ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION
GUNNERY STAFF/CAREER COURSES

RADAR TRANSMITTERS

INTRODUCTION

1. The need to improve the angular accuracy and resolving power of radar called for the use of shorter wavelengths but, until the invention of the multi-cavity magnetron, no useful amount of power could be generated at wavelengths much shorter than 3 metres. The great merit of the magnetron was that it not only oscillated at frequencies corresponding to the centimetre wavelengths but also produced enough power to be directly usable as a radar transmitter without further amplification. The klystron soon followed suit but without quite the same power levels.

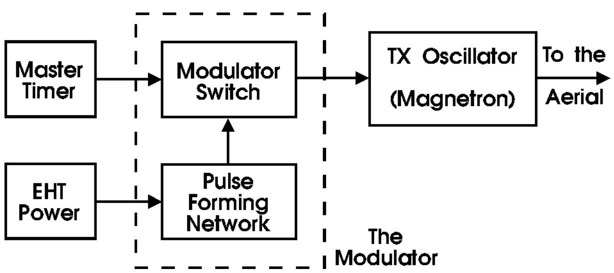


Fig.1. Radar Transmitter

2. Radar transmitters differ from communications transmitters only in their modulators and the greater part of this handout will therefore be devoted to a description of modulator techniques that have been developed for radar. The transmitter oscillator is almost invariably a magnetron or a klystron, which have both been previously studied. Thus, the major concern here is to consider how a pulse can be formed that contains the necessary features to convert a DC supply to a RF power output of the order necessary for a radar transmitter.

3. Fig.1, illustrates the basic components of a radar transmitter and shows that they are in concept very simple devices. The components of the master timer, EHT supply and transmitter oscillator have all been discussed during earlier handouts. It therefore remains to complete the picture by considering the modulator.

THE MODULATOR

4. In radar the modulator is required merely to turn the transmitter on at regular intervals for a specified period. In this section the final stages of the modulator will be looked at, and is that part which directly controls the oscillator. Preceding this stage there may be several stages concerned with converting the basic timing waveform into a 'trigger' signal which will precisely time the switching action of the final stage of the modulator.

5. Normal EHT techniques do not work at the power level and PRF required of a radar so special methods are employed. It will be understood from previous work that a coaxial line is effectively formed from a series of elements, each comprising inductance and capacitance and that signals delivered onto the line take time to travel along it from end to end. The effect can be very much exaggerated by increasing the values of capacitance, C, and inductance, L, for each section, as shown at Fig.2. The device is then referred to as a **delay line**.

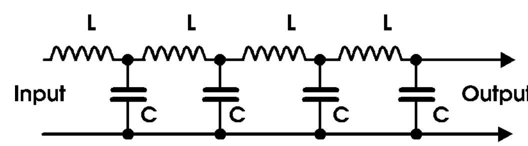


Fig.2. Delay Line Construction

6. The changes, or signals, delivered onto the line take time to build the electrostatic and electromagnetic fields around the components, and the larger they are, the longer it takes the changes to pass from end to end. The delay time from one end to the other is determined by n, L and C, where 'n' is the number of sections in the line. It is also true to say that, energy reflected from the end of the line creates a standing wave which causes those reflected changes to be returned in-phase. Both of these effects are normally used in the modulator of a radar.

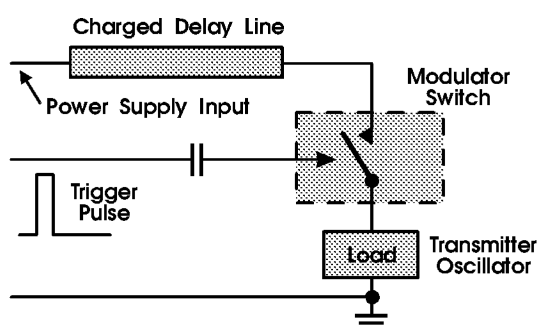


Fig.3. A Radar Modulator

7. The fundamental arrangement is illustrated at Fig.3, and comprises a length of line, which can be 'charged' to a given DC level by the power supply input, a very fast acting switch and the necessary trigger input signal. The last element is the transmitter oscillator, a magnetron or klystron as required. The delay line must be able to cope with the power being delivered to the transmitter oscillator, which may be of the order megawatt, and the switch must act very quickly indeed to deliver the line voltage to the transmitter oscillator for the duration of the pulse.

8. The load resistance, R is chosen to be equal in value to the characteristic impedance of the line, Zo. Assuming that the line is charged, while the modulator switch is open, by a DC supply to a voltage, V. If the supply is then removed and the load connected, a current flows whose magnitude is equal to V/(Zo+R), but as R has been made equal to Zo, the current is V/2R. The passage of this current creates a potential drop of R×V/(2R)=V/2 across the load, which means that the original voltage, V, across the line has been divided at the load end, into two parts, half appearing across the load and half across the line. Thus, closing of the modulator switch suddenly reduces the voltage across the line, at the load end, from V to V/2.

9. This change of voltage is transmitted down the line at a velocity governed by the line constants until it reaches the far end of the line. This is an open circuit, because the power supply was removed as the modulator switch closed. Here the change of voltage, which may be considered to be propagated as a voltage wave of magnitude V/2, is reflected without change of phase and travels back to the load end of the line reducing the voltage to zero.

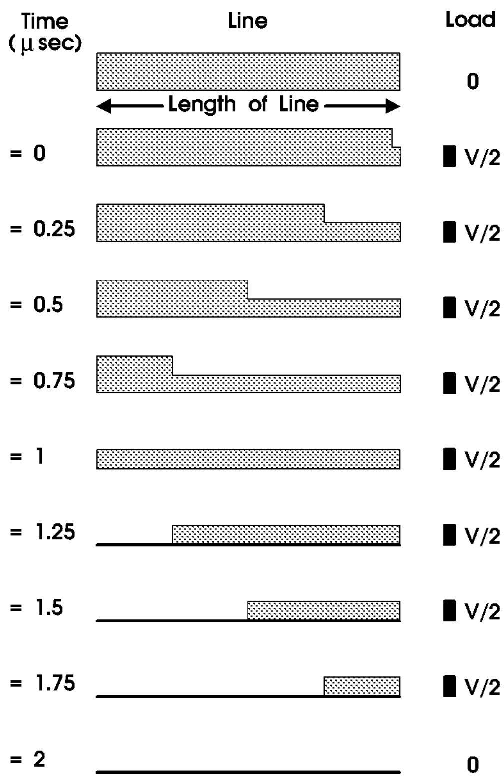


Fig.4. Distribution of Line Voltage During a Transmitter Pulse

10. The voltage across the load has remained constant, at a value equal to V/2 all the time that the voltage wave has taken to travel to the open end of the line and back. The sequence of events can best be understood by reference to Fig.4, which shows, in diagrammatic form, the voltages across the line and the load at different instants. The line constants in this example have been chosen so that the voltage wave takes 1μs to travel from one end to the other.

11. It can be seen that such a delay line, charged to a voltage, V, acts as a source of constant voltage V/2 for a time precisely determined by its length. The velocity of propagation in an artificial transmission line of this kind is equal to 1/√(L×C) sections per second. The time taken to traverse 'n' sections is therefore n√(L×C) seconds and the pulse length will therefore be 2n√(L×C) seconds.

Delay Line Choke Charging

12. The method of charging the delay line has a number of variations. The obvious method is to charge it from a high voltage DC supply, and this would lead to the line becoming charged to the voltage of the supply, V, making the voltage available to the load V/2. If the power supply is connected to the line via a choke (large inductance L), voltage multiplication may be obtained by ensuring that the choke, in conjunction with the capacitance of the delay line (its inductance is quite small), form a series resonant combination at a frequency equal to half the pulse repetition frequency. Specific details of this technique are a little beyond the scope of this handout.

Modulator Switch

13. The two most commonly used modulator switches are the triggered spark gap and the hydrogen thyratron. The latter were fully described during thermionic valves. Suffice it to say here that the hydrogen thyratron is particularly suitable for radar applications since the high mobility of the light hydrogen ions makes possible the rapid growth of current during the pulse, and the rapid de-ionisation in this type of valve enables high pulse repetition frequencies to be used.

Pulse Transformer

14. Another component of the complete modulator is the pulse transformer. This transformer is invariably used with magnetron transmitters and is employed to step up the voltage of the modulator pulse and to ensure the correct impedance match between modulator and magnetron. The heater of a magnetron is connected to its cathode in directly heated form, and therefore is subjected to the full pulse voltage. By winding the secondary of the pulse transformer with two wires (the so-called bifilar winding) the need to have a very highly insulated heater transformer can be avoided, as shown at Fig.5.

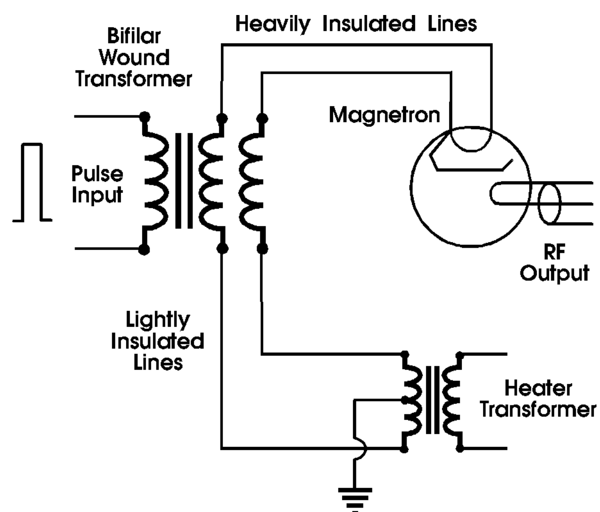


Fig.5. Magnetron Pulse Transformer

15. In this arrangement the two secondaries both rise to the output voltage at the same time, say 10,000V, however, a smaller AC heater voltage, say 6.3V is superimposed at their low voltage end. This means that instead of the heater to cathode potential difference rising to almost 10,000V, as in conventional directly heated cathodes, resulting in almost certain breakdown, the difference between the two bifilar windings is only 6.3V, removing the insulation problem and allowing the heater to operate efficiently. In effect, the heater voltage of 6.3V is superimposed upon two lines, each of which reaches a voltage of 10,000V during the pulse.

16. The sign of the voltage pulse applied to the magnetron cathode is always negative because the anode is maintained at zero volts to prevent accidental shock to personnel. In a practical modulator employing a pulse transformer a diode is connected between the cathode and the anode of the magnetron. The need for this arises from the tendency of the transformer windings to 'ring', or oscillate, under the influence of the pulse and so produce a waveform like that of Fig.6.

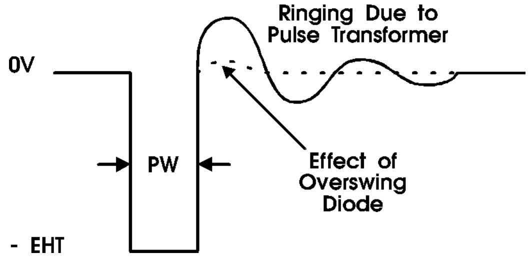


Fig.6. Magnetron Waveform Due to Pulse Transformer

17. The ringing is due to energy storage within the inductance of the transformer reacting with the inter-winding capacitance. If this ring were allowed to take place it could cause the magnetron to emit a second pulse. By placing a diode across the pulse transformer the first positive half cycle of this ring is short-circuited and this effectively damps the oscillation by removing the stored energy from the transformer. Thus further oscillations are eliminated. The additional components are shown at Fig.7, and the diode is normally referred to as the 'overswing diode'.

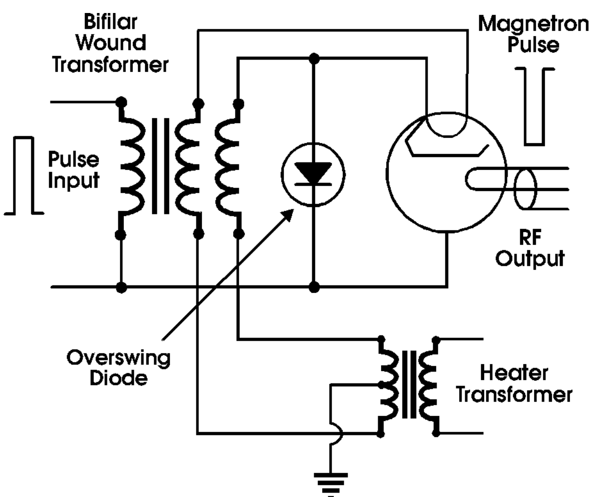


Fig.7. Pulse Transformer With Overswing Diode

TRANSMITTED PULSE SPECTRUM

18. Direct-current pulses such as are produced by radar modulators, recurring at constant period, τ, and constant rate equal to the PRF, can be analysed by Fourier methods. The analysis is simplified if the time scale is taken from the centre of a pulse, as the Fourier series then consists only of cosine terms, together with a constant term. The first few terms in this infinite series are:-

$$V=A0+A1\cos(\omega t)+A2\cos(2\omega t)+A3\cos(3\omega t)+.....\text{etc.}$$

Where $\omega=2\times\pi\times f$, and the frequency, f, is equal to the PRF. The value of A0, A1, A2, etc., is dependent upon a sine function with zero points related to the pulse width in use. Each zero point occurs at a time $1/\tau$, $2/\tau$, $3/\tau$, etc. The overall spectrum for this series is illustrated at Fig.8.

19. In a typical radar modulator, f, the PRF, might be 1,000pps and τ, 1μs. The complete spectrum of this pulse modulation would consist of lines every 1,000Hz. The first zero would occur after 1,000 such lines, at a frequency of 1MHz, the second at a frequency of 2MHz and so on.

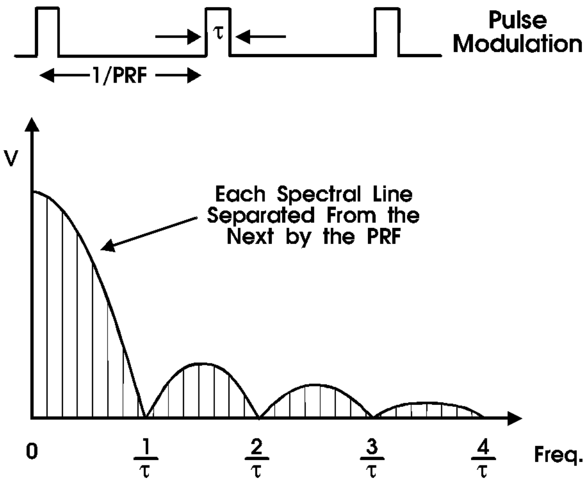


Fig.8. Frequency Spectrum of Pulse Modulation

20. If a radio frequency oscillator of frequency, fc, is modulated by DC pulses, each component of the series into which the pulse has been analysed above, results in two side frequencies, which is also exactly what happened in the radio transmitter previously met for voice signals.

21. If the PRF and pulse width were absolutely constant and the RF oscillator were not only of constant frequency but were also **coherent** (that is to say, each time it is switched on by the modulator, the phase of the oscillation is the same as it would have been had it been running continuously) the spectrum would consist of this infinite series of lines spaced apart by the PRF. The full spectrum is illustrated at Fig.9.

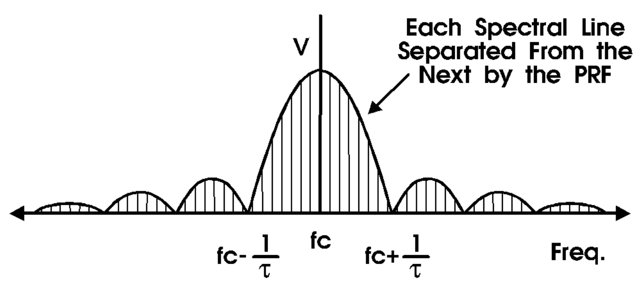


Fig.9. Frequency Spectrum of Transmitter Output

22. Careful examination of Fig.9, would show that the great majority of the energy transmitted is contained between the first zeros on either side, corresponding to a bandwidth of $2/\tau$. In fact 75% of the energy is contained within half of this bandwidth, i.e., the band between $fc+1/(2\tau)$ and $fc-1/(2\tau)$.

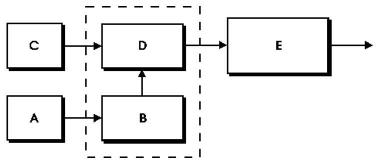
SELF TEST QUESTIONS

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

1. A pulse radar transmitter is usually driven by a modulator, the purpose of which is to:-

   a. frequency modulate the trigger pulses
   b. produce a high power short duration pulse
   c. phase modulate the trigger pulses
   d. drive the master timer

2. The following block diagram shows the transmitter chain of a standard radar. The block marked with an 'A' is the:-

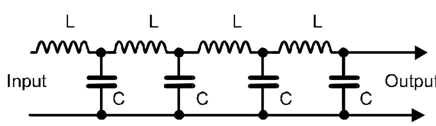


   a. EHT power supply
   b. pulse forming network
   c. modulator switch
   d. master timer

3. Many radar transmitters employ a delay line such as that illustrated below. They are used because:-

   a. a delay is always required between triggering the transmitter and the pulse being formed
   b. it is the only way possible to produce the required pulse length
   c. the delay ensures that the pulse starts at the correct time
   d. normal modulation techniques are inadequate at the power level and PRF in use

4. The following diagram shows a four section delay line containing inductances of 20mH and capacitances of 10pF. The time taken for energy to travel from one end to the other is:-



   a. 0.9ns
   b. 1.8ps
   c. 3.6µs
   d. 1.8µs

5. A four section delay line is used in a pulse radar transmitter. The delay line is comprised of sections with L=5mH and C=200PF. When the pulse is formed it will have a duration of:-

   a. 2ns
   b. 8ns
   c. 2µs
   d. 8µs

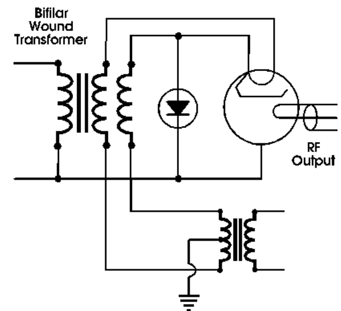
6. A six section delay line which has L=25mH and C=10PF is used in a radar transmitter. The delay line is charged initially to 2,000V. The waveform delivered to the pulse transformer of the transmitter oscillator would be:-

   a. 1,000V in amplitude and 3µs in duration
   b. 2,000V in amplitude and 3µs in duration
   c. 1,000V in amplitude and 6µs in duration
   d. 2,000V in amplitude and 6µs in duration

7. The block diagram of a radar transmitter is shown at Q2. The block marked with a 'D' is the:-

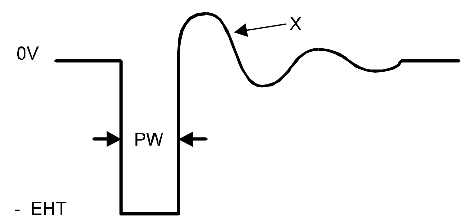
   a. EHT power supply
   b. pulse forming network
   c. modulator switch
   d. master timer

8. The diagram below shows the pulse transformer and Magnetron of a pulse radar. The Bifilar wound transformer has:-



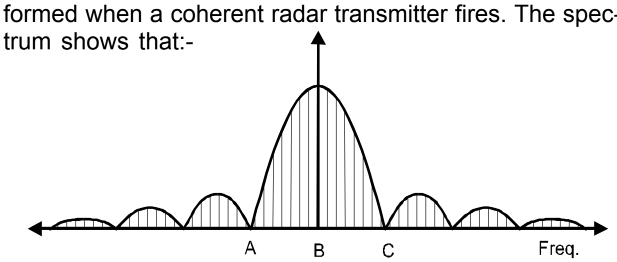
   a. one output that is positive and another that is negative
   b. two inputs that combine to provide a common output
   c. two outputs that produce identical voltages
   d. the heater voltage for the magnetron fed to its primary

9. The following diagram shows the waveform delivered by a bifilar wound transformer to the cathode of a pulse radar magnetron. The oscillation shown at 'X' is:-



   a. removed by the use of an overswing diode
   b. necessary to make the magnetron fire repeatedly
   c. produced by energy storage in the heater transformer
   d. not significant and can be ignored

10. The following diagram shows the spectrum of frequencies formed when a coherent radar transmitter fires. The spectrum shows that:-



   a. the normally accepted bandwidth is between A and B
   b. the interval between A and C contains an infinite number of harmonics
   c. most of the energy transmitted occurs between A and C
   d. a receiver must operate outside the range A to C

11. A pulse radar operates at a PRF of 10,000pps and pulse width of 100ns. The number of spectral lines contained within the normally considered bandwidth is:-

   a. 1000
   b. 101
   c. 201
   d. 2001