ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION
GUNNERY STAFF/CAREER COURSES

DOPPLER RADAR

INTRODUCTION

1. EM waves that are directed at and reflected from a target, moving with respect to the transmitter, are subject to a frequency shift. Discovery of this phenomenon is attributable to an Austrian physicist, professor **Johan Doppler**. Many modern radar systems use the effect he discovered during the processing of their signals.

2. As a result of extracting any frequency changes present on the radar echo from a moving target, two important objectives may be met. The first is that of clutter removal, and the second, acquisition of target radial velocity. The radial velocity of a target should not be confused with its actual velocity. Radial velocity is that component of velocity which is along the line between radar and target, it may be substantially lower than the actual velocity of the target. Fig.1, illustrates the difference, and will be returned to later in the text.

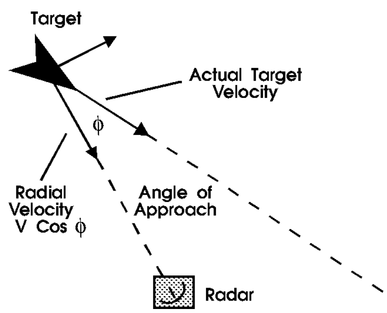


Fig.1. Target Radial Velocity

3. Clutter, caused by stationary reflections from hills, buildings, trees, etc., can prevent target detection and accurate position fixing, so its removal is beneficial for efficient radar system operation. Stationary target echoes are not shifted in frequency, only the echo from a moving target will have that change normally called the **Doppler Shift**. Thus, by excluding from its processing any target echo that has not been shifted, i.e., those which return at exactly the same frequency as when transmitted, a radar can effect reasonably efficient clutter rejection. When clutter removal is the sole reason for using **Doppler Processing** the radar is referred to as a **Moving Target Indicator** or **MTI** radar.

4. Some radars attempt to predict the probability of interception and might subsequently control the firing of defensive weapons at moving targets. To perform this function an accurate estimate of target velocity is required. The signal processing performed by such equipment is rather more complex than in those used for the MTI function. In these cases the equipment is referred to as a **Pulse Doppler Radar** system.

5. Both the type and the role of a radar employing doppler processing can fit into various categories, the structure chart of Fig.2, shows the possibilities. Extraction of range signature from a pure CW system is not possible, so the introduction of some form of modulation is required by which to mark the start and finish points for range timing. In this case the range signature may not be so accurate as that obtainable from a pulse radar. On the other hand, if accurate range signature is required, a pulse system is necessary, which can be of either the **Coherent** or **Non-Coherent** type, details of which will be discussed later in the text.

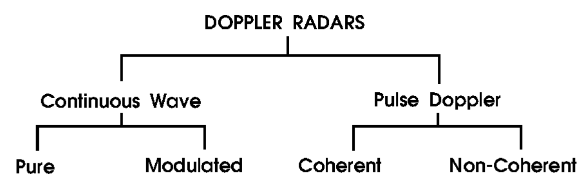


Fig.2. Doppler Radars

THE DOPPLER PHENOMENON

6. The **Doppler Phenomenon** produces a change of frequency at any receiver that is moving with respect to its transmitter. The mechanism by which this change occurs was discussed during the handout on the **Doppler Phenomenon**. The degree to which it affects a radar signal will depend upon a number of circumstances, some of which are outlined below. As a result of the doppler shift, the received frequency, fr, becomes:-

$$\mathbf{fr = ft \pm fd}$$

Where ft = The TX frequency
And fd = The Doppler Shift component
Also $fd = \frac{ft \times v}{c}$

7. It is convenient to illustrate the effect in the form shown at Fig.3, and to write the equation as follows:-

$$\begin{aligned} fr &= ft \pm fd \\ &= ft \pm \frac{ft \times v}{c} \\ &= \frac{c}{\lambda} \pm \frac{c}{\lambda} \times \frac{v}{c} \\ &= \frac{c}{\lambda} \pm \frac{v}{\lambda} \quad \text{or} \quad = \frac{c \pm v}{\lambda} \end{aligned}$$

Where c/λ is the transmitted frequency and v/λ is the doppler shift component.

Both Transmitter and Receiver Moving

8. Should the case arise where both TX and RX are moving relative to each other, then the Doppler Shifts occurring due to both movements must be taken into account. If the two are directly closing at the same velocity then the increase in frequency will be double that for either one, on the other hand, if the two are receding, or opening, at the same velocity then the decrease in frequency will again be double that for either one.

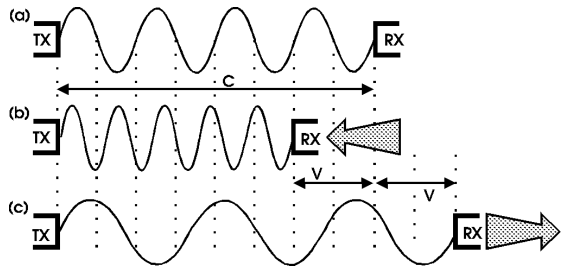


Fig.3. The Doppler Effect

9. When both transmitter and receiver are moved in the same direction at the same velocity, effectively on a parallel path, then the relative velocity between them is zero and no Doppler Shift in frequency on the received signal occurs. e.g., if two cars on a motorway proceed in the same direction at say 60mph, a receiver mounted on the second processing signals transmitted from the first, will not experience any Doppler Shift, because there is no relative movement between the two. Doppler shift can only occur where there is relative movement between transmitter and receiver.

Practical Cases

10. Many everyday examples illustrate the effects of the Doppler Phenomenon. A favourite example, because of its clarity, is that sensed by the ear when a train with its whistle blowing passes close to an observer. A quite clear change of pitch is heard as the direction changes from approaching to receding over a relatively short distance close to the path of the train. The Doppler Shift changes the received sound from an increased frequency to a reduced frequency, and the faster the train the greater the pitch change. The same effect can be experienced with traffic noise in the street and racing cars on the track.

REFLECTIONS FROM MOVING TARGETS

11. The phenomenon of Doppler Shift can now be applied to a target echo. Extraction of velocity is not quite so simple as might appear at first sight and in order to clarify the degree of frequency shift present on a returning signal, target reflections will now be examined.

12. The target illustrated at Fig.4, is approaching a radar at velocity, v. The radar transmission arrives at the target and is reflected, returning to the receiver. For the radar energy, the two legs of the journey must be separated in order to understand the extraction of total Doppler Shift. In the first leg the target may be considered to act as a receiver and the signal will have a Doppler Shift upon arrival. For the second leg, the target may be considered to act as the transmitter, sending out a signal already Doppler Shifted during the first leg, which will once again be Doppler Shifted when it arrives back at the radar. Each of the two legs produces a Doppler Shift in the signal to be processed by the radar receiver.

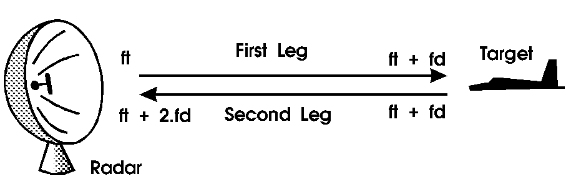


Fig.4. Radar Reflections from a Real Target

Transmission from Radar to Target

13. During this leg the radar signal frequency will be Doppler Shifted by an amount +fd, determined from $fd=v/\lambda$, where $\lambda=c/ft$, and $fd=ft\times v/c$. The signal arriving at the target, and effectively received there, becomes $fr = (c+v)/\lambda$, which is exactly that anticipated from the basic Doppler Phenomenon.

Reflection from Target to Radar

14. For the return leg, the signal effectively transmitted by the target towards the radar is $ft = (c + v)/\lambda$, and this is again Doppler Shifted by an amount determined by v/c. Thus the signal arriving at the radar receiver has been Doppler Shifted twice, and:-

$$fr = \frac{(c + v)}{\lambda} + \frac{(c + v)}{\lambda}\times\frac{v}{c}$$

Where v/λ in the first term is the first leg Doppler Shift and the whole of the second term is the second Doppler Shift. Sorting out the terms gives:-

$$\begin{aligned} fr &= \frac{c}{\lambda} + \frac{v}{\lambda} + \frac{v.c}{c.\lambda} + \frac{v.v}{c.\lambda} \\ &= \frac{c}{\lambda} + \frac{2v}{\lambda} + \frac{v.v}{c.\lambda} \end{aligned}$$

15. This last term, $v^2/(c.\lambda)$, is insignificant at the frequencies in use and can be completely disregarded. e.g., at a target velocity of 500m/sec, or roughly 1,000 knots, and transmission frequency of 3GHz, where λ=0.1m, the term produces a value of 0.009Hz, which against the remaining terms is minute.

$$\text{Thus}\quad fr = \frac{c}{\lambda} + \frac{2v}{\lambda}$$

and the Doppler Shift component has doubled. In effect the same shift in frequency occurs for both out and return legs. The formula is usually written in the following form to accommodate both approaching and receding targets:-

$$fr = \frac{c \pm 2v}{\lambda} = ft \pm \frac{2\times ft\times v}{c}$$

The Actual Frequency Change

16. Much has been said of the fact that a frequency change occurs due to the Doppler Phenomenon but, to this point, no figure has been attached to the amount of shift, fd, which is present on the received signal. As an example, take a stationary transmitter operating at a frequency of 9GHz with a receiver moving directly towards it at a velocity of 500 m/sec. The frequency of the received signal may be calculated as follows:-

$$\begin{aligned} fr &= ft + fd \\ &= 9GHz + \frac{9GHz\times v}{c} \end{aligned}$$

Where $c = 3\times10^8$ m/sec.

And $v = 500$ m/sec.

Hence $$fr = 9GHz + \frac{2 \times v \times 9GHz}{c}$$

$$= 9 \times 10^9 + \frac{2 \times 500 \times 9 \times 10^9}{3 \times 10^8}$$

$$= 9.000030000 \text{ GHz}$$

Thus, fd = 30 kHz, and forms the Doppler Shift Component.

17. The same calculation carried out at a transmitter frequency of 3GHz yields:-

$$fr = 3GHz + \frac{2 \times v \times 3GHz}{c}$$

$$= 3 \times 10^9 + \frac{2 \times 500 \times 3 \times 10^9}{3 \times 10^8}$$

$$= 9.000010000 \text{ GHz}$$

Thus, fd = 10 kHz, and forms the Doppler Shift Component.

Note. Attempting to mix knots and metre/sec in a calculation will cause error, so speed in knots must always be converted to m/sec by using the factor 1knot=0.514m/s. A quick idea is given by doubling the number of m/s to get knots or halving the number of knots to get m/s.

18. It can be seen from the calculations above that, as the transmitted frequency increases the Doppler Shift for a given receiver velocity increases. Also a reduction in receiver velocity to 50 m/sec reduces the Doppler Shift by a factor of 10. It is common in Doppler systems to refer to the shift in Hz/m/sec. Hence, for the circumstances of paragraph 16, in which ft=9GHz, the target is moving at 500 m/s and the shift is 30kHz, the shift in Hz/m/sec becomes:-

$$\frac{30{,}000}{500} = 60 \text{ Hz/m/sec}$$

on the other hand for the target of paragraph 17, where ft=3GHz and the target is moving at the same velocity of 500 m/s but the Doppler shift is10kHz, the shift in Hz/m/sec is:-

$$\frac{10{,}000}{500} = 20 \text{ Hz/m/sec}$$

Effect of Radial Component

19. During the introduction, Para.2, it was indicated that the velocity with which the radar must work, called the Radial Velocity, is $v = V \times \text{Cos}\phi$, where V, is the actual target velocity and ϕ, is the angle of approach for that target. If this effect is implemented in the equation defined above, then the full Doppler Shift equation becomes:-

$$fr = c \pm \frac{2V \times \text{Cos}\phi}{\lambda}$$

Where $$fd = \pm \frac{2V \times \text{Cos}\phi}{\lambda}$$

is the Doppler Shift component of the equation.

20. For a target approaching at an angle of 60° to the radar, the Doppler Shift is modified by Cos(60°)=0.5, and the frequency shift at the receiver is halved against that which would occur if the target was flying directly towards, or away from it. Placing both these factors in the example of an approaching target with actual velocity of 500m/sec, transmitted frequency 3GHz ($\lambda = c/ft = 300 \times 10^6 / 3 \times 10^9 = 0.1$m) and angle of approach 60°, then:-

$$fr = c + \frac{2v \times \text{Cos}\phi}{\lambda}$$

And $$fd = + \frac{2 \times 500 \times 0.5}{0.1}$$

$$= 5000 \text{ Hz}$$

Giving $fr = 3 \text{ GHz} + 5 \text{ kHz}$

When considering Doppler Radar operation, it is convenient to use examples that are multiples of 3GHz transmitter frequency and to extract the Doppler Shift for a head-on approacher or receder. i.e., $\phi = 0° \therefore \text{Cos}\phi = 1$.

21. At low transmitter frequencies the Doppler shift is small. This means that detection of receiver velocity by measuring the Doppler Shift is more difficult at those frequencies, where the received frequency changes are lower. It might seem at first sight that the obvious answer to this problem is the use of higher transmitter frequencies, however, such a tactic produces yet more operational problems relating to the maximum speed detection capability of a radar. These and other difficulties will be discussed later in the text.

TARGET CROSSING THE FRONT

22. A situation typical of that which is likely to occur in practice is illustrated at Fig.5. Here a target is crossing the front of an Air Defence radar equipment at the same height as the radar. The diagram shows a plan view of the scene. The actual target velocity, V, and track is assumed to be constant, which would probably be the case during a weapons delivery run and will serve here for the purposes of illumination.

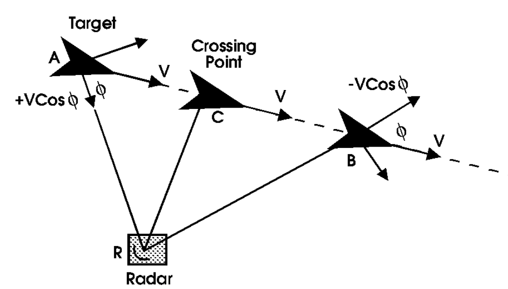


Fig.5. The Crossing Target

Approaching Target

23. The first point of interest is that marked A in Fig.5. At this point the target is seen by the radar as an approacher which has a radial component of velocity given by $+V \times \text{Cos}\phi$, and the received frequency will be higher than that transmitted.

Receding Target

24. The second point of interest is that marked B in Fig.5. At this point the target is seen by the radar as a receder which has a radial component of velocity given by $-V \times \text{Cos}\phi$, and the received frequency will be lower than that transmitted.

Target at the Crossing Point

25. A point may be determined, C, at which the direction of travel for the target is perpendicular to the line along which the radar is trying to detect it. This is normally called the **Crossing Point**. At the crossing point the component of

radial velocity is neither positive or negative, indeed it has fallen to zero, since at this exact point there is no element of velocity along the line of radar sight. The crossing point is a very interesting one from the Doppler Radar systems point of view, because at this point a target being processed by virtue of its velocity will disappear from the radar, the system is **Blind** to it.

The Clutter Filter

26. All radars employing Doppler techniques must necessarily be designed with a minimum target velocity in mind. A decision has to be made as to how much clutter can be tolerated and, therefore, the false alarm rate, against the possible loss of slow moving targets. Implementation of this decision will mean that a block of target speeds around zero, for both approachers and receders, must be eliminated, usually by signal filtering. A typical value for the filter velocity might be +/-50 m/sec and the filter employed to remove targets below that velocity is usually called the **Clutter Filter**.

The Blind Period

27. To get some idea of what the clutter filter can produce in terms of operational difficulties the following example shows the blind period for a crossing target. A Doppler radar operates at 3GHz with a clutter filter velocity of +/-50 m/sec. A target is crossing its front at a speed of 225m/sec, and range of 5km to the crossing point. The target reaches point A of Fig.5, at which time it enters the clutter filter. The angle of approach may be calculated from the Doppler Shift equation for fd, which will allow the blind arc and, therefore, the blind period, to be calculated. This is achieved as follows:-

Where $fd = \pm \dfrac{2V \times \cos\phi}{\lambda}$

$\therefore \quad \cos\phi = fd \times \dfrac{\lambda}{2V}$

28. It was shown in para.28, that the Doppler Shift at 3GHz is 20Hz/m/sec. Also, the wavelength at 3GHz is 0.1m.

Thus $\cos\phi = \dfrac{50 \times 20 \times 0.1}{2 \times 225}$

$= 0.2222$

$\therefore \quad \phi = 77.160^\circ$

This is angle RAC in Fig.5, so angle ARC=90°-77.16°=12.84°, and the **Blind Arc** is twice this at 25.68°.

29. The distance from the radar to the crossing point, RC, is 5km, so the distance the target covers after entering the clutter filter and arriving at the crossing point, AC, is RC×Tan(ARC) and the **Blind Distance** is twice this at 2×RC×Tan(ARC).

Thus 2×RC×Tan(ARC)

= 2×5000×Tan12.84°

= 2279m to the nearest metre.

Now time = dist/speed and at 225m/sec the **Blind Period** is:-

$BP = \dfrac{2279}{225}$ sec

$= 10.13$ seconds.

It may well be that the design of the system in which the radar is used ensures that this apparently intractable problem is either overcome or avoided, it should, however, be borne in mind as a possible difficulty.

EXTRACTION OF VELOCITY

30. The discussion so far has centred upon the facts that the radar echo from a moving target has a Doppler Shift superimposed upon it and that the shift may be used for clutter removal or velocity calculation. To this point no mention has been made of the method by which radial velocity may be extracted from the echo signal.

31. Two major considerations in the choice of method for velocity extraction are whether a single target is to be tracked and the required accuracy of velocity information. The final selection will be very much influenced by that choice.

32. The methods of extraction available are frequency counting, frequency discrimination, filtering and fast Fourier trans-

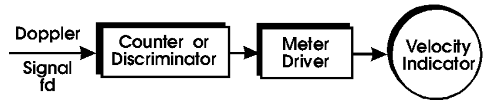


Fig.6. An Electronic Velocity Indicator

form (FFT, which is the subject of another handout), the first two being much slower and normally single target dedicated processes. The Doppler Shift must first be separated from the RF and then velocity is extracted.

Shift Frequency Determination

33. The process of frequency extraction is illustrated at Fig.6. In its simplest form it is a counter, electrically similar to the rectification process met during power supplies, or the demodulation (Detection) stage seen in the AM radio receiver. A frequency discriminator of the type discussed in FM radio demodulation could also be used but is a little more complex.

34. It is obvious that this system has to be dedicated to a specific single target and it must also be said that it is rather slow to lock to a new target. That may be unacceptable in the context of a specific system design, particularly where rapid processing of high speed, low level targets is required.

Velocity Filtering

35. A very simple, but sometimes rather crude, alternative to the frequency counter is the velocity filter. This system has the distinct advantages of being very much faster than frequency counting and it can switch to a new target almost instantaneously. The disadvantage is that the accuracy of the method is limited by the number of filters required to cover a velocity range, however, if in the interests of operational requirements that limitation is acceptable, the system can be very fast and efficient.

36. The technique consists of employing a block of filters with response curves adjacent to each other as illustrated at Fig.7. The curves shown are idealised and in a practical design it is essential that filter overlap is reduced to a minimum, in order to ensure that a signal is processed by only one filter, if that is possible. The number and frequency range of the filters is system dependent.

CW RADAR

37. The concept of CW radar was outlined during the introduc-

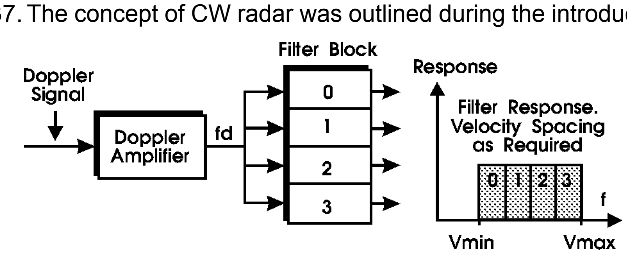


Fig.7. Velocity Filtering

tion to tactical sensors and radar. The transmitter operates without interruption, continuously emitting the same frequency. The receiver processes the returning signals in such a way that the target of interest is tracked and its radial velocity extracted. Automatic tracking will be the subject of a separate handout elsewhere in the course.

38. It is not possible to draw range information from a pure CW system because without some form of interruption, or modulation, timing of one transmitted cycle with respect to the others is impossible. The need for range signature, however crude, led to the introduction of modulation in the CW system, however, the modulation is such that transmission is still continuous. The two types of CW radar are thus designated **PURE** and **MODULATED** respectively.

Pure CW Radar

39. A radar typical of the CW type was used in the past to determine muzzle velocity of artillery weapons. It was called an Electronic Velocity Analyser (EVA). The diagram at Fig.8, shows an example of such a device. By use of the Doppler technique, the velocity of a projectile travelling along a known path upon exit from a gun barrel is extracted and displayed.

40. It is important that the transmitter and receiver displacements from the line of travel be measured and recorded. This allows a correction to be applied to the computed velocity, that will offset the effects produced by measuring radial as against actual projectile velocity. A later system called PACER was designed to be clamped to the end of the gun barrel, which eliminated the need for the offset corrections and measured actual velocity.

41. The transmitter oscillator is a klystron operating at about 10GHz with very low power output, around 50mW. At the

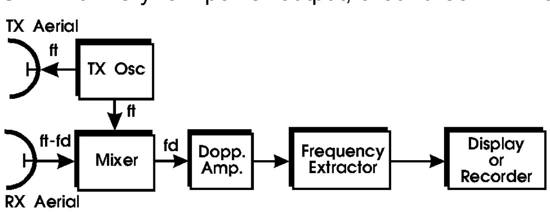


Fig.8. A Typical Doppler Based Electronic Velocity Analyser (EVA)

same time as being delivered to the TX aerial the klystron output, ft, is injected at the receiver mixer stage. The other input to the mixer is the received energy, with the Doppler Shift superimposed upon it, ft - fd. The reader is left to decide why the received signal will not include an ft + fd component. The output of the mixer stage is the difference between received and transmitted signals, fd, the Doppler Shift component. This signal is amplified and then applied to the frequency extractor followed by a display or recording system.

Modulated CW Radar

42. It was indicated above that range signature could not be obtained from pure CW radar systems and that in order to acquire it some sort of modulation would need to be introduced. Modulation is applied to the transmitter frequency in such a way that there is a regular variation in the radar output between two specified frequencies, -fc and +fc. This type of signal is shown at Fig.9a. Because of the modulation, the received signal from a stationary target shows up clearly delayed on the transmitted version. Thus range can be extracted as proportional to the average, or mean, beat frequency. The differences are shown in Fig.9b as fb1 and fb2. At constant range the differences are the same for each half cycle.

43. When a moving target is detected, the echo signal has a Doppler Shift (fd) superimposed upon it which causes all

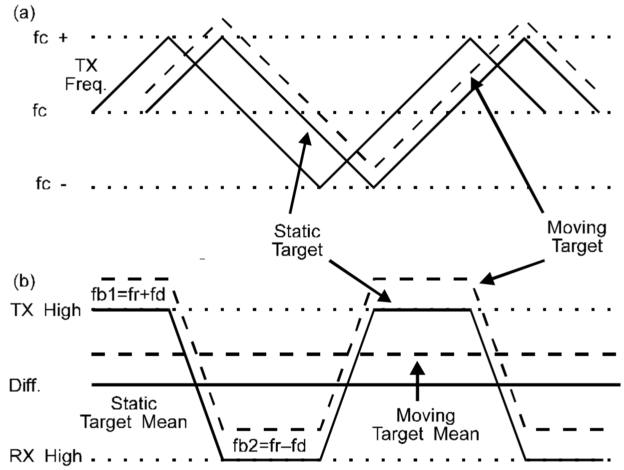


Fig.9. The Frequency Modulated CW radar Signal

range beat frequencies (fr) to be either higher or lower, creating a difference in the beats fb1 and fb2. The effect is seen in Figs.9a and b. Now, fb1=fr+fd and fb2=fr–fd and from these two the range, fr, and velocity components, fd, are extracted as the mean and difference of the beats:-

$$fb1 = fr + fd \quad \text{and} \quad fb2 = fr - fd$$

Thus

$$fr = \frac{fb1 + fb2}{2} \quad \text{and} \quad fd = \frac{fb1 - fb2}{2}$$

PULSE DOPPLER RADAR

44. A Pulse Doppler Radar is operated in one of two basic forms, **Coherent** or **Non-Coherent**. In the latter case it is important that the normally unwanted ground clutter is present at the same time as the required target signal. This tends to limit its application to the ground surveillance role. The coherent system has no such limitation but is rather more complex in design.

45. A **Coherent Pulse Doppler Radar** is one in which the **transmitted and received signals bear a fixed phase relationship to each other**. The transmitter frequency is controlled by, or locked to, a highly stable, continuously available source, which also feeds the local oscillator, or oscillators, of the associated Doppler receiver.

Standard Pulse Radar

46. A standard pulse radar is comprised of separate TX and LO devices which operate independently, but with a difference frequency equal to the required intermediate frequency. Should the TX frequency drift, the automatic frequency control (AFC) system causes the LO to follow, which then maintains the IF difference.

47. When the AFC system is in the process of following the TX frequency small differences from the required IF centre frequency will exist, however, the bandwidth of the IF amplifiers is wide enough to ensure that this minor shift of centre frequency does not result in a severe loss of spectral content and subsequent echo distortion.

Spectral Components of a Pulse Radar

48. The spectral content transmitted by a pulse radar system

is shown at Fig.10. The bandwidth (BW) of the transmitted signal may be taken as $2/\tau$ Hz, where τ is the pulse width. Spectral lines occur above and below the transmitted centre frequency, fc, at intervals equal to the pulse recurrence frequency (PRF) of the system. Thus the first upper side spectral line is fc+PRF, the second is fc+2×PRF, etc. The first lower side frequency is fc-PRF, the second is fc-2×PRF, etc. The total number of spectral lines, N, contained within the specified BW is N=1+BW/PRF.

49. If system pulse width, τ, is reduced, this widens the bandwidth and more spectral components are generated. The

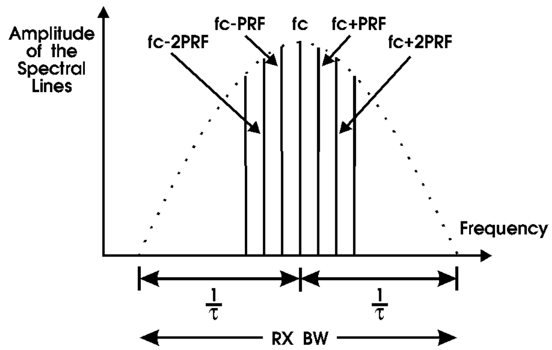


Fig.10. Spectral Content for a Pulse Radar

result is a reduction in power for each single component because total transmitter power is effectively constant. On the other hand, increasing the PRF decreases the number of spectral lines again, raising the power contained within each. This is an important feature and is employed within coherent pulse doppler radar systems. If a radar transmits at a PRF of 500pps using a pulse width, τ, of 1µsec, then the number of spectral lines, N, contained within the pulse is:-

$$N = 1 + \frac{BW}{PRF}$$

now $$BW = \frac{2}{\tau} = \frac{2}{1\times10^{-6}} = 2\ \text{MHz}$$

$$\therefore\ N = 1 + \frac{2\times10^{6}}{500} = 1 + 4000 = 4001$$

Effects Due to Loss of Spectral Components

50. Should the transmitter, in the example above, be operating at say 10GHz and drift by 5kHz due to magnetron frequency shift. The percentage change against the transmitted RF is $(5{,}000/(10\times10^{9}))\times100$, or 0.00005%. Such a small change is extremely unlikely to be even detected by the AFC system let alone corrected. The loss of spectral content, assuming the receiver has the specified BW of 2 MHz, will be 5,000/500=10 spectral lines. This loss of 10 signal lines from the 4001 transmitted leaves 3991 to form the echo pulse at the receiver, which is highly unlikely to reduce the operational efficiency at all and is found acceptable in practice.

The Need for Coherence

51. From the last example it is evident that small undetected shifts of transmitter frequency have very little effect upon the efficiency of a standard pulse radar. The same frequency shift within a Doppler radar system can lead to gross errors in the velocity calculation. The erroneous transmitter frequency would lead to an error in the Doppler Shift, fd, of 5kHz. Since $fd=2\times V\times \cos\phi/\lambda$, the error in the velocity calculation would be:-

$$v = \frac{fd\times\lambda}{2\times\cos\phi} \qquad \text{Where } \cos\phi=1$$

$$= \frac{5000\times3\times10^{8}}{2\times1\times10\times10^{9}} \qquad \text{Using } \lambda=c/ft$$

$$= 75\ \text{m/sec.}$$

$$= \frac{75}{0.514}\ \text{knots}$$

$$= 146\ \text{knots}$$

If the transmitter frequency is changed to 3GHz the error increases to about 250m/sec (486 knots), because the Doppler Shift per knot at this lower frequency is much smaller.

Coherent Pulse Doppler Radar

52. It is clear, from the example of the last paragraph, that even the tiny frequency errors acceptable within the standard radar equipment, could not possibly be tolerated within a Pulse Doppler Radar. Thus it is very important that the TX/RX IF difference frequency and phase relationship be maintained within such systems. Where that is achieved the system is referred to as being **Coherent**.

53. Coherent systems employs a coherent oscillator (COHO) and a series of stages that relate TX and LO frequencies. They do so in such a way that drift of either is compensated for, or prevented from introducing large errors into the velocity computation. A stable local oscillator (STALO) is also used that determines the IF frequencies and, therefore, helps to maintain coherence.

54. The Doppler receiver is made a double superhet. By this device it is able to provide both second and adjacent channel rejection, at the same time as processing the required Doppler component. Second and adjacent channels are likely because of the possibility that other systems operating nearby will have similar transmitter frequencies. The system forms its IF in such a way that it is almost independent of the actual transmitter frequency, which can be changed to avoid mutual interference. A series of parameters typical of this type of radar are outlined as follows:-

COHO	= 93.75 MHz	(Ftx/32)
STALO	= 20 MHz	(f)
∴ Ftx	= COHO×32	
	= 3,000 MHz	(3GHz)
First LO	= 32(Ftx/32 + f/32)	
	= Ftx + f	
	= 3,020 MHz	(3.02GHz)
RF Echo	= Ftx +/- fd	
	= 3,000 MHz +/- fd	
First IF	= First LO - Received Echo	
	= (Ftx + f) - (Ftx +/- fd)	
	= f +/- fd MHz	
	= 20 +/- fd MHz	
Second LO	= f + f/80	
	= 20 + 0.25 MHz	
	= 20.25 MHz	
∴ Second IF	= Second LO - First IF Signal	
	= (f + f/80) - (f +/- fd)	
	= f/80 +/- fd MHz	
	= 0.25 +/- fd MHz	
	= 250 kHz +/- fd	

55. The second IF is formed at the relatively low frequency of 250kHz, with the Doppler Shift superimposed upon it. For

a target radial velocity of the order 500m/sec the Doppler Shift at 20Hz/m/sec, will be in the region of 10kHz. Hence, the overall bandwidth of the filters would need to be 260-240=20 kHz for full velocity extraction up to about 500 m/sec, or about 1,000 knots.

Velocity Extraction

56. Velocity extraction techniques were discussed earlier, suffice it to say at this point that, in the interests of speed, both for target acquisition and for switching targets, either the filter method or fast Fourier transform (FFT) will be employed. It was shown in the CW radar description that the muzzle velocity of a gun could be determined using the Doppler Shift technique, however, the transmitter was of the pure CW type, which meant that a single target signal was being processed from which the doppler shift must be extracted. In pulse doppler radar, a spectrum is being dealt with, each component of which is related to the transmitter RF, the pulse width, τ, and the PRF of the system.

Spectral Frequency Shift

57. Referring back to Fig.10, When the echo from a moving target returns to the receiver, each of the spectral components will have shifted in frequency, either higher-to the right, or lower-to the left. There are some radars, notably aircraft navigation equipments, which deal with the whole content of the returning spectrum, however, it is far more sensible in the context of both ranging and velocity extraction to pick one spectral component and concentrate the processing on that. This produces a distinct advantage in bandwidth terms, because the full spectrum does not need to be processed by the receiver, providing lower noise levels and consequently longer range at a given TX power level.

58. Since the single spectral component containing the great-

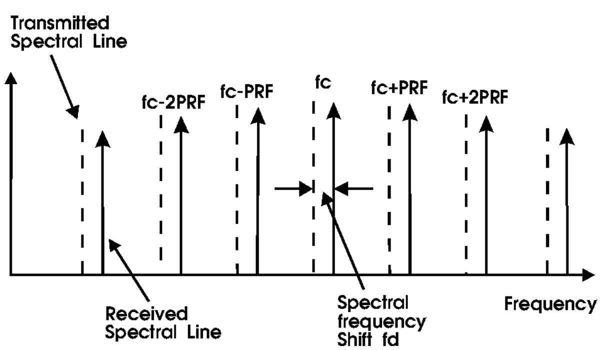


Fig.11. Spectral Shift for an Approaching Target

est transmitter power is fc, that is the one upon which the velocity extraction and ranging processes are based. The point of interest now is the range of frequencies the velocity filters should cover. If the spectral shift of the echo signal is

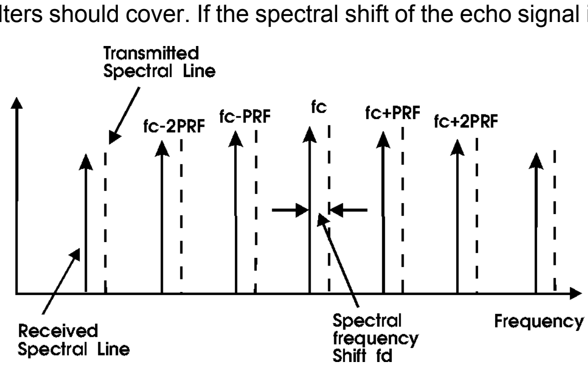


Fig.12. Spectral Shift for a Receding Target

considered for a target with closing velocity, as illustrated at Fig.11, it can be seen that all spectral components are to the right of fc, or higher in frequency, than the transmitted spectrum. On the other hand, for a target with receding velocity, all the spectral components are to the left of fc, or lower in frequency, than the transmitted spectrum, as illustrated at Fig.12.

59. For a closing target, it can be seen there will be a certain

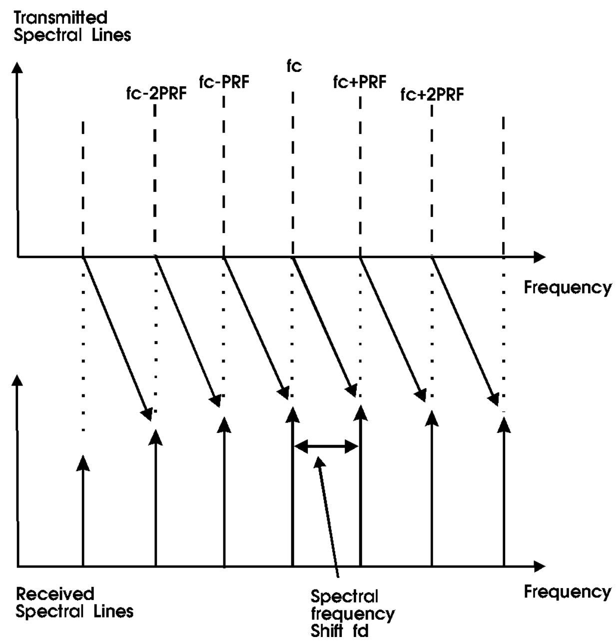


Fig.13. The First Blind Speed for an Approacher

velocity at which the spectral shift causes the moving target spectral components to become coincident with the stationary target spectral components. This is illustrated at Fig.13, where fc for the moving target is coincident with fc+PRF for the stationary target, and so on. If a clutter filter is employed within the radar, the system is now **Blind** to this target. This is true for all such circumstances, of which there could be many, they are referred to as **Blind Speeds**.

Blind Speeds

60. The blind speeds that can occur within a pulse doppler radar system lead to velocity ambiguities, which are almost certainly unacceptable in operation. Thus the system will normally be operated in such a way that the blind speeds are, as much as is possible, out of range for the operational parameters of the equipment.

61. Taking the example of para.49, which used a PRF of 500pps. Blind speeds would occur at intervals of 500Hz, whatever the frequency at which the transmitter is operating. Assuming a TX frequency of 3GHz, the Doppler Shift will be 20Hz/m/sec, for any target being processed. Thus blind speeds will occur at 500/20=25m/sec intervals, or about every 50knots.

62. This means that for any target detected on the basis of a single spectral component, its speed could lie in an interval between 0-25m/sec, 25-50m/sec, 50-75m/sec, 75-100m/sec, 100-125m/sec, etc., depending upon which of the spectral intervals is chosen for examination. The system would not be able to discriminate between these values without more and complex processing.

63. Blind speeds at such a small interval are obviously use-

less, so it is important to either move the PRF to a level at which the blind speeds do not interfere, or to reduce the transmitter frequency, and hence the Doppler Shift, so that a wider speed range is achieved. For other reasons, such as wavelength and aerial structure, the latter choice is not likely to be available, so the PRF must be increased.

64. When the PRF is increased to say, 10,000pps, the blind speeds now occur at 10,000/20=500m/sec, or about 1,000knots, a far more suitable choice for modern air defence weapons. It should be noted that the maximum PRF is limited by the maximum unambiguous range of the radar, a further factor that produces problems in design

Spectral Component Changes

65. It should be clear at this stage that, when the PRF is increased, the number of spectral lines in the transmitted pulse is decreased. Using the example of para.49, if the PRF is increased to 10,000pps, the number of spectral components falls to 201. Consideration of the unused transmitter power shows that even this small number of spectral components leaves a great deal of power wasted in unused spectral components. However, it is an improvement over the lower PRFs.

66. A further reduction of spectral lines may be achieved by an increase in the pulse width. This would reduce the bandwidth of the transmitted spectrum, automatically reducing the number of spectral lines, and a much higher proportion of the transmitter power is contained within the components of interest, particularly, fc, fc+PRF and fc-PRF.

67. Increases of pulse width must be balanced against the corresponding increases in minimum range and range discrimination but if that is an acceptable loss within the system, higher spectral power is the result with consequent improvements in range performance. At a pulse width of 10µsec, and PRF of 10,000pps, the number of spectral lines falls to 21, a tremendous improvement over the standard radar pulse.

Velocity Filters

68. The echo signal spectral component applied to a set of velocity filters, which includes fast Fourier transform analyzers, must be unique. More than one spectral component from a given target processed at the same time leads to confusion, thus, the filter block must be placed between two spectral components. A layout for the filter block is shown at Fig.14. It is placed in the interval between fc and fc+PRF because these have the highest echo power available. (The block could also be placed between fc and fc-PRF)

69. In this case an approacher causes fc to occur on the right,

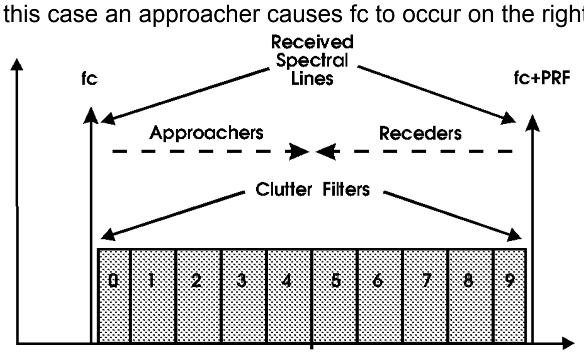


Fig.14. Filter Block for Velocity extraction

in filters 0 to 4 and a receder causes fc+PRF to occur on the left, in filters 9 to 5. Clearly, it is not possible to unambiguously detect velocities greater than half of the PRF for the system, so for a PRF of 10,000pps and employing a transmitter frequency of 3GHz, which gives a Doppler Shift of 20Hz/m/sec, the maximum unambiguous velocity that can be detected is 5,000/20=250m/sec (about 500 kts).

70. A more conventional layout is shown at Fig.15, in which the

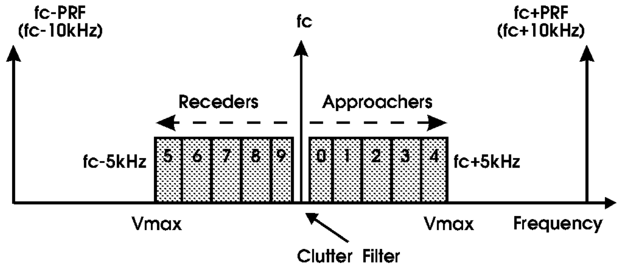


Fig.15. Conventional Pulse Doppler Filter Layout

filter block is centred upon fc. The receder filters have been moved below fc and a single central clutter filter is used to remove low speed targets. This filter, or lack of it, is often called a **Notch Filter** because it is active only in creating a gap in the filtering. Any signal at these frequencies will not be processed. In this case filters 0, 1, 2, 3, and 4 are for approachers and filters 9, 8, 7, 6, and 5 are for the receders. Each filter would have a velocity range of the order 50m/sec, or about 100knots.

71. The range of velocities that this system can cover is somewhat limited because of the PRF in use. If the PRF is increased, the maximum range of the system will be reduced dramatically. e.g., at 20,000pps the maximum unambiguous range falls to 7.5km, which may be far too low for the system to operate efficiently. Thus a technique must be found that will allow a greater range of velocities without increasing the PRF or reducing the transmitter frequency.

72. Careful study of the velocity filter block in Fig.15, will reveal

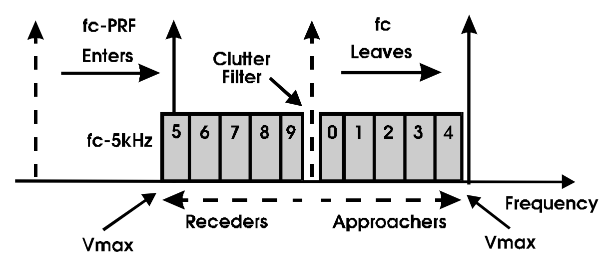


Fig.16. An Approacher Exceeding Unambiguous Vmax

that when fc occurs at a frequency higher than that which filter number 4 can handle, fc-PRF appears in filter number 5, reserved for the fastest receder. This is illustrated at Fig.16. If the approaching target velocity is higher fc-PRF occurs in the next filter block towards the notch, i.e.,6, then 7, then 8 etc.

73. The opposite is also true and when fc occurs at a frequency lower than that which filter number 5 can handle, fc+PRF appears in filter number 4, reserved for the fastest approacher. This is shown at Fig.17. For a higher velocity receding target, fc+PRF appears in the next lower filter block nearer the notch, i.e., 3, then 2, etc. It is also possible that target manoeuvres creating velocity changes could cause the spectral line to change filters whilst being tracked.

74. An opportunity is available here to increase the velocity

coverage of the filter block, albeit with the introduction of ambiguity. The signal being processed is now considered to be from either one of two possible target configurations, an approacher or a receder. Resolution of this ambiguity is not so difficult as may seem to be the case initially.

75. Target direction of movement can be determined not only

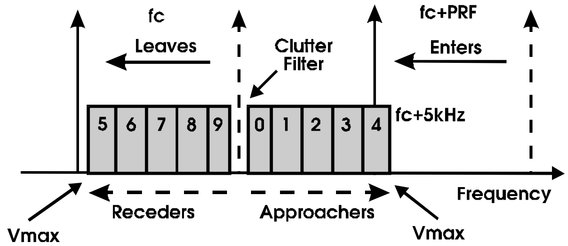


Fig.17. A Receder Exceeding Unambiguous Vmax

from the Doppler Shift present upon the echo but also by the fact that its range is changing. It will be necessary to follow the target for a little longer, however, the benefits of doing so may outweigh the disadvantages, particularly if this is done at a range where engagement would not be envisaged anyway. Velocity extraction could then be based on the fact that the return signal being processed could be fc, fc+PRF or fc-PRF.

76. As a result of this change, each of the velocity filters has a double role, one for the approacher and one for the receder. For example, filter 0 is for a slow approacher, as originally designed, but it can also be for a fast receder. i.e., one that has caused fc+PRF to enter the filter block from the right.

77. On the other hand, filter 9 is now for a slow receder, as originally designed, or for a fast approacher. i.e., one that has caused fc-PRF to occur in the filter block on the left of fc. The ambiguous filter block structure is shown at Fig.18, which doubles the velocity range at the expense of ambiguity in target direction.

78. The maximum frequency range of the filters used in the

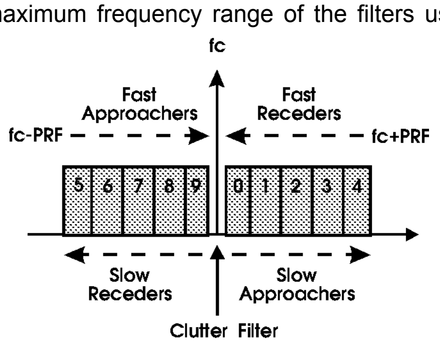


Fig.18. Filter Block for Ambiguous Velocity Extraction

velocity extraction block has already been indicated as being 10kHz, for a radar with PRF of 10,000pps. This may be broken down into say 10 individual filters, each covering 1kHz, or 1,000/20=50m/sec. Remembering that the clutter filter must take out 25m/sec, either side of zero, filters 0 and 9 will both have their lower 500Hz areas notched out. This has the side effect of restricting the highest velocity for approacher and receder, thus, the highest velocity that can be detected is now 9,950Hz, which is equivalent to 475m/sec, or about 950knots. Some radars do not adopt the linear layout of filters suggested here, so it is essential to look at the design parameters of a system prior to making any assumptions about it.

COHERENT PULSE DOPPLER DESIGN

79. Several concepts have been taken separately in these notes. In order to attempt some sort of clarification, a hypothetical system is now specified and the techniques that were discussed incorporated so that the manner in which target information is extracted may be understood.

Design Fundamental

80. The basis for design is that fundamental system of inequalities originally specified by **John Thynne** and **Colin Barron**, by whom the **Rapier** system was conceived, at the **Royal Signals and Radar Establishment**, as it then was, at **Malvern**. The inequalities are as follows:-

$$\frac{\lambda}{2\times V_{max}} \geq T_o \geq \frac{2\times R_{max}}{c}$$

Where λ = Transmitted wavelength
T_o = Time interval
c = Velocity of EM waves
R_{max} = Maximum **unambiguous** range
V_{max} = Maximum **ambiguous** velocity

81. These relationships are based upon the necessity to produce a spectrum of ambiguous velocity information, within the specified maximum range and transmitted wavelength requirements. The ambiguity being that target speed is obtained but direction, whether approaching or receding must be found in some other way. As a first step, each of the two individual inequalities will be examined in turn. The results will show that both are slightly unusual presentations of elements discussed previously, either within these notes or earlier in the course.

To >= 2×Rmax/c

82. This relation is fundamental to the radar range requirement, which is that a transmitted pulse of energy must be allowed to reach targets at maximum range and return to the receiver before the next pulse is emitted. In this form it takes little or no account of any dead time requirement, but that problem can be overcome by the use of rather special receiver processing techniques unique to the Rapier system to be discussed later. An example employing the relation and extracting a value of 'To' for a given maximum range requirement of 15km, is:-

$$T_o \geq \frac{2\times R_{max}}{c} \quad \text{(Also caled pulse interval)}$$
$$\geq \frac{2\times 15{,}000}{3\times 10^8}$$
$$\geq 100\ \mu\text{sec.}$$

83. This is the minimum time period required between pulses in order that the range of 15km can be obtained. Any less and the maximum range will be reduced. The inverse of this figure is the required PRF for 15km range, which has been seen to directly affect the maximum velocity measurable by the filters. In this case PRF=1/100μsec.=10,000pps. In practice most standard radars incorporate a period of dead time which reduces the PRF even further, however, this problem is avoided in the Coherent Pulse Doppler equipment.

λ/(2×Vmax) >= To

84. The left hand side of this second relation is the Doppler Shift formula inverted. i.e., fd=2×Vmax/λ (Cosφ=1). In effect 'To' is the time period for one cycle at the maximum **Ambiguous Doppler** shift frequency to be carried on the returning echo signal. This part of the relation is indicating that, if the range

of velocities that the system must be able to detect is to fit between fc and fc+PRF, or any other pair of spectral lines for this radar, then the wavelength at which the transmitter is operating must not be less than a certain value, λ.

85. Taking the 15km range specified by the last relation. It has determined that the time between pulses must not be less than 100µsec, in other words the PRF must be not greater than 10,000pps. A maximum ambiguous velocity of 500m/sec will be assumed as the system requirement for the moment. The relations can be operated on using normal algebraic procedures, thus from:-

$$\frac{\lambda}{2\times V_{max}} >= To$$

Multiplying both sides by 2×Vmax gives

$$\lambda >= To\times 2\times V_{max}$$
$$>= 100\times 10^{-6}\times 2\times 500$$
$$>= 10^{-1}m$$

Which shows that λ must be >= 0.1m (ft<=3GHz) otherwise the required velocity range cannot be obtained.

86. That might seem a little dry at first sight so another way of looking at this relation is to invert both sides, giving:-

$$\frac{2\times V_{max}}{\lambda} <= \frac{1}{To} \quad \text{(Also called PRF)}$$

It is obvious that the left hand side is the Doppler Shift formula with Cosϕ=1, and that it must be equal to the interval between two spectral lines for maximum possible velocity extraction. Fig.19, should be referred to if necessary to confirm this. For a target velocity maximum of 500m/sec, and transmitter frequency of 3GHz, this means that the LHS must be equal to 10kHz. On the other hand, the right hand side is an inverted version of the time between pulses, 1/To, which is of course equal to the PRF of 10,000pps.

87. Thus by using these relations with any two of the specified operational parameters, the other is determined without choice. e.g., Once the PRF of 10,000pps was specified through the maximum range requirement, along with the ambiguous speed range of 500m/sec, there was no choice but to have a transmitted wavelength >= 0.1m in order to obtain that speed range.

88. The diagram at Fig.19, is intended to help summarise the

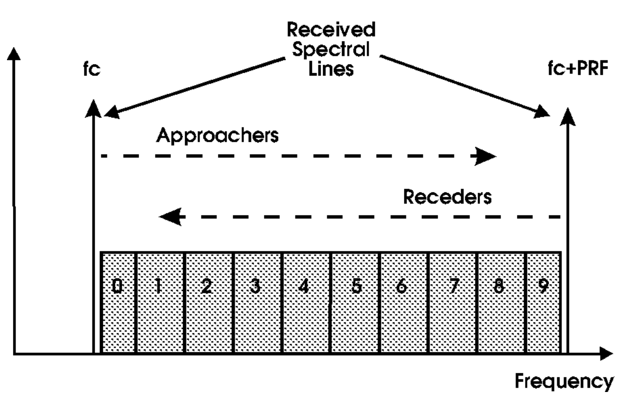


Fig.19. Summary Diagram of Coherent Pulse Doppler Radar Relations

relationships involved as follows.

a. If the maximum range requirement changes then the PRF will change which causes the interval between spectral lines, e.g., fc and fc+PRF, to increase or decrease. If more range is required then the PRF must fall and as soon as that occurs the interval between lines decreases, reducing the maximum detectable velocity. On the other hand, if less range is required then the PRF increases, which means a higher velocity range is available.

b. If the maximum velocity requirement changes then either the PRF or the wavelength of transmission must change.When the wavelength is reduced (ft increases) then the Doppler Shift in Hz/m/sec increases. As a result the range of velocities available between two spectral lines will fall. e.g., at PRF=10,000pps and ft=3GHz, the Doppler Shift is 20Hz/m/sec, giving a maximum detectable speed of 10,000/20=500m/sec. If ft is increased to 15GHz, then the Doppler Shift rises to 100Hz/m/sec giving a maximum detectable speed of 10,000/100=100m/sec. A large increase in frequency reduces the maximum velocity significantly, however, it also reduces the size of equipment and aerial system aperture required to obtain the specified beamwidth, which might be very acceptable. The question of PRF changes was discussed in para.a, above.

c. If the wavelength requirement changes, perhaps due to the need to make an equipment portable or to acquire the necessary transmitter power, then either the maximum detectable speed or the PRF must change. Both changes have been discussed in paras. a and b, above. More portable systems means smaller equipment, which again means higher frequencies and shorter wavelengths. At shorter wavelengths the Doppler Shift/m/sec. rises, reducing the velocity range for a given PRF. Hence, either the maximum velocity requirement must be reduced or the PRF must be increased. Increasing the PRF reduces the range, etc.

89. In order to help clarify use of the relations the following example, including typical requirements, is explained. It is assumed that the radar must have a maximum range of 30km and that the maximum unambiguous speed to be detected must not be less than 750m/sec. Thus:-

$$\frac{\lambda}{2\times V_{max}} >= To >= \frac{2\times R_{max}}{c}$$

Where λ = Transmitted wavelength
To = Time interval
c = Velocity of EM waves
Rmax = Maximum **unambiguous** range
Vmax = Maximum **ambiguous** velocity

From $$To >= \frac{2\times R_{max}}{c}$$
$$>= \frac{2\times 30\times 10^{3}}{3\times 10^{8}}$$
$$>= 200\times sec$$

Which when inverted gives a PRF of 1/To=5,000pps. This is now used in the left hand relation as follows:-

$$\frac{\lambda}{2\times V_{max}} >= To$$
$$\lambda >= 200\times 10^{-6}$$

2×750

Multiplying both sides of the relation by 2×750 gives:-

$$\lambda >= 200\times10^{-6}\times2\times750$$
$$>= 300 \text{ mm.}$$

Thus, the wavelength of transmission, λ, must not be less than 300mm (ft<=1.0GHz), in order to ensure that both 30km maximum range and 500m/sec maximum velocity can be met by the system. This can be shown by starting with the PRF and working back through the calculation for Doppler Shift to the maximum velocity obtainable by the system.

90. After all that has been explained in the preceding paragraphs it is important to get the whole subject in perspective. Ambiguous velocity has been spoken of many times and the reader should be in no doubt that this refers to direction. Velocity ambiguity and blind speeds still exist within any Coherent Pulse Doppler system, all that has been done is to attempt push them outside the range of interest. e.g., taking the standard 3GHz radar with PRF at 10,000pps, which provides velocity cover to 500m/sec. A target approaching at 725m/sec will show up as ft - PRF in filter number 7, however, the likelihood of an aircraft adopting a low flying attack profile at about 1,500 knots is pretty remote.

91. One final point is to state that the original Thynne and Barron equation was based on unambiguous velocity cover, which meant that the detectable velocity range against ambiguous cover would be halved, as follows:-

$$\frac{\lambda}{4\times V_{max}} >= T_o >= \frac{2\times R_{max}}{c}$$

In other words, when designing for the maximum velocity requirement (Vmax) at the given maximum radar range (Rmax), asking for unambiguous information means that the wavelength of transmission must be doubled. This longer wavelength means consequently larger radar equipment at a given beamwidth.

PROBABILITY OF DETECTION

92. Any system operating at short range must necessarily have a high detection probability, otherwise target confirmation and acquisition by any associated tracking system may occur too late for action to be taken. One of the factors that can create such conditions is that of search rate. High aerial scanning speeds, of the order one revolution per second, will ensure frequent target update and assist in raising the detection probability.

93. The other significant factor here is the equipment PRF, which if high, will ensure many target returns during each scan of the search area. Target hits per scan is also affected by aerial beamwidth, and the wider it is the longer the beam dwells on a target during each rotation, providing more chances to detect the target. From this it can be seen that the number of hits on target during a single scan of the aerial system is:-

$$\text{Target Hits} = \text{PRF} \times \frac{\theta_B}{360 \times S_R}$$

Where θ_B is the aerial beamwidth in degrees and S_R is its scanning rate in revolutions per second.

94. A typical Pulse Doppler radar might be using a PRF of 10,000pps with beamwidth of 10°. If the rate at which the aerial scans is twice per second, then:-

$$\text{Target Hits} = \frac{10,000 \times 10}{360 \times 2} = 139$$

This will help to produce a high probability of detection, and in some systems aerial beamwidths approaching that used here may occur. Such beamwidths are in sharp contrast to the 0.5° used in many longer range search radars.

RANGE CONSIDERATIONS

95. The two features of major interest as far as range is concerned, are minimum range and range discrimination. Maximum range has already been discussed at some length and will not be considered further. The number of spectral components present within the spectrum of the transmitted pulse was reduced to prevent wastage of power within the unused ones. A side effect of this is that the remaining components are more powerful and, therefore, enhance the maximum range obtainable, however, one of the methods of producing this effect, namely increasing the pulse width, affects both minimum range and range discrimination.

96. The minimum range and range discrimination of a pulse radar system may be taken as 150m for every microsecond of the pulse width. Thus, the 10µsec PW used previously to reduce the number of spectral lines creates a minimum range and range discrimination cell, within which multiple targets could merge, of 1,500m.

97. The long minimum range could well be acceptable on the grounds that, since the probability of detection is very high, any target will have been identified and action taken long before its range reduces to 1,500m. As for range discrimination, this, if a rough knowledge of range will suffice, particularly when it is obtained quickly allowing further action to be taken in some other way, presents no major obstacle to system operation.

Range Gating

98. Extraction of range can be achieved at very high speed by the use of gating. In such a system the returning signal is offered a choice of parallel paths depending upon its time of arrival. Each of the circuits on offer has a gating pulse applied to open it for a short interval of time during which the returning signal is permitted to pass through for further processing. No two gates ever have their gating pulses applied at the same time.

99. Sequencing of a gate pulse series is shown at Fig.20. They are so arranged that one gate at a time is opened, for a short period determined by system design, and then closed again at the same time as the next one is opened. This is done during an interval commencing at the minimum range and ending at the maximum range. Thus as the signal passes through a particular gate it corresponds to a particular range discrimination cell.

100. Taking a maximum range of say 15km, and a minimum range of 1500m, the difference between the two may be broken up into say 9 blocks at the width of a range discrimination cell, in this case 1,500m/cell. There is little point in trying to be more accurate than this because of the range discrimination. Thus the blocks would be numbered 0 to 8

in increasing range.

101. A signal arriving back at the receiver from a target at 5,000m would only be permitted to pass through range gate 2, because all other range gates would be closed when it arrives. This signal is now identified as occurring between 4,500 and 6,000m. Some of the signal content will continue to return when range gate 2 is closed and range gate 3 has opened, PW=10µsec, giving 1,500m. By assessing the change of signal content in consecutive gates, closing or receding targets may be determined, however, this process will require at least one more search scan by the radar.

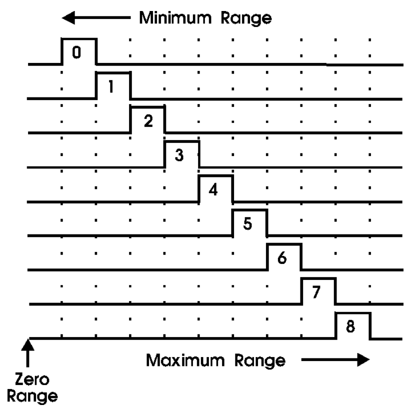


Fig.20. Range Gating Pulses

102. The block diagram of a possible RF section is shown at Fig.21. It will be familiar to the reader and no time will be spent examining the various blocks. Points worthy of note are that the Master Oscillator/Timer produces all the fundamental frequencies required by the system and that the mixer produces f +/- fd as its output. It is the first of two mixing stages involved in the double superhet receiver.

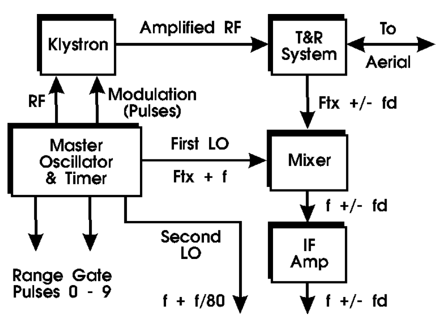


Fig.21. Coherent Pulse Doppler. RF Section.

Non-Coherent Pulse Doppler

103. This system is employed in such a way that no attempt is made to measure the Doppler Shift on the radio frequency content of each transmitted pulse. Therefore, coherence as outlined previously is not required. The method relies upon the interaction, or beating, that will occur when the reflected signal from a moving target is summed with that from a stationary target, or clutter. Thus both must be present at the same time within the radar beam. The radar is also called a **Clutter Reference System** for that reason.

104. The illustration at Fig.22, indicates that the space between radar and target may be considered as split into a large number of wavelengths, e.g., at 10GHz RF, the portions would be 3cm in length. When the radar is pointing at a stationary target, the number of wavelengths between target and radar do not change and the returned signal can be used as a reference against which other signals may be compared.

105. If a moving target and a static target are present in the radar beam at the same time, as shown at Fig.23, the number of wavelengths between the moving target and the radar will be constantly changing, whereas that from the static target will not. The reflected signal from the moving target will move in and out of step with the reflected signal from the static target. hence, the composite received signal will be constantly changing in amplitude, depending upon whether the static and moving target signals are in step, partially out of step or completely out of step.

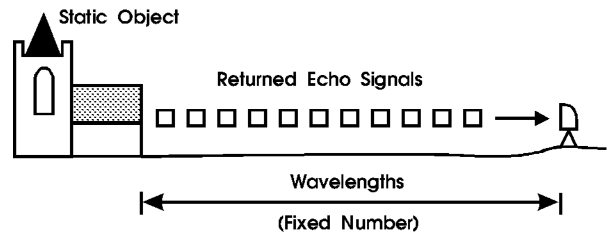


Fig.22. Static Target Range to Wavelength Relationship

106. Each complete pulse in the composite signal arriving at the receiver is amplitude varied similarly to a standing wave by the moving to static target overlap. The rate of change of this modulation is dependent upon the velocity of the target with respect to the static echo. The effect of the composite signal is illustrated at Fig.24, and it can be shown that the rate of change of this modulation is the Doppler Shift frequency, fd.

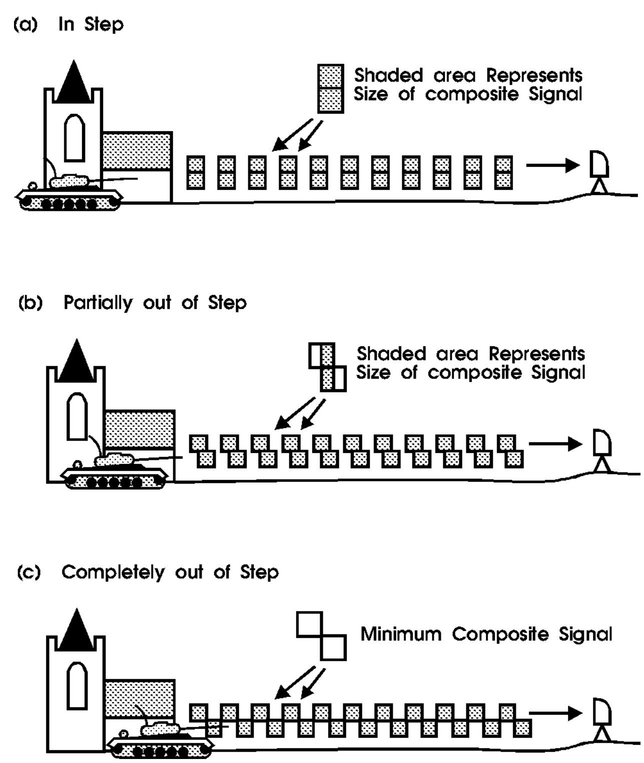


Fig.23. Composite of Moving and Static Targets

107. Since the received pulse train is amplitude modulated, the doppler shift frequency can be processed by normal superheterodyne techniques. Velocity extraction may be by either of the methods previously described, however, in some roles, the human ear is used as a filter. An operator can become skilled in identifying a particular type of doppler shift by its audio content, providing important additional information to the velocity displayed by the system.

108. The advantages of the clutter reference system are:-

   a. It is simpler than the coherent system.

   b. A very short pulse width can be used, which means that minimum range can be extremely short if required.

   c. By using a high transmitted RF, typically 10GHz or more, the Doppler Shift is relatively high from slow moving targets, which makes the technique very useful for ground surveillance systems.

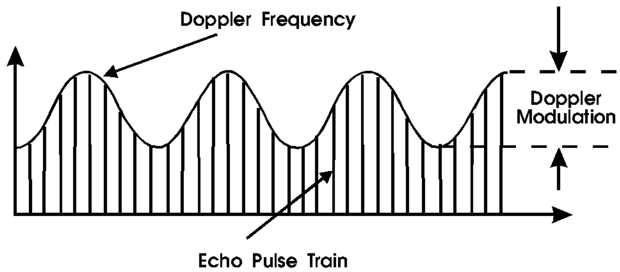


Fig.24. Doppler Modulated Pulse Train

109. The disadvantage of a clutter reference system is that it can only be used when static clutter is present in the beam at the same time as the target. It follows that the system may not be effective when:-

   a. Used in the ground surveillance role over flat featureless country, e.g., flat desert or water.

   b. In the air defence role against fast jets or missiles, although it can be used for detecting helicopters or propeller driven aircraft because of the beating effect from the rotor or propellers.

SELF TEST QUESTIONS

Read each question carefully and then select the single answer that you consider to be fully correct

1. The maner in which Doppler shift is used by an MTI radar system:-

   a. determines the number of filters used to cover the velocity range of interest
   b. means that target radial velocity is unknown
   c. allows the extraction of actual target velocity
   d. means a fast Fourier transform analyzer can be used to extract the target velocity

2. When considering radars employing Doppler processing, the two that can form pulse Doppler radar systems are classified as:-

   a. pure CW or Coherent
   b. modulated CW or non-coherent
   c. pure CW or non-coherent
   d. coherent or non-coherent

3. A target is moving across the front of an Air Defence Radar at a velocity of 275m/s on a track of 195°. The target is flying at the same horizontal level as the radar and is detected on a bearing of 065°. The radial component of velocity when it is first detected is:-

   a. 211m/s
   b. 177m/s
   c. –71m/s
   d. 116m/s

4. A target is moving across the front of an Air Defence Radar at a velocity of 275 kts on a track of 195°. The target is flying at the same horizontal level as the radar and is detected on a bearing of 320°. The radial component of velocity when it is first detected is:-

   a. 158m/s
   b. 81m/s
   c. 211kts
   d. 177kts

5. A target is moving across the front of an Air Defence Radar at a velocity of 300m/s on a track of 270°. The radar is in the same horizontal plane as the target which is detected at a range of 6km on a bearing of 060°. The time taken for the target to reach the crossing point is:-

   a. 10 sec
   b. 16 sec
   c. 17.32 sec
   d. 19.2 sec

6. An Air Defence Radar detects an approaching target on its own horizontal level, and azimuth 240° at a range of 3250m. The target arrives at the crossing point 90 seconds after initial alarm. Radar azimuth at the crossing point is 315° at a range of 1500m. The actual speed of the target is:-

   a. 35.64 m/s
   b. 114.32 m/s
   c. 3.46 m/s
   d. 37.76 m/s

7. When considering targets in motion and the associated Doppler shift on their radar echoes. It is true to say that:-

   a. received frequency is lower for an approacher and higher for a receder
   b. Doppler shift is negative for an approacher and positive for a receder
   c. the local oscillator in a Doppler receiver determines the amount of Doppler shift available for processing
   d. if the target has a different altitude at a given range the Doppler shift will change

8. A transmitter operates at a frequency of 1.5GHz and a receiver is moving directly towards it at 60m/s. The frequency received and Doppler shift on this signal respectively will be:-

   a. 1,500,300Hz and 300Hz
   b. 1,500,000,300Hz and 300Hz
   c. 1,500,600Hz and 600Hz
   d. 1,500,000,600Hz and 600Hz

9. A radar receiver is moved directly towards a transmitter that is operating at 18GHz. The doppler shift, in Hertz per metre per second (Hz/m/sec), that will be present on this one way received signal for any target velocity will be:-

   a. 120 Hz/m/s
   b. 60 Hz/m/s
   c. 30 Hz/m/s
   d. –60 Hz/m/s

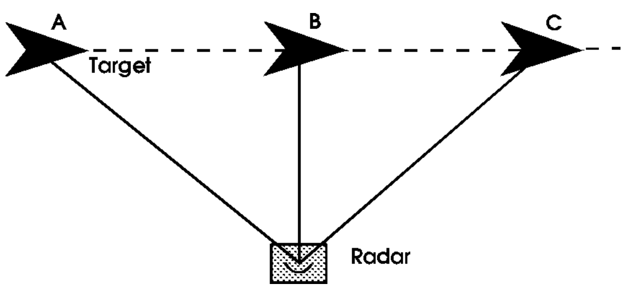
10. A doppler radar system that is operating at 9.5GHz has a target that is moved directly away from it along a radial line. The doppler shift, in Hertz per metre per second (Hz/m/sec), that will be present on the received signal for any target velocity will be:-

   a. 32 Hz/m/s
   b. –64 Hz/m/s
   c. –32 Hz/m/s
   d. 64 Hz/m/s

11. A receiver is moved away from its transmitter along a radial path at a velocity of 20m/s and the Doppler shift present on the received signal is –1.5kHz. The wavelength of transmission is:-

   a. 22.5MHz
   b. 11.24GHz
   c. 22.5GHz
   d. 11.24MHz

12. The following diagram shows the plan view of an airborne target being tracked whilst crossing the front of a Pulse Doppler air defence radar. In this radar it is true to say that:-



   a. when moving between A and B the received frequency would be above that transmitted
   b. at C the frequency recieved would be identical to that transmitted
   c. when moving between B and C the received frequency would be above that transmitted
   d. all of the above are true

13. A Doppler radar receives an echo from a target that has passed the crossing point and is receding. As far as this echo is concerned:-

   a. the received frequency is higher than that transmitted
   b. the Doppler shift component is $fd = -V\cos\phi/\lambda$
   c. no difference is detected by the radar between transmitted and received signals
   d. any frequency shift at the receiver is about double that for the journey from antenna to target

14. A Police Doppler radar operates at a frequency of 5GHz. It detects an approaching vehicle at an angle of 35° to the road which is moving at 45mph. The Doppler shift at the receiver will be:-

   a. 550Hz
   b. 275Hz
   c. 615Hz
   d. 307Hz

15. A radar receiver is processing a signal that contains a Doppler shift of 3kHz which has been reflected from a target approaching at a radial velocity of 60kph. The frequency of the transmitter is:-

   a. 1.349GHz
   b. 13.49GHz
   c. 26.98GHz
   d. 2.698GHz

16. One reason why pulse radar systems employ Doppler techniques is because a reasonable degree of clutter rejection is available. A disadvantages of the system is that:-

   a. range signature is not available
   b. a good echo from the target can disappear at certain times
   c. as the wavelength gets shorter more Doppler shift occurs for approaching targets than for receding ones
   d. all of the above are true

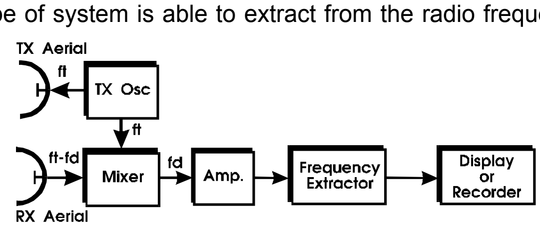
17. An MTI radar operating at 6GHz employs a 750Hz clutter filter. The minimum target velocity that this radar will process is:-

   a. 38m/s
   b. 19m/s
   c. 50m/s
   d. 22m/s

18. During signal the processing in air defence Doppler radar systems such as Rapier:-

   a. accuracy of velocity is sacrificed in the interests of processing speed
   b. accuracy of range signature is sacrificed in the interests of processing speed
   c. velocity extraction may be by filter or fast Fourier transform
   d. all of the above are true

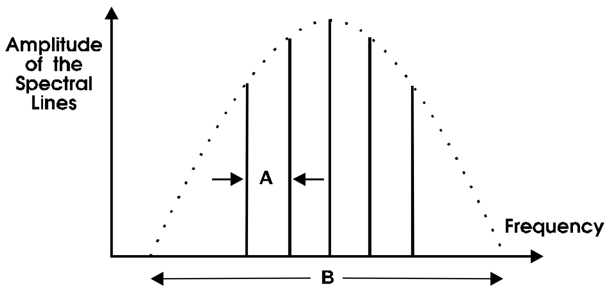
19. The block diagram of a pure CW radar is shown below. This type of system is able to extract from the radio frequency



target echo, information about:-
   a. velocity
   b. range
   c. azimuth and elevation

d. all of the above

20. The following diagram shows the spectrum of radar frequencies considered for use by a pulse radar. The interval



at 'A' would be equal to the:-
a. PRF
b. pulse width
c. bandwidth
d. transmitter frequency

21. The diagram at Q20 shows the spectrum of radar frequencies considered for use by a pulse radar. The interval at 'B' would be equal to the:-

a. PRF
b. pulse width
c. bandwidth
d. transmitter frequency

22. A pulse radar is operating at a PRF of 8,000pps and pulse width (τ) of 5μs. The number of spectral lines contained within the normally considered bandwidth of this radar is:-

a. 50
b. 25
c. 26
d. 51

23. One of the drawbacks in requiring frequency coherence in a pulse Doppler radar is that:-

a. a local oscillator must be used to change all received frequencies to the IF frequency
b. a fixed phase relationship must exist between transmitted and local oscillator frequencies
c. filters are necessary to extract the Doppler shift and determine target velocity
d. the receiver must be a double superhet

24. A 2GHz pulse Doppler radar operates to a maximum range of 30km without dead time. The first spectral components either side of the transmitter frequency (fc), would occur at frequencies of approximately:-

a. 2GHz and 2.000005 GHz
b. 1.99999995GHz and 2GHz
c. 2.005GHz and 1.995GHz
d. 1.999995GHz and 2.000005GHz

25. A pulse Doppler radar operates at 6GHz and PRF of 4,000pps. The first blind speed for this radar is at:-

a. 100m/s
b. 200m/s
c. 300m/s
d. 400m/s

26. An airborne target is crossing the front of a 3GHz Pulse Doppler Air Defence Radar at a speed of 350m/s. The radar employs a 40m/s clutter filter and the crossing point is 3km away. The blind period for this target will be:-

a. 3.94 seconds
b. 1.97 seconds
c. 0.99 seconds
d. 5 seconds

27. A pulse Doppler radar is designed with a certain transmitter wavelength and PRF. During later operation the blind speeds are considered to occur at too small an interval. If the maximum range is to be unchanged, the alternative means of increasing the velocity cover is to:-

a. get the targets to slow down
b. reduce the transmitted wavelength
c. increase the aerial aperture
d. increase the transmitted wavelength

28. An Air Defence Pulse Doppler Radar operates at a PRF of 12,000 pps and produces a Doppler Shift on the echo of 25Hz/m/sec. The highest unambiguous velocity that it is designed to detect is:-

a. 480m/s
b. 240m/s
c. 960m/s
d. 120m/s

29. The maximum unambiguous range of a certain Pulse Doppler Radar is to be reduced and the transmitter frequency must remain the same. This means that the:-

a. maximum unambiguous velocity is increased
b. PRF must be reduced
c. maximum unambiguous velocity is reduced
d. the time between transmitter pulses must be increased

30. A pulse Doppler radar has a maximum range of 40km and maximum ambiguous velocity of 450m/s. This means that the frequency of transmission must not:-

a. be less than 1.25GHz
b. exceed 2.5GHz
c. be less than 2.5GHz
d. exceed 1.25GHz

31. A 4.5GHz pulse Doppler radar is designed to work at a maximum range of 35km . This means that the maximum ambiguous velocity is:-

a. 285m/s
b. 143m/s
c. 350m/s
d. 72m/s

32. A 2.8GHz pulse Doppler radar has a maximum unambiguous velocity of 650m/s. This means that the approximate value of the PRF must not:-

a. be less than 12kHz
b. exceed 12kHz
c. be less than 6kHz
d. exceed 6kHz

More Doppler Self Test Questions

1. A target is moving across the front of an Air Defence Radar at a velocity of 275kts on a track of 195°. The target is flying at the same horizontal level as the radar and is detected at a range of 2.75km, on bearing 340°. Calculate the:-

   a. time it will take to reach the crossing point.
   b. radial component of velocity when it is first detected.

2. An Air Defence Radar detects an approaching target on its own horizontal level, and azimuth 240°, which is flying at such a speed that it arrives at the crossing point 90 seconds after initial alarm. Radar azimuth at the crossing point is 315° at a range of 1500m. Calculate the:-

   a. actual speed of the target.
   b. radial component of velocity at initial detection.

3. A transmitter is operating at a frequency of 1.5GHz, and a receiver is moving away from it at a velocity of 60mph. Calculate the:-

   a. Doppler Shift frequency at the receiver.
   (Note. 1yard or 3feet = 0.9144m)
   b. actual frequency received. (To the nearest Hz)

4. A receiver is moved away from its transmitter along a radial path at a velocity of 20m/s, and the Doppler Shift present on the signal is 1.5kHz. Calculate the:-

   a. wavelength of transmission.
   b. frequency of transmission.
   c. NATO waveband in which the system is operating.
   d. specific frequency designation within the NATO classification system.

5. An Air Defence Radar, operating at 10GHz, is mounted on a tracked vehicle moving at a speed of 70mph to the north. It detects an incoming target on a bearing of 060° which is on a track of 250° and flying at a speed of 150kts. The target is at the same height as the vehicle. Calculate the;-

   a. closing speed of vehicle and target at the instant of detection.
   b. Doppler shift on the radar signal
   c. Doppler Shift on the radar signal assuming the vehicle to be stationary.

6. A Police Doppler Radar is operating at a frequency of 5GHz, and detects an incoming vehicle at an angle of 35° to the road, which is moving at a velocity of 45mph. Calculate the:-

   a. Doppler Shift at the receiver.
   b. Doppler Shift for the system, in Hz/mph.
   c. expected doppler Shift for a vehicle moving at 75mph in the same circumstances.

7. A receiver is processing a signal which contains a Doppler Shift of 3kHz when reflected from a target moving at a radial velocity of 60kph. Calculate the:-

   a. wavelength of the transmitter.
   b. frequency of the transmitter.

8. An Air Defence Pulse Doppler Radar, operating at a frequency of 6GHz, employs a 750Hz clutter filter. A target, flying at 375kts, has a crossing point at a range of 3.5km. Calculate the:-

   a. clutter filter speed range. (In knots)
   b. blind period for this target.

9. An airborne target flying on a track of 135° is crossing the front of a Pulse Doppler radar system. The target is flying at the same horizontal level as the radar, which detects it at a range of 5km and bearing of 350°, when the Doppler Shift is 3.6kHz. The radar is operating at 5GHz using a PRF of 15000PPS and pulse width at 12μs. It also has a 1285Hz clutter filter incorporated within the receiver. Calculate the:-

   a. actual velocity of the target in knots.
   b. maximum unambiguous range for the system.
   c. system blind speeds in knots.
   d. number of spectral components transmitted.
   e. maximum unambiguous velocity for the system in knots.
   f. blind period for this target.

10. The design of an Air Defence Pulse Doppler Radar is such that it must have a maximum unambiguous range of 25km and maximum velocity detection of 750kts. Calculate the:-

   a. highest frequency which may be used for transmission.
   b. new velocity maximum if a frequency of 3GHz is used for transmission

ANSWERS

1. a. 15.94 Seconds.
   b. 225.267 knots.
2. a. 62.2 m/s.
   b. 60.08 m/s.
3. a. 134 Hz.
   (To the nearest Hz)
   b. 1,499,999,866 Hz.
4. a. 13.333r mm.
   b. 22.5 GHz.
   c. K Band.
   d. K2 + 500.
5. a. 91.58 m/s.
   b. 6.105 kHz.
   c. 5.062 kHz.
6. a. 549 Hz
   b. 14.9 Hz/mph.
   c. 915 Hz.
7. a. 11.111r mm.
   b. 27 GHz.
8. a. +/- 36.5 kts.
   b. 3.55 seconds.
9. a. 256.5 kts.
   b. 10 km.
   c. 875.5 kts.
   d. 12.
   e. 437.7 kts
   f. 13.3 Seconds
10. a. 1.167 GHz.
   b. 292 kts.