

## 6.8 MODULATORS

The function of the modulator is to turn the transmitting tube on and off to generate the desired waveform. When the transmitted waveform is a pulse, the modulator is sometimes called a *pulser*. Each RF power tube has its own peculiar characteristics which determine the particular type of modulator to be used. The magnetron modulator, for instance, must be designed to handle the full pulse power. On the other hand, the full power of the klystron and the traveling-wave tube can be switched by a modulator handling only a small fraction of the total beam power, if the tubes are designed with a modulating anode or a shadow grid. The crossed-field amplifier (CFA) is often cathode-pulsed, requiring a full-power modulator. Some CFAs are d-c operated, which means they can be turned on by the start of the RF pulse and turned off by a short, low-energy pulse applied to a cutoff electrode. Some CFAs can be turned on and off by the start and stop of the RF pulse, thus requiring no modulator at all. Triode and tetrode grid-controlled tubes may be modulated by applying a low-power pulse to the grid. Plate modulation is also used when the radar application cannot tolerate the interpulse noise that results from those few electrons that escape the cutoff action of the grid.

The basic elements of one type of radar modulator are shown in Fig. 6.13. Energy from an external source is accumulated in the energy-storage element at a slow rate during the interpulse period. The charging impedance limits the rate at which energy can be delivered to the storage element. At the proper time, the switch is closed and the stored energy is quickly discharged through the load, or RF tube, to form the pulse. During the discharge part of the cycle, the charging impedance prevents energy from the storage element from being dissipated in the source.

**Line-type modulator.** A delay line, or pulse-forming network (PFN), is sometimes used as the storage element since it can produce a rectangular pulse and can be operated by a gas-tube switch. This combination of delay-line storage element and gas-tube switch is called a *line-type modulator*. It has seen wide application in radar because of its simplicity, compact size, and its ability to tolerate abnormal load conditions such as caused by magnetron sparking.<sup>1,24,25</sup> A diagram of a line-type pulse modulator is shown in Fig. 6.14. The charging impedance is shown as an inductance. The pulse-forming network is usually a lumped-constant delay line. It might consist of an air-core inductance with taps along its length to which are attached capacitance to ground. A transformer is used to match the impedance of the delay line to that of the load. A perfect match is not always possible because of the nonlinear impedance characteristic of microwave tubes.

The switch shown in Fig. 6.14 is a hydrogen thyratron, but it can also be a mercury ignitron, spark gap, silicon-controlled rectifier (SCR), or a saturable reactor. A gas tube such

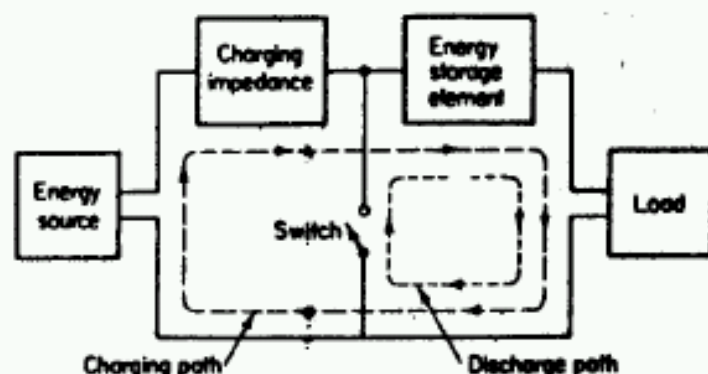


Figure 6.13 Basic elements of one type of radar pulse modulator.

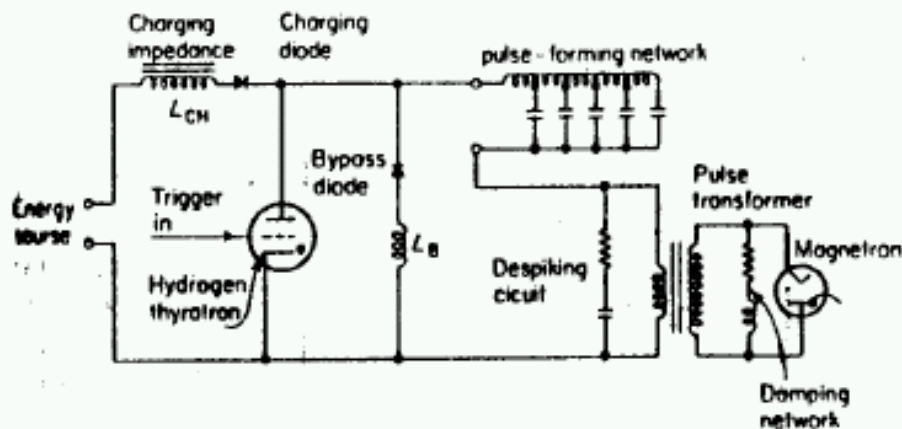


Figure 6.14 Diagram of a line-type modulator.

as a thyratron or ignitron is capable of handling high power and presents a low impedance when conducting. However, a gas tube cannot be turned off once it has been turned on unless the plate current is reduced to a small value. The switch initiates the start of the modulator pulse by discharging the pulse-forming network, and the shape and duration of the pulse are determined by the passive circuit elements of the pulse-forming network. Since the trailing edge of the pulse depends on how the pulse-forming network discharges into the nonlinear load, the trailing edge is usually not sharp and it may be difficult to achieve the desired pulse shape.

The charging inductance  $L_{ch}$  and the capacitance  $C$  of the pulse-forming network form a resonant circuit, whose frequency of oscillation approaches  $f_0 = (2\pi)^{-1}(L_{ch}C)^{-1/2}$ . (The inductance of the pulse-forming network and the load are assumed small.) With a d-c energy source the pulse repetition frequency  $f_p$  will be twice the resonant frequency if the thyratron is switched at the peak of maximum voltage. This method of operation, ignoring the effect of the charging diode, is called *d-c resonant charging*. A disadvantage of d-c resonant charging is that the pulse repetition frequency is fixed once the values of the charging inductance and the pulse-forming-network delay-line capacitance are fixed. However, the charging, or hold-off, diode inserted in series with the charging inductance permits the modulator to be operated at any pulse repetition frequency less than that determined by the resonant frequency  $f_0$ . The function of the diode is to hold the maximum voltage and keep the delay line from discharging until the thyratron is triggered.<sup>26</sup> Although the series diode is a convenient method for varying the prf, it is more difficult to change the pulse width since high-voltage switches in the pulse-forming network are required.

The bypass diode and the inductance  $L_b$  connected in parallel with the thyratron serve to dissipate any charge remaining in the capacitance due to tube mismatch. If this charge were allowed to remain, the peak voltage on the network would increase with each cycle and build up to a high value with the possibility of exceeding the permissible operating voltage of the thyratron. The mismatch of the pulse-forming network to the nonlinear impedance of the tube might also cause a spike to appear at the leading edge of the pulse. The *despiking circuit* helps minimize this effect. The *damping network* reduces the trailing edge of the pulse and prevents post-pulse oscillations which could introduce noise or false targets.

**Hard-tube modulator.**<sup>1</sup> The hard-tube modulator is essentially a high-power video pulse amplifier. It derives its name from the fact that the switching is accomplished with "hard-vacuum" tubes rather than gas tubes. Semiconductor devices such as the SCR (silicon-controlled rectifiers) can also be used in this application.<sup>1</sup> Therefore, the name *active-switch modulator* is sometimes used to reflect the fact that the function of a hard-tube modulator can

be obtained without vacuum tubes. Active-switch pulse modulators can be *cathode pulsers* that control the full power of the RF tube, *mod-anode pulsers* that are required to switch at the full beam voltage of the RF tube but with little current, or *grid pulsers* that operate at a far smaller voltage than that of the RF beam.

The chief functional difference between a hard-tube modulator and a line-type modulator is that the switching device in the hard-tube modulator controls both the beginning and the end of the pulse. In the line-type modulator, the switch controls only the beginning of the pulse. The energy-storage element is a capacitor. To prevent droop in the pulse shape due to the exponential nature of a capacitor discharge, only a small fraction of the stored energy is extracted for the pulse delivered to the tube. In high-power transmitters with long pulses the capacitor must be very large. It is usually a collection of capacitors known as a *capacitor bank*.

The hard-tube modulator permits more flexibility and precision than the line-type modulator. It is readily capable of operating at various pulse widths and various pulse repetition frequencies, and it can generate closely spaced pulses. The hard-tube modulator, however, is generally of greater complexity and weight than a line-type modulator.

**Tube protection.**<sup>1,27</sup> Power tubes can develop internal flash arcs with little warning even though they are of good design. When a flash arc occurs in an unprotected tube, the capacitor-bank discharges large currents through the arc and the tube can be damaged. One method for protecting the tube is to direct the arc-discharge currents with a device called an *electronic crowbar*. It places a virtual short circuit across the capacitor bank to transfer the stored energy by means of a switch which is not damaged by the momentary short-circuit conditions. The name is derived from the analogous action of placing a heavy conductor, like a crowbar, directly across the capacitor bank. Hydrogen thyratrons, ignitrons, and spark-gaps have been used as switches. The sudden surge of current due to a fault in a protected power tube is sensed and the crowbar switching is actuated within a few microseconds. The current surge also causes the circuit breaker to open and deenergize the primary source of power. Crowbars are usually required for high-power, hard-tube modulators because of the large amounts of stored energy. They are also used with d-c operated crossed-field amplifiers and mod-anode pulsed linear-beam tubes which are connected directly across a capacitor bank. The line-type modulator does not usually require a crowbar since it stores less energy than the hard-tube modulator and it is designed to discharge safely all the stored energy each time it is triggered.

## 6.9 SOLID-STATE TRANSMITTERS

There have been two general classes of solid-state devices considered as potential sources of microwave power for radar applications. One is the transistor amplifier and the other is the single-port microwave diode that can operate as either an oscillator or as a negative-resistance amplifier. The silicon bipolar transistor has, in the past, been of interest at the lower microwave frequencies (*L* band or below), and the diodes have been of interest at the higher microwave frequencies. Gallium arsenide field-effect transistors (GaAs FET) have also been considered at the higher microwave frequencies. Both the transistor and the diode microwave generators are characterized by low power, as compared with the power capabilities of the microwave tubes discussed previously in this chapter. The low power, as well as other characteristics, make the application of solid-state devices to radar systems quite different from high-power microwave tubes. The almost total replacement of receiver-type vacuum tubes by solid-state devices in electronic systems has offered encouragement for replacing the power vacuum tube with an all solid-state transmitter to obtain the advantages offered by that