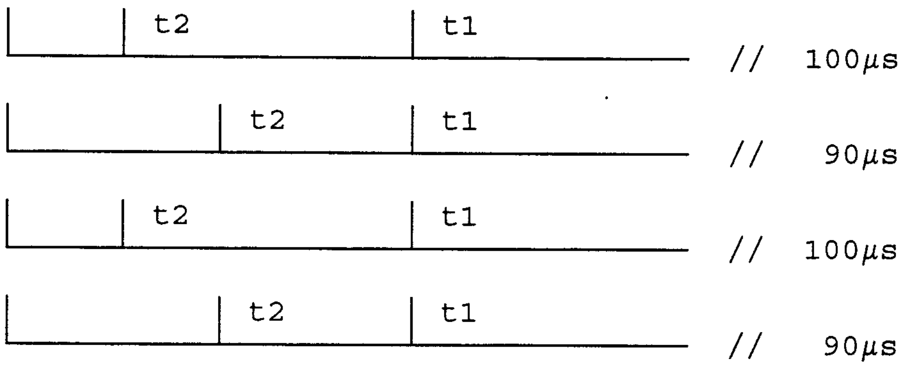


fig. 11.1:6

Return from target beyond the MTUR will have its presentation shifted by the PRI difference on each successive sweep. The false target can then be eliminated by suitable equipment circuitry.

The above example using two PRIs each fired alternately is referred to as TWO ELEMENT, TWO POSITION STAGGER or more commonly just Two Position Stagger.

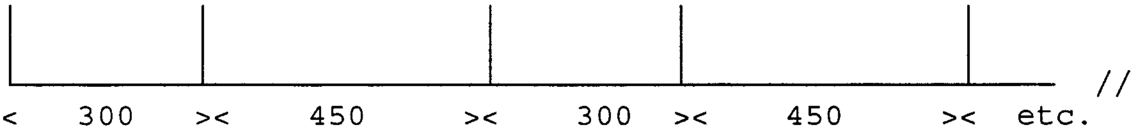
Components which make up the composition of a pulsed stagger signal are :-

ELEMENTS	*Number of different, individual PRI's*
POSITIONS	*Total number of PRIs in the sequence*
CYCLIC LENGTH	*Total time taken for PRI sequence to be transmitted*
FIRING ORDER	*Order in which PRIs fired in the transmission sequence.* As a collector, the true firing order will be unknown but is reported by assuming that the shortest PRI as the first one fired in the sequence.
MEAN PRF	*The reciprocal of mean PRI*, may not equate to any of the PRI values used. Can be calculated as follows :-

$$\frac{1}{t} \times \text{No. of Positions} \quad \text{or} \quad \text{Cyclic Rate} \times \text{No. of Positions}$$

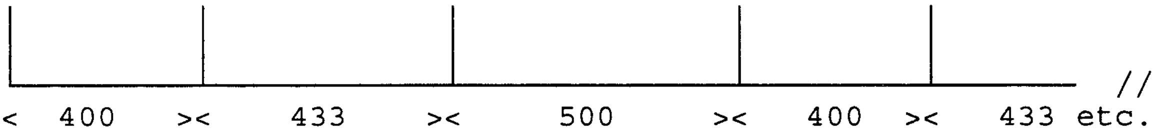
(*where t = cyclic length*)

Regular Stagger Where differences between PRIs equal and element / position ratio the same ie. 2 element 2 position. (See fig. 11.1:7 below)



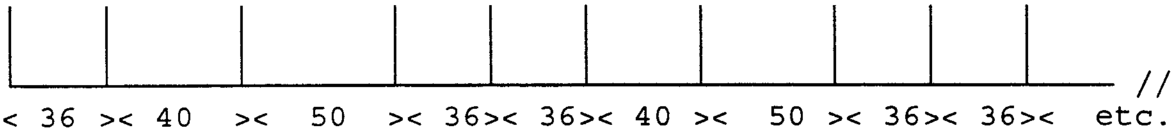
Firing order 300, 450, 300, 450, 300, 450 etc.

Irregular Stagger PRI spacing unequal but element/position ratio still the same ie. 3 positions with PRIs of 400/433/500μs. (See fig. 11.1:8 below)



Firing order 400, 433, 500, 400, 433, 500 etc.

Complex Stagger Where element/position ratio unequal ie. one or more PRIs fired more than once during the sequence, number of positions greater than number of elements. (See fig. 11.1:9 below)



Firing order 36, 36, 40, 50, 36, 36, 40, 50 etc.

11.2 - Stagger Ratios and System Blind Speeds

As well as each individual Pulse Repetition Interval in a stagger sequence being measured, there will be occasions when PRIs will be required to be shown as a ratio to each other in order that the resultant minimum MTI Blind Speed response produced by using more than one PRI can be determined. So it will be best if we come to terms with this method when dealing with stagger.

To show a **STAGGER RATIO,** we reduce each PRI in the sequence to their **LOWEST COMMON MULTIPLIER,** their **LCM.**

For instance, say we had a 2 element, 2 position stagger with PRIs of 750 and 1250μs. The LCM of these, that is the lowest number which both can be reduced to by being divided by the same value, will be 750 ÷ 250 = 3, and 1250 ÷ 250 = 5. So for these PRIs, the stagger ratio will be 3:5.

There may be cases where the LCM is not readily evident. In these cases it should be possible to determine it by the following method.

Take the largest value, say a PRI of 366.57μs, and subtract the smaller value from it, say other PRI in sequence is 353.24μs.

So 366.57 - 353.24 = 13.33

DIVIDE BOTH PRIs BY THIS NUMBER

366.57 ÷ 13.33 = 27.5
353.24 ÷ 13.33 = 26.5

Since the ***LCM MUST BE A WHOLE NUMBER,*** in this case it can be seen that, by doubling up both 26.5 and 27.5 we arrive at the LCM's of 53 and 55, giving stagger ratio of 53:55 accordingly.

The effect of blind speeds can be significantly reduced without incurring range ambiguities by operating with more than one PRF. Operating on more than one RF will also effect the MTI Blind Speed as the Doppler shift will increase with frequency. This occurs as the higher the frequency, the shorter the wavelength therefore the greater number that will be shifted for any given target.

With pulse stagger the composite effect of the multiple PRIs will create a blind speed which will be several times that produced by each individual PRI. It is the RATIO BETWEEN THE PRIs that is the greatest factor in determining the final blind speed and can be found by the following formula.

$$V = \frac{Vb\ (\text{Ratio } 1 + \text{Ratio } 2 + \text{Ratio}^{n})}{\text{Number of Stagger Elements}}$$

where Vb = Mean PRF Blind Speed

So to calculate the blind speed of a radar operating on an RF of 9120 MHz with PRI's of 272 and 288μs, first we find the mean PRI (272 + 288 ÷ 2 = 280μs). This gives us a PRF of 3571.4 pps and, using the formula .54 x PRF ÷ RF (GHz) = .54 x 3571.4 ÷ 9.12 gives 211.5 kph.

To find the stagger ratio, we require both PRI's to be reduced to their Lowest Common Multiple. An easy place to start is take the highest PRI (288) then subtract the lowest (272), this gives us a figure of 16. Divide both PRI's by this number and we arrive at a ratio of 17:18.

Applying that to the formula gives :

$$V = \frac{211.5 \text{ x } (17 + 18)}{2} = \underline{3{,}700 \text{ kph}}$$

THE COMPOSITE BLIND SPEED OF A MULTIPLE PRI SEQUENCE IS KNOWN AS THE

SYSTEM BLIND SPEED.

BY CHANGING THE STAGGER RATIO BUT MAINTAINING THE SAME MEAN PRI, THE RADAR CAN VARY THE MTI BLIND SPEED WHILE RETAINING THE SAME MTUR.

In the above example, if the PRI's were changed to 252 and 308μs, the *mean* would remain at 280 μs but now the ratio has changed to 9 : 11 with a subsequent system blind speed of

211.5 kph × 20 ÷ 2 equalling **2,115 kph**.

MTI Composite Blind Speed Response Curves

As we can see from the illustration below, when we combine the output from two or more PRI's, minimum/maximum response to targets will occur at different target velocities. The resultant response curve '*smooths*' out and minimum response can be designed to occur beyond the velocity range the radar system can be expected to handle by choosing suitable PRI values.

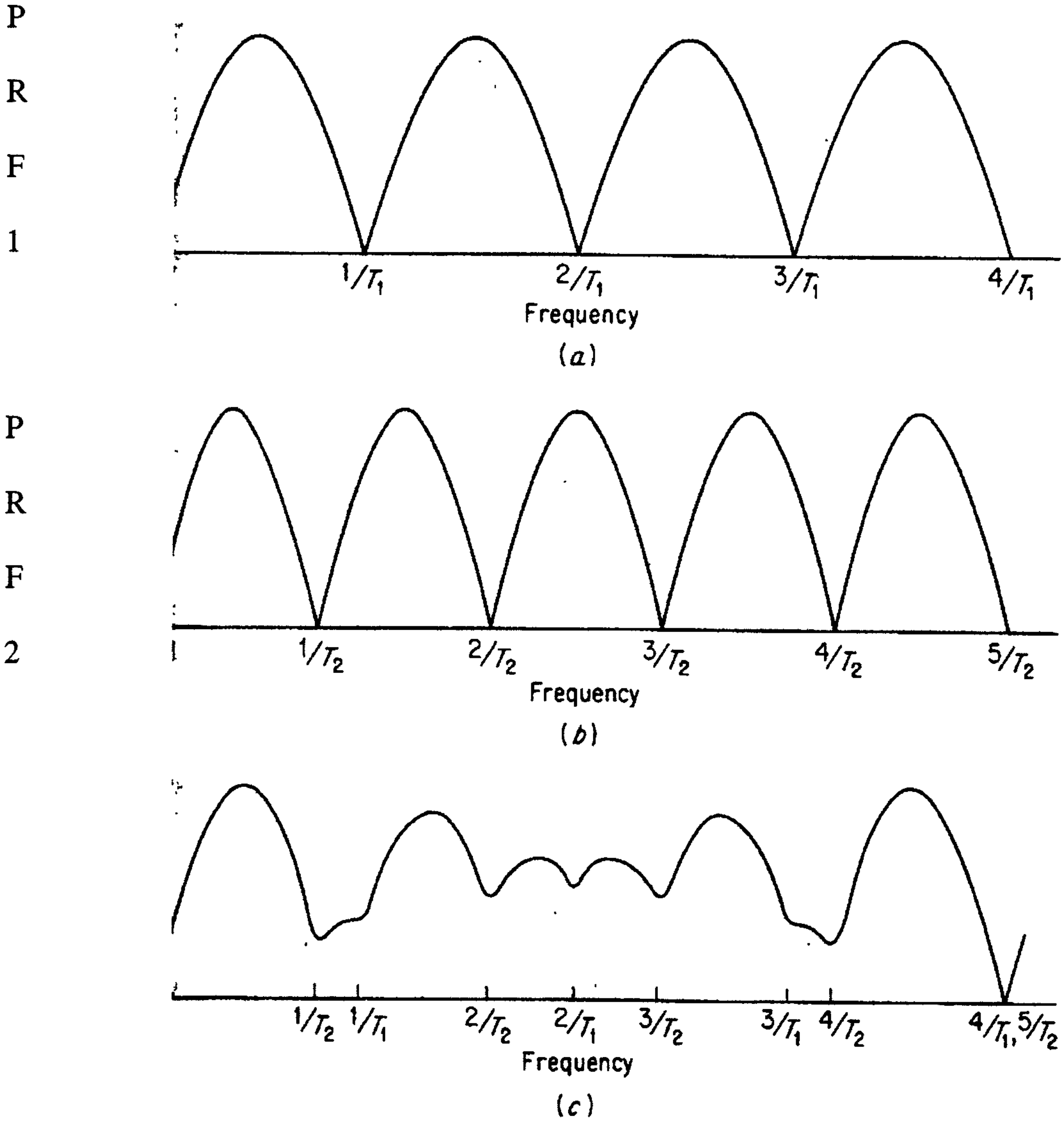


fig. 11.2:1

COMPOSITE MTI BLIND SPEED RESPONSE

11.3 - Pulse Interval Modulation (PIM)

In Pulse Interval Modulation, the PRI is varied significantly on a pulse-to-pulse basis in an apparent random non-recurring manner, there will be **NO CYCLIC RATE.** Commonly referred to as

'JITTER'

ADVANTAGES

Avoids pulse '*eclipsing*'

Eliminates range ambiguities

EPM (Electronic Protection Measures)

Can increase MTUR and blind speeds

Two distinct forms of Pulse Interval Modulation are commonly used, **Discrete** and **Indiscrete**. In the former, each PRI is separated by the same value from its neighbour in the sequence whereas each is different in the latter.

DISCRETE P.I.M.

Typical display

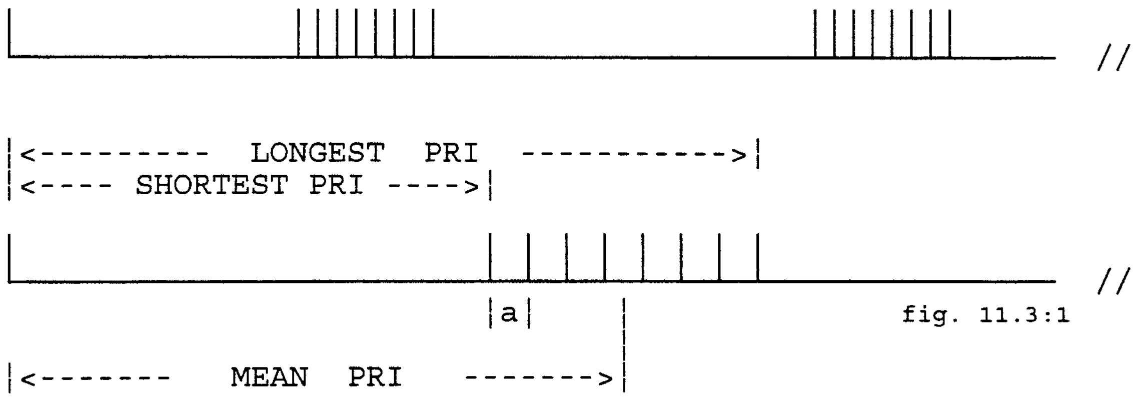


fig. 11.3:1

As illustrated,

Each PRI within the sequence is separated by the same value.

Indiscrete P.I.M (Random Jitter)

Typical display

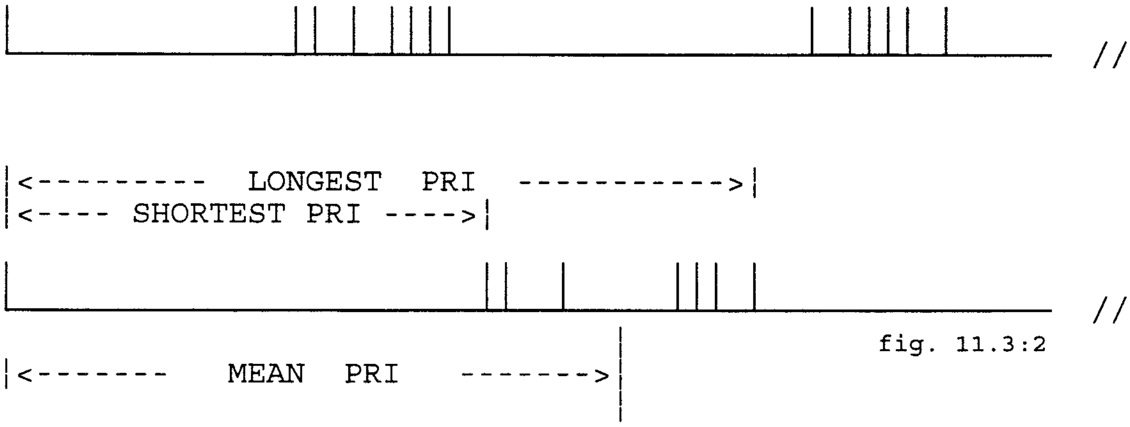


fig. 11.3:2

To produce Indiscrete PIM, the radar fires any PRI within its operating range in an apparent random manner. With some radar systems the generated 'jitter' can be unintentional, being produced by faulty components or poor design and maintenance. Modern systems on the other hand can produce computerised algorithm generated sequences that, although random to the collector, allow the return echoes to be processed with reference to the known PRI sequence. Such modulation techniques are often referred to as pseudo- or quasi-random jitter.

EXAMPLES OF USERS / FUNCTIONS

Used where range measurement close to the radar are required such as in Fire-Control radars and seen being applied as radar altimeters.

11.4 - Pulse Frequency Modulation (PFM)

Similar to P.I.M except that the PRI is varied between limits at a **SUPERIMPOSED CYCLIC RATE.** This can be sinusoidal, sawtooth or triangular.

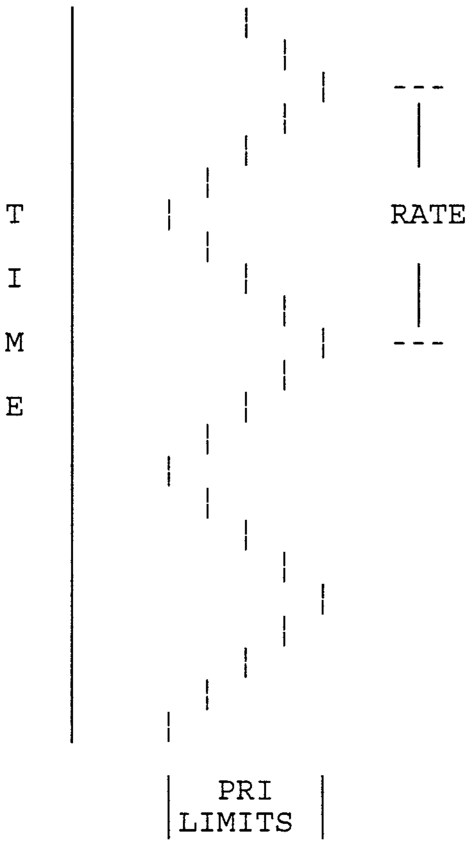


fig. 11.4:1

Since in PFM intervals varied at a set rate about the mean PRI,

A MEAN PRF VALUE IS PRESENT AND DISCERNIBLE.

EXAMPLES OF USERS / FUNCTIONS

Like P.I.M. used where close range measurements are required and utilised for same purposes.

11.5 - PRI Dwell Switching

WHERE A NUMBER OF PRIs OF THE SAME VALUE ARE FORMED INTO A SEQUENCE, MORE THAN TWO SEQUENCES ARE CONSTRUCTED AND EACH IS PROGRESSED THROUGH UNTIL ALL SEQUENCES ARE TRANSMITTED, THE SEQUENCE LENGTH, AND THE CYCLE STARTS AGAIN.

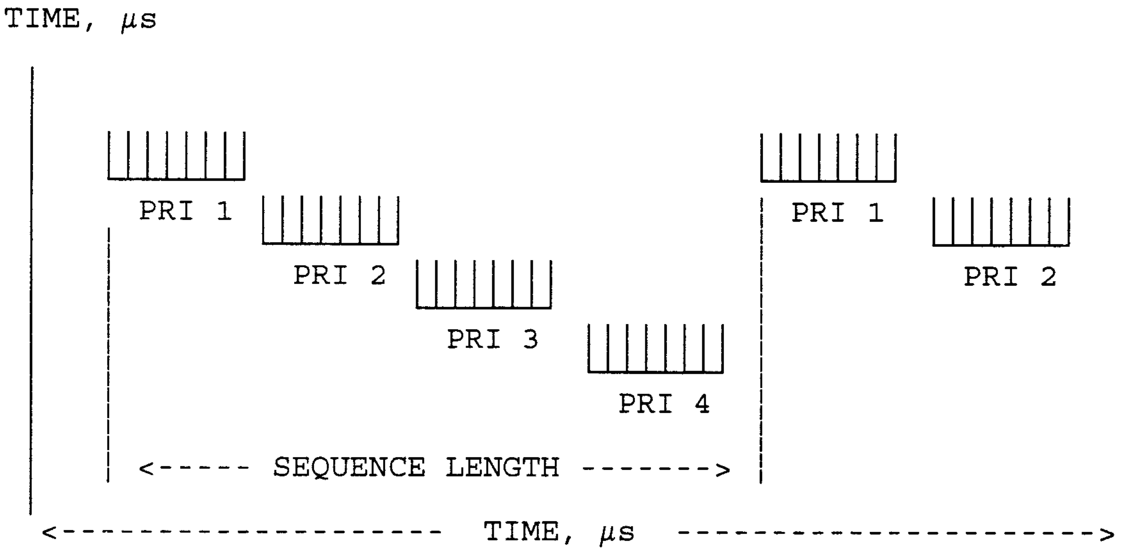


fig. 11.2:1

For a signal where there are the same number of PRIs per dwell, the number of PRI's per dwell can be calculated :

$$\text{PRIs per dwell} = \frac{1{,}000{,}000}{\text{Mean PRI} \times \text{Elements} \times \text{Switching Rate}}$$

Note that Switching Rate equates to Cyclic Rate (reciprocal of Sequence Length)

The advantages of using PRI Dwell Switching are :

Determines 2nd time around echoes

Increases Maximum Unambiguous Range (MUR)

Eliminates Blind Speeds and Ranges

Produces unambiguous velocity information

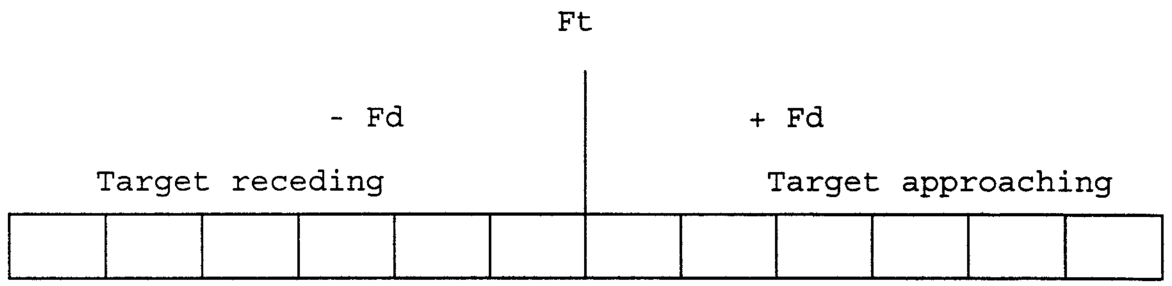
12. PULSED DOPPLER

Distinct from MTI radars, pulsed doppler radars are usually defined as having **UNAMBIGUOUS VELOCITY MEASUREMENT BUT RANGE MAY BE AMBIGUOUS**. There are **NO BLIND SPEEDS WITHIN THE RANGE OF EXPECTED DOPPLER SHIFT BUT MULTIPLE TIME AROUND ECHOES MAY OCCUR DUE TO THE HIGH PRFS NECESSARY**.

Consider the RF spectrum of a pulsed signal. This consists of spectral lines at the PRF within the envelope created by the pulse duration, any return echo from a moving target will have the spectral lines shifted by the Doppler frequency value. If, in the receiver processing we can **COMPARE THE TRANSMITTED FREQUENCY OF A SINGLE SPECTRAL LINE TO ITS RECEIVED FREQUENCY**, then we can detect and measure the Doppler shift created.

THIS ENABLES A HIGH PRF PULSED DOPPLER RADAR TO DETECT MOVING TARGETS AND RESOLVE, WITHOUT AMBIGUITIES, ITS RADIAL VELOCITY.

The means of achieving this is by passing the echo signal through a series of frequency conscious filters grouped either side of the transmitted frequency. Should an echo from a moving target be received, its frequency will have been shifted one side or the other of that transmitted depending on whether target approaching or receding. In practice the **OVERALL FREQUENCY RANGE OF THE FILTER BANK HAS TO BE AT LEAST TWICE THAT OF THE EXPECTED DOPPLER SHIFT** to ensure that adjacent spectral lines will not intrude and cause ambiguity. It should be mentioned that when we relate this to an airborne emitter, the frequency range also has to allow for the fact that two high speed aircraft closing on each other head on will have to contend with its own speed plus the speed of the closing target. This will necessitate the need for a large number of filter banks.



FILTER BANK fig. 12.0:1

As previously shown with respect to a Continuous Wave radar, the formula for deducing the Doppler shift is :

$$fd = \frac{2 \times RF \times Vr}{C} \quad \text{(where Vr = Radial Velocity)}$$

$$\text{or} \quad \frac{2 \times Vr}{\text{Wavelength}}$$

Say we have an aircraft approaching us at 1,600 kph and our radar is operating on 9,000 MHz, what would be the Doppler shift frequency ?

$$\frac{2 \times \overbrace{9{,}000 \times 1{,}000{,}000}^{\text{RF in Hertz}} \times \overbrace{1{,}600 \times 1{,}000}^{\text{Speed in m}}}{\underbrace{3 \times 100{,}000{,}000}_{\text{Radio Velocity}} \times \underbrace{3{,}600}_{\text{Hrs to Secs}}} = \underline{26{,}666.66 \text{ Hz}}$$

$$\text{or } \underline{26.666 \text{ kHz.}}$$

Therefore since the target is **APPROACHING**, the received frequency will be **HIGHER** THAN THE TRANSMITTED. In this case it will be ft (9,000 MHz) plus the frequency shift (26.666 kHz), resultant frequency being 9,000,026,666 Hz or 9,000.0266 MHz. Were the target flying away from us, **RECEDING** then the resultant received frequency would be **LOWER**, ie. 9,000 MHz - 26.666 kHz = 8,999,973,334 Hz.

Suppose a radar designer was asked to build a pulse doppler radar operating on a radio frequency of 11,009.68 MHz and being able to cope with targets having a maximum speed of Mach 1 (1,225 kph). What PRF would be used ?

So, we know that $$f\text{d} = \frac{2 \times \text{RF(Hz)} \times \text{Vr(m/sec)}}{\text{C (m/sec)}}$$

This can be simplified to $$\frac{2 \text{ x RF (MHz) x Vr (kph)}}{1{,}080}$$

(1,080 derived from 300,000 x 3,600 ÷ 1,000,000)

In this case $$f\text{d} = \frac{2 \text{ x } 11009.68 \text{ x } 1225}{1{,}080} = \underline{24{,}975.6 \text{ Hz}}$$

or, rounded up, 25 kHz

The resultant filter bank would be as shown below.

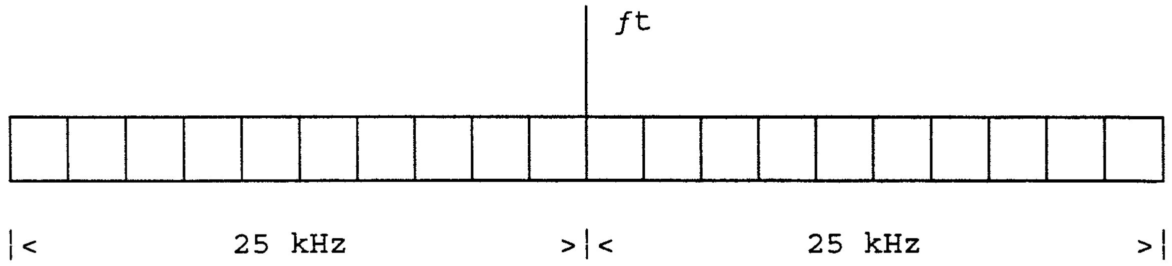


fig. 12.0:2

NOT part of the syllabus, but the Number of Filters required can be derived from the formula :

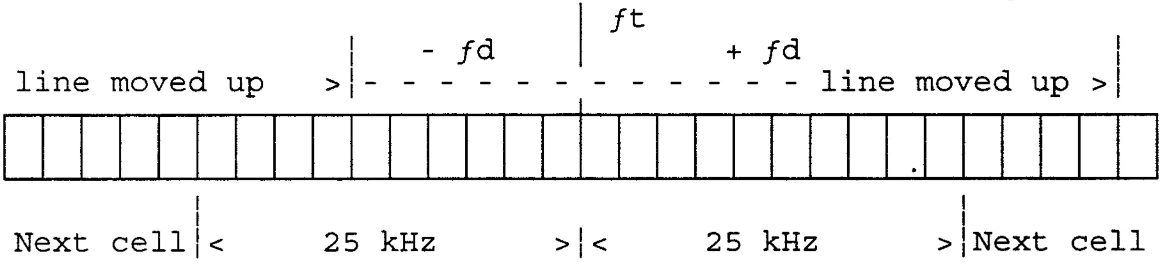
$$\text{No. of Filters} = \frac{\text{First Blind Speed (Vb)}}{\text{Radial Velocity (Vr)}}$$, in this case 10

Now consider a target approaching at a speed greater than that designed for, that is having a Doppler shift higher than 25 kHz. How would this now appear in the filter bank?

Say the target's velocity is approximately 1,720 kph, this would equate to a Doppler shift of 35 kHz so the spectral line would be shifted UP in frequency by that amount. As can seen, this would now place it outside our 25 kHz filter bank.

However, it must be borne in mind that ALL SPECTRAL LINES WILL BE SHIFTED. This means that, while the line spectral line within the filter bank has moved out, the line lower in the transmitted sideband will move up into the - *f*d bank indicating erroneously that the target was RECEDING.

fig. 12.0:3



This is the basic reason why the Doppler shift frequency of the filter bank MUST BE AT LEAST TWICE THAT OF THE SHIFT DISPLAYED BY THE INTENDED TARGET, as indicated by the '*Nyquist Theory*'.

So to effectively deal with a target up to a velocity of Mach 1, we would have to allow our filter bank to cope with twice that speed, that is 50 kHz.

The use of such high PRF's will have an extremely detrimental effect on the radar's range but this can be overcome by using multiple PRF's ie. Pulse stagger, PRI dwell switching etc.

Any technique used to resolve target range unambiguously under these circumstances is generally known as

'Ranging Beyond the MTUR'.

12.1 - Ranging Beyond the MTUR

One method to measure beyond the MTUR is by splitting the PRI into a number of '***Range Bins***', each bin equating to the basic clock/timing period. As the PRF's used will mean that the target in all cases will be beyond the MTUR, range is determined by noting the number of bins the echo is shifted when PRF is switched. True range is then defined as number of bins shifted times the total bin range.

True range = n × Range unambiguous (R_u) + Range apparent (R_a)
(where n = number of bins shifted)

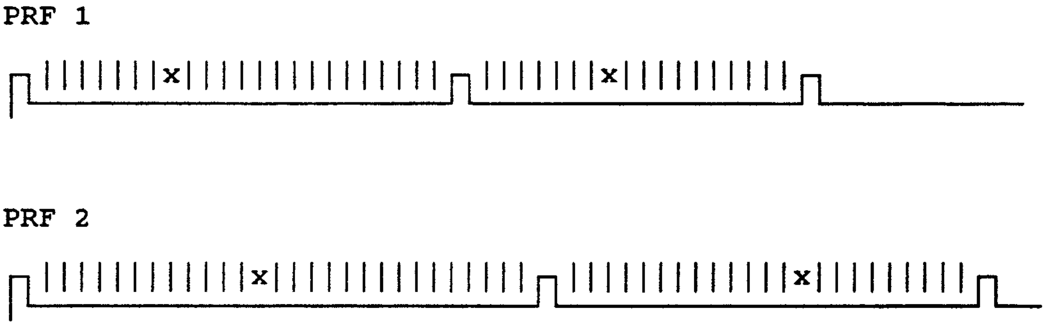


fig. 12.1:1

As shown above, the target in PRF 1 is in range bin 8 while in PRF 2 it now appears in bin 13, five bins away or 5 times the MTUR of PRF 1.

The target's true range will therefore be 5 × MTUR (*R_u, range unambiguous*) of PRF 1 plus range measured by PRF 1 (*R_a, range apparent*).

So if PRF 1's MTUR equated to 30km and target was measured as being at 16 km, then true range would be :

5 x 30km + 16km = 166km

13. INTRAPULSE MODULATION TECHNIQUES

Pulse Compression

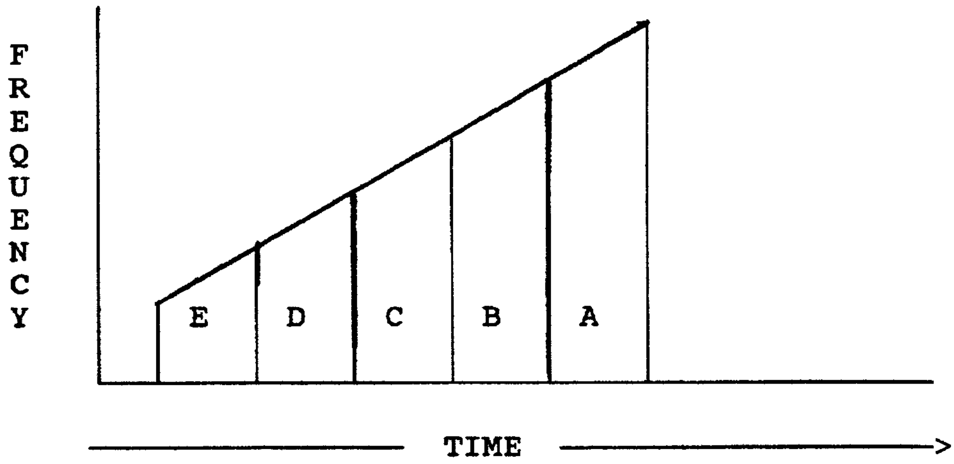
DEFINITION - A RADAR PROCESSING TECHNIQUE WHERE, FOR MAXIMUM RANGE, A LONG DURATION, HIGH POWER PULSE IS TRANSMITTED BUT TREATED AS A LARGER NUMBER OF MUCH SMALLER PULSES AT THE RECEIVER TO RESTORE ADEQUATE RANGE RESOLUTION.

As average power output of a radar is directly proportional to its pulse duration, those requiring a high average power output, ie. Early Warning, Ground Controlled Intercept radars, require long pulse durations. However, as range resolution is inversely proportional to the pulse duration, resolution degrades as pulse duration increases.

In order that range resolution between multiple targets can be maintained, techniques known as **PULSE COMPRESSION** can be adopted. These cause the LONG DURATION transmitted pulse to be modulated (coded) in **FREQUENCY** or **PHASE** for example in a deliberate and programmed manner. Return echoes from targets are then subjected to demodulation (decoded) during which the pulse is compressed and treated as a number of much smaller pulses thereby restoring adequate range resolution.

13.1 - Frequency Modulation On the Pulse (FMOP)

Also known as '*Chirp*', is where the radio frequency of each transmitted pulse is altered, ie increased or decreased, at a constant rate throughout its length. Where every pulse has the same linear frequency change, known as Linear Frequency Modulation on the Pulse (LIFMOP). The received echoes are passed through a series of frequency sensitive delay lines, known as a Dispersive Delay Line, the delay decreasing linearly with frequency change at exactly the same rate of the modulation on the transmitted pulse. This causes the final output to be delayed long enough so that ALL the frequencies emerge simultaneously, the output now being a LARGE AMPLITUDE NARROW PULSE.



LINEAR FREQUENCY MODULATION ON THE PULSE

fig. 13.1:1

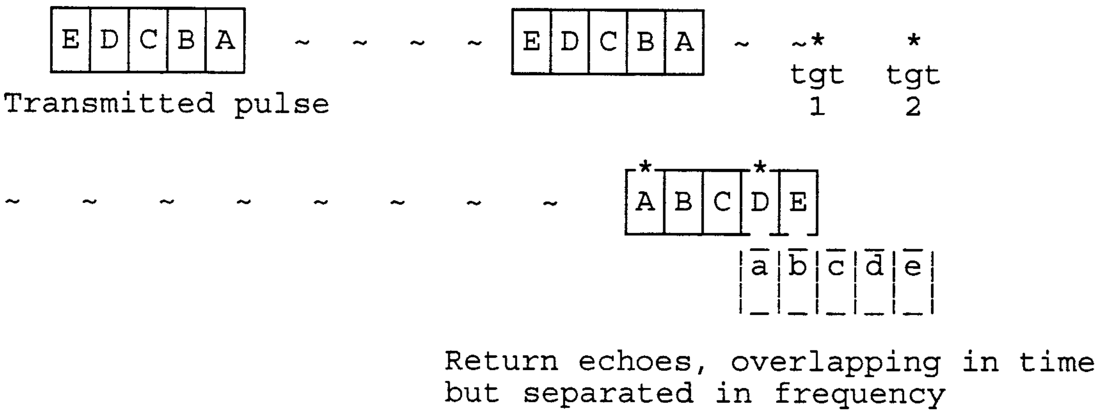


fig. 13.1:2

The transmitted long duration pulse strikes target 1 and is reflected. Target 2 although separated in range, is close enough to be within the return pulse echo BUT WILL APPEAR IN A DIFFERENT SEGMENT OF THE PULSE, A DIFFERENT FREQUENCY TO THAT OF TARGET 1.

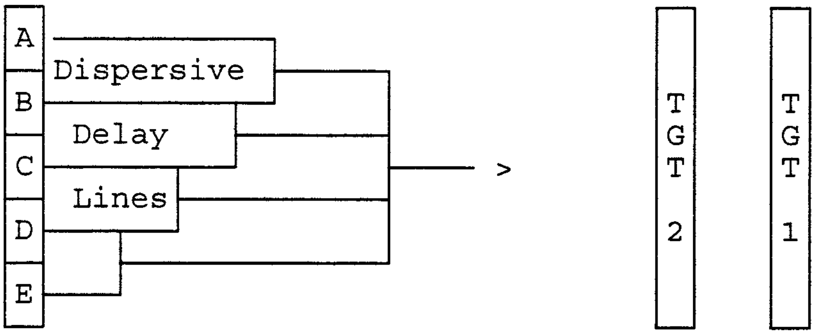


fig. 13.1:3

The returned echo is applied to the dispersive delay line, the highest modulated frequency being delayed the longest. This causes individual line outputs to '*bunch up*' before finally being outputted when lowest frequency is processed. Targets now resolved with frequency difference translated to time ie. DISTANCE.

Types of Frequency Modulation On the Pulse (FMOP)

Presently, the most common form of FMOP is LInear Frequency Modulation On the Pulse (LIFMOP) where frequency changes at a constant rate throughout the duration of the pulse. However the frequency change may be -

- **Continuous** - Changes frequency at a continuous rate and direction from one transmitted frequency limit, Highest Modulation Frequency (HMF) or Lowest Modulation Frequency (LMF), to the other limit.

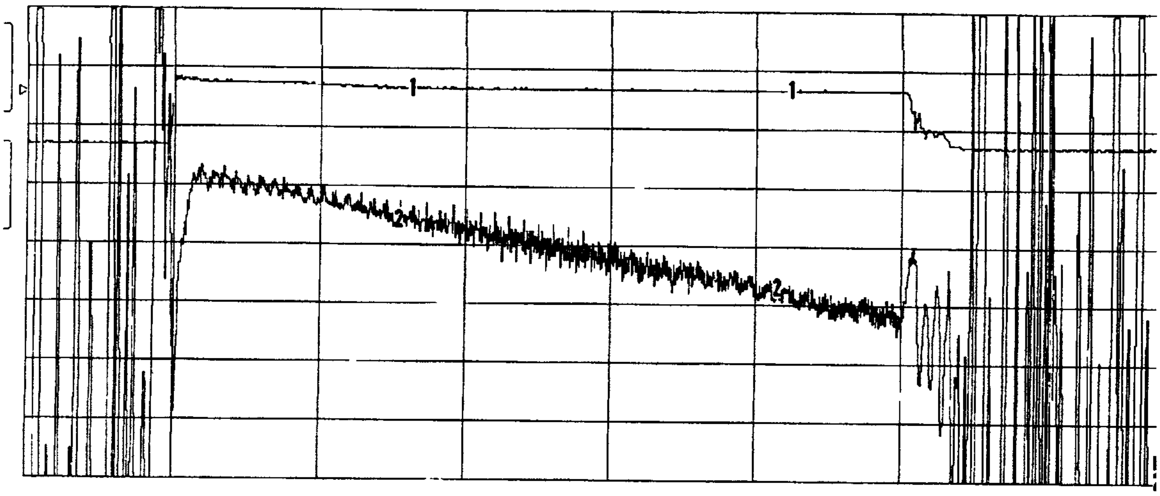


fig 13.1:4 - Linear Frequency Modulation On the Pulse (FMOP) displayed on a 50µs pulse. Top trace is AM detected, lower trace FM discriminator output.

- **Stepped** - Frequency changed in a linear manner but transmitter dwells on values within the intended frequency limits for a time segment of the overall pulse duration. The frequency value within each segment may be constant or changing. Direction of frequency change may vary from segment to segment.

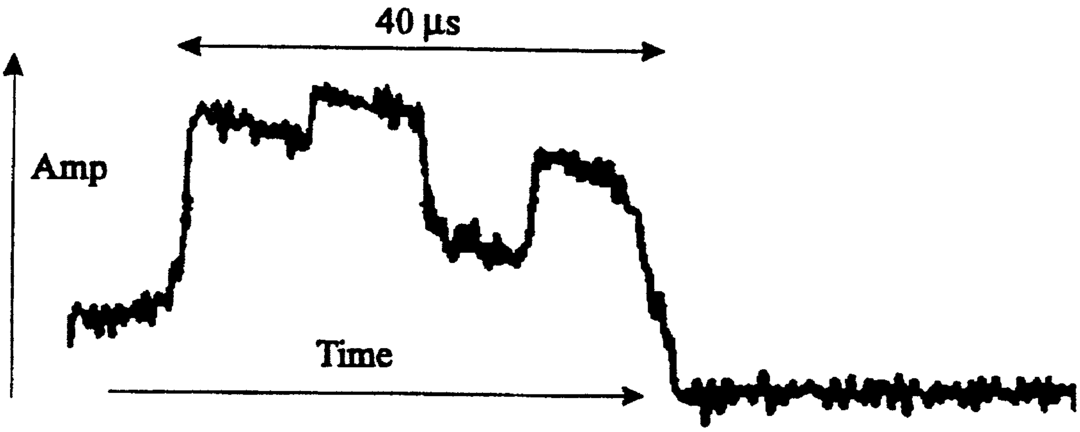


fig. 13.1:5 - 40µs pulse constructed by 4 × 10µs segments. Each segment is transmitted on a different RF and individually exhibit LIFMOP.

- **Non-Linear** - Emitter changes frequency within segments of the overall pulse duration but the rate and/or direction of change will not be constant.

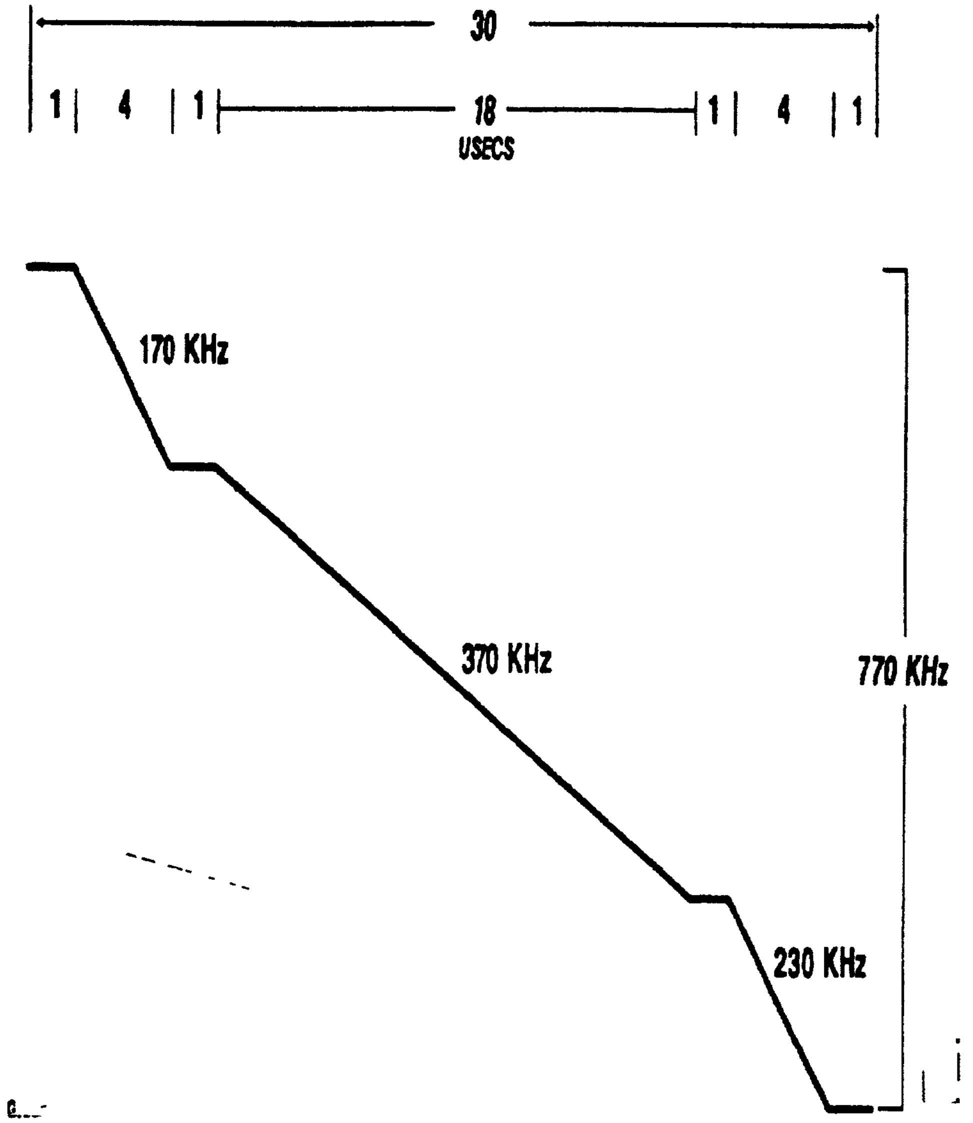


fig. 13.1:6 - Representation of Non-Linear FMOP. Pulse constructed of time segments, some with no frequency change others with FMOP but rate of change being different from segment to segment.

13.2 - Phase Modulation On the Pulse (PMOP)

A modulation technique where each pulse is divided into equal time segments, '*bits*', the change in bit value being denoted by a phase reversal of the waveform. Common reversals occur at 180° (bi-phase) and 90° (quad-phase). Some sophisticated systems even use a mixture of phase reversals, this being known as polyphase shifting.

Basically each transmitted waveform is uniquely coded using several phase reversals and, when received, a digital technique is used to match the time response of the returned pulse against the pulse replica to determine the exact time of arrival. This is known as AUTOCORRELATION and produces maximum output when the received '*echo*' waveform exactly matches in coding the transmitted signal. Other smaller amplitude outputs do occur these being called time sidelobes, and can mask returns from other targets. Specific bit sequences have been found which produce sharp main response combined with very low timed sidelobes, these are known as BARKER CODES and are commonly used with this type of modulation. So far no Barker sequence above 13 bits has been found to provide the desired result, sequences used are 2, 3, 4, 5, 7, 11 and 13 bit.

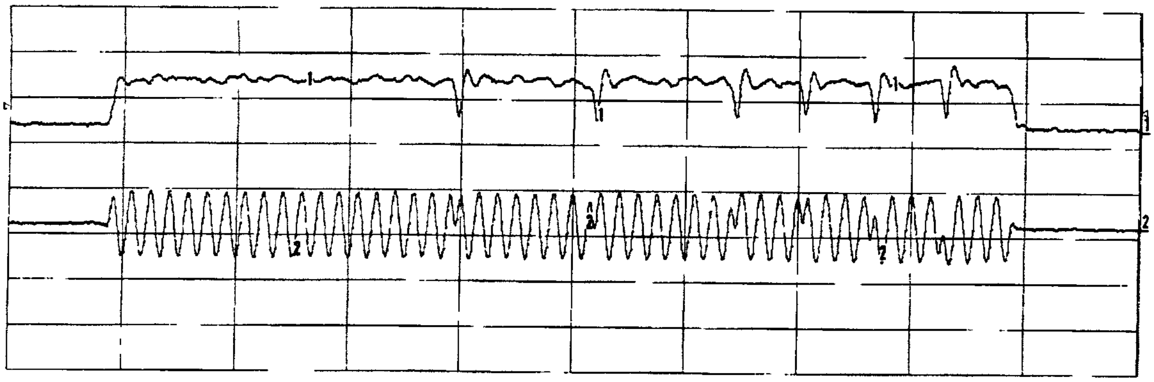


fig. 13.2:1 - Bi-phase modulated pulse displaying 13 bit 'Barker Code'. AM detected trace on top with Pre-Detected output beneath showing 180° phase reversals on transmitted RF.

ADVANTAGES OF PULSE COMPRESSION TECHNIQUES

- Enables good range resolution to be maintained while using long, high power pulse for long range.
- By providing increased sensitivity from the receiver, the radars maximum unambiguous range (MUR) is increased.
- In FMOP, as signal spread over greater RF bandwidth, more resistant to Electronic CounterMeasures (ECM).
- In PMOP, signal spectrum created at 'chip' rate and all transmitted power will be concentrated within resultant narrow bandwidth. Any ECM would require high power to avoid 'burn through' and subsequent detection.

Representations of other BARKER CODES.

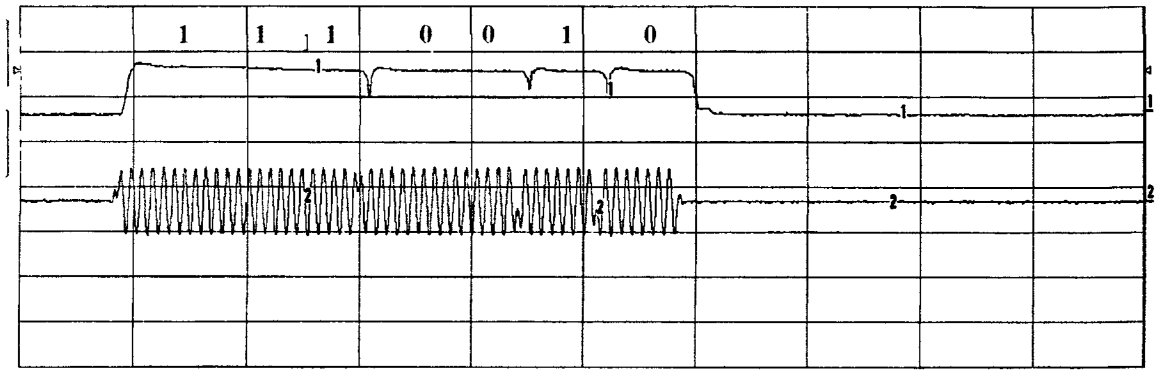


fig. 13.2:2 - 7 bit 'Barker Code' constructed using bi-phase shift keying (BPSK). As with all 'Barker Codes', the unique code shown, 1110010, may be reversed if required.

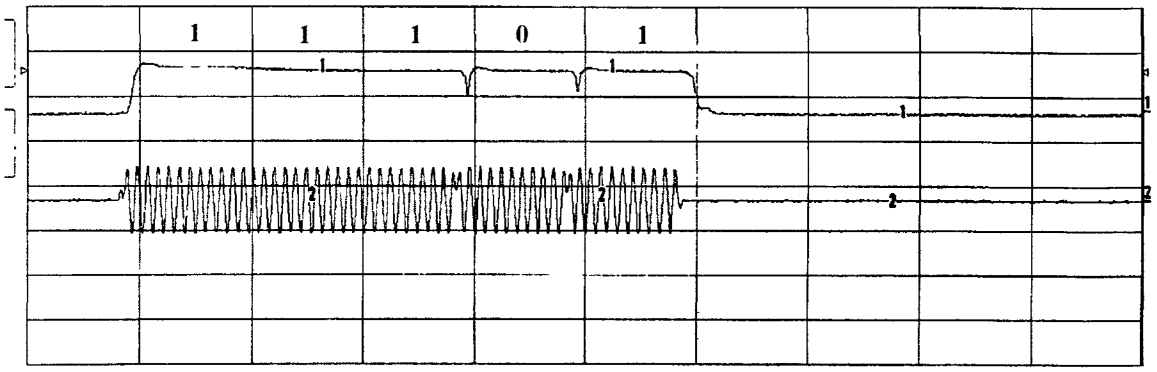


fig. 13.2:3 - 5 bit 'Barker Code', processed bit coding 11101 or, reversed, 00010.

14. PHASED ARRAYS

A Phased Array is a directive antenna which is made up of many separate isotropic elements, these normally being omni-directional, that is transmitting/receiving equally through 360°. When the individual elements are formed into an array critically spaced, say ONE WAVELENGTH of the desired radio frequency apart, a beam pattern can then be formed by applying **FREQUENCY, PHASE or TIME DELAY** between the elements. Commonly used is digitally switched delay line, with the delay time related to the wavelength of the frequency used. In the receive mode, the antenna beam can be guided by adjusting the amplitudes and delays in each of its elements so that they constructively combine at the receiver.

By varying the **FREQUENCY**, the beam can be steered. When the wavelength matches that of the antenna elements, maximum power can be achieved. The greater the mismatch between wavelength and spacing of elements, the lower the response. Adjustment of the frequency will therefore cause the maximum point of response to move accordingly, we have steered the beam.

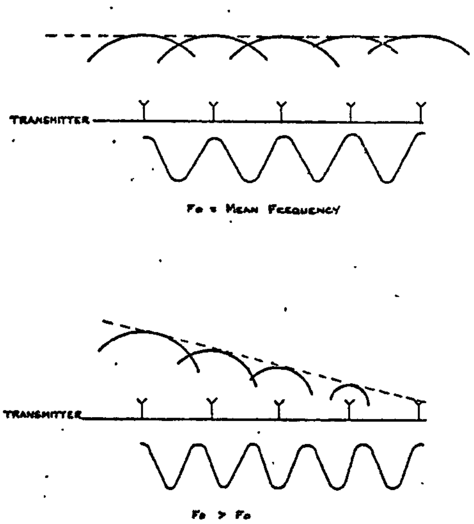


fig. 14.0:1

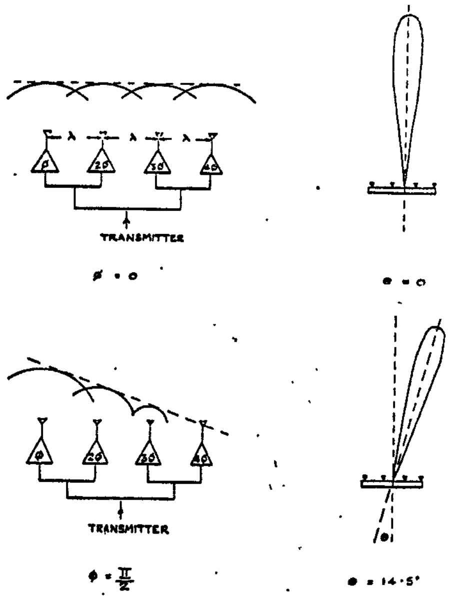
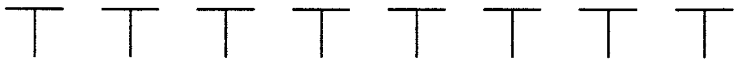


fig. 14.0:2

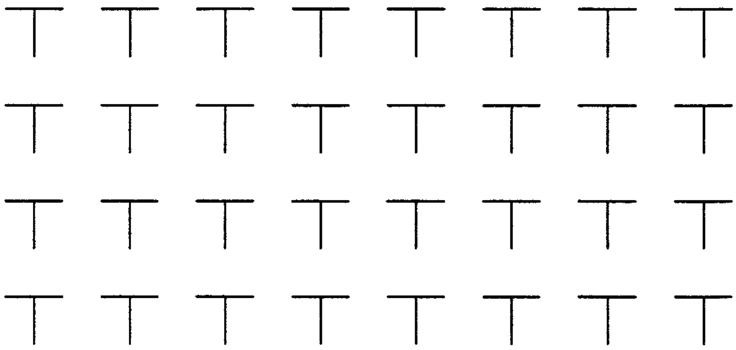
As in frequency beam steering, by adjusting the **PHASE** of the signal the point of maximum response in desired plane of the array can be altered. This can be done by using phase-shifters or by introducing a delay line process.

Arrays which comprise of regularly spaced element aligned in **ONE DIMENSION,** are called **LINEAR ARRAYS.** Beam patterns formed normally, at 90° to array, is called a *BROADSIDE,* those along the length of the elements, collinear, an *ENDFIRE.*



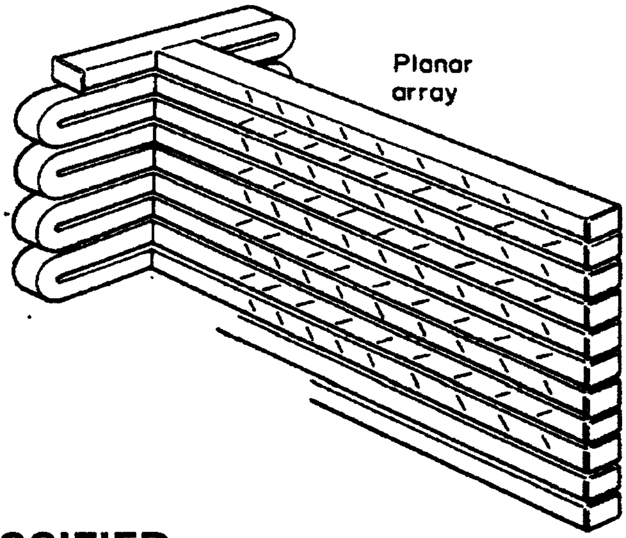
LINEAR ARRAY fig. 14.0:3

When elements are formed into **TWO DIMENSIONS,** a **PLANAR ARRAY,** the radiation pattern is merely a combination of the patterns of its composite linear arrays.



PLANAR ARRAY fig. 14.0:4

In practise, a *SLOTTED WAVEGUIDE* may well be used to radiate the desired beam pattern. Slots cut in the waveguide allow the signal to radiate in the desired direction. By creating a 'stack' of these slotted waveguides to form a Planar Array, (see fig. 14.0:5 right), varying the transmission frequency or phase can steer the beam in elevation. Mechanically scanning the antenna allows target information in azimuth to be resolved. This is the basic mode of operation of many modern '3-D' radars.



Elements can even be formed to **match the contours of specific hardware,** say on an aircraft, these being called **CONFORMAL ARRAYS.**

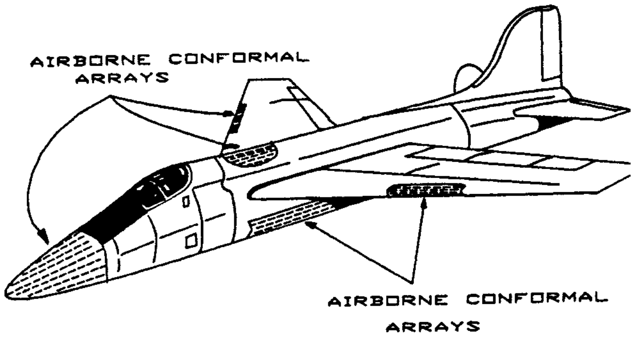


fig. 14.0:6

Phased Arrays have many advantages, some of which are listed below:

RAPIDLY STEERABLE (AGILE) BEAMS

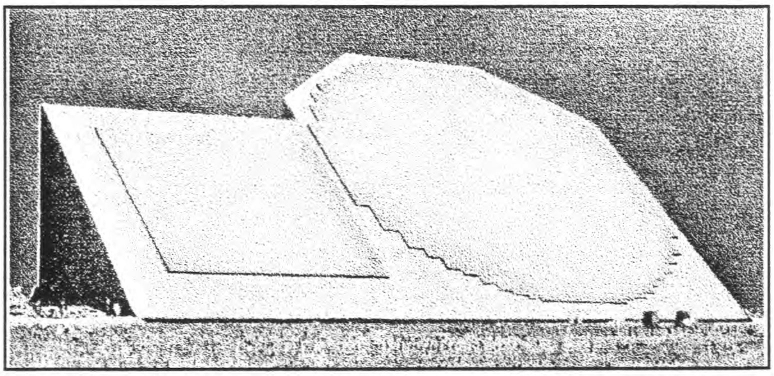
CAPACITY FOR MULTI-FUNCTION OPERATION

WITH ABILITY TO HAVE FLEXIBLE BEAM DWELL TIME, CAN RESPOND TO LOW RADAR CROSS SECTION TARGETS, ADAPTIVE TRACKING.

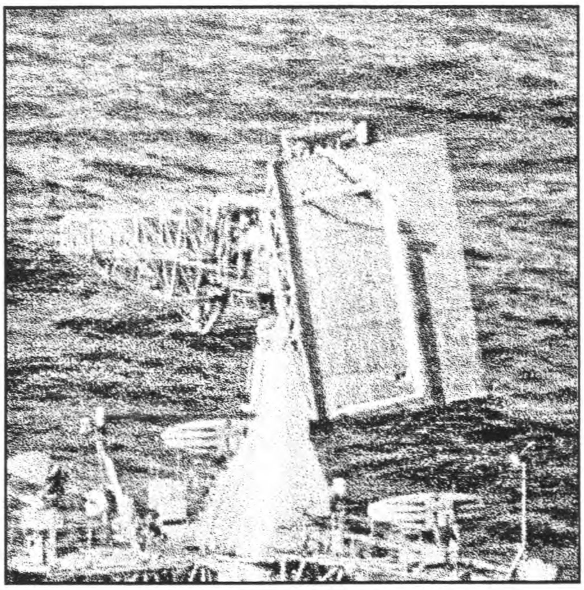
AUTOMATIC ACQUISITION OF LOST TARGETS, CAN MEMORISE WHERE THE TARGET WAS.

Despite numerous advantages, arrays were not without their disadvantages, the primary one being the increased complexity with matched cost. Phased Arrays were generally used only when warranted by the application. Advances in manufacturing techniques have decreased costs to the point where such antenna, especially slotted waveguide, are to be found in use by many different customers, both civil and military.

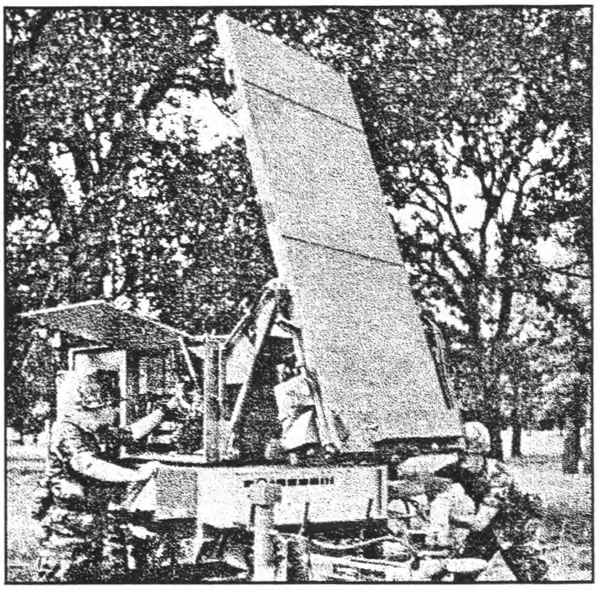
Typical phased arrays in service



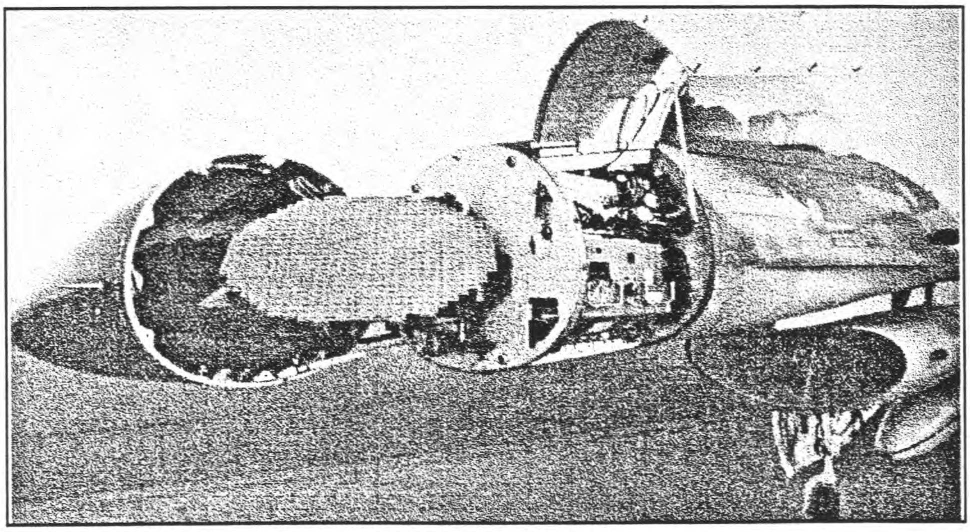
AN/FPS-85 EARLY WARNING RADAR, fig. 14.0:7



RUSSIAN 'TOP STEER', fig. 14.0:8



AN/TPQ-36, fig. 14.0:9



AN/APG-66 RADAR FITTED IN F-16 FIGHTER AIRCRAFT, fig. 14.0:10

14.1 - Frequency Scanning Radars

As discussed in Phased Arrays, there are various ways of steering a radar beam electronically. Frequency Scanning (FRESCAN) is one technique where the beams are steered by varying the radio frequency used.

A common use of this technique is where the antenna is mechanically scanned in azimuth with simultaneous electronic scanning in elevation. This can create a Three Dimensional (3D) plot of a target showing azimuth, range and elevation (height) information from the one radar antenna. Typically a different frequency is allocated to each elevation beam, with the number of frequencies used being proportional to the number of beams. By sending more than one PRI, dwelling, on certain beams, the radar can concentrate on any particular part of the scanned area ie. increase the time spent on say the lower altitude beam. The rate spent on each RF will equate to the Elevation Scan Rate, that is the time taken to scan through his beam sequence.

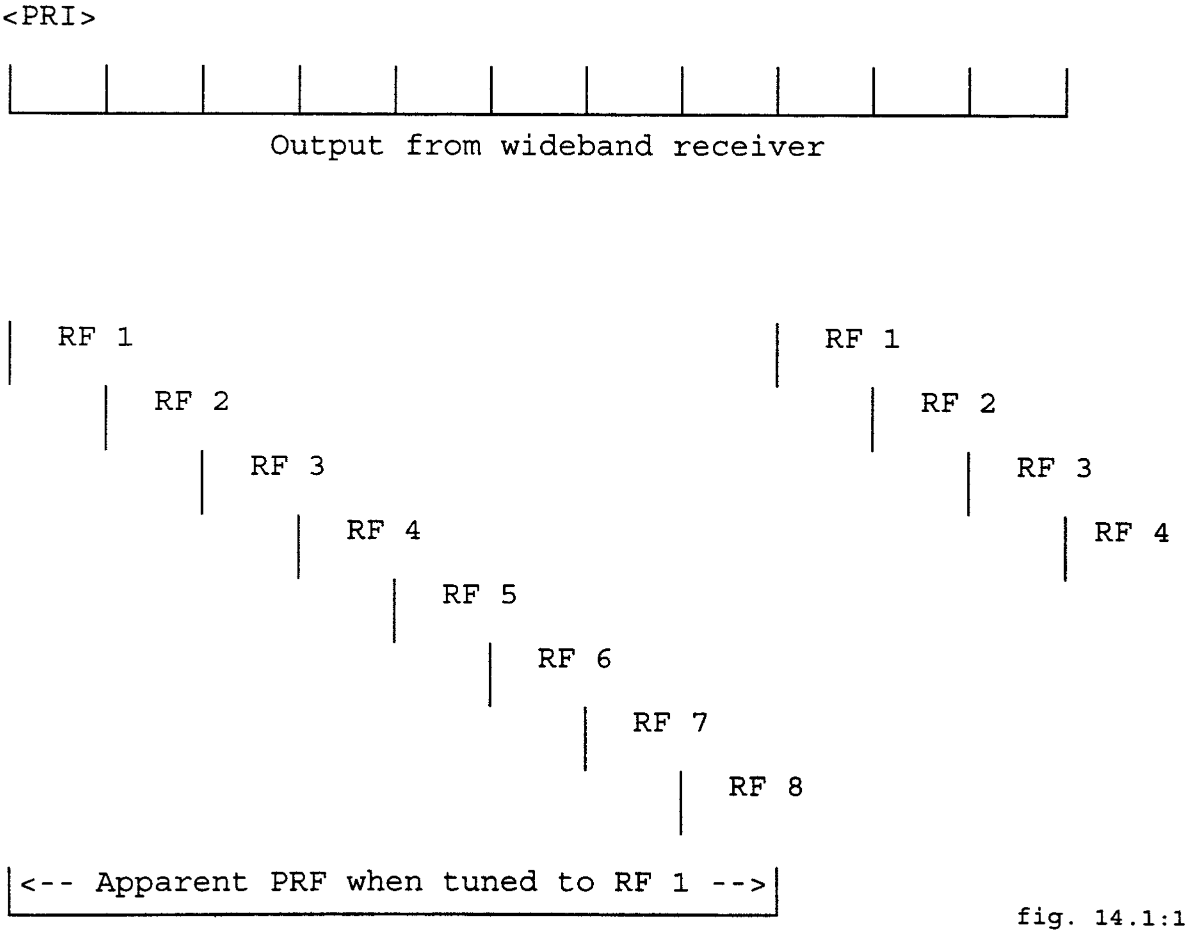
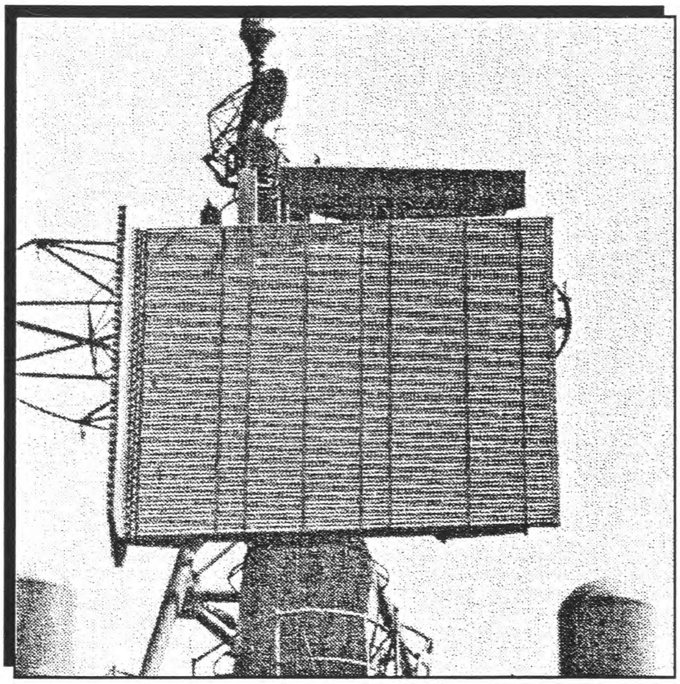


fig. 14.1:1

Modulation rate on single RF = Elevation Scan Rate

Typical Frequency Scanning Radars



Fitted to a variety of United States Navy vessels, the ITT Gilfillan AN/SPS-48 long range air surveillance radar shown on the left utilises FRESCAN techniques to provide '3-D' target information. Operating in E/F bands, the antenna scans mechanically in azimuth and electronically in elevation. With a range of over 400 km, it has eight operating modes including Moving Target Indication (MTI) and Automatic Detection and Tracking. During its operational life upgrades have allowed the radar to meet changing threats and now provides early detection of anti-shipping missiles.

fig. 14.1:2

Essentially similar in concept and operation to the AN/SPS-48 is the Hughes Aircraft Company's AN/SPS-52. Again a FRESCAN radar, it is in wide use not only with the United States Navy but also those of Australia, Germany, Italy, Japan and Spain. The antenna assembly comprising of slotted waveguide radiators and is tilted back at 25° from the vertical.

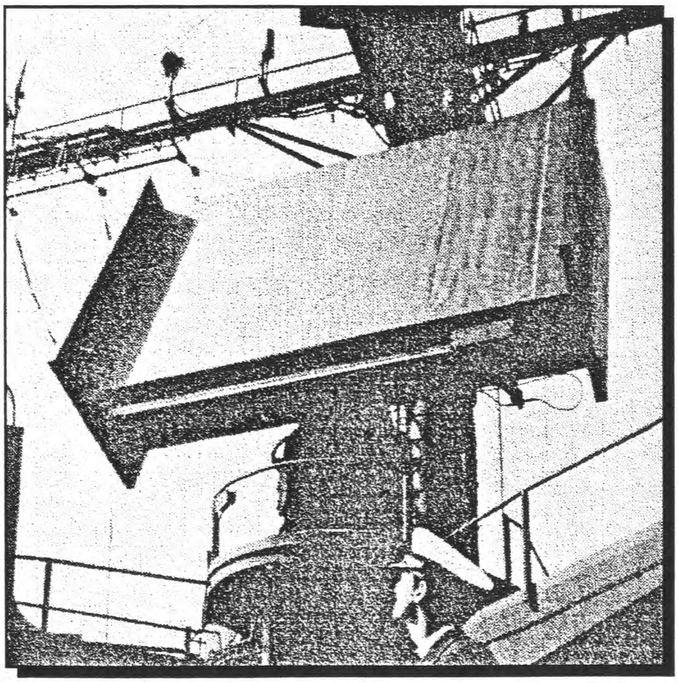


fig. 14.1:3

14.2 - Active Arrays

A further advance on phased array principles, the ACTIVE ARRAY, not only employs electronic phase shifters to provide antenna beam steering, but also contains solid-state RF power amplifiers and low noise preamplifiers for transmission and reception respectively. These are formed into a matrix forming the desired beam pattern replacing the slotted waveguide.

A typical active array is shown below and the system offers advantages in the areas of power management and efficiency, reliability, signal reception, beam steering, target detection and system performance.

Owing to the distributive nature of the active array transmit/receive system, performance reliability is increased. Within an active array there will be no single point failure and any failures within a single module will lead to a gradual reduction in overall performance, not total failure. This is often referred to as '*graceful degradation*'

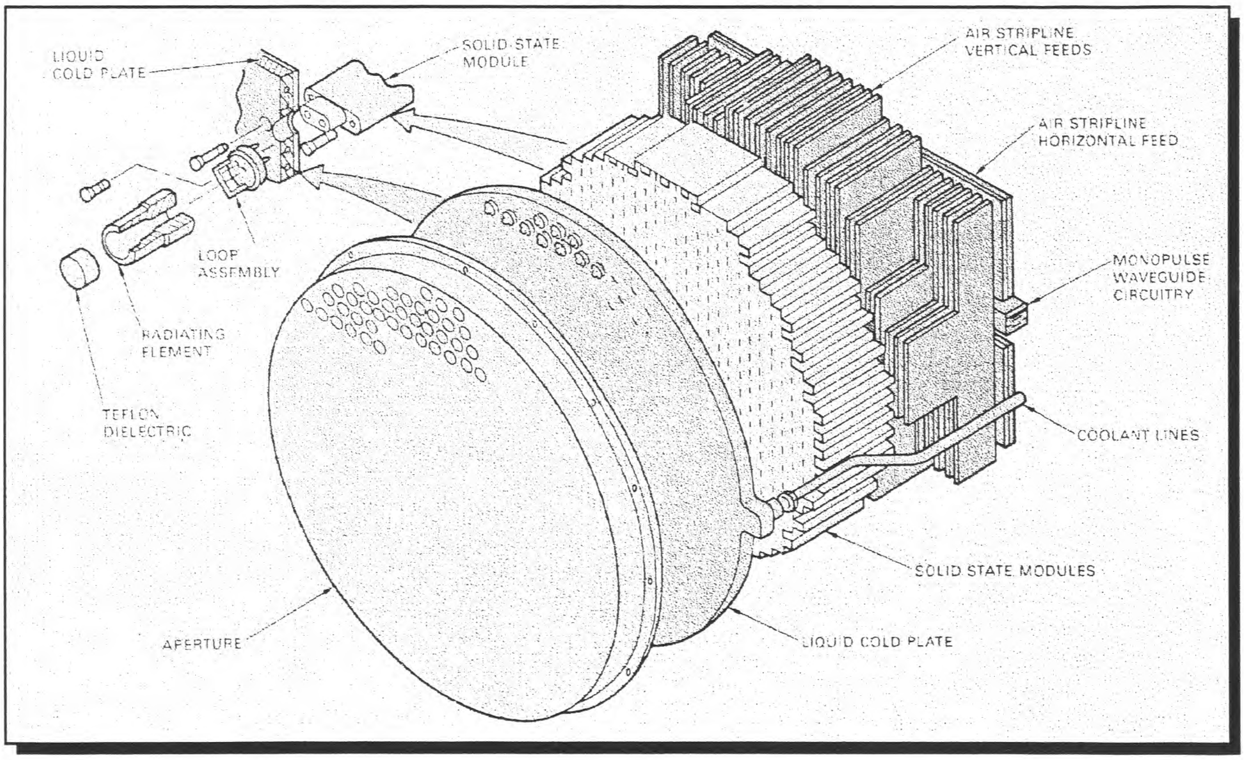


fig. 14.2:1

Standard Frequency (Hertz) Units			
Unit		Value in Hertz	
kilohertz	kHz	1,000 Hz	10^3 Hz
Megahertz	MHz	1,000,000 Hz	10^6 Hz
Gigahertz	GHz	1,000,000,000 Hz	10^9 Hz
Terahertz	THz	1,000,000,000,000 Hz	10^{12} Hz

Standard Units of Time (Seconds)			
Unit		Value in parts of a second	
millisecond	ms	1/1,000 th	10^{-3} sec
microsecond	μs	1/1,000,000 th	10^{-6} sec
nanosecond	ns	1/1,000,000,000 th	10^{-9} sec
picosecond	ps	1/1,000,000,000,000 th	10^{-12} sec

Standard Metric Units of Length (Metres)			
Unit		Value in Metres	
kilometre	km	1,000	10^3 m
decimetre	dm	1/10 th	10^{-1} m
centimetre	cm	1/100 th	10^{-2} m
millimetre	mm	1/1,000 th	10^{-3} m
micrometre	μm	1/1,000,000 th	10^{-6} m

SUMMARY OF FORMULAE

RADAR HORIZON $= 4.1\,(\sqrt{h^{o}})$ or $4.1\,(\sqrt{h^{o}} + \sqrt{h^{t}})$ Kms

(where h^{o} = height of radar, h^{t} = height of target in metres)

TIME (τ) is the reciprocal of **FREQUENCY** i.e. $\tau = \frac{1}{f}$ $\quad f = \frac{1}{\tau}$

VELOCITY OF ELECTROMAGNETIC WAVES = 300,000,000 mtrs/sec

or 300,000 kms/sec

WAVELENGTH (λ) $= \frac{C}{R.F}$ (note, where RF in MHz, divide 300 by RF value, answer in mtrs)

FREQUENCY $= \frac{C}{\text{WAVELENGTH }(\lambda)}$

MAXIMUM THEORETICAL UNAMBIGUOUS RANGE $= \frac{C}{2 \times \text{PRF}}$ = Km

or **150,000 ÷ PRF** or **150 ÷ PRF (kHz)**

RANGE RESOLUTION / MINIMUM RANGE = 150m per μs

$$\textbf{ANTENNA BEAMWIDTH} = \frac{67 \times \text{WAVELENGTH } (\lambda)}{\text{ANTENNA DIAMETER (MTRS)}} = \text{DEGREES } (^\circ)$$

conversely

$$\textbf{ANTENNA DIAMETER} = \frac{67 \times \text{WAVELENGTH } (\lambda)}{\text{ANTENNA BEAMWIDTH}^\circ} = \text{METRES}$$

$$\textbf{PULSES PER PAINT} = \frac{\text{PRF} \times \text{BEAMWIDTH}}{\text{SCAN IN DEGS PER SECOND}}$$

$$\textbf{PULSE SPECTRUM BANDWIDTH} = \frac{2}{\text{PD}} \text{ Hz} \quad \text{or} \quad \frac{2}{\text{PD}(\mu\text{s})} \text{ MHz}$$

$$\textbf{DUTY CYCLE} = \text{PRF} \times \text{PD} \quad \text{or} \quad \text{PD} = \text{DUTY CYCLE} \div \text{PRF}$$

$$\text{PRF} = \text{DUTY CYCLE} \div \text{PD}$$

$$\textbf{AVERAGE POWER } (\mathbf{P_{AV}}) = \text{Peak Power} \times \text{Duty Cycle}$$

$$\textbf{PEAK POWER } (\mathbf{P_T}) = \text{Average Power} \div \text{Duty Cycle}$$

DOPPLER SHIFT (Fd) $= \dfrac{2 \times RF \times Vr}{C} =$ Hertz (where Vr = Velocity, Relative)

(*'RULE OF THUMB'*, 18.5 Hz per 100 MHz per 100 kph.)

MOVING TARGET INDICATOR (MTI) BLIND SPEEDS:-

FIRST BLIND SPEED (Vb) $= \dfrac{C \times PRF}{2 \times RF}$ **MTRS/SEC**

or $\dfrac{.54 \times PRF}{RF \text{ in GHz}}$ **KPH**

SYSTEM BLIND SPEED $= \dfrac{Vb\ (\text{Ratio } 1 + \text{Ratio } 2 + \text{Ratio}^{n})}{\text{Number of Elements}}$

ANNEX B - GLOSSARY OF TERMS

AAA - Anti-Aircraft Artillery

AC VOLTAGE - A voltage that periodically changes in magnitude and/or polarity, tending to produce Alternating Current (AC).

AEW - Airborne Early Warning. A specialised role in which an aircraft is equipped with an early warning radar providing much greater range than its normal navigational radar. The radar picture obtained can either be processed on-board or transmitted direct for off-board processing.

AWACS - Airborne Warning And Control System. Term given to AEW aircraft which have an integrated radar/communications package allowing direct control of air defense interceptor aircraft.

ALTERNATING CURRENT - An electrical current which reverses its direction of flow at regular intervals.

AMPLIFIER - A device used to increase the amplitude of a signal voltage, current or power above the level of the input.

AMPLITUDE MODULATION - Variation in the amplitude of a carrier wave in accordance with the intelligence signal to be transmitted

ANALOGUE SIGNAL PROCESSING - Performing various operations such as range measurement and filtering, on electrical signals with analogue devices.

ANTENNA - An electrical conductor arranged to radiate radio frequency (RF) energy into space, or to collect such energy originating at another source, usually designed for specific coverage of a certain pattern in space.

APDS - Armour Piercing Discarding Sabot ammunition round

APFDS - Armour Piercing Fin Stabilised Discarding Sabot ammunition round

APERTURE - Literally an opening. In the case of an antenna, the area normal to the axis of the antenna's mainlobe, over which the radiation is distributed. An antenna's gain increases in proportion to the area of the aperture in square wavelengths. The beamwidth in any one plane decreases in proportion to the ratio of the wavelength to the width of the aperture in that plane. During reception, the area of the aperture determines how much of the returned energy is received by the antenna.

AZIMUTH - The measurement of direction with respect to true north, in degrees of angle (measured clockwise, or to the right, of north).

BANDWIDTH - The width of the section of the electromagnetic frequency spectrum occupied by the band of frequencies in a particular signal, or covered by a particular kind of equipment (receiver, antenna etc.).

BARKER CODES - A family of binary phase modulation codes widely used for pulse compression. They have the particular property that the range sidelobes which are produced when the pulses are compressed have an amplitude of either +1 or -1 times the amplitude of the uncompressed pulse, regardless of the length of the code. Only codes of 2, 3, 4, 5, 7 and 13 bits are known to exist.

BLANKING - Desensitising the receiver of a pulsed radar during selected periods in which the radar is transmitting.

BORESIGHT - The pointing direction of a radar antenna. This may be the central axis of the antenna's mainlobe or, if lobing is employed, the axis about which the lobes are symmetrically positioned.

CHAFF - Thin, light strips of foil or metal coated fibres that may be scattered in the air to obscure targets or otherwise confuse the operation of an enemy's radar. The length of the strips is usually made equal to ½ wavelength employed by the target radar to maximise the chaff's Radar Cross Section (RCS)

COMMAND AND CONTROL (C^2) - Remote method of conveying required target information to a weapon system.

COMMAND, CONTROL AND COMMUNICATIONS (C^3) - A combination of C^2 information with unrelated administrative/logistics data for transmission typically using multi-channel/interleaved signalling techniques.

COMMAND, CONTROL, COMMUNICATIONS and INTELLINGENCE (C^3I) - Integrated network combining C^3 with input from other information/intelligence sources/sensors.

CYCLE - The shortest interval in a periodic series of events (such as a wave pattern) before the pattern of the event repeats. The number of such cycles occurring in a specified time (usually one second) is the frequency of the event.

DELIVERY SYSTEM - Method employed to bring a weapon within effective range of the target. This may be integral to the weapon, an artillery rocket for instance, or external as in an aircraft delivering ordnance to the target area.

DETECTOR - Sometimes called a Demodulator, the detector is the part of a receiving system which recovers the original information signal from a modulated carrier wave.

DISCRIMINATOR - A device which produces an output voltage signal, the amplitude of which is proportional to the frequency of an input signal. Used in frequencies and for detection of Frequency Modulated (FM) waves.

DUTY CYCLE - The proportion of time which a device is turned 'on', expressed as a decimal fraction or percentage of the total time. For rectangular pulse waveforms, the duty cycle is equal to the Pulse Duration divided by the Pulse Repetition Interval.

EARLY WARNING (EW) - The initial target detection stage at long range to allow maximum weapon system reaction time.

ELECTRONIC COUNTERMEASURES (ECM) - Measures taken using either active, jamming etc., or passive, chaff for example, techniques to deny a target's positional information to a radar emitter. The correct and successful use of ECM relies on the knowledge of target emitter parameters, function and operations.

ELECTRONIC PROTECTION MEASURES (EPM) - Techniques used to counter the affects of ECM. These include the ability to modify the source emission for example by using RF/PRF/Scan agility, or measures taken to protect electronic hard/software. Formerly ECCM (Electronic CounterCounter Measures).

ELECTRONIC SUPPORT MEASURES (ESM) - Equipment, either manually operated or automatic, which by comparing measured radio signal parameters against those held in a computerised library, can identify an emitter and, in certain cases, advise the operator of its potential threat value.

FILTER - A combination of circuit elements designed to pass definite range of frequencies, attenuating all others.

FINAL ENGAGEMENT - Relates to weapon systems when the weapon is fired/launched. Target positional information can be transmitted allowing corrections to be made by the weapon/aiming device to ensure target destruction. Final destruction of the target is achieved by explosive or kinetic means.

FMOP - Abbreviation for *Frequency Modulation On the Pulse*. A type of intrapulse modulation where the carrier frequency within the duration of each transmitted pulse is intentionally caused to vary in a linear/non-linear fashion. Also referred to as '*Chirp*'.

FLIR - Forward Looking Infra-Red. Directable passive heat sensing detector.

FREQUENCY - Defined as the number of repetitions of a regular event occurring in a definite time, such as the number of complete cycles per second of a periodic wave.

FREQUENCY MODULATION - Variation in the frequency of a radio frequency carrier signal in accordance with the intelligence signal to be transmitted.

FUSING - A method of intentionally detonating explosive warhead/charge. See Proximity/Impact fuse.

GBU - Glide Bomb Unit. Additional aerodynamic surfaces fitted to a free-fall bomb enabling it to manouver in flight. The inclusion of a laser detection unit allows it to steer towards reflected laser energy from a target. See LGB.

HARMONIC FREQUENCIES - Pure, or sinewave, frequencies of waves that are multiples of the fundamental frequency of a complex waveform, which, when added to the pure fundamental frequency wave, change its shape into that of the complex wave.

HEAT - High Explosive Anti-Tank warhead

HESH - High Explosive Shaped Head warhead

IMPACT FUSE - Fusing method triggering when weapon strikes target. May incorporate delay device, electrical or mechanical, causing warhead/charge to explode momentarily after impact.

IRST - Infra-Red Search and Track sensor, normally associated with fighter aircraft, enabling detection and tracking of target by its infra-red emissions.

JAMMING - The practice of purposely radiating a radio frequency signal designed to interfere with another. The active form of ECM.

LASER - Light Amplification by Stimulated Emission of Radiation. Active devices which utilising a crystal source to transmit frequencies normally outside those of visible light. The extremely short wavelengths employed, 1 - 1.5μm, enable such devices to be used to measure range accurately. Also used to illuminate targets enabling weapons to passively home on to the source of reflected light.

LGB - Laser Guided Bomb ('Smart Bomb'). Passively homes on to the reflected laser energy from a target that has been illuminated by a laser.

MAD - Magnetic Anomaly Detection. Technique used to detect metal objects by the localised disturbance they naturally create with respect to the earth's magnetic field. Extensively used in Anti-Submarine Warfare (ASW).

MANPADS - MAN Portable Air Defense System, term given to shoulder launched surface-to-air missile system, BLOWPIPE/GRAIL/GREMLIN/REDEYE/STINGER etc.

MIXER - A combination of circuit elements designed to mix two or more frequencies together in order to obtain frequencies not originally present. Usually this device mixes two frequencies to obtain a product frequency equal to their difference.

MODULATION - A process by which a carrier wave is varied in frequency, phase or amplitude by imposing upon it the waveform of an intelligence signal of lower frequency content.

MOP - Abbreviation for Modulation On the Pulse, applied to pulse waveforms in which the radio frequency carrier is modulated within each pulse.

OCTAVE - A term originating in the field of music, meaning the progression from a given note of the musical scale through eight notes to the corresponding note of a higher or lower scale. Since this change in pitch corresponds to an exact doubling or halving of the frequency, this has become the general meaning of the term, basically to mean a two to one (2:1) change in frequency.

OPTRONICS - Sensor package combining both optical and electronic devices. The optics may be visible light or infra-red with an associated radar sensor.

OSCILLATOR - A circuit capable of generating alternating current of a controlled frequency, needing only a source of power.

OSCILLOSCOPE - Electronic equipment which can display visually the frequency, voltage or amplitude of a suitably applied signal. This is usually achieved by causing the signal to replicate its properties by moving a controlled electron beam within a cathode ray tube (CRT).

OSCILLOSCOPE, ANALOGUE - An oscilloscope where any form of modulation on an applied signal is displayed as instantaneous voltage/time variations.

OSCILLOSCOPE, DIGITAL - Unlike the analogue oscilloscope, any form of modulation present on an applied signal is sampled at a preset rate and voltage/time variations measured are stored internally in digital form. These can then be displayed synthetically by reconstructing the sampled 'bits' in the desired display format, for example amplitude versus time/frequency versus voltage etc.

PERIOD - The time required for repetition of one cycle of any regularly repeating waveform.

PGM - Precision Guided Munitions. Conventional munition rounds which can be guided following the addition of a guidance package which may include fitting aerodynamic surfaces.

PHASE - The measure of the timing of each cycle of a wave with respect to a reference. The reference may be either an identical wave or the same wave at a different instant in time. Phase is usually measured in degrees of angle, with one cycle time corresponding to a 360 degree phase angle.

POLARISATION - The direction of vibration of a transverse wave, perpendicular to the direction of wave travel, and usually defined in terms of horizontal, vertical or circular. For an electromagnetic wave, polarisation is defined as the direction of the electrostatic or 'E' field.

PD - PRI - PRF - Abbreviations applied to pulse waveforms, standing for (respectively) Pulse Duration, Pulse Repetition Interval and Pulse Repetition Frequency. The PRI of a regularly spaced series of pulses is equal to the period of the waveform.

PROXIMITY FUSE - A device, either passive or active, which triggers the fuse when within lethal distance from a target.

PULSED DOPPLER - Radar technique allowing a pulsed radar to determine the radial velocity of a target by the difference between its transmitted radio frequency and that of the received reflection. Known as the DOPPLER SHIFT, this is a natural phenomenon created by any velocity dissimilarity between frequency source and reflecting object.

PULSE MODULATION - The process by which a radio frequency signal is transmitted in bursts or pulses. A specialised form of Amplitude Modulation (AM).

RADAR - RAdio Detection And Ranging. The method used to detect an object from its reflection of a directed electromagnetic emission at radio frequencies.

RF - Abbreviation for Radio Frequency, often used to describe the basic frequency of the broadcast signal of a transmitter upon which the intelligence is placed by the process of modulation.

RMS - Abbreviation of the effective Direct Current (DC) equivalent power, voltage or current in an Alternating Current (AC) wave. It is derived from Root Mean Square, the mathematical process by which this is determined.

SCAN - The means by which a large area in space is observed, illuminated, etc. through the successive coverage of small sections.

SENSOR - Method used to locate and identify target. May employ active or passive techniques.

SINE WAVE - A wave whose form of vibration or variation follows the shape of a graph of the trigonometric sine function. A sine wave is the only wave which contains no harmonic frequencies; we call this a wave of pure frequency.

SIDEBANDS - The bands of frequencies which appear at frequencies in the spectrum on either side of the radio frequency carrier as a result of any kind of modulation. All the information in a radio signal is carried in the sideband frequencies.

SONAR - SOund Navigation And Ranging. Method used to detect objects from either reflections of directed audio frequency energy or by their self-generated emissions within the same frequency range. Principally used for underwater purposes.

SPECTRUM - The range of values for any quantity, usually applied to describe the frequencies possible for a wave phenomenon. The radio frequency spectrum is defined as the range of frequencies associated with radio wave energy.

TARGET ACQUISITION - When the search radar/sensor serving a weapon system detects and identifies specific target. Also referred to as Target Designation.

TARGET TRACKING - Occurs when the weapon system sensing system concentrates on detected target and provides accurate 'real time' aiming data.

THERMAL IMAGING - Passive method used to detect infra-red heat sources.

VIDEO - Generally taken to mean the information carrying, or modulation, signal of a transmitted wave. For example, the detected signal of a receiver is a video signal. In television engineering, only the picture carrying signal is referred to as video.

VIDEO SPECTRUM - The range of frequencies associated with video, or information signals; the video spectrum covers the range of frequencies extending from zero Hertz (Hz), or direct current, up to an indefinite limit (depending on the nature of the signal) usually acknowledged to be in the vicinity of ten Megahertz (MHz).

WAVELENGTH - The actual length which one cycle of a travelling wave occupies in space. The wavelength is a function of the frequency and the velocity of propagation.

WEAPON - Hardware used to destroy target. Means of destruction may be explosive or kinetic.

WEAPON SYSTEM - The means of destroying an intended target by location and positive identification using local/remote sensors.

WEAPON SYSTEMS PLATFORM - Structure on which weapon system is mounted. This may be airborne, surface or sub-surface (land/water) and carry more than one system.