Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management Training School

Academic Principles Organisation

AVIONICS PART 2 PHASE 3
Radar

BOOK 4
Radar Techniques

WARNING

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MILITARY SENSORS

OBJECTIVES

T.O.s – 42.1, 42.2, 42.3, 42.13

E.O. - **S99-02 Aircraft Radar Systems**

KLP Ref – **S92-02-03 - Airborne Interception System**

Frequency Agile Radars

Monopulse Radar Techniques

Track While Scan (TWS) systems.

Moving Target Indication (MTI) systems

Pulse Compression

Pulsed Doppler, multimode radar

Synthetic Aperture Radar

Inverse Synthetic Aperture Radar

Performance – Describe Aircraft Radar Systems

S99-02 Aircraft Radar Systems

S92-02-03 Airborne Interception System

CONTENTS :

S92-02-03- AIRBORNE INTERCEPTION SYSTEM

Introduction

1. The principle purpose of the Airborne Intercept (AI) radar is to detect, identify and classify airborne targets to enable the timely use of appropriate tactics and weapons. The detection of low flying aircraft at the longest possible range – ranges in the region of 50-200 nm are required. The AI system must have the ability to undertake a threat classification process and then carry out threat prioritisation. The identification of detections as friend or foe using an IFF system covered later in this course AI radar should be able to track, measure flight parameters of, and predict flight paths for multiple targets simultaneously, so as to provide the fighter crew with an overall air picture.AI radar systems will also be required to provide cueing and guidance signals for air launched weapons such as radar guided missiles. At closer range, the radar should be able to provide accurate steering information so that visual identification of a target can be accomplished. In close combat, the radar may be required to provide range and angle rate data for gun aiming.

2. In this part of the course you will cover some of the techniques a modern AI radar system may use:

- Frequency agile Radars.
- Monopulse Radar Techniques.
- Track While Scan (TWS) systems.
- Moving Target Indication (MTI) systems
- Pulse compression
- Pulsed Doppler multimode Radar
- Synthetic Aperture radar
- Inverse Synthetic aperture radar

FIXED FREQUENCY & FREQUENCY AGILE RADARS

Introduction

1. The pulses transmitted by basic pulsed radar systems comprise of bursts from the RF oscillator at a set frequency and therefore are classed as ‘Fixed Frequency’ (FF) radars.

2. The term 'Frequency Agile' is used to describe radar that is capable of operating at different frequencies within a given band of frequencies on a pulse-to-pulse basis. This means that the transmitted frequency for each pulse is slightly different. A typical range could be + - 300Mhz either side of the fixed frequency.

Fixed Frequency Radar problems

3. There are many operational problems associated with ‘Fixed Frequency’ (FF) Radar that makes its performance a compromise. Three of these problems are:

  a. Clutter.

  b. Interference (accidental and deliberate).

  c. Scintillation

  d. Correlation.

Clutter

4. The response from ground clutter is such that there will be peaks of intense clutter mixed clutter at weak and normal levels This irregularity of the clutter level makes it difficult for both the human eye and automatic systems to see targets in the clutter.

Interference (accidental and deliberate)

5. If another radar or other equipment operates locally on or about the same frequency, then interference will take place. The severity of the interference depends mainly upon how close the two frequencies are and the strength of the interfering signal.

  a. **Accidental interference** usually produces a pattern of false echoes if the source is another radar. If the source is not pulsed then a more general bright-up or increased signal level is seen on the display.

  b. **Deliberate interference (ECM jamming)** can have a more catastrophic effect due to the much higher signal strengths from the jammer, particularly if the jammer is a narrow-band type where the available transmitter power is concentrated into a small frequency range. In Peacetime, frequency agility is not normally used.

c. **Scintillation** Different surfaces of a target will reflect a complex e-m wave. The received pulse could comprise of many separate reflections with an amplitude and phase which is unpredictable and variable this is particularly true when the target attitude changes. This variation in amplitude and phase is called Scintillation.

d. **Correlation** In reality the attitude and range of a target is continually changing between pulses. In one sweep of a beam the returns from a target say about 20 returns could have energy reflected in antiphase which would return such a low power level that the target is not detected. Equally the returns could be at a much larger power level and give the impression a larger target. If the phases of the returns are nearly identical they are said to be **correlated** if there is no similarity the returns are said to be de-correlated.

ADVANTAGES OF FREQUENCY AGILE RADAR

6. Frequency Agile (FA) radar has overcome problems that FF Radar have in the areas of:

a. Clutter.

b. Interference (accidental and deliberate).

c. Scintillation and Correlation.

d. Detection Range.

7. **Clutter**

a. In Frequency Agile (FA) systems, each returning pulse is of a different frequency to the last one, and are not in phase with each other (they are not correlated).

b. Because the target and clutter echoes are not correlated, the target echo will stand out from the more limited range of clutter signal strengths.

c. This makes the detection of a target amongst clutter much easier whether the detection is done by eye or automatically.

d. In practice it has been found that it is as if the clutter has been reduced by as much as 15 dB in a FF radar system.

8. Interference

a. Accidental interference

i. In frequency agile systems, accidental interference is unlikely to be a problem as the chances of two radars being on the same frequency as each other for more one pulse at a time is minimal.

ii. Modern radars are designed to ignore a "target" which only appears for one cycle of the PRF.

iii. If the interference is CW rather than pulsed, its signal strength is likely to be fairly small and at one frequency, so again its effect will be very much reduced.

b. Deliberate interference (ECM jamming)

i. This is treated just like accidental interference if it is narrow-band in nature.

ii. Broadband jamming may cover the complete bandwidth of the agile radar but only at a reduced power level so reducing its effectiveness.

9. Scintillation and Correlation

a. The effect of frequency diversity can be judged from our everyday visual experiences. We are surrounded by objects which are changing in attitude and range yet their optical images do not suffer from Scintillation. This is because we view them in light which has a wide band frequency content (approx. 450 000 GHz to 750 000 GHz). It is true to say that some frequencies may give us a reduced and some increased image intensities but on average the image has a steady intensity as it is de-correlated. As far as airborne Radar Systems are concerned, the only practical solution is to de-correlate the echo, and therefore prevent scintillation. In other words use a FA Radar which can transmit a range of frequencies sequentially. The returns are averaged over time and the effects of Scintillation and Correlation are reduced improving probability detection and increasing the maximum range of the target.

10. **Detection Range.**

a. The chances of detecting targets at long ranges are very much higher with FA radar than with the FF system.

i. This is mainly due to the reduced effects of clutter and interference.

ii. A comparison of the FA and FF systems (Refer figure 1) shows that the range at which there is a 90% chance of detecting a target can be almost doubled for FA radar.

iii. During Factors Affecting Radar Performance (KLP S92-01-05), for a basic (FF) radar system, improvements in the radar detection range could only be obtained by large increases in the transmitter peak power.

iv. Therefore for long-range search radars, frequency agility offers distinct advantages over fixed-frequency system.

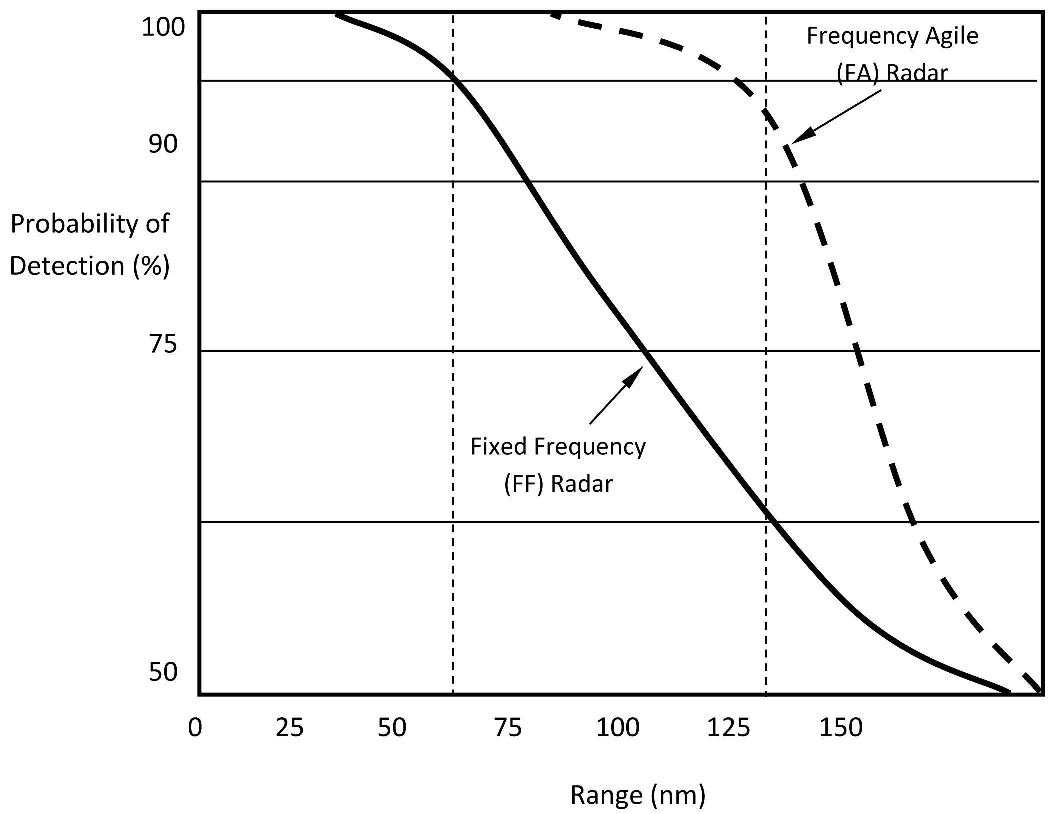

Figure 1 – Comparison of FA and FF Radar Detection Ranges

Frequency Agile Methods

11. There are several transmitter methods used to obtain the necessary frequency agility, two of the main ones are:

a. Spin-Disc Magnetron.

b. Frequency Agile Master Oscillator Power Amplifier (FAMOPA)

Spin-Disc Magnetron

12. (Refer figure 2). Within the Magnetron, in close to its cavities is a spinning disc with metallic vanes driven by a motor. As the vanes pass over the cavities they alter the resonant frequency of the cavities and the magnetron output.

13. Although it is an older frequency agile method than the FAMOPA, it still used on the Tornado GR4 in the transmitter of the Terrain Following Radar (TFR).

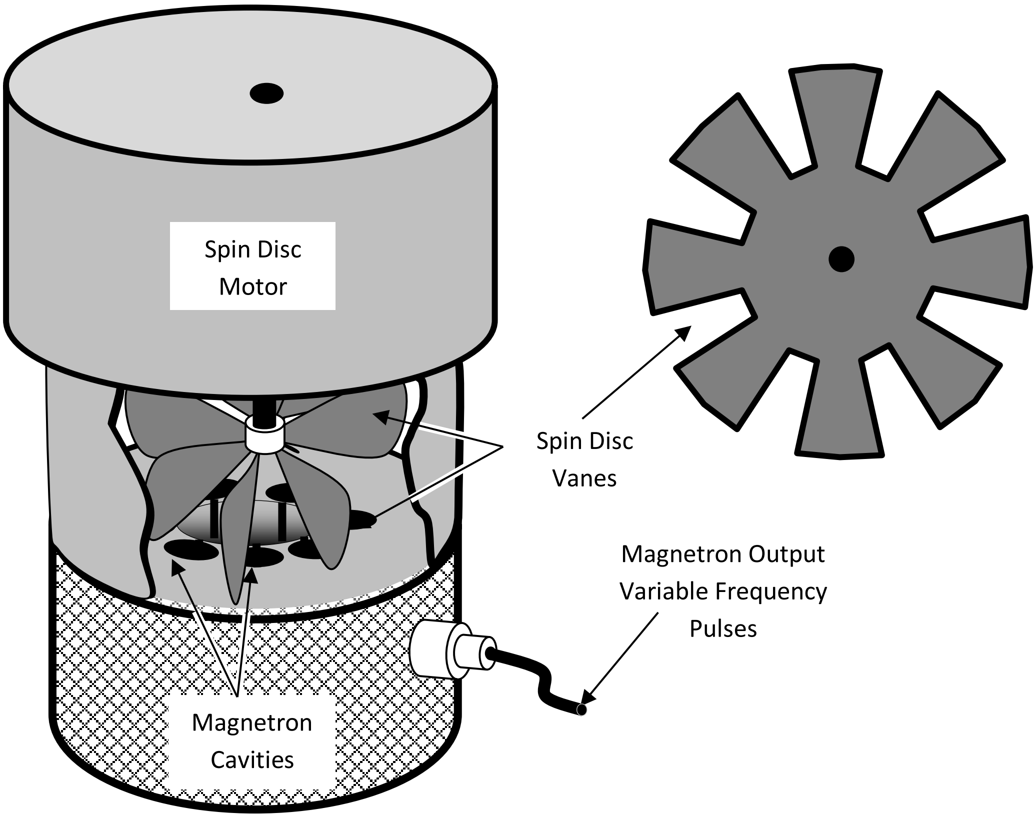

Figure 2 – Spin-Disc Magnetron

Frequency Agile Master Oscillator Power Amplifier (FAMOPA)

14. Refer Figure 3. The simplicity of the FAMOPA design lies in the fact that it has inbuilt Automatic Frequency Control (AFC).

a. For this frequency agile method the intermediate frequency (IF) of the receiver is added to the master oscillator frequency, the resultant is the transmitter frequency (f_t) used in the production of the output pulses.

b. When the echo pulses return the master oscillator frequency is simply subtracted from them so there can be no error in the value of intermediate frequency (f_{IF}) fed to the IF Amplifiers.

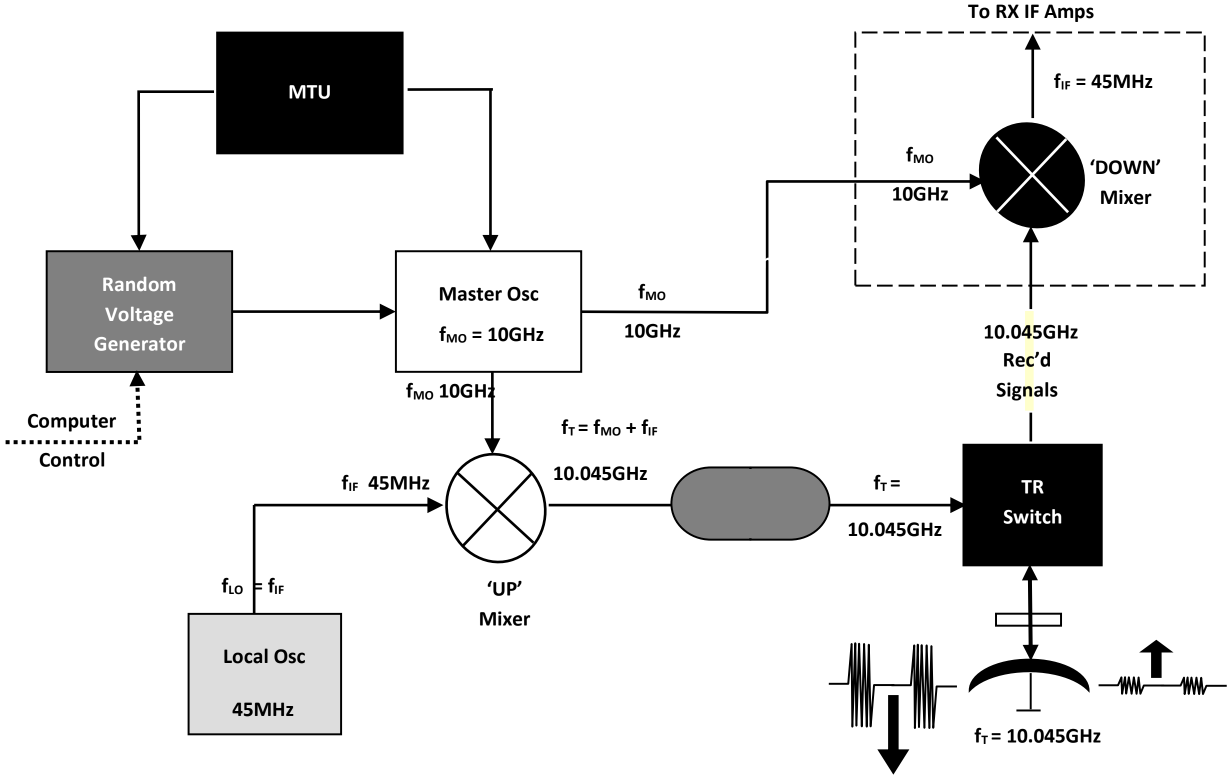

Figure 3 – Frequency Agile MOPA Transmitter (FAMOPA)

15. The basic function of each block in the FA-MOPA diagram: (refer figure 3)

16. **Master Timing Unit (MTU).** The master timing unit (MTU) provides two outputs; one switches the master oscillator "on" & "off". The other output triggers a change in the voltage from the random voltage generator, which controls the frequency of the master oscillator.

17. **Master Oscillator (MO)**. The master oscillator (MO) is a voltage controlled oscillator (VCO) that runs continuously, its output being a variable but relatively low frequency determined by the voltage from a random voltage generator. These low frequencies are then sent to frequency multiplying stages within the oscillator that raises them in to the microwave region (f_{MO}).

18. **Random Voltage Generator (RVG).** The random voltage generator produces a range of dc voltages necessary to control the frequency output of the master oscillator. The tuning voltage changes every time the generator receives a trigger from the MTU. The tuning voltage is random except when under computer control during electronic warfare conditions, when the system can avoid frequencies where interference or frequency jamming occurs.

19. **Local Oscillator (LO).** The important features of the local oscillator are:

a. The local oscillator frequency is added in the transmitter stage and not in the receiver.

b. The oscillator runs at a fixed frequency equal to the intermediate frequency (IF), so that $f_{IF} = f_{LO}$.

20. **Up Mixer.** Mixes both the MO (f_{MO}) and LO (f_{IF}), frequencies, the sum of its output being the final transmitted frequency f_{TX} such that $f_{TX} = f_{MO} + f_{IF}$. The important feature being that the transmitted frequency f_{TX} contains the IF required by the RX.

21. **RF Power Amplifier Stages.** The range of transmitted frequencies can be extremely wide and so the RF PA stages should be capable of the same bandwidth. Typically travelling wave tubes (TWT's) could be used as they would have the necessary bandwidth and power capabilities. The output stages may comprise a medium power TWT followed by a high power TWT.

22. **T/R switch**. The aerial feed may be via a three or four port circulator type TR switch.

23. **Down Mixer**. Mixes the RF frequency of the returning echo pulse from the aerial (f_{TX}) with the MO output (f_{MO}). This produces the difference frequency (f_{IF}), which is the wanted IF.

24. The rest of the receiver from IF stage to video amp is of conventional superheterodyne design.

MONOPULSE RADAR

Angle Tracking Radar

25. In order to track the angular movements of an airborne target, a single radar beam or a number of beams are positioned around the target, typically in a formation known as a Target Tracking Quadrant (Refer figure 4).

26. Any movement of the target is determined by comparing the beams for changes in of the size of the echo returns and driving the scanner accordingly. Ideally with the target in the centre of the quadrant the echoes in the four beams would be the same.

27. Older methods of angle tracking in airborne interception (AI) that used Target Tracking Quadrants included Conical Scanning or Sequential Lobing.

28. The accuracy of these older methods suffered because:

a. The amplitude of echo pulses can be affected by slight changes to the targets position during the scan.

b. The four different pulses transmitted to the four beams of the quadrant would not be identical so returns would vary reducing accuracy.

29. A more accurate method of airborne angle tracking with pulse radar is to use a monopulse (one pulse) system.

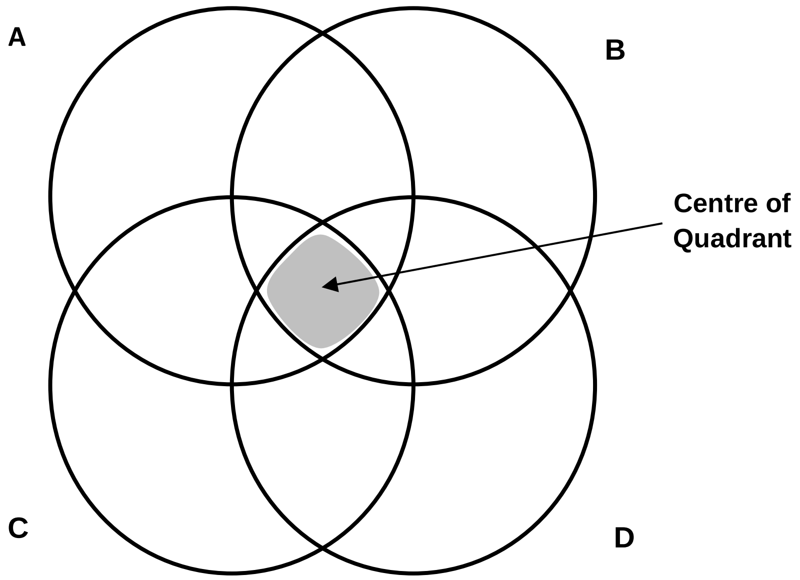

Figure 4 – Target Tracking Quadrant

Monopulse (or Simultaneous Lobing) Tracking.

30. The monopulse (one or single pulse) technique provides highly accurate range information that can be used for:

a. Terrain Following Radar (TFR).

b. Ground Mapping Radar (GMR)

c. Continuous tracking of airborne targets in AI modes.

d. Continuous tracking of ground targets in GMR modes.

31. Monopulse tracking is so called because it can obtain the target position information from a single pulse unlike sequential Lobing, which uses four different pulses or conical scanning which uses a continuous stream of different pulses.

32. The target tracking quadrant principle (refer figure 4) is also used in monopulse tracking.

33. The accuracy of the monopulse system is achieved by transmitting the same pulse simultaneously in four separate beams.

34. Therefore one source of error is removed, because the pulses transmitted to each quadrant are identical.

35. The monopulse radar is designed so that the individual echo pulses from each beam can be identified, usually by employing a different polarization to each beam or some other coding process

36. Electronic Counter measure (ECM) techniques used against monopulse radar find it is very difficult to deceive in angle tracking modes. However monopulse radar is just as easy (or hard) to deceive as with any other radar in range tracking modes.

37. Most of today's tracking systems incorporate some variation of the monopulse system.

Monopulse Ranging

38. Single Beam (Refer figure 9). Although radar provides slant range information for use in some applications, often it is the ground (or plan) range to the target that is required e.g. during weapon aiming.

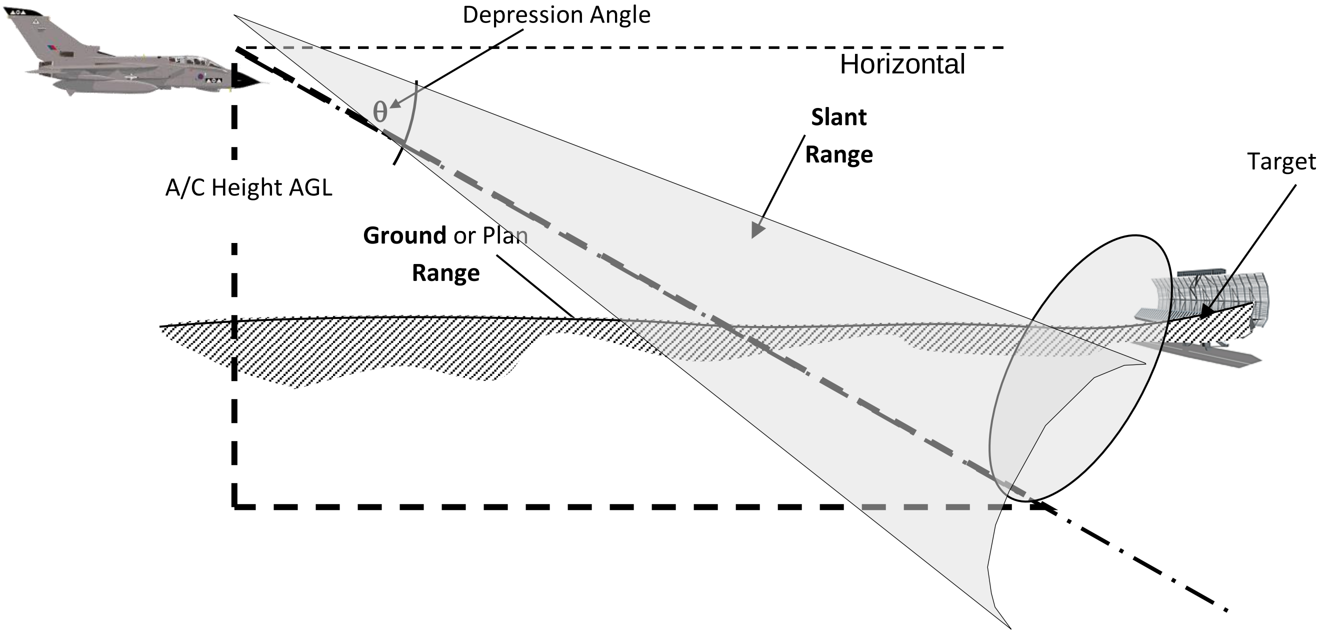

Figure 5 – Slant Range and Ground Range

39. Ground range can be easily calculated using simple trigonometry from the following information:

a. The radar beam depression angle θ.

b. Slant range

40. However achieving the accuracy required is a problem when using a conventional pulse radar beam, as neither the slant range nor the depression angle θ is known precisely enough as the target could be anywhere in the beams width this problem is removed by using 2 beams.

The Operation of Basic Two-Beam Mono-Pulse Ranging

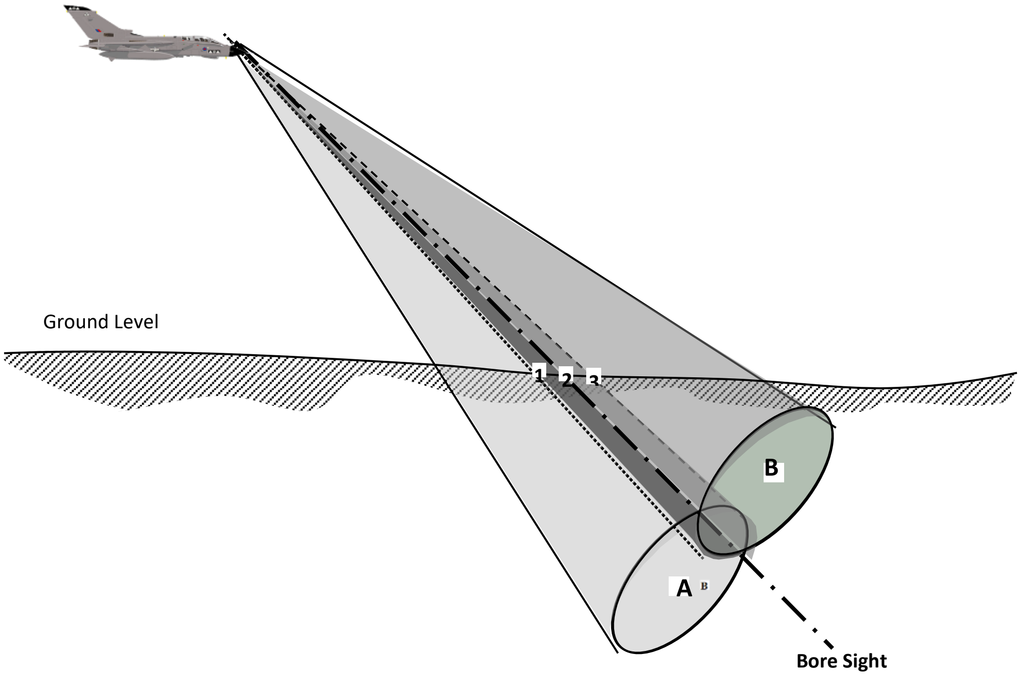

Figure 6 – Basic Two-Beam Mono-Pulse Ranging

41. Refer figure 6. Two overlapping monopulse beams (A and B) are transmitted to the ground and which are equally positioned in EL about the bore sight, which is in the centre where the two beams overlap.

42. For ground targets illuminated by the beams at positions 1, 2 & 3 the relative returns would be:

a. Target at 1, both beams A and B would return echoes, however because target is nearer the centre of beam A its echo would be bigger than the echo from beam B this would cause the beam angle to be depressed more.

b. Target at 2, both beams A and B would return echoes and because the target is equally spaced from the centre of both beams. The amplitude of the echo returns would also be equal indicating that the target is in the "on bore sight" position where the slant range and θ the depression angle should be measured.

c. Target at 3 similar to Target at 1, both beams A and B would return echoes, however because target is now nearer the centre of beam B its echo would be bigger than the echo from A. This would cause the beam angle to be depressed less.

43. Every time the "on bore sight" condition at target position 2 occurs, a pulse is generated telling the system to measure the slant range and depression angle θ.

TRACK WHILE SCAN (TWS) RADAR

44. One of the main disadvantages of dedicated angle tracking systems is that because the aerial always points at one target it cannot detect or look for any others.

45. Modern radar systems track multiple targets with a Track While Scan (TWS) feature. (Captor the radar fitted to the Typhoon can simultaneously track 20 targets).

46. The Track While Scan (TWS) feature is usually found in digital and computerised radar systems and operates by:

> a. Scanning repeatedly in a 1, 2, or 4-bar pattern (refer figure 7), the positions of target returns are digitally processed and located within the memory map of a computer.
>
> b. On subsequent scans of the same area, the positions of new returns are compared with those stored in the memory map.
>
> c. If a good match is found, then over a number of scans (usually three or more) the TWS system can calculate for each of the targets; their track, speed, elevation and azimuth position.

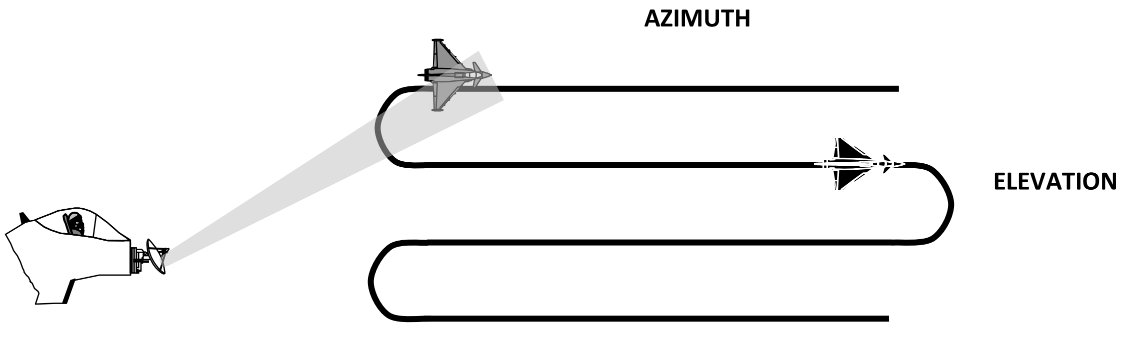

Figure 7 –Typical Bar Scan Pattern

47. Track While Scan (TWS) positional information is not as accurate a dedicated angle tracking systems (conical scan or monopulse) because target positions are updated only once every scan and not continuously.

48. However this is not a problem if used with modern "fire and forget" missiles such as AMRAAM (Advanced Medium-Range Air-to-Air Missile) that are directed to a location and can then guide themselves in the final stages of flight to the target.

MOVING TARGET INDICATION (MTI) RADAR

49. MTI radar is closely associated with pulse Doppler radar.

50. Any target, which moves in relation to the ground, is likely to be of interest, whereas those that do not are normally unwanted.

51. As the Doppler Effect shifts the frequency of echoes from moving targets, this provides a powerful basis for distinguishing between wanted and unwanted targets.

52. Coherent frequency radar is needed to recognize echoes containing a frequency shift.

53. Echoes from moving targets vary in amplitude from pulse to pulse at the Doppler frequency corresponding to the relative velocity of the target.

54. Echoes returned from fixed targets do not vary in frequency.

55. The effectiveness of MTI increases with the number of pulses-per-scan and it is therefore better to apply MTI to broad beamed radar than to a narrow one.

56. As with other Doppler systems a disadvantage of MTI radars is the existence of blind speeds. When the target's direction and velocity away from the radar is the same as that of the radar itself i.e. there is no relative velocity.

57. MTI is used in airborne early warning, AI, Anti-Submarine Warfare (ASW) radars, search and reconnaissance radars.

58. In order for airborne MTI to be able to see targets that move with respect to the Earth, it is first necessary to compensate for the velocity of the aircraft. If it uses a scanning beam the compensation must also be continually changing.

PULSE COMPRESSION

59. From the earlier Radar Principles lessons it was determined that for long-range radar, high-energy transmission was needed and that could be obtained from very wide pulses at low PRF and PP.

60. However very wide pulses do not give good target discrimination (range resolution).

61. This problem can be overcome by using a technique called **Pulse Compression.** Where wide pulses are transmitted to obtain the energy required for long-range detection capability, but they are processed as narrow pulses on reception giving good target resolution.

62. Pulse compression techniques are of particular value in Airborne Interception (AI) Radar where an increase of transmitter peak power beyond a certain limit could introduce an unacceptable increase in weight.

Basic Pulse Compression Technique

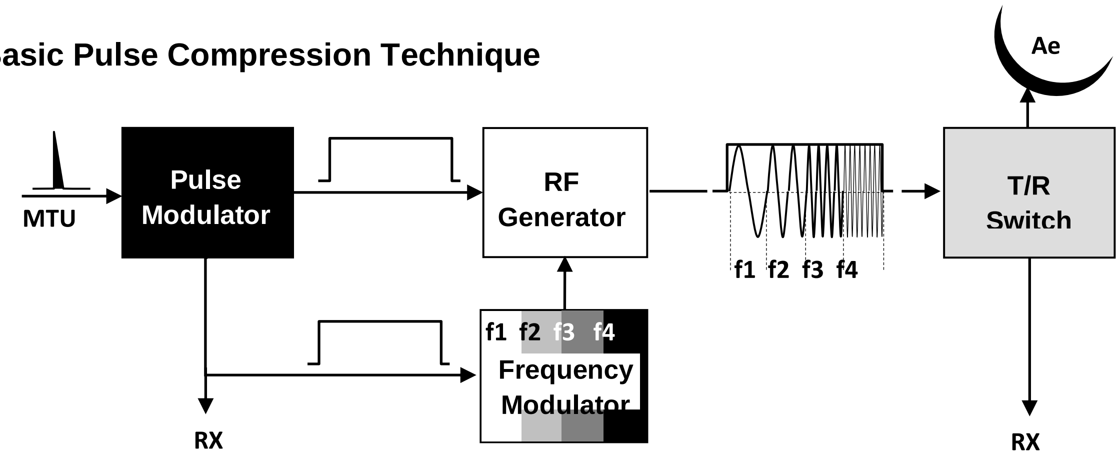

Figure 8 – Basic Pulse Compression Transmitter BSD

63. The function of each block in figure 4 The Basic Pulse Compression Transmitter is: **Pulse Modulator** governs the PW and switches the RF Generator on for a specific period of time e.g. 4μs

.

64. **Frequency Modulator** controls the modulating frequency output of the RF Generator, changing the frequency at 1μs intervals during pulse transmission.

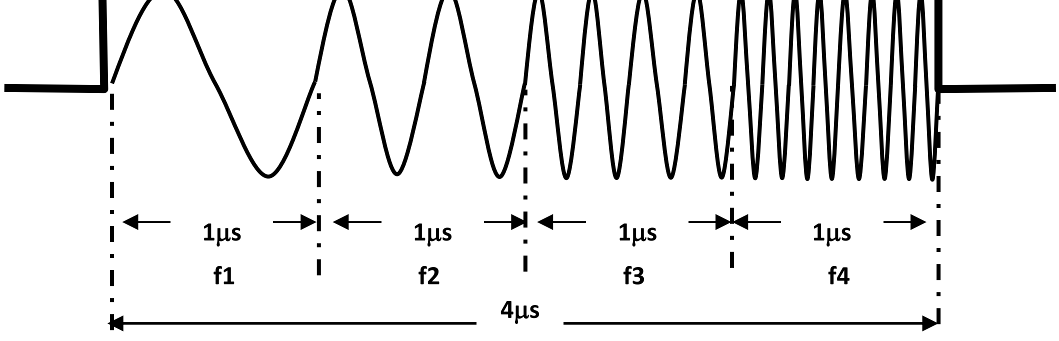

Figure 9 – Frequency Coded RF Pulse

65. **RF Generator** (refer figure 9) produces a frequency coded RF pulse of energy made up of four parts of equal duration i.e. 1μs each. During the transmission the frequency is modulated (with four different frequencies) and the amplitude is kept constant.

a. The complete pulse of 4μs duration consists of:

i. 1μs at a frequency of f_1 hertz (lowest freq).

ii. 1μs at f_2 hertz.

iii. 1μs at f_3 hertz.

iv. 1μs at f_4 hertz (highest freq).

b. The composite pulse is transmitted with the lowest frequency of f_1 leading.

66. **TR Switch** as per a basic pulse radar system.

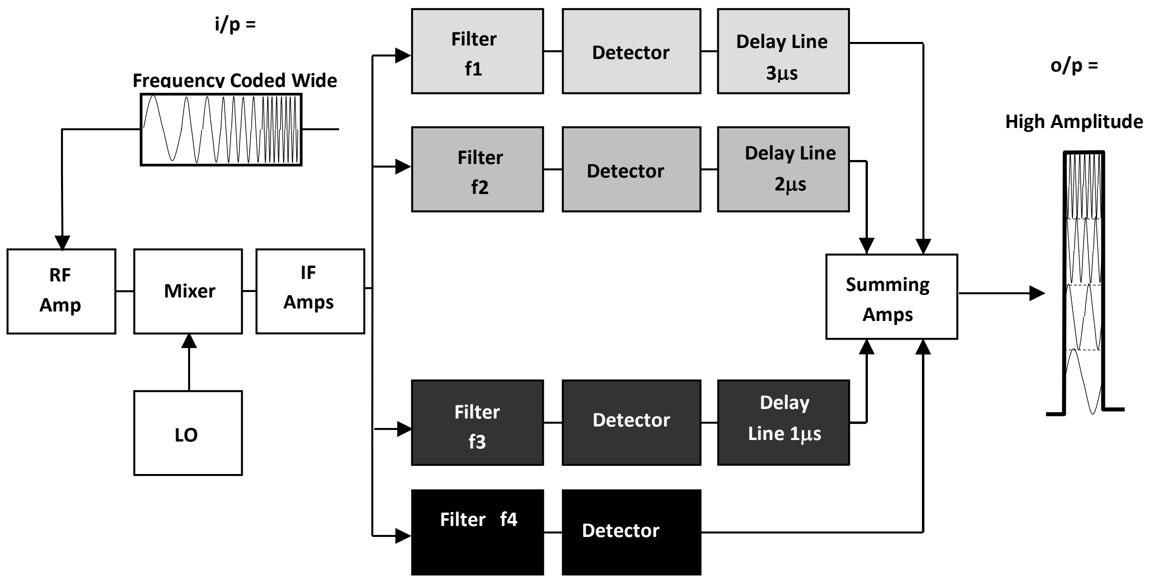

Figure 10 – Basic Pulse Compression Receiver

67. Refer figure 10. The pulse compression receiver is basically a modified superheterodyne receiver and the function of each of block is.

a. **RF amp** - as per a basic pulse radar system.

b. **Mixer -** as per a basic pulse radar system.

c. **LO -** as per a basic pulse radar system.

d. **IF amps -** as per a basic pulse radar system.

e. **Filters -** The IF is fed to a bank of four filters, one for each frequency component added at the transmitter. These only allow its particular frequency to pass through it, effectively dividing the 4μs video pulse into four equal 1μs video pulses.

f. **Detectors** -as per a basic pulse radar system.

g. **Delay lines** -because the frequency components are staggered in time (f_1 lowest frequency first and f_4 highest frequency last), the delay lines are used to bring the first three 1μs video pulses into time coincidence with the last one:

i. Frequency f_1 (lowest freq transmitted first) is delayed by 3μs.

ii. Frequency f_2 is delayed by 2μs.

iii. Frequency f_3 is delayed by 1μs.

iv. Frequency f_4 has no delay.

v. The four coincident waveforms are now fed to the summing amp.

h. **Summing Amp** -the four coincident waveforms are now processed into a pulse, which is a quarter (1μs) of the original PW (4μs), and four times the amplitude of the individual video pulses.

68. Because noise and interference does not have the necessary frequency coding, it is not compressed. Therefore S/N ratio is improved and can reveal targets previously hidden in the noise, as well as giving some resistance to jamming by Electronic Counter Measures (ECM).

Improvements to the Basic Pulse Compression Method

69. The basic system used just four different frequencies to code the pulse.

70. If more frequencies were used i.e. eight this would result in a narrower pulse with a higher amplitude.

71. The greatest improvement therefore could be had by having a very large number of frequency steps, each lasting a fraction of the PW. To achieve this, the RF Generator can be modulated with a linear frequency sweep (Refer figure 11).

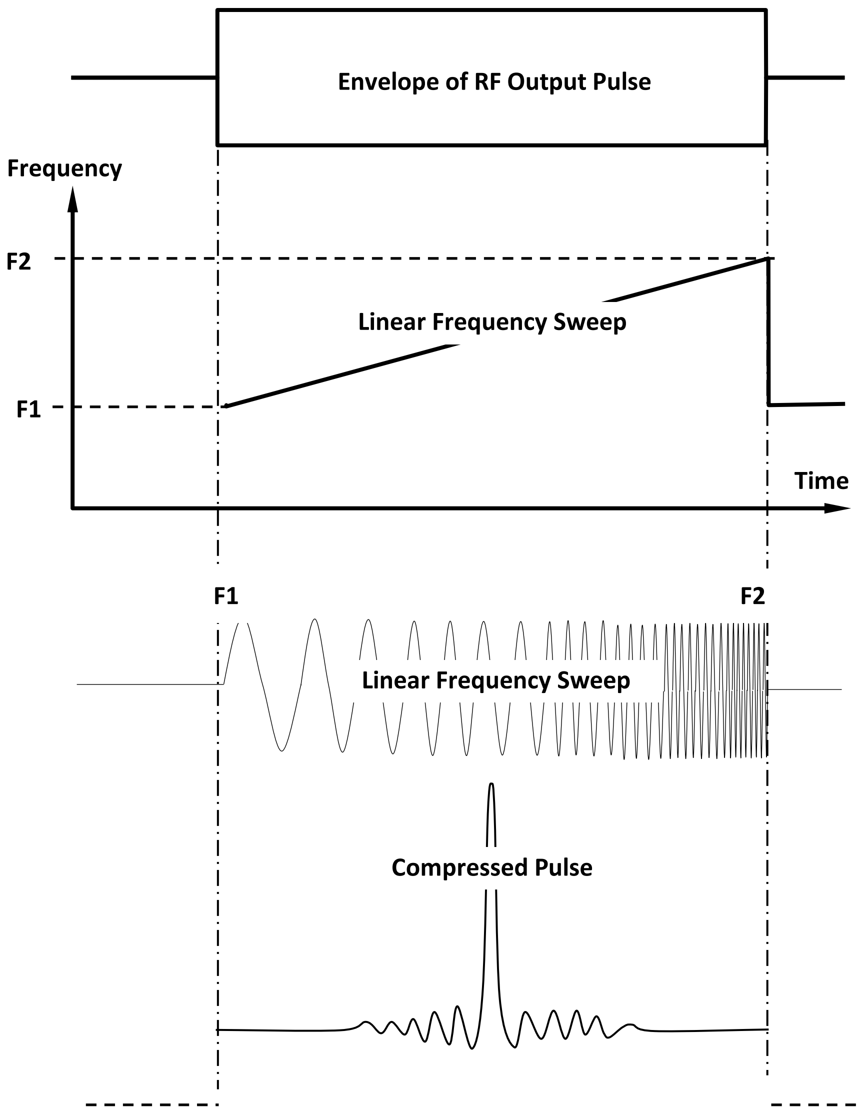

Figure 11 – RF Output Pulse with Linear Frequency Sweep

72. Radar systems that use pulse compression with a linear frequency sweep are sometimes described as “CHIRP” radars, which is supposed to be similar to the linear modulations made by the sound grass hoppers and crickets!.

73. One area not improved by pulse compression of course is minimum range, which is based on the transmitted PW.

PULSE DOPPLER, INTERRUPTED CW (ICW) MULTIMODE RADAR (KLP S92-03-03)

Introduction

74. Pulsed Doppler CW radar provided a huge step forwards in performance compared to basic pulse radar. Pulsed Doppler can; detect aircraft at long ranges, moving targets against ground clutter, track more than one target at a time and display high resolution ground maps.

75. Such diverse requirements cannot be met with one type of radar transmission, and modern AI radars are able to operate in a number of modes, the most appropriate being selected for any particular situation. The capabilities of these various modes can only be realised with the aid of an airborne computer capable of processing the signals and of providing the necessary inputs to a synthetic display

76. Using a pure Pulse or pure CW radar system will not give the best target, range, or velocity discrimination required. Most AI systems therefore, use a combination of the characteristics of both pulse and CW transmission to achieve the best range and velocity data from a target return. In the case of the AST, FMICW is used.

77. The Air Intercept mode is able to detect, identify and engage targets at long range and be adaptable to the changing threat. To facilitate this, particular modes or functions are selected automatically adaptable to the changing threat and allowing optimization of the on-board sensors at weapon system level and to ease operator workload.

78. Requirements for Multi-mode ICW Radar. An AI radar must be able to detect targets at long ranges from a range of altitudes. At all speeds and any LOS angle relative to the aircraft. With a zero closing rate, (i.e. target has the same speed and direction as aircraft).

79. These diverse requirements cannot be met with just one type of ICW radar mode.

80. Most modern AI radars are able to operate in number of transmission modes, the most appropriate being selected for any particular situation.

81. During the Introduction to radar phase it was found that the Basic CW radar and Basic Pulse radar systems when compared together had the following advantages and disadvantages.

82. Basic Pulse radar advantages:

a. Measures slant range

b. Only needs one aerial (except Rad Alt)

83. Basic Pulse radar disadvantages:

a. Receiver requires a wide bandwidth.

b. Has a finite minimum detection range.

c. Requires high peak power.

d. Cannot determine target velocity.

e. Suffers from clutter.

84. Basic CW radar advantages:

a. Transmits a single frequency, therefore receiver bandwidth may be very narrow.

b. Can use Doppler shift to identify target echo from clutter (moving target indicator MTI radar) and to measure target velocity.

c. Requires low PP which is the same as its MP

85. Basic CW radar disadvantages:

a. Cannot measure range (unless FM is incorporated).

b. Cannot discriminate against multiple targets in the beam at the same time.

c. Two aerials are required one for transmitting and one for receiving, which is not practical for tracking radar, fitted in the nose of an aircraft.

Pulsed Doppler or 'Interrupted CW' (ICW) Multimode Radar Systems.

86. Combines the best features of the Pulsed and CW systems, such as:

a. Uses a single aerial for both transmitting and receiving.

b. Uses coherent pulsed transmissions i.e. by cutting the pulses from a CW output, the phase of each pulse is coherent or consistent, enabling the Doppler frequency to be easily measured.

c. ICW systems can determine target relative velocity and range (dependent upon the PRF).

d. However if ICW radar is trying to determine both range and velocity at the same time, then one or both will always be ambiguous (confused or in error).

87. Figure 12 is a diagram of a basic Pulsed Doppler or ICW Radar System

Modern Pulsed Doppler (ICW) Radar System

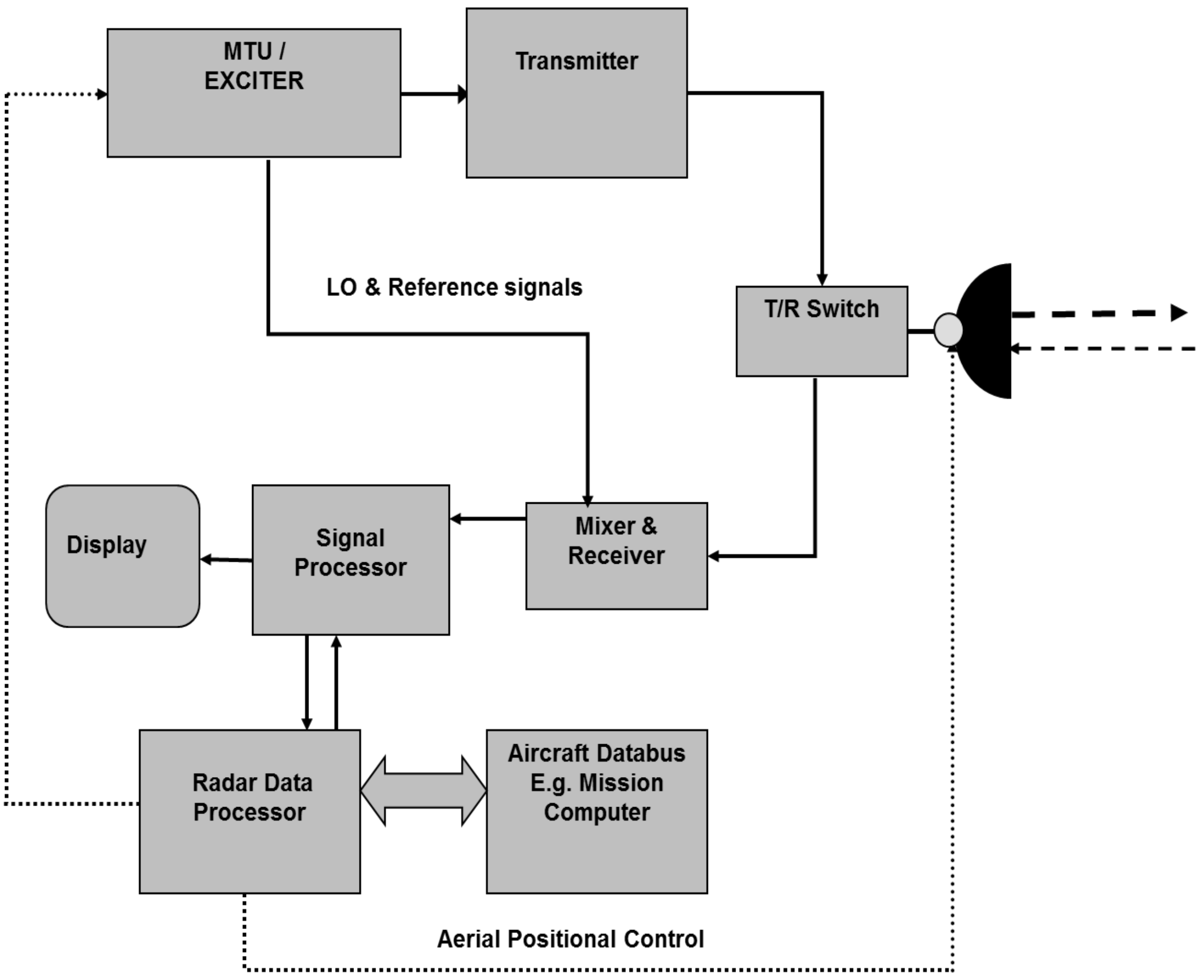

Figure 12 Basic Pulsed Doppler or ICW Radar System

88. During radar transmitters it was seen that the basic Master Oscillator Power Amplifier (MOPA) transmitter would function as the coherent transmitter in an ICW system.

89. (Refer Figure5). The function of each block in the basic Pulsed Doppler or ICW Radar System a diagram is:

90. **MTU/Exciter -** Determines PRF and triggers the Transmitter providing reference signals for the Transmitter and providing the Stable Local Oscillator (STALO) frequency sent to the mixer. It also receives control functions from the Radar Data Processor RDP.

91. **MOPA -** During radar transmitters it was seen that the basic Master Oscillator Power Amplifier (MOPA) transmitter would function as the coherent transmitter in an ICW system.

92. **T/R Sw & Ae-**As per basic pulse radar

93. **Mixer/Receiver-**The superheterodyne receiver, processes the very low power echo pulses through low noise factor circuits, then amplifies, demodulates and presents the signal in a suitable format for display.

94. **Signal Processor -** A digital signal processor undertaking filtering and data manipulation and processing the pulses together with their “Doppler” shift signal (fd) into a suitable format for a display or use by the RDP.

95. **Display** - Multi-function digital display.

96. **Radar Data Processor (RDP)-**Essentially a computer that is central to the operation of the radar. The RDP performs the control functions for the Radar it also interacts with the aircraft data architecture for use with other systems and sensors on board. It also controls the antenna position.

Multi-mode ICW Radar in Airborne Interception (AI)

97. Airborne Interception (AI) radar must be able to detect targets under varying conditions, such as:

a. At long ranges from a range of altitudes.

b. At all speeds and any line of sight (LOS) angle relative to the aircraft.

c. With a zero closing rate, (i.e. target has the same speed and direction as aircraft).

98. These diverse requirements cannot be met with just one type of ICW radar mode.

99. Most modern Pulsed Doppler AI radars are able to operate in number of modes, the most appropriate being selected for any given situation.

Frequency Clutter in Pulsed Doppler (ICW) Radar

100. (Refer Figure13.This shows a standard spectrum of frequency returns.

101. If basic CW radar was used as an airborne interception (AI) radar, then In addition to the Doppler shifted frequency in the received echo generated by the target, there will also be a spectrum of clutter frequencies returned including:

a. Strong frequency return known as Main Beam Clutter (MBC). This is due to the main lobe of the radar beam striking the ground, resulting in a measurement of some portion of the aircraft's groundspeed component, which can hide the presence of targets

b. Strong frequency return known as the Altitude Return (F_O). This is due to Side Lobes of the radar beam striking the ground immediately below the aircraft and any portion of the transmission going directly to the receiver. This results in a strong return at the transmitter frequency

c. Many weak frequency returns known as Side Lobe Clutter (SLC). These is due to the side lobes of the radar beam striking the ground as a result of the aircraft's groundspeed component, which can hide the presence of targets.

d. The frequency returns from target 1 and target 2 are dependent on their relative velocities to the AI carrier. Target 1 is a high speed closing target so the returns are at the high end of the spectrum conversely Target 2 is an opening target (going away) so those returns are shown at the lower end of the spectrum.

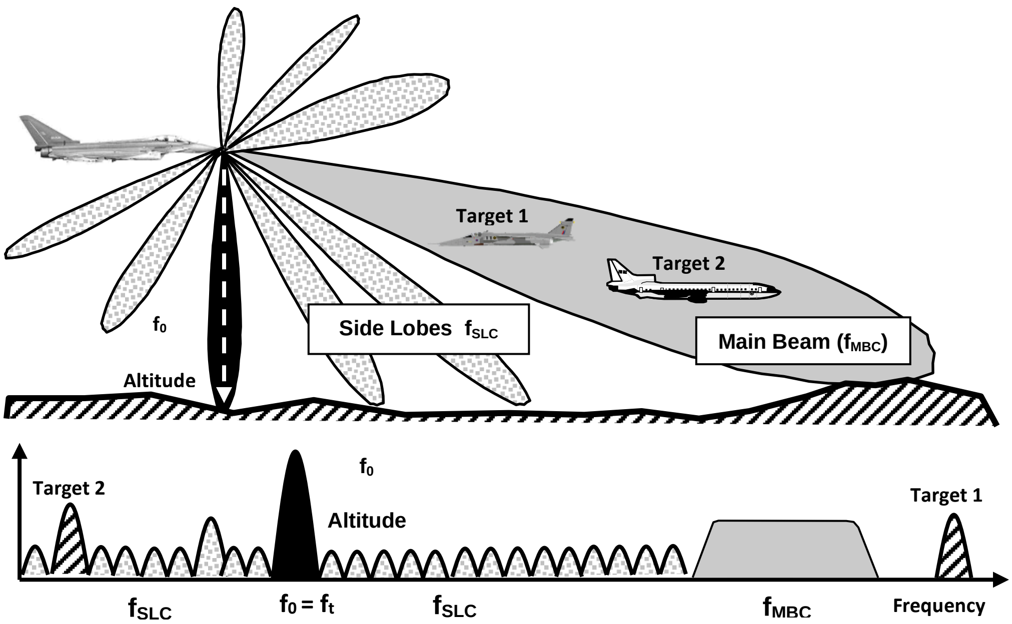

Figure 13 – CW Doppler Frequency Spectrum

102. One of the desirable features of AI radar is the ability to detect targets at low level against a terrestrial background, there will always be a small frequency spread due to terrain variation and aircraft climb and descent. The Doppler frequency sensed by the main beam will vary with radar angle, terrain profile, and of course, with the carrier aircraft's velocity. In some systems the peaks due to altitude and Main Beam Clutter (MBC) can be removed using filters, leaving a band of clutter of low level fairly level amplitude extending either side of the central frequency.

103. There are clutter free frequency zones above and below those due to the aircrafts ground speed components, where targets can be easily identified.

104. The frequency relationship between the target and the clutter will also depend on the target's relative velocity to the carrier aircraft. In order to detect a target readily, its Doppler shift must lie outside of the clutter region. Whether this will be the case depends on the target's relative velocity.

105. 1 knot of closing rate airspeed produces 35Hz of Doppler shift frequency. In a hypothetical situation a maximum closing rate between two aircraft could be say 2000kts this gives us a Doppler shift of +70kHz. A target aircraft flying away (opening) at is maximum speed from an aircraft at minimum cruising speed would be say -600kts this gives us -21kHz. That gives the Radar Receiver a frequency Spectrum of over 90kHz to contend with.

106. During factors affecting radar performance the relationship between PRF and Maximum Range was covered. The Choice of PRF therefore becomes very critical, as we will see the higher the PRF, the wider are the clutter-free frequency zones, but the maximum range becomes is reduced.

Frequency Spectrum of ICW Transmission/Reception

107. Earlier in the Avionics Introduction when discussing Pulse Code Modulation It was shown that a perfect square wave pulse is made up of an infinite number of odd harmonic frequencies (or sideband frequencies).

108. The frequency interval or spacing between these sideband frequencies (spectral lines) for a pulsed radar system is determined by the Radar PRF. Therefore if the PRF was 1kHz each sideband frequency (spectral lines) would be separated from the next by 1kHz.

109. Each sideband frequency would contain its own Doppler frequency spectrum.

110. Figure 14 shows the energy distribution and the relationship between PRF, PW and the number of sideband frequencies (spectral lines).

111. The bandwidth of the main lobe is **inversely proportional** to the Pulse width.

112. The Spacing is set by the PRF. High PRF will give wide spacing conversely low PRF will give narrow spacing between spectral lines.

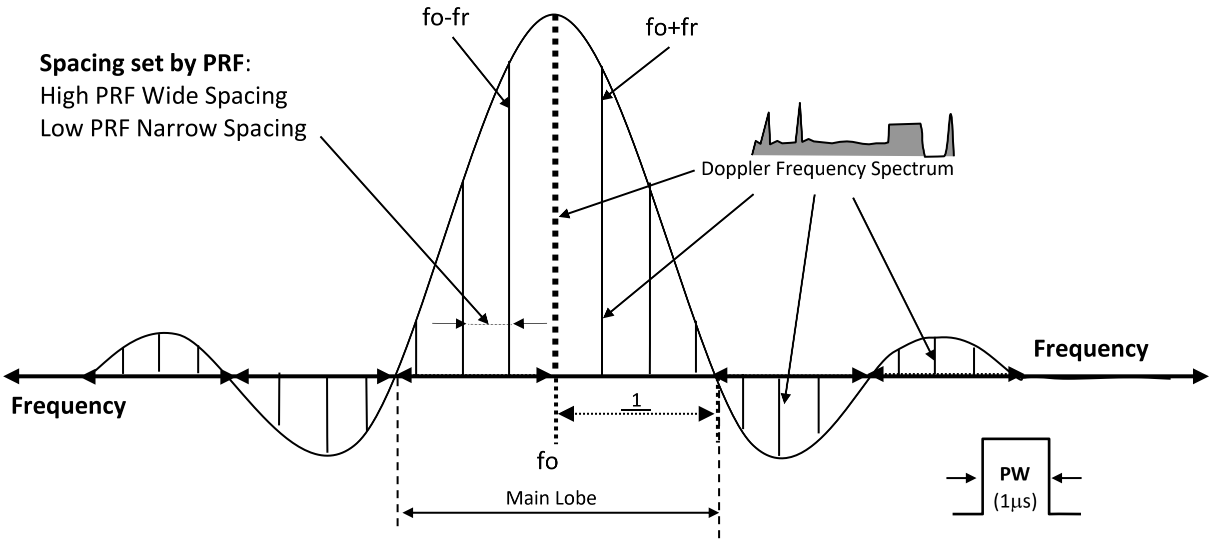

Figure 14 – Spectral Lines or Sideband Frequencies in a Square Wave

Velocity and Range Ambiguity (uncertainty).

113. In Radar technology the word ambiguity is commonly used to describe uncertainty or confusion. For any pulsed radar system that measures target Velocity and Range, it is essential that each returning echo can be associated with its own transmitted pulse. In this way ambiguity in velocity or range (uncertainty or confusion) is avoided.

Velocity Ambiguity.

114. The single, CW frequency spectrum of returns shown in figure 6 seems relatively easy to interpret.

115. If a pulsed Doppler radar system has a sufficiently high PRF, the spacing is wider between (spectral lines).Then clear or frequency clutter free regions will exist. If a target's Doppler shift frequency falls into a clear region it is relatively easy to detect since it is competing only with noise.

116. In a Pulse Doppler or ICW system there will be a Doppler spectrum for each of the sideband frequencies (spectral lines). However, in the complex return of sideband frequencies see figure 14 ambiguity can occur between the velocities of low and high speed targets on adjacent lines leading to velocity ambiguity.

117. **Worked Example 1:** (Refer figure 14)

Question: How many sideband frequencies make up the main lobe?

Given: PRF = 1 kHz and the PW = 1μsec.

Answer: Main Lobe Frequency width = 1 ÷ PW x 2

= 1 ÷ 1μsec x 2

= 1MHz x 2

= 2MHz

Number of Sideband Frequencies = Main Lobe Frequency width ÷ PRF

= 2MHz ÷ 1 kHz

= 2,000 Sideband Frequencies

118. This means that each of the 2,000 Sideband Frequencies will return a frequency spectrum; these would obviously overlap and be impossible to interpret.

119. So if the PRF is a low value then the clutter spectrums overlap and determining which particular spectrum the return belongs to is not possible, so accurate measurement of the target velocity is not possible.

120. Therefore, the problem of velocity ambiguity can be avoided by using a sufficiently high PRF to reduce the number of sideband frequencies to a point where the spectrums do not overlap, but this leads to the problems of range ambiguity.

121. In worked example 1 if the PRF was increased to 200kHz the number of sideband frequencies in the main lobe would drop to:

= 2MHz ÷ 200 kHz

= 10 Sideband Frequencies

122. The number of sideband frequencies or spectral lines is determined by the PRF, therefore:

a. The **lower** the PRF the **greater** the **number** of sideband frequencies.

b. The **higher** the PRF the **smalle**r the **number** of sideband frequencies.

123. Refer figure 15 showing Doppler spectrum at high and low PRF.

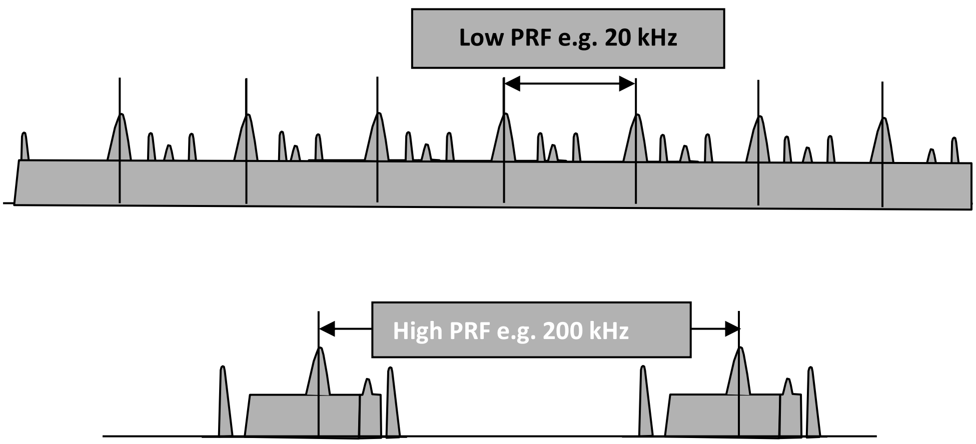

Figure 15 – Doppler Spectrum at High and Low PRF.

Range Ambiguity

124. .In a pulsed radar system it is essential that if range ambiguity (uncertainty or confusion) is to be avoided, that each return echo is linked to its own transmitted pulse.

125. Radar range is determined by timing the interval between the transmission pulse and reception of the target echo.

126. To avoid range ambiguity all echoes must be received before the next pulse is transmitted.

127. Using a high PRF reduces the reception time available between transmissions, and therefore increases the chances of range ambiguity, because we cannot be sure that each echo can be linked with its own transmitted pulse (2nd time around echo problems) covered in Factors Affecting Radar Performance.

128. **Worked Example 2:**

Question: Determine the pulse spacing (PS) and the maximum unambiguous range in km.

Given: PRF = 200 kHz

Answer: PS = 1 ÷ PRF

= 1 ÷ 200 kHz

PS = 5μsec

Range in km = PS ÷ Range Time for 1km

= 5μsec ÷ 6.7μsec

Range ≈ 0.75km

Eclipsing Blind Ranges and Jittering

129. **Eclipsing**. This problem occurs in pulse radars. Since a common aerial is used for transmission and reception, the receiver is only able to accept returning echoes when the radar is not transmitting. As a result of this, the information from many returning echoes will lost. This effect is known as eclipsing.

130. **Blind Range**. When eclipsing occurs in pulse radars that measure range and the target stayed at this same relative range, it would never be detected. This is known as a blind range.

131. **Jittering.** By jittering (varying) the PRF the problem of eclipsing and blind ranges can be reduced. This will ensure that eclipsing is temporary and there are no permanent blind ranges.

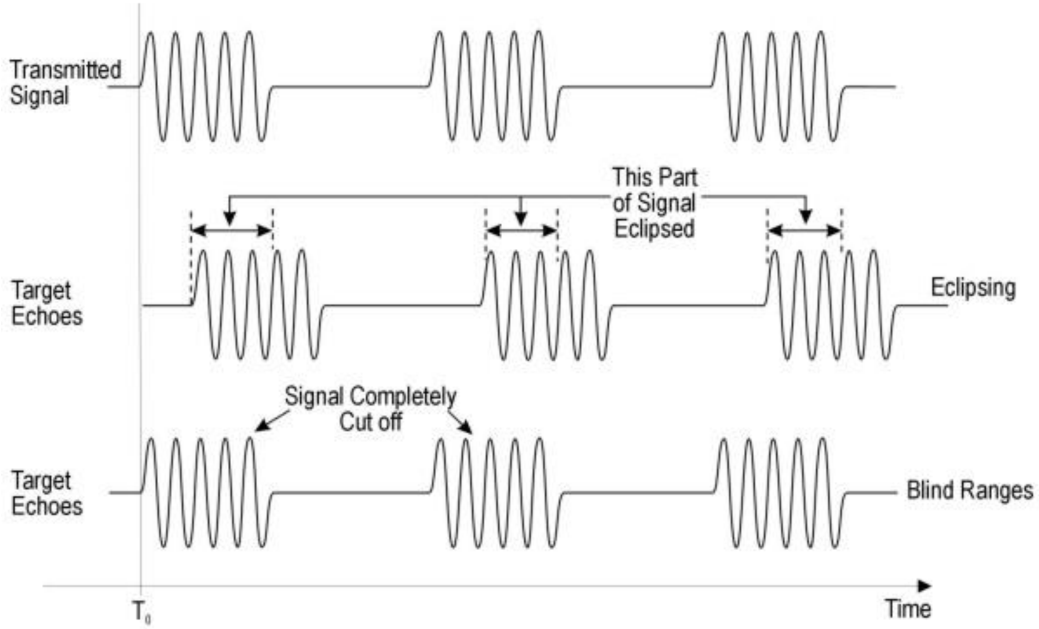

Figure 16 – Eclipsing and blind Ranging

FMICW Ranging

132. This will overcome any range ambiguities and reduced ranges caused by High PRF.

133. (Refer figure 17) The transmitted RF energy is frequency modulated in a linear fashion over a fixed range, which effectively applies a timing mark to the transmitted and received echo pulses.

134. During the linear ramping phases of the FM modulation, a comparison is made of the currently transmitted frequency and the echo pulse frequency. This produces a difference frequency that will be proportional to the range.

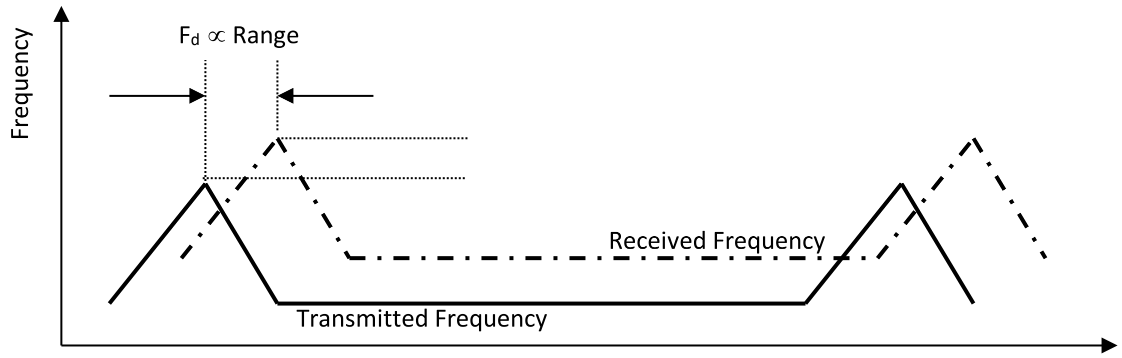

Figure 17 – Principle of FMICW Ranging

Summary of PRF Selection

135. Few parameters of pulsed radar are more important than PRF. This is particularly true of pulsed Doppler radars.

136. Other conditions remaining the same, the PRF determines to what extent the observed ranges and velocities are ambiguous.

137. This, in turn, determines the ability of the radar not only to measure range and relative velocity directly, but also to reject ground clutter.

138. In situations where substantial amounts of clutter are encountered, the ability to reject clutter crucially affects the radar's detection capability.

139. In pulsed Doppler radars, operating at I-band frequencies (8 - 10GHz), typical examples of PRF values are:

LOW PRF……………………. 250Hz – 4 kHz

MEDIUM PRF………………. .10 kHz – 20 kHz

HIGH PRF……………………100 kHz – 300 kHz

140. By using a medium PRF both range and Doppler frequency are ambiguous, but with careful selection of the PRF, the ambiguities can be resolved and provide good all-aspect performance.

141. PRF jittering can also be used to improve performance, but will limit the detection range.

142. Determination of range in ICW systems can also be achieved by use of FM techniques and is called FMICW.

143. Pulse Doppler (ICW) PRF Characteristics are listed in Table 1:

PRF	RANGE	VELOCITY
Low 250Hz – 4kHz	**Unambiguous**	**Ambiguous**
Medium 10kHz – 20kHz	**Ambiguous**	**Ambiguous**
High 100kHz – 300kHz	**Ambiguous**	**Unambiguous**

Table 1 – Pulse Doppler PRF Characteristics

144. In some systems the PRF is continually switched between High and Medium. This provides the ability to detect both targets with high relative velocity (high PRF) and low relative velocity (medium PRF) at near maximum range.

145. As well as switching the PRF the multimode radar can adapt to target scenarios in many ways for example:

- Pulse Width (PW) selection: This will be dictated by the attack mode of the aircraft.

- Short PW are generally required at close range to ensure a reduced ‘eclipsed zone’. They are also used to improve target resolution.

- Longer PW are generally used at longer ranges to ensure measurable returns.

146. **Scan Rate Selection -** Scan rate selection will be dictated by the attack mode of the aircraft. The selection will be relative to engaging long or short-range targets.

147. **Scan Width selection -** Enables adjustable azimuth scan widths. The requirement for different sector scan widths is relative to engaging long or short-range targets.

148. **Target Display Symbology -** Airborne Intercept radar systems commonly use shape and a colour coding to classify the threat that a particular target poses. All air intercept targets are initially displayed. The shape and colour then changes if verification is carried out using the IFF interrogator. The IFF system interrogates unknown platforms to assist in identification of friendly forces. As well as the target symbology changing shape and colour, there are further icons attached that give more depth data of the targets on the display i.e. altitude of target and climb rate.

SYNTHETIC APERTURE RADAR (SAR) (KLP S92-03-03)

149. Synthetic aperture radar (SAR) is a form of radar in which sophisticated processing of radar data is used to produce extremely sharp and clear images after processing. It can only be used by moving instruments over relatively immobile targets, but it has seen wide applications in remote sensing and mapping. Operationally SAR has several advantages over traditional ground mapping radar techniques.

150. It has a comparatively small physical aerial operating at the low frequencies suitable for long-range mapping and at the same time gives Az resolutions of 0.35m.

151. Secondly if the length of the Ae is increased in proportion to the area to be mapped, the resolution (detail obtained) can be made independent of range.

152. In a typical SAR application, a single radar antenna will be attached to the side of an aircraft.

153. A single pulse from the antenna will be rather broad (several degrees) but because it uses a large antenna this helps to produce a very narrow effective beam, which is suitable for long-range mapping and at the same time giving Azimuth resolutions of 0.35m (1foot).

154. This fine resolution is obtained not only at short ranges of a few miles but also at long ranges of 100 miles.

155. The pulse will also be broad in the vertical direction; often it will illuminate the terrain from directly beneath the aircraft out to the horizon.

156. The SAR emits a series of pulses as it travels, then the results from these pulses can be combined. Effectively, the series of observations can be combined just as if they had all been made simultaneously from a very large antenna; this process creates a **synthetic aperture** much larger than the length of the antenna (and in fact much longer than the aircraft itself).

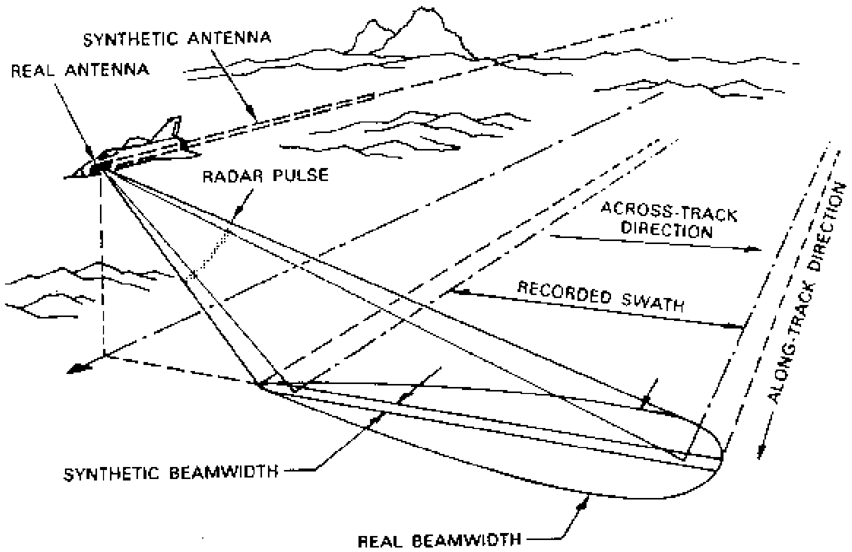

Figure 18 - Synthetic Aperture Radar

157. SAR systems can produce images that are as finely detailed as conventional photographs.

158. Compared with conventional photographic mapping, radar based imaging systems have a number of advantages:

a. Not affected by weather (clouds or rain etc.)

b. Operational day or night

c. Maps are in plan views (looking straight down) even at shallow grazing angles

INVERSE SYNTHETIC APERTURE RADAR (ISAR) (KLP S92-03-03)

159. ISAR is a technique to generate a two-dimensional high resolution image of a target, in situations where other radars display only a single unidentifiable bright moving pixel, the image from ISAR is often good enough to be able to discriminate between various missiles, military aircraft, and civilian aircraft.

160. A high resolution image of some fixed object can be generated by flying a Synthetic Aperture Radar (SAR) around the object.

161. Exactly the same image can be generated with a fixed radar by rotating the object.

162. Inverse Synthetic Aperture Radar (ISAR) is a well-established technique to achieve high range resolution.

163. The availability of a two-dimensional high resolution image permits the radar to better identify the target and it can also be useful for the purpose of target classification.

164. ISAR is utilized in maritime surveillance for the classification of ships and other objects. In these applications the motion of the object due to wave action often plays a greater role than object rotation.