ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION

Radar Transmitters & Receivers

INTRODUCTION

The transmitter and receiver of a radar system work together to produce and detect echoes from targets in the surrounding volume of space. The two must be designed as a pair because the receiver must be able to receive the echo from the pulse that the transmitter sent out. There is also a requirement for effective discrimination between echoes from interesting targets (e.g. hostile and friendly FGA), other echoes (e.g. birds, the terrain and ECM) and noise.

In addition to target identity, the radar might also need to determine the target's azimuth, range, elevation, velocity and course - all by extracting information from a number of radar echoes. For this to function effectively then the outgoing radar pulse must have certain 'special' properties that are changed on reflection from the target. By observing the differences between the properties of the echoes and the original pulses then the radar system can determine the required information about the target.

This handout covers the basics of transmitter and receiver theory so that the student will be able to describe the function of the main component blocks of radar transmitters and receivers. The example system is a 'generic' Air Defence Radar (based loosely on Rapier, FSB2) but, for security reasons, the numerical values used to illustrate the system (e.g. operating Frequency: 3.2 GHz) are representative values, not those actually used by any particular radar.

RADAR TRANSMITTER

A simplified block diagram of a radar transmitter is shown in Figure One. Missing from this diagram is the network of low-voltage power supplies that supply each block with dc electricity for its electronics components. The function of each block is summarised below:

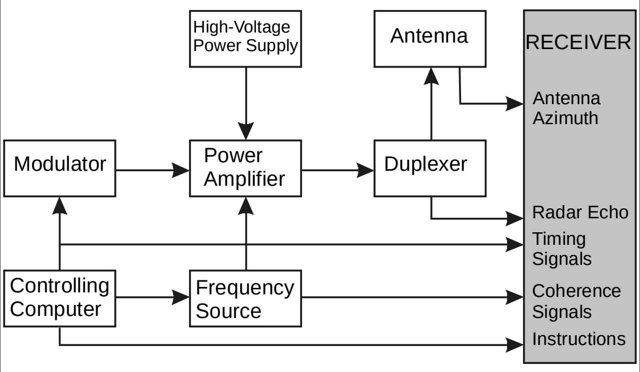

Figure 1: Simplified Block Diagram of a Radar Transmitter

Antenna: transmits and receives radar signals along a known direction (azimuth). The rotating base incorporates a sensor that converts the azimuth of the antenna into an electrical signal that will be used by the receiver to determine the bearing to the target. For further details then refer to the BST 'Antenna Theory' Handout.

Duplexer: allows the same antenna to be used for both transmit and receive. Energy in at one port can only leave from the next (clockwise circulation); thus, the outgoing pulse can pass from transmitter to antenna and the echo can pass from antenna to receiver. Virtually no energy can pass directly from transmitter to receiver (this is a good thing as the receiver would be damaged by the very high energy). For further details then refer to the BST 'Waveguides' Handout.

High-Voltage Power-Supply: Unlike the lower-voltage supplies, which generally have a fairly constant amount of power drawn from them, the high-voltage supply must be able to cope with pulsating power, in time with the radar transmissions. This supply must be capable of going from zero to a few Amperes in much less than one micro-second whilst maintaining a steady output of around 5 000 V. Some form of energy storage (e.g. inductor/capacitor) will usually be necessary and the energy can be replenished in between the pulses.

Frequency Source: this produces a low-power version of the signal that will be transmitted from the radar. It is a low-power signal but very stable in phase and frequency. The emphasis in this block is on precision and stability as this also supplies copies of the transmitted signal to be used in the receiver. This runs continuously - it is **not** switched on and off in time with the outgoing pulses.

Power Amplifier: a Klystron (FSB) or Travelling-Wave Tube (FSC) would be used to amplify the small (e.g. 200 mW, 23 dBm) signals from the oscillator up to the very large power (e.g. 2 kW, 63 dBm) required for transmission. The amplification should take place without appreciable change to the shape of the wave (i.e. little distortion). For further details then refer to the BST 'Microwave Valves' Handout.

Modulator: a very rapid on-off switch that operates the power amplifier when a radar pulse is to be transmitted. Since the radar pulse might last for only a few micro-seconds then this switch must switch on within a few nano-seconds when instructed, remain on for the ten micro-seconds of the pulse and then switch off again, very rapidly.

Controlling Computer: The radar system operates under the control of one or more computers that completely direct the operation of the system. The operator relies entirely upon the computer's program and sees

SPECIMEN RADAR PARAMETERS

Basic Parameters

Carrier Frequency	3.2 GHz
Peak Power	3 kW
Pulse Duration (Width)	10 µs
Pulse Repetition Frequency	10 kHz
Coherent Frequency	200 MHz
Rotation Rate	1 Hz

Derived Parameters

Wavelength	9.375 cm
Mean Power	300 W
Pulse Interval	100 µs
Duty Cycle	10% (0.1)
Pulse Energy	30 mJ

information only about those targets that the computer wants him to know about.

RADAR OUTPUT POWER

The radar system might divide its time between transmit and receive so that typically it spends 10% of the time transmitting and 90% of the time listening for an echo. This means that the transmitter is actually off for 90% of the time. (Of course, this is necessary in a pulsed radar so that the receiver can listen for the very weak echo.)

The power that is transmitted during the pulse is called the ‘Peak Power’ (3 kW, in our example radar) but this is not necessarily a good indicator of the performance of the radar in illuminating targets. The ‘Mean Power’ or ‘Average Power’ is a better measure of the radiation output of the radar and this is calculated by taking into account the ‘Duty Cycle’ as described below:

- **Duty Cycle**: is the proportion (or percentage) of the time that the transmitter is actually operating. In this example, the radar transmits for 10% of the time so the Duty Cycle is 0.1 or 10%. The Duty Cycle can be calculated using the formula:

DC = Pulse Duration ÷ Pulse Interval
or
DC = Pulse Duration × PRF

- **Mean Power**: this is calculated by multiplying the Peak Power by the Duty Cycle. This represents the effective, continuous power of the radar. In this example, the Mean Power is 300 W.

Mean Power = Peak Power × Duty Cycle

If the parameters of this radar were changed to give a Pulse Width of 5 µs and Peak Power 6 kW, or 1 µs and 30 kW, etc., then the Mean Power would not alter because the Duty Cycle would change as the Pulse Width changed.

An alternative measure of the illuminating ability of a radar is the amount of energy in each transmitted pulse. Energy is calculated using the formula:

Energy = Power × Time *(standard formula)*
= Peak Power × Pulse Duration

In this example, the energy in one pulse is 3 kW × 10 µs or 30 mJ. You should be able to see that for the different combinations of Pulse Duration and Peak Power that were quoted in the previous paragraph then the energy in the pulse remains the same.

Do not be deceived into thinking that radars with very high pulse powers are necessarily very effective - it is the mean power and pulse energy that are important in determining how effectively a radar illuminates targets. (There are many other factors, such as beamwidth, rotation rate, integration time, that are involved as well as power and energy.)

PRF CHANGES

For various operational reasons, that are explained in other BST Handouts, a military radar will change its Pulse Repetition Frequency (PRF) from time to time. An increase in the PRF will have the following consequences:

- If the PRF were increased then this means that a greater number of pulses are being transmitted each second.
- If the pulses themselves are unchanged then the Duty Cycle will increase because the Pulse Interval will have decreased.
- The mean power (Peak Power × Duty Cycle) will increase.

Older radars tended to operate best when their mean power remained constant as this resulted in operation of the transmitter at relatively constant internal temperature. If the power levels fluctuate then the temperature inside the transmitter will also fluctuate and this can adversely affect the stability of the transmitter. Such radars would be designed to maintain a constant Duty Cycle and Peak Power during PRF changes.

One simple means of maintaining constant mean power is to reduce the duration of the pulse as the PRF increases so that the Duty Cycle (=Pulse Duration × PRF) remains constant. For example, if one PRF were 10 kHz with a Pulse Duration of 10 µs then at a PRF of 15 kHz the Pulse Duration would be 6.67 µs and at a PRF of 20 kHz the Pulse Duration would be 5 µs, etc.

FREQUENCY SOURCES

The transmitted signal from the radar leaves the antenna at a frequency of 3.2 GHz and the radar echo will, therefore, also be at 3.2 GHz (with, perhaps, a small amount of Doppler Shift). Electronic circuits that operate at these high frequencies are very difficult to produce so the radar system is designed to operate internally with much lower frequencies, such as 200 MHz.

The Frequency Sources make use of very stable solid-state oscillators and generate three frequencies that are used by both the transmitter and the receiver. This means that the receiver has detailed information about the signal that was transmitted; it knows the frequency and the phase. (One benefit of knowing the phase is that this information cannot be obtained by a jammer.) The receiver also requires this information in order to extract the Doppler Shift from the echoes.

RADAR RECEIVERS

The block diagram of a basic radar receiver is shown in Figure Two. One significant difference between a radar transmitter and a radar receiver is that the amount of power in the signal is hundreds of millions of times smaller in the receiver. This also means that the level of spurious signals, such as interference and noise, is much higher. Consequently, the main task of the receiver is in distinguishing what is an echo and what is not. A brief description of each block of a basic radar receiver follows:

RF Amplifier: The signal enters from the antenna, via the duplexer and is immediately amplified by a small amount (e.g. 10 dB) using a low-noise amplifier. The low-noise amplifier is important here, as any noise that it produces will be amplified by the remaining amplifiers and will adversely affect the performance of the receiver. The bandwidth of this amplifier is matched to the operating frequency range of the transmitter so that it excludes signals outside the operating frequencies of the radar.

First Mixer: combines the echo signal (3.2GHz + phase information + Doppler) with a signal from the Frequency Source (3.4 GHz) to produce the First Intermediate Frequency (First IF) of 200 MHz + phase information + Doppler. Amplitude and phase information contained in the echo is preserved during this process. Mixers must be carefully designed to avoid introducing spurious phase changes into the signal.

IF Amplifier: the 200 MHz signal that emerges fromthe first mixer is still farily small and has to be amplified further by the IF amplifier. The amplification is performed here, at the relatively low frequency, because it is easier both to obtain the required bandwidth and to amplify at 200 MHz than it is to amplify the 3.2 GHz of RF. Furthermore, when the radar changes carrier frequency (frequency agility) then the 3.2 GHz will change to another frequency (e.g. 3.3 GHz) but the First Mixer will continue to produce 200 MHz, because the mixing frequncy will be changed to 3.5 GHz by the Frequency Source (called a 'Solid-State Drive' in FSB2).

Automatic Gain Control (AGC): this is not shown as a specific box in the diagram as it can be applied to any of the amplifier stages (often in the IF stages). The AGC controls the gain of the radar receiver so that it is turned down when a strong echo is received and turned up when a weak echo is received. This reduces the range of signal powers that the receiver has to handle and reduces distortion in the system. It can be combined with 'Sensitivity Time Control' where the gain of the receiver is automatically adjusted so that it is low immediately after the transmitter operates and then increases steadily as time passes. This prevents echoes from very close targets from overloading the receiver.

Second Mixer: combines the signal from the First Mixer (200 MHz + phase information + Doppler) with a signal from the Frequency Source of 200 MHz to give just the phase information and the Doppler.

Range Gates: sample the signal at regular intervals during the 'listening time' to produce a series of data representing the echo from different ranges. For example, sampling the echo 50 µs after transmission would collect data from targets at a range of 7.5 km (using the 'radar' rule that each micro-second represents 150 m of range). The radar pulse has a finite duration (e.g. 10 µs) giving the radar a certain range resolution (e.g. 1.5 km) so sampling the echo signal after 50 µs would collect echoes from a 'Range Cell' of length 1.5 km, centred on a range of 7.5 km (i.e. between 6.75 km and 8.25 km).

Analogue to Digital Converters: computers perform operations on data in digital form so, as soon as the range gate has sampled the data, it must be converted into digital form for further processing. As the range of possible signal strengths is very large then the converter needs to use as many bits as possible. Using 12 bits allows a range of echo powers covering about 70 dB (10,000,000:1); using 16 bits would allow a range of echo powers covering more than 90 dB (1,000,000,000 : 1). However, using more bits requires more processing power and storage.

Coherent Detection: older radar systems would simply detect signals that were received at around the same frequency that was transmitted, but this did not use any phase information and was inefficient. Modern radar receivers mix (combine) the echo signal with a 'reference' signal that is linked to the phase of the original signal to give an output that contains information about both the strength of the echo and its phase. This is called 'Coherent Detection', which refers to signals that are linked by their phase. Using coherent detection allows the radar receiver to extract much more information from the radar echo, and is necessary for Doppler processing. The 200 MHz signal, used both in the transmitter and receiver, is the signal that provides the coherence. (Note that its frequency does not have to be 200 MHz, this was just chosen to illustrate the principle.)

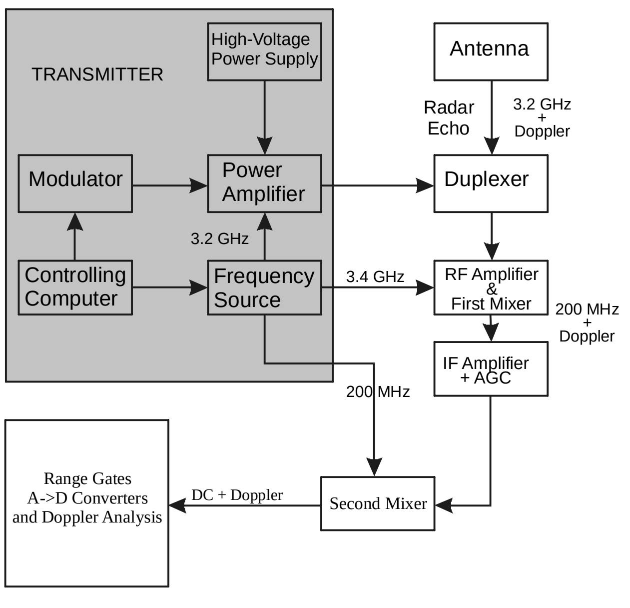

Figure 2: Simplified Block Diagram of a Radar Receiver

COHERENT DETECTION

The signals that enter a radar receiver are a mixture of echoes from stationary targets, moving targets and spurious signals, such as jamming, noise and interference. At any instant, the signal that enters the receiver could be considered to be the sum of all these and the problem is to separate the desired echo from the rest. Older radars would process the signals so that the total signal was used - this makes the radar vulnerable to noise and jamming and also 'wastes' some of the information that is contained in the radar echo. Coherent detection allows the radar receiver not only to extract more information from the echo but also to reduce the effects of spurious signals.

The coherent detector is sensitive both to the amount of echo (amplitude) and also to its phase (relative timing compared to the original signal). The echo signal has been outside the radar - it has travelled to the target, been reflected and travelled back - this changes the phase of the signal and the coherent detector can measure this change. A stationary object (clutter) will produce an echo that is significantly different from that of a moving target and different from that of a jammer. Consequently, coherent detection can be used to discriminate between different types of echo.

Phase: The phase of the radar echo depends on how far it has travelled since the signal left the transmitter. A target that is an exact number of half-wavelengths from the radar would produce an echo whose phase was the same as that of the transmitted signal. This occurs because the EM-Wave would have travelled an exact number of whole-wavelengths during its two-way trip. A target that is an exact number of quarter-wavelengths from the radar would produce an echo that in is anti-phase with the transmitted signal. The different types of target affect the echo as follows:

- **Stationary Target**: a stationary target produces a series of echoes whose phase is constant because the target's distance does not change. Each radar pulse that is transmitted produces an echo with the same phase in relation to the transmitted signal.
- **Moving Target**: a moving target will produce a series of echoes with steadily changing phase caused by its movement between each radar pulse. Each radar pulse that is transmitted produces an echo with a different phase because the distance to the target is changing as it moves. If the target moves at constant velocity then the phase change from one pulse to the next is constant. The faster the movement then the greater the phase change.
- **Jamming Signal**: the jammer does not have access to the 200 MHz signal and, consequently, cannot duplicate it. Any jamming signal would have a randomly changing phase because it could not be locked to the 200 MHz signal. (Of course, a very powerful jamming signal could mask a real echo.)

OPERATION OF A COHERENT DETECTOR

The radar receiver must process the echo signal so that both its amplitude and phase are determined. This requires a special process called 'phase-sensitive detection' which requires two input signals: the signal being tested (the echo) and the signal against which it is being compared (the original transmission). This type of circuit produces an output that depends on the phase-difference between its two inputs.

In the coherent detector, the received signal is multiplied by the signal that was transmitted (the reference signal). In this example, the 200 MHz signal is used as a reference. Although the actual signal that was transmitted was at 3.2 GHz, the original 200 MHz signal was used to generate it, so this signal includes phase information from the original 200 MHz signal. The 3.4 GHz signal is also derived from the 200 MHz signal and also contains its phase information. The first mixer removes the 3.2 and 3.4 GHz signals from the echo and leaves, effectively, the echo from the 200 MHz part of the signal,

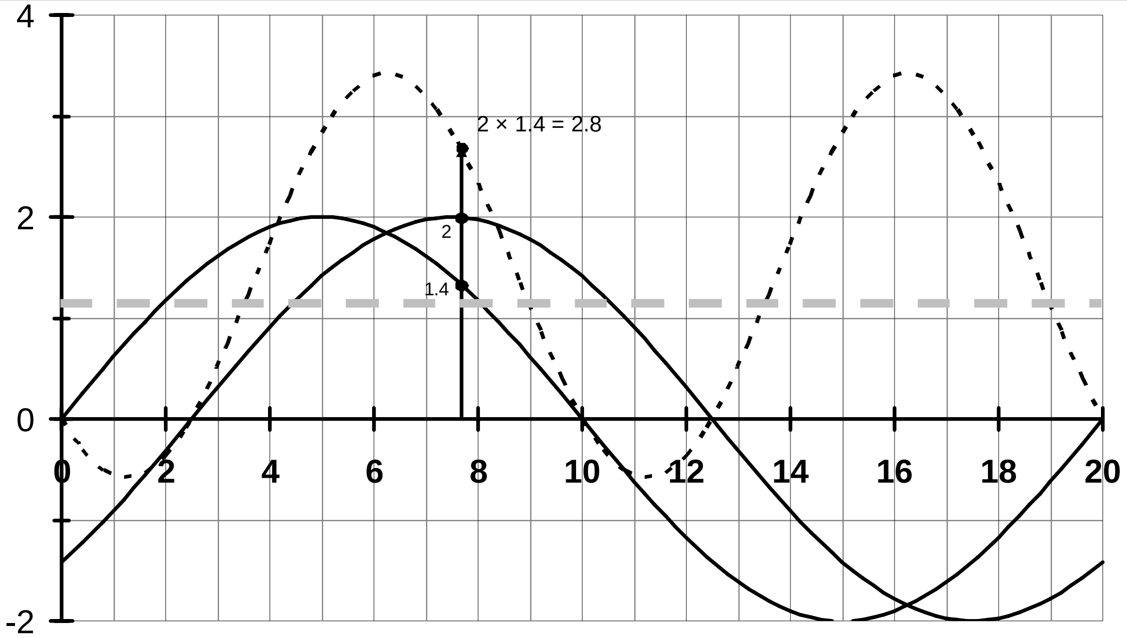

Figure 3: Illustrating Coherent Detection, where Two Sinusoids (Solid Lines) and Multiplied to Produce a Product Wave (Dotted Line).

plus any modifications caused by its journey to and from the target. The coherent detector (second mixer) then multiplies the processed echo signal by the original 200 MHz signal to provide its output.

The Multiplication Process: the multiplication is carried out electronically and it is the equivalent of taking each point on the reference signal and multiplying it by the corresponding point on the echo signal, as shown in Figure Three, where the points marked are 1.4 and 2.0 on the Reference and Echo waves, giving a product of 2.8 on the resultant wave. The output of the coherent detector is the average value of the resultant wave. This is indicated in Figure Three by a grey, dotted line at about 1.25. The average value can be obtained by using it to charge a capacitor (analogue circuit) or by calculating it (digital circuit).

DETERMINING PHASE AND AMPLITUDE

When two signals are combined in a coherent detector then the output depends on their amplitudes (‘A’) and phase-difference (ϕ). Since the reference signal has a constant amplitude and phase then it is the amplitude and phase of the echo signal that determines the amplitude of the output. Mathematically, the output signal is given by the formula:

Output = A × Cos ϕ

This means that when the output of a phase detector changes then the change could have been caused by a change in either the phase or the amplitude - and we don’t know which changed when only one coherent detector is used (both might have changed, too).

The radar receiver needs to know both the amplitude and the phase - this cannot be achieved with a single coherent detector. Practical radar receivers must use a pair of coherent detectors. The first acts exactly as described above, using a reference that is in-phase with the signal that was originally transmitted. This in-phase (or ‘I’ channel) produces an output of A Cos ϕ. The second coherent detector operates with a reference signal that has been shifted in phase by 90°. Since 90° is one-quarter of a cycle then this is called a ‘Quadrature’ or ‘Q’ channel.

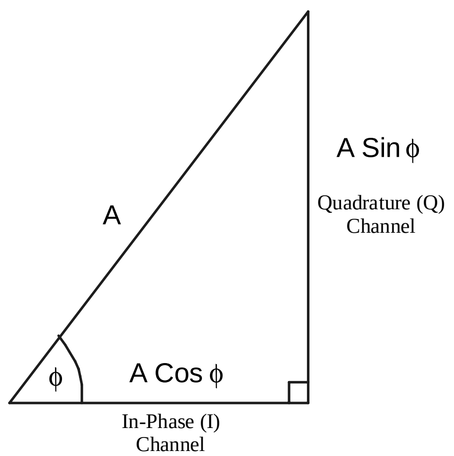

Figure 4: Illustrating the ‘I’ and ‘Q’ Outputs of a Pair of Coherent Detectors

You might recall from Basic trigonometry that a Cosine wave that is shifted by 90° becomes a Sine wave – this causes the output of the second coherent detector to be:

Output_2 = A × Sin ϕ

Once we have the two outputs then we can represent them as sides of a right-angled triangle, as shown in Figure Four. Once these signals have been converted from analogue to digital then the data processing computer can use the Rule of Pythagoras to combine the ‘I’ and ‘Q’ signals to get the amplitude of the echo ($A^2 = I^2 + Q^2$) and the equation for Tangent of an angle to calculate the phase angle ($\phi = \text{Tan}^{-1}[Q/I]$). If the amplitude changes then both the ‘I’ and ‘Q’ signals will change but their ratio, used to calculate the phase angle, will remain constant. Conversely, if the phase angle changes then, again, both the ‘I’ and ‘Q’ signals will change but the calculation of ‘A’ (using Pythagoras) will give the same result.

DATA COLLECTION

A single echo conveys no useful information about a target’s velocity because, as explained above, the movement of the target causes a change of phase from one radar pulse to the next. Consequently, the receiver must collect a sequence of pulses (e.g. 32 pairs of ‘I’ and ‘Q’ signals) from each range cell at each azimuth. Once these data have been collected then they can be inspected by the computer to see whether there is a consistent phase shift in the series.

The amount of data that must be collected and analysed during one rotation of the antenna can be estimated from the parameters of the radar, as follows:

- During one revolution of the antenna the radar emits 10,000 pulses.
- The maximum range of the radar is 15 km (based on its PRF) and its range resolution is 1.5 km (based on its pulse duration so there might be ten range cells.
- During one revolution there will be 100,000 pairs of data collected or 200,000 ‘I’ and ‘Q’ values.
- Each value might require two Bytes of storage, giving a data size of 400 kBytes per antenna revolution.

The radar could have two such sets of storage: one in the process of being filled with data from the current revolution of the antenna and a duplicate that contains the data collected during the previous revolution that the computer is in the process of analysing.

To provide faster results, then the memory could be organised into areas that store much less than that from a full rotation of the antenna. For example, if the antenna had a beamwidth of 9° then, usefully, one set of memory stores could hold data from the previous 3° of rotation and be undergoing analysis whilst data from the next 3° are being collected. This would have the advantage that data from any individual target could be analysed up to three times as it was scanned by the beam and the three results could be checked for consistency (e.g. to defeat jamming attempts).

NOISE

It would not be unusual for a radar echo to so weak that its power is comparable with that of the noise in the receiver. All electronic systems produce random noise signals that can be reduced by careful design but never eliminated. Noise can also be produced by external sources and enters the receiver via the antenna. (This is less of a problem for Air Defence radars as they generally look upwards, whereas many noise sources are at ground level.) In order to detect an echo that is comparable to the noise the receiver must exploit differences between the two signals.

In a simple receiver, a threshold level could be set. Whenever the signal exceeds this threshold then the radar could declare that it had found a target. The problem is to determine the level that this threshold should be set to. This exploits the difference between noise and signal where the signal is bigger than the noise.

Noise signals are random and, although there is an ‘typical’ value, the value at any instant is unpredictable. A noise signal will normally have an average value of zero - as it is just as likely to be positive as negative. Noise is an alternating signal and its value is usually expressed as an rms value. (This is covered in the BST Handout on Alternating Current.)

Statistical theory predicts that a noise signal with an rms value of One Unit (e.g. 1 μV) will have a value between zero and ± 1 Unit for 68% of the time, so for 32% of the time then the noise signal exceeds its ‘typical’ or rms value. This implies that if the threshold for recognising a radar echo is only slightly greater than the noise then many false alarms will be generated. If there were ten range gates then, on average, three would detect a false target that was really noise.

When the threshold is twice as great as the noise (e.g. 2 μV) then there is a 5% chance that the noise signal will exceed the threshold. When the threshold is set to be three-times greater than the noise then there is only a 0.5% chance that a noise signal will be mistaken for a target. There is no level that will give certainty, as the noise signal can have any value - but the bigger the value the less likely that it will occur.

Many radar receivers use a variable threshold. The noise at each instant is measured and the threshold adjusted accordingly.

INTEGRATION

The noise is random in phase frequency and amplitude whereas the signal is consistent in both. A coherent detector is designed to respond best to a signal that matches the reference signal. Noise might, by chance, have the correct phase, and amplitude, for a short period of time but this is unlikely to last. Phase detectors produce better quality signals than conventional detectors because of this factor.

Additionally, since noise is not consistent over time then we can make the radar receiver detect a target using a sequence of pulses - not just a single pulse. If the radar transmits, say, sixty-four pulses and then tries to determine how many produced an echo in a particular range gate then noise might produce, say, ten echoes above a threshold (at random) whereas a genuine, but weak, echo from a target target might produce, say, fifty-five.

This accumulation of a signal over a period of time is called ‘integration’. The improvement factor depends on the square-root of the number of pulses accumulated. Thus, using sixty-four pulses gives an improvement of eight times over using a single pulse. (In other words, the effect of noise is reduced by eight times.)

ACCURACY

Noise always reduces the performance of a radar system. All measurements that the radar makes are less accurate when noise is present and there will be an increase in false alarms. For this reason, most radar systems are carefully designed to keep noise levels low and to designed to recognise the difference between random noise and a wanted signal. One useful side-effect is an increased resistance to some forms of jamming that attempt to insert noise into the radar receiver.

BANDWIDTH

Noise is usually produced over a very wide range of frequencies but the power of the noise signal that can affect a receiver depends on the bandwidth of that receiver. If a receiver is operating in an environment where there is, say, 10 μW of noise over a 5 MHz bandwidth and that receiver has a bandwidth of, say, 1 MHz then only 2 μW of that noise can affect the receiver. For this reason, receivers generally have no more bandwidth than the signal that they are designed to receive.

The bandwidth of a simple, pulsed-radar signal is calculated using the formula:

$$\text{Bandwidth} = \frac{1}{\text{Pulse Duration}}$$

For a radar with a pulse duration of 10 μs then the bandwidth would be 100 kHz. The bandwidth decreases as the pulse length increases.

When frequency agility is used then the transmitted frequency might vary over a range of 300 MHz - but this is not the bandwidth that the receiver uses. The noise level would be far too high in such a wide bandwidth. Instead, as the transmitter changes to a new frequency then the receiver is also changed to that frequency and the narrow bandwidth just moves sideways to cover the new frequency. There are 3,000 distinct 100 kHz bands in a range of 300 MHz and the system only uses one at a time.

A jammer, trying to detect emissions from a radar that is frequency agile does not know which band will be in use at any particular time. Consequently, he must set his receiver to cover all possible frequencies, with a wide bandwidth that causes his noise levels to be significantly higher than those of the radar receiver. Although this makes the jammer’s job more difficult, it does not make it impossible.

SELF-TEST QUESTIONS

1. One purpose of a duplexer in a radar system is to direct energy from:

   a. transmitter to receiver.
   b. antenna to transmitter.
   c. antenna to receiver.
   d. receiver to transmitter.

2. The frequency source in the transmitter runs continuously so that the radar can use:

   a. frequency agility.
   b. long pulses.
   c. short pulses.
   d. coherent detection.

3. A radar transmitter has a duty cycle of 5% and a peak power of 2 kW. This means that it:

   a. has an average power of 100 W.
   b. uses high energy pulses.
   c. stops transmitting for 5% of the time.
   d. must be switched off for 5 minutes in every hour.

4. A radar receiver with ‘sensitivity time control’ operates with lowest gain when:

   a. receiving echoes from maximum range.
   b. determining the Doppler shift.
   c. receiving echoes from minimum range.
   d. there are many echoes.

5. A range gate that operates 40 μs after the radar pulse is transmitted will collect echoes from a range of:

   a. 6 km.
   b. 4 km.
   c. 12 km.
   d. 40 km.

6. A radar receiver would integrate echoes from a number of transmitted pulses in order to reduce the effects of:

   a. Doppler shift.
   b. noise.
   c. phase changes.
   d. frequency changes.

7. One effect of an increase of noise on a radar receiver would be to:

   a. increase the Doppler shift.
   b. decrease the Doppler shift
   c. increase measurement accuracy.
   d. decrease measurement accuracy.

8. In order to measure both the amplitude and the phase of the radar echo then the receiver needs to have:

   a. two, coherent detectors.
   b. a Doppler processor.
   c. a narrow beamwidth.
   d. a stationary target.

9. One means that a radar receiver can use to reduce the effects of noise is:

   a. integration.
   b. a low threshold.
   c. a wide bandwidth.
   d. a range-gate.

10. When a radar receiver gets a series of echoes from a stationary target then:

   a. each echo has a different phase from the previous echo.
   b. each echo has the same phase as the previous echo.
   c. there will be a large Doppler shift.
   d. the bandwidth of the echo will increase.

Answers

1. c.	2. d.	3. a.	4. c.
5. a.	6. b.	7. d.	8. a.
9. a.	10. b.		

Teaching Objectives		Comments
J.02.01 Recognise the functions of the components in a block diagram of a radar transmitter		
J.02.01.01	Describe the state of the signal at each part of the block diagram in terms of the input and output of each block.	
J.02.01.02	Describe the purpose of each block.	
J.02.01.03	Identify the blocks required for coherence.	
J.02.02 Describe the properties of the frequency sources		
J.02.02.01	Describe the concept of a 'master oscillator'.	Include continuous operation to mainta in coherence.
J.02.02.02	Describe the concept of frequency multiplication.	
J.02.02.03	State that the signals are made available to the receiver.	
J.02.02.04	State that the frequency and phase of the signals can be changed.	Include gross changes (e.g. c hirp and frequency agility) and subtle changes (e.g. Δf 1 in 10^{-6} and small $\Delta\Phi$ for approach/recede discrimination)
J.02.03 Describe the properties of the pulse modulator		
J.02.03.01	State that the modulator switches the output pulses on and off in a controlled way.	Duration: pulse width (e.g. 10 µs), freque ncy: Pulse Repetition Frequency (e.g. 10 kHz)
J.02.03.02	State that the modulator controls the power amplifier.	Might have to operate at tx power levels (e.g. Cmd Tx).
J.02.04 Describe the properties of the power amplifier		
J.02.04.01	State that the pow er amplifier is a Klystron or Travelling-Wave Tube.	Separate handout for details.
J.02.04.02	State that the power amplifier increases the power of the signal to the level required for transmission.	E.g. from about 200 mW (23 dBm) to 2 kW (63 dBm)
J.02.04.03	Perform calculations relating mean power, peak power and duty-cycle.	
J.02.05 Describe the properties of the power supplies		
J.02.05.01	State that the power supplies convert the ac supply into a range of dc supplies.	
J.02.05.02	State that the power amplifier requires around 5 kV and about 1 A.	
J.02.06 Describe the means of determining the orientation of the antenna		
J.02.06.01	State the requirement to measure antenna azimuth.	
J.02.06.02	Describe an optical method of determining antenna orientatio n.	FSB, can be affected by contamination from dust or oil.
J.02.06.03	Describe a magnetic method of determining antenna orientation.	FSC, Inductosyn, unaffected by small amounts of contamination.

Teaching Objectives		Comments
J.02.07 Recognise the functions of the components in a block diagram of a radar receiver		
J.02.07.02	Describe the state of the signal at each part of the block diagram in terms of the input and output of each block.	Assume dig ital system – no conventional display (except for illustration purposes).
J.02.07.02	Describe the purpose of each block.	
J.02.07.03	Identify the blocks required for coherence.	
J.02.08 Describe the properties of the amplifiers.		
J.02.08.01	State that the RF amplifier requires wide bandwidth and low noise.	Rest of receiver will amplify any noise. Operates at carrier freq, e.g., 3 GHz
J.02.08.02	State that the IF amplifier requires narrow bandwidth and high gain.	Operates at lower freq, e.g. 60 MHz.
J.02.08.03	Describe the need for and the operation of automatic gain control (AGC).	Include time-dependent AGC and gated AGC
J.02.09 Describe the operation of a mixer.		
J.02.09.01	State that the RF signal has too high a frequency for processing.	
J.02.09.02	Describe the process of mixing an RF signal to IF.	Also called heterodyning or frequency changing
J.02.09.03	State that mixers must be carefully designed to preserve amplitude and phase whilst avoiding the generation of noise and spurious signals.	
J.02.10 Describe the operation of coherent and non -coherent detectors.		
J.02.10.01	Describe the function and waveforms of a non -coherent detector.	Disadvantages: no phase information – can't use for Doppler.
J.02.10.02	Describe the functions and waveforms of a coherent detector.	Advantages: phase retained – can use for Doppler.
J.02.10.03	Describe the use of I and Q phases.	$\theta = \tan^{-1}(I/Q)$ and $A = \mathrm{Sqrt}(I^2 + Q^2)$
J.02.10.04	Describe the improved noise performance of coherent detection.	Integrate 'n' pulses to improve S/N by factor 'n' for coherent but only $\sqrt{n}$ for non-coherent.
J.02.10.05	State that the detector's output is converted from analogue to digital for further processing.	
J.02.10.06	Describe the effects of noise in a radar receiver.	
J.02.10.07	Describe the effects of integration on noise and signal.	