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Pulse radar systems offer obvious advantages over a CW-type system. Any application that requires range, elevation, or altitude information will use pulse modulation. As the transmitter is online for only a brief amount of time, the receiver can be isolated from it. That allows a much higher output power without interference or damage. Greater power translates into better resolution and range characteristics. Disadvantages would be its power consumption, resulting large size, and cost. This technique has many uses, both civilian and military, and is the most common type in use today. Air traffic control, weather radar, threat detection, weapons direction, and observation from space of weather, crops, and natural resources are just a few areas where it is used. Nondestructive examination of crucial parts is a major industry that uses pulse radar technology. A small, portable radar system has been developed that aids in locating pipes and conduit under roads and possible failure points in bridges and roads.

A crucial function performed by the modulator is controlling the RF output pulse developed by the transmitter. It accomplishes this through the application of a modulation pulse of the desired amplitude and duration to the RF generator. To ensure accurate system operation, the modulator and RF output pulses must meet demanding criteria. Pulse shape is similar for both the modulator and RF generator. Figure 2-22 illustrates the proper appearance of pulses and compares it to common failures found in the field. A correct pulse has an almost instantaneous rise time from zero to its maximum value, and it should remain there for the entire time interval that the transmitter is to be producing an RF output. At the end of transmit time, it should decrease to zero almost instantaneously.

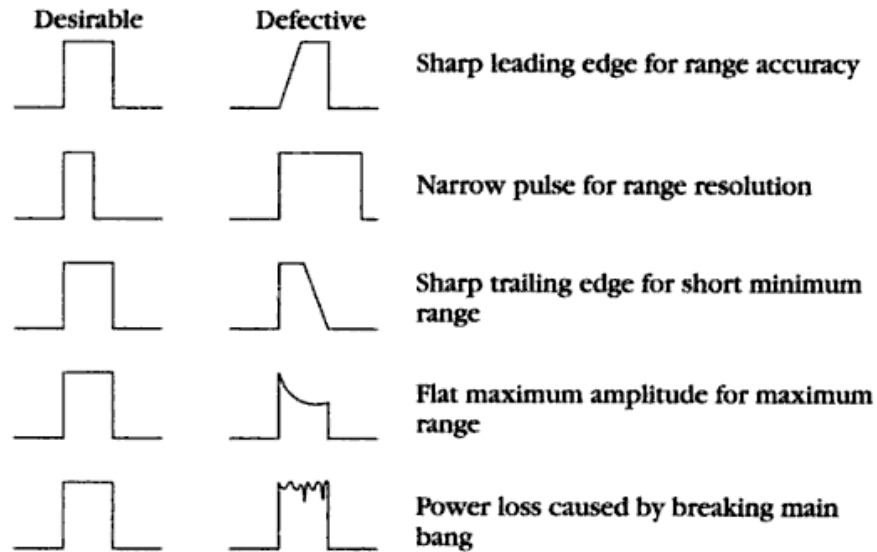
The modulator pulse characteristics are required for several important reasons. The leading edge of the transmitted RF pulse is used for range measurements. If the leading edge is indistinct and sloping, the resulting range measurements will be inaccurate and would vary from PRT to PRT. The trailing edge of the transmitted pulse affects minimum range. A steep trailing edge allows objects to be observed closer than if the edge were sloping. The maximum value of the pulse should be constant, as that indicates the most efficient level of transmitter operation. If it varies, that causes a fluctuating transmitter out-

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2-22 Transmitted pulse shapes and effects on system operation.

put power, lowering peak and average power. Decreased power out in turn will affect range resolution and maximum range.

The two most common types of radar modulators are the hard-tube and the line-pulsing. The *hard-tube* is based on the operation of a vacuum tube. Vacuum tube modulators are found in older radar systems and heavy-duty industrial X-ray systems. The vacuum tube functions as a driver. It forms a pulse from the trigger input, which is then amplified and routed to the modulator. Although the arrangement is effective, it suffers from several drawbacks, including lower efficiency, complex circuits, higher operating voltage requirement, and it is more susceptible to line voltage variations. The *line-pulsing* modulator is the more common modulator used in current radar designs. This type uses the same circuit components to store energy and form modulation pulses. It has the advantages of more compact size and less complexity than previous designs.

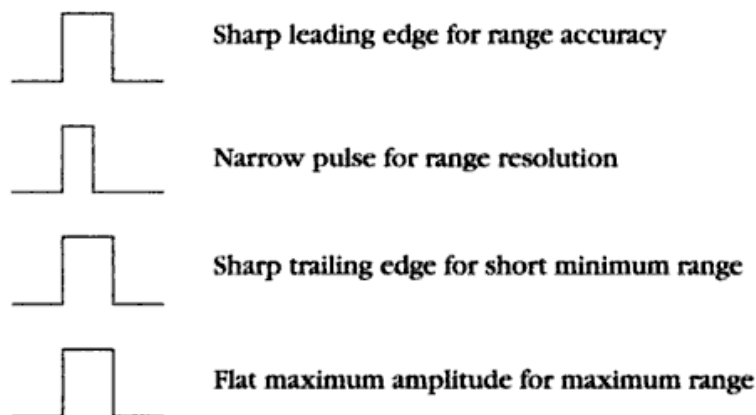
A line-pulsing modulator consists of a power supply, charging impedance, storage element, and a switching arrangement. The function of the power supply is to provide the correct amounts of current and voltage to the modulator. The time the energy storage element is charged is controlled by the charging impedance. Switching the energy storage element from charge to discharging through the RF oscillator and back to charge is controlled by the switching arrangement. The basis of this function is usually a vacuum tube called a *thyatron*. The most common type of energy storage elements are the pulse-

forming network (PFN) and artificial transmission line. The desired output from both is the same, a charge pulse that is rectangular in shape, with sharp rise and fall times, and of the required time duration.

Radar modulator

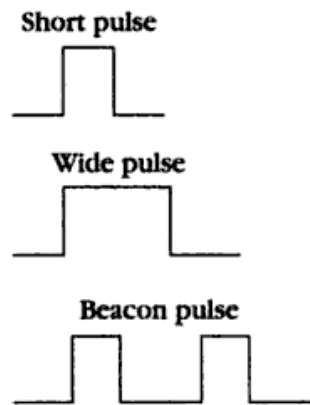
The radar modulator is considered to be a vital function within any radar system. The primary function of the modulator section is to produce accurately timed pulses of the proper high-voltage amplitude, current, duration, and polarity to allow for accurate system operation. The output pulses generated by the modulator are used as the high-voltage, high-current driving pulse to key the radar transmitter RF generator.

The pulse developed by a modulator must meet a specific criterion. As stated, the pulse must have a specific amplitude, duration, PRT, and shape. The pulse must have steep leading and trailing edges for accuracy and a flat top for maximum power. Peak power of radar is determined by the amplitude of the modulator pulse. Figure 2-23 illustrates desirable modulator pulses. The modulator pulse leading edge must rise from zero to its maximum value almost instantaneously to ensure accurate range measurements. As the transmitted pulse is the minimum range of any radar system, a sharp trailing edge is needed to connect the receiver to the antenna system as quickly as possible. The RF generator is unable to produce maximum power unless the top surface of the pulse is flat. If it is slanted, or even worse, breaking up, output power is greatly reduced. Reduced power decreases system maximum range and the ability to detect small targets, and it induces excessive noise levels into the receiver.



2-23 *Transmitted pulse shapes.*

All radar modulators share several characteristics. For proper operation, they require stable high-voltage and high-current inputs at the proper time interval. The typical circuit consists of a high-voltage switching device, an energy storage component, and protection circuitry. It is common for many radars to be designed with more than one pulse width selectable by the operator to increase system flexibility. For example, short pulse, long pulse, and beacon are frequent pulse widths that are encountered in several radars. Figure 2-24 compares the three different pulse widths.



2-24
Radar pulse widths.

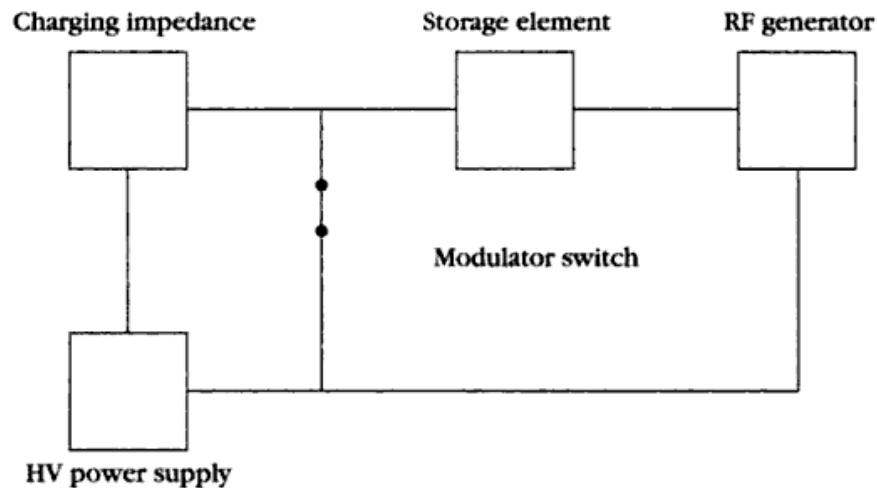
Short pulse widths are used for high-resolution applications, such as tracking close range targets, navigation in congested waters, separating multiple targets, or targets obscured by chaff and clutter. Short pulse is considered to be low-powered system operation because the RF generator is enabled for a shorter period of time. Long-pulse-width operation would be used for tracking long-range targets or targets obscured by electronic jamming, as both situations call for high-powered outputs. Beacon is a special-purpose operation that is becoming less common. In this type of operation, a radar system functions as a high-powered, long-range beacon to act as a navigation aid to other ships, aircraft, or personnel on shore. In this instance, a radar system generates two output pulses per PRT. It has been replaced by special equipment such as TACAN and VOR. TACAN is a military beacon, whereas VOR is used by civilian air traffic control organizations.

Modulator components

The two most common types of modulators in use are the hard-tube modulator and the line-pulsing modulator. The hard-tube design is based on a vacuum tube that is used to form the pulse, which is then

amplified to a usable level by additional tube. The hard-tube modulator is being replaced, as it has several limitations, including the need for a larger power supply, less efficiency, a more complex design, and high rate of failure. The line-pulsing modulator is more common, as it is simpler in design, more efficient, and uses the same component for energy storage and pulse formation.

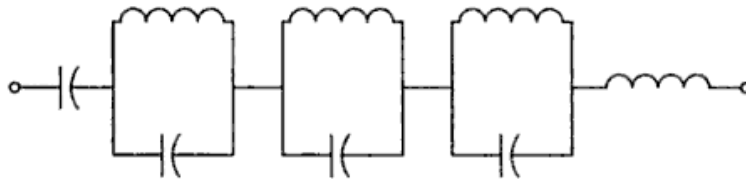
Figure 2-25 is an expanded block diagram of a representative radar modulator. Notice that it consists of four major subassemblies: high-voltage power supply, charging impedance, storage element, and switch. The power supply and energy storage element control the system's maximum power. The charging impedance has two functions: to control the charge time of the energy storage element and to prevent short circuiting the power supply during modulator pulse formation. The final component, the switch, fires to discharge the energy storage element into the RF generator.



2-25 Radar modulator block diagram.

Although the energy storage element is vital to system operation, it is very simple in concept. Depending on the age and sophistication of a system, it can be as simple as a capacitor, or as complex as a massive encased, oil-filled LC network. Capacitive storage elements are found only in radars with a dc power supply, limiting its use to very low-powered applications. The more prevalent devices are either artificial transmission line or pulse-forming networks (PFN). Figures 2-26 and 2-27 illustrate the internal construction of both components.

The function of an artificial transmission line is to store energy between transmitted pulses and, when discharged, form the rectangular modulator pulse. A schematic diagram of an artificial transmission line energy storage element is illustrated in Fig. 2-26. As shown, it consists of a series of LC tanks. The duration of the high-voltage pulse developed by the modulator determines the length of time that the RF generator will produce and radiate an RF output.

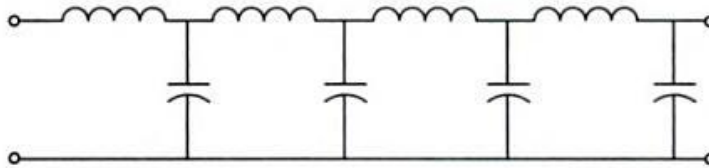


2-26 Artificial transmission line.

Modulator pulse duration in the artificial transmission line energy storage element is a result of the number of LC sections and their value. An artificial transmission line is fabricated so that the output end is electrically an open circuit. When voltage is applied, each section, starting from the input side, charges. Discharge begins when the modulator switch closes. The transmission line then discharges through the modulator switch and the primary of the pulse transformer. The discharge action develops a difference in potential. When the potential difference is felt on the output side of the transmission line, its characteristic open is reflected down the entire transmission line, discharging each section in turn.

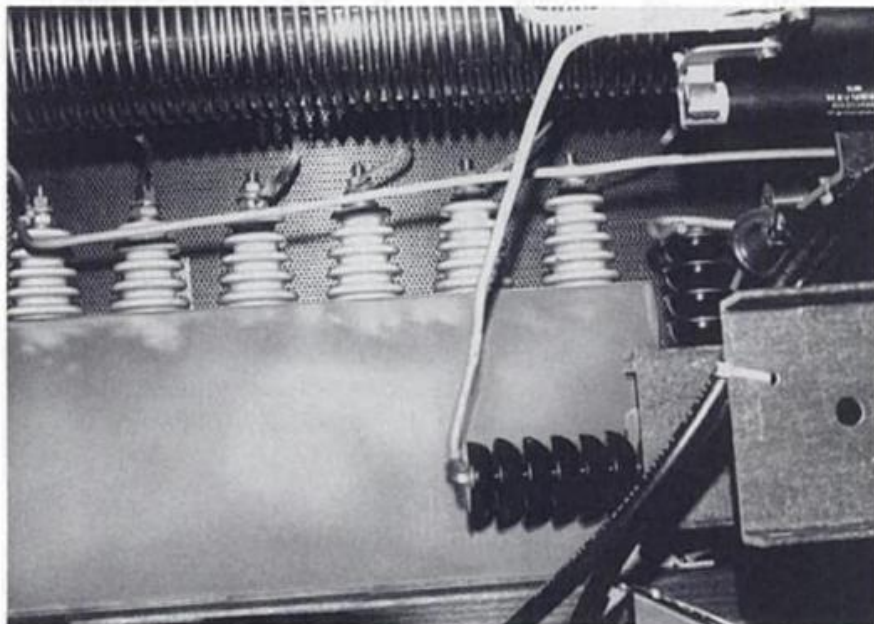
The pulse ends when the last section on the input side is discharged. Output pulse width is determined by the time it takes the voltage to travel from the input, output, and back again. The time is controlled by the number of sections in the line and values of capacitance and inductance of each section. Because each section of the transmission line feels the full potential of the applied voltage, insulation is vital to prevent possible breakdown and damage.

The pulse-forming network (PFN) is similar to the artificial transmission line, as it is constructed from inductors and capacitors. By examining Fig. 2-27, you will notice that the PFN consists of a series of parallel LC networks. Because of this arrangement, individual capacitors (with the exception of C-1, the input capacitor) do not have to be capable of carrying the full value of applied voltage. That is because the total applied voltage is divided equally among the series of LC networks.



2-27 *Electrical characteristics of a pulse-forming network.*

A PFN is a one-piece, nonrepairable, electronic component. As high voltages and currents are encountered, the unit is immersed in oil to provide insulation, and it is hermetically sealed in a metal case. Figure 2-28 is a photograph of a typical PFN. This one is installed in a Linatron, which is a high-powered commercial X-ray system heavily based on radar technology and components. Notice that external connections are provided to couple energy into and out of the assembly. The connections are the six insulated bolts along the side of the PFN. Markings are provided on the case so that characteristics such as pulse width, impedance, voltage, and current are readily accessible by repair personnel. This is important, as manufacturers often fabricate different radar systems, each requiring unique parts. Also, the end user might have multiple radars to support, so it is imperative that parts are legibly marked.



2-28 *Pulse-forming network.*

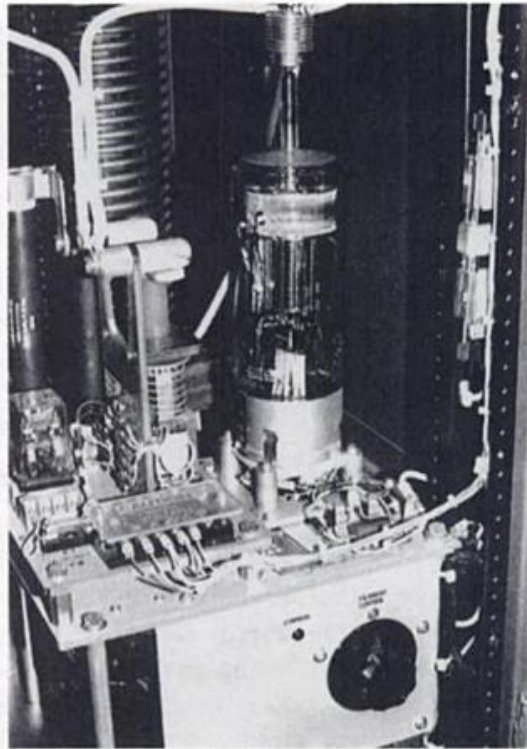
Maintenance is limited to cleaning all surfaces and components to remove dust, dirt, and oils. Cleanliness is vital because any foreign matter can form conductive paths to ground. Unwanted ground paths can lead to high-voltage components arcing, causing equipment damage plus exposure of maintenance personnel to electrical hazards. A leaky PFN must be replaced because the oil insulates the capacitors and inductors from the grounded metal case. If you look closely at Fig. 2-28, you'll notice the number of leads that are visible. All of them carry high voltages and currents. Cleanliness is vital, due to the close proximity of conductors.

During system operation, the energy storage device must alternatively charge and discharge. To allow switching between charge and discharge modes, an electronic switch is required. A suitable electronic switch must be able to rapidly switch states and handle high power. First, the electronic switch must close, or go into conduction, in less than a microsecond to allow the PFN to discharge. Secondly, it must open, or cease conduction in less than a microsecond to allow the PFN to begin the charging cycle. While it is rapidly going from conduction to cutoff, it must be subjected to a current flow in the hundreds of amps at a potential of thousands of volts. Finally, it must operate efficiently, consuming a small amount of power.

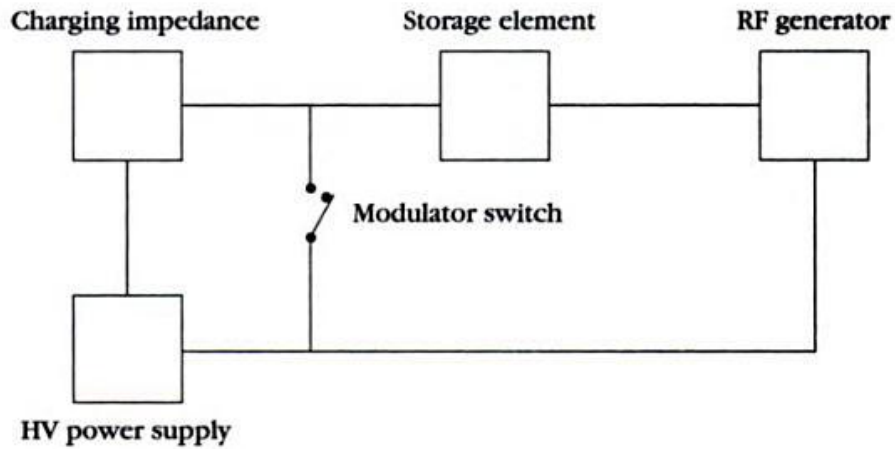
The requirements are best met by an electron tube called a *thyatron*. Figure 2-29 is a photograph of a typical thyatron vacuum tube. This particular tube is installed in a Varian 3000A, High-Energy Linatron. Just below the tube is a three-position switch to control the value of filament voltage applied to the thyatron. The filaments are selectable to compensate for minor differences between tubes. Ideally, a tube will function with the voltage set to midrange. A thyatron is a gas triode or tetrode that is designed specifically for high-powered switching and control applications. It differs from a conventional vacuum tube in the manner in which the control grid functions. Plate current begins to flow almost instantaneously when grid voltage achieves a particular value. At that time, the grid has no further effect on tube operation. Current continues to flow through the device until plate voltage is either cut off or reverses polarity. Operation should sound very familiar, as it functions the same as a solid-state device, the silicon-controlled rectifier (SCR).

Modulator operation

Basic modulator operation will be covered using Figs. 2-30 and 2-31. Figure 2-30 is the simplified block diagram of a modulator. In this illustration, the modulator switch is open, which allows the storage ele-

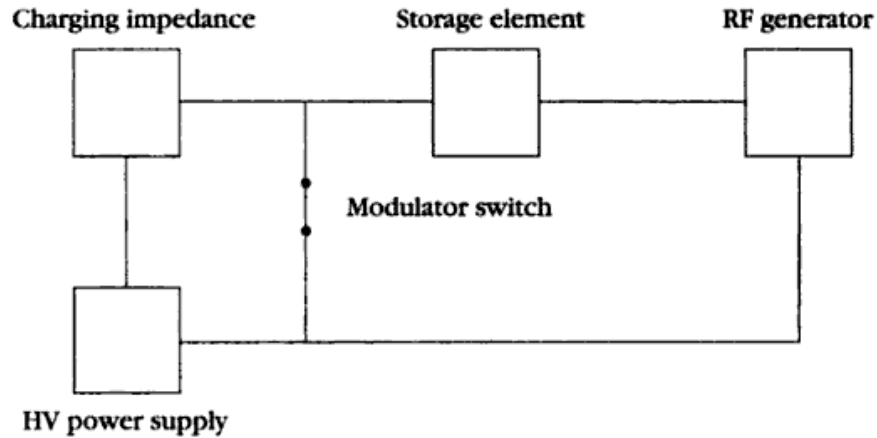


2-29
Thyatron deck.



2-30 Modulator block diagram with electronic switch open and PFN charging.

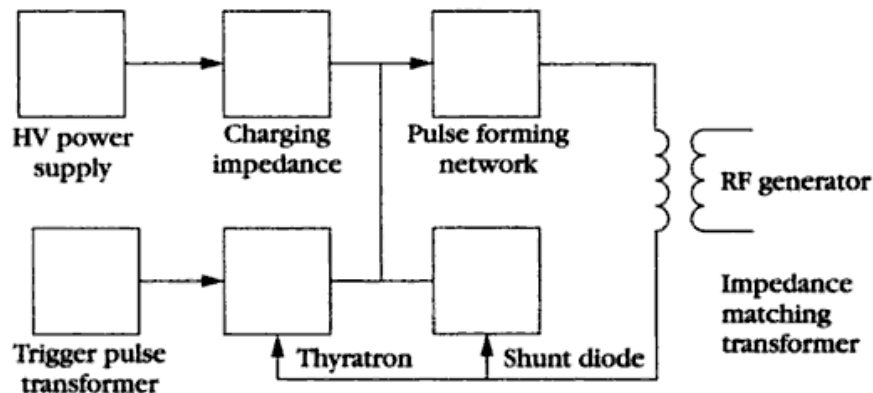
ment to begin charging. The charge path is from the storage element, through the charging impedance, the high voltage power supply, and back to the storage element. Figure 2-31 has the modulator switch closed. That condition occurs when the thyatron fires. The discharge



2-31 Modulator block diagram with electronic switch closed and PFN discharging.

path is from the energy storage element, through the modulator switch, the RF generator, and back to the storage element.

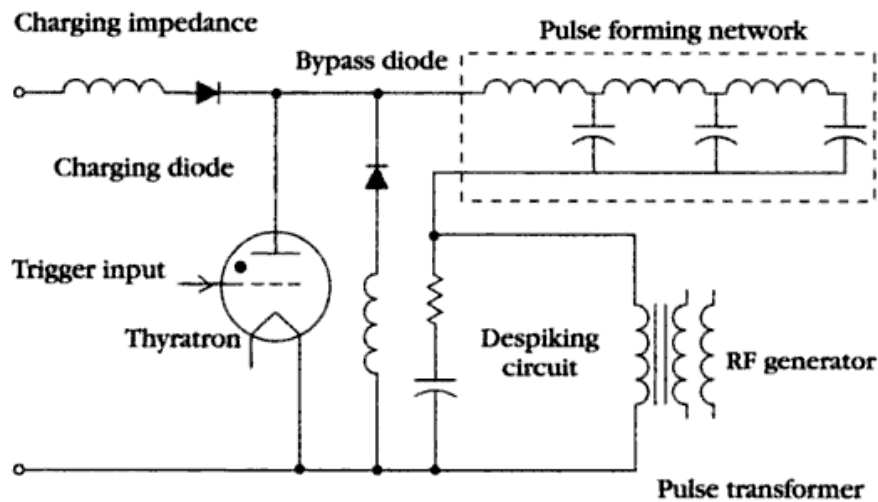
Actual modulator construction is more complex than four blocks, as can be seen in Fig. 2-32. Function operation begins on the left side of the diagram. The high-voltage power supply provides all voltages required by the assembly. The trigger pulse transformer, the lower-left block, couples the trigger pulse into the modulator and steps it up to a level high enough to trigger the thyatron. The PFN stores the high energy needed to form the modulator output pulse. Two new blocks are the shunt diode and the impedance matching transformer. The shunt diode is vital because often, when a PFN discharges, it will swing negative. That is due to the inherent impedance mismatch be-



2-32 Radar modulator block diagram.

tween the PFN and the RF generator. The final block, the matching transformer, is used to reduce or eliminate impedance mismatches between the modulator and the RF generator.

Because the artificial transmission line and PFN-type modulators function the same, only the PFN will be discussed. Figure 2-33 is the schematic diagram of a representative modulator. After the system is energized, dc high voltage is applied to the modulator, charging the PFN. Current flows from the negative terminal, through the primary of the pulse transformer, the PFN, charging diode, the charging impedance, and back to the positive side of the power supply. The internal capacitance and inductance of the PFN form a resonant charging circuit. With the application of dc high voltage, the PFN attempts to complete a sinusoidal rise to nearly twice the value of the input. After one-quarter cycle, the PFN attempts to discharge as the sinusoidal voltage is decreasing, but as the shunt diode is reverse biased, the charge voltage is maintained. The positive trigger developed by the trigger generator is applied to the primary of the pulse transformer. The transformer secondary develops the high-amplitude pulse required to trigger the thyatron into operation. The application of a positive trigger causes the thyatron to conduct, discharging the PFN. The resulting high-voltage, high-current pulse from the PFN is routed to the RF generator via the pulse transformer.



2-33 Radar modulator schematic diagram.

The function of a pulse transformer is to step up the output pulse from the PFN and provide impedance matching between the modu-

lator and the RF generator. The output waveform of a PFN is complex, consisting of many high-frequency components. Because of that fact, transformer design is crucial. To ensure that the pulse has a steep leading edge, leakage inductance must be minimized by the use of close coupling between the primary and secondary windings. That is accomplished by winding the primary directly onto the secondary. The secondary is typically *bifilar winding*. A bifilar winding is constructed with two insulated conductors wound next to each other. That results in the same value of voltage being induced in each one. Both windings act as separate secondaries with the same value of in phase voltage induced in each. The advantage of a bifilar winding is that it eliminates the need for high-voltage insulation.

After the PFN is discharged by the thyatron, it attempts to charge negative because of overshoot. That is because there will be an impedance mismatch between the PFN and the RF generator. To prevent the undesirable overshoot, the diode, called the *charge restorer sbunt diode*, is forward biased and conducts, totally discharging PFN.

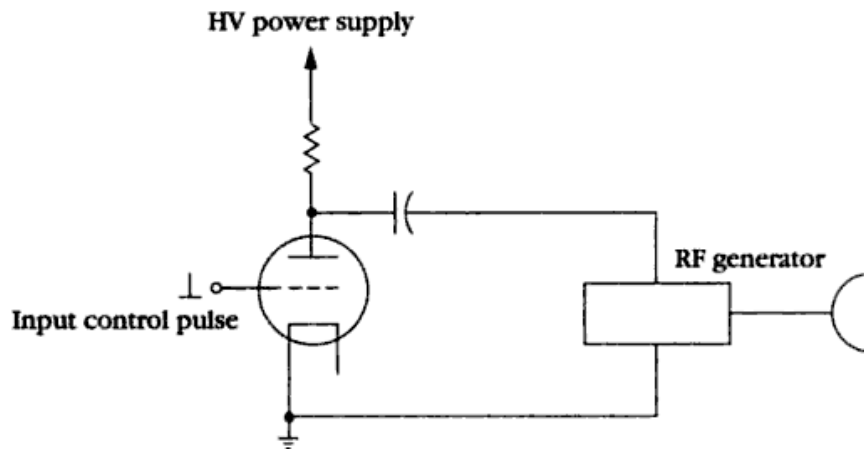
Modulator protection

Although a modulator is designed to withstand high voltages and currents, protection is required to prevent unusual conditions from damaging components. One such condition is *overvoltage*. That happens when the energy storage element charges to a higher-than-normal value. It can cause excessively high pulses to be applied to the magnetron. Such an overvoltage condition can cause the magnetron to internally arc, possibly causing damage to the device. The installation of a spark gap connected across the secondary of the pulse transformer eliminates this problem. Stray capacitance and leakage current in the pulse transformer can cause oscillations to occur after the main pulse fires the RF generator. The resulting negative portion of PFN oscillations can cause spurious outputs from the magnetron. If this should occur, the most pronounced symptom is a loss of close-in targets. A damping diode, connected in parallel with the magnetron, eliminates this problem. The diode is reverse biased during the positive alternations of the modulator pulse. If the pulse goes negative, it is then forward biased and conducts the unwanted pulse to ground.

Despiking is warranted when a spike is present at the leading edge of the modulator pulse. A magnetron has a nonlinear impedance. As a result, under some operating conditions, an impedance mismatch with the output waveguide and antenna might be evident. If a mismatch does exist, the most common symptom is a spike at the leading edge of the pulse. A network to remove, or despike, the

waveform must have a resistance that is equal to the impedance of the PFN. The series capacitor must have a very low capacitance so that it will charge rapidly after the PFN output draws full-load current. With the proper selection of network components, any spikes are passed to ground and eliminated.

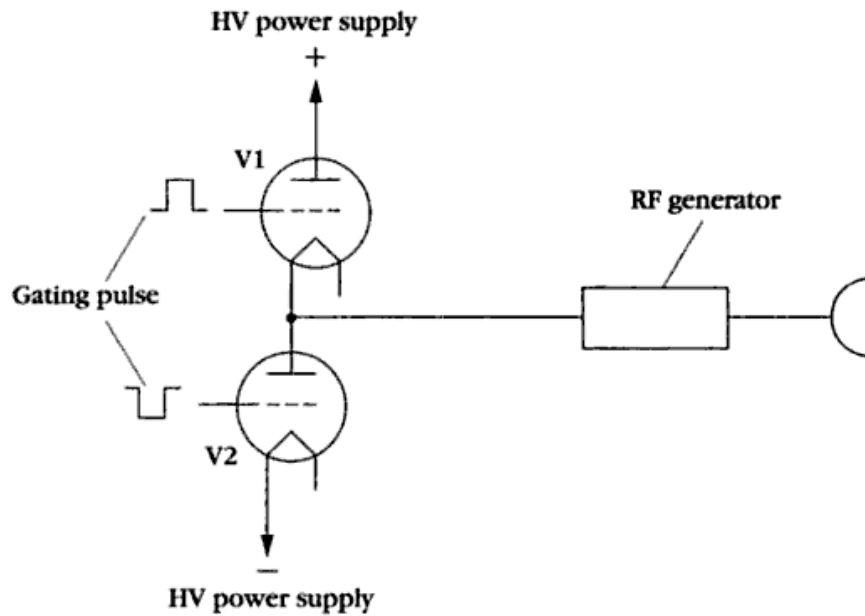
There are several other types of modulators that are in current use. One is called a hard-tube modulator, illustrated in Fig. 2-34. As shown, this circuit is a vacuum tube that is operated as a class C amplifier. Although it is more complex and expensive, it is one of the more versatile modulators. It can be configured with capacitors and transformers as the coupling elements to the load. It is very flexible in terms of duty cycle and pulse widths. Its main drawback would be its sheer size and cost.



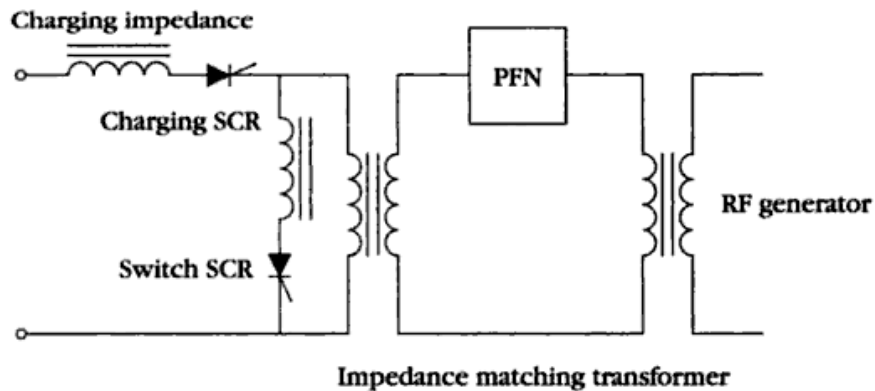
2-34 Hard-tube modulator block diagram.

A variation is the floating deck modulator, and it is illustrated in Fig. 2-35. This type of circuit is associated with RF generators such as the traveling wave tube (TWT) and the klystron. Tube 1 and 2 will never be in conduction at the same time. When the RF generator is not producing an output, tube 1 is conducting, and tube 2 is cut off. To bring the RF generator into operation, tube 1 is cut off, and tube 2 is conducting. Gating pulses are coupled to the tubes using either transformers or capacitors.

Solid-state modulators are gaining in popularity. A representative SCR modulator is depicted in Fig. 2-36. The higher cost of solid-state modulators is offset by an increase in reliability. The main limiting factor is a much lower current and voltage-handling capability. The



2-35 Floating deck modulator block diagram.

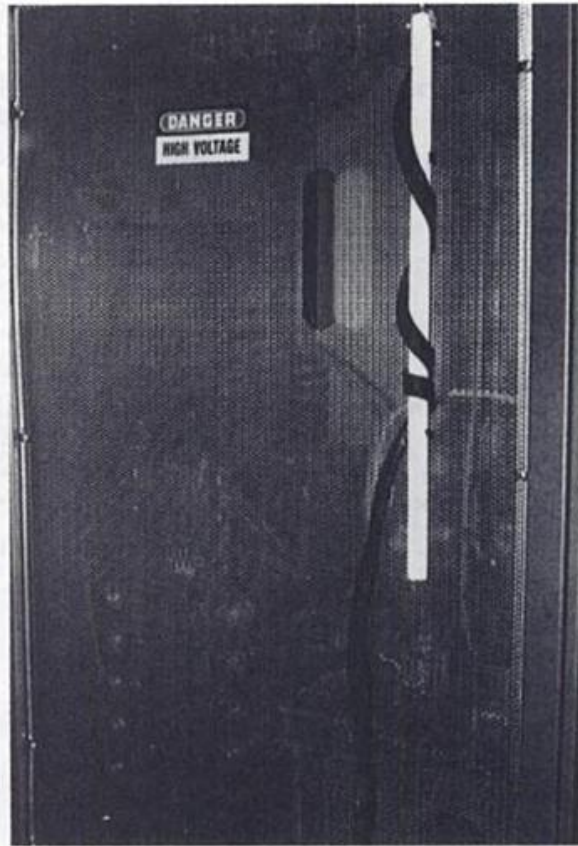


2-36 Magnetic SCR modulator.

lower power capabilities can be compensated for by using saturating magnetic cores in series with the SCRs. The time delay inherent with a charging coil limits the current flow through the SCRs until they are completely turned on.

Troubleshooting hints

Any time maintenance is performed in the modulator, extreme caution is required. Figure 2-37 is a photograph of a modulator section. Notice the screen mesh enclosing the chassis. The screen has several



2-37
*Modulator cage with
shorting probe.*

functions. First, it prevents someone from accidentally coming in contact with high voltage. The mesh is held in place by eight screws, so it will take a conscious effort to enter the section. Secondly, it acts as an RF shield, grounding stray emissions to prevent interference with other equipment. To warn personnel of the possible danger, a high danger sign is prominently displayed.

All radar modulators are constructed from components capable of withstanding high voltages and currents. When the equipment is operating, never attempt to place your hands inside of the modulator subassembly. There is never a reason for anyone to do that. Because of the lethal voltages and currents, the presence of your limbs would provide a convenient path to ground, leading to injury or death. If any internal maintenance must be performed, a grounding stick is permanently installed on the cabinet for maintenance personnel. If you look at Fig. 2-37, the grounding stick is the white stick on the right side of the photograph.

If the modulator is the suspected failed subassembly, is it firing? If you have a vacuum tube thyratron, this is easy to determine. A

properly operating tube should glow purplish. That is because when triggered into conduction, the tube ionizes. If it isn't glowing, ensure that the modulator is receiving triggers of the proper amplitude and timing. Another good check is to ensure that it has the correct filament voltage. Due to differences in manufacturing, not all tubes will fire with the same filament voltage. Another common failure is the charging diode. Ensure that it isn't shorted or open. If you still have not isolated the failure, check all inputs to the subassembly. That includes triggers, low-voltage power supplies, high-voltage power supplies, and filaments.

Arcing in the modulator is more common than you would imagine. The most common cause is cables and wires too close together. If you suspect this problem, turn out lights to verify where it is occurring. With this type of problem, you must be patient because sometimes the arcs are barely visible. When you do locate the offending point, carefully move the cables. Exercise care because in curing one arc, you might cause another.

RF generators

The function of an RF generator is to produce high-energy output pulses of the required waveshape, frequency, and repetition rate. To accomplish this task, it receives a high-powered input from the modulator and outputs the resulting high-energy, high-frequency pulse to the antenna system for transmission through free space. As always with radar equipment, the technology is constantly evolving, improving RF generator operation and characteristics.

Characteristics of a given radar design are determined by the primary application for the system. These vital and important characteristics include: peak power, average power, radiated pulse length, PRF, stability, distortion, tunability, bandwidth, system cost, useful operational life, efficiency, physical size, weight, and (gaining in importance with every passing year) mean time between failure (MTBF). MTBF is becoming more crucial as it drives support requirements such as spare parts, number of maintenance personnel, and level of maintenance training, all costly line items under constant scrutiny.

RF generating devices

Klystron

The klystron was first developed in the early 1950s. Due to its design, it is capable of a higher peak power than a magnetron, up to 20 megawatts (MW). The high power is possible as the major compo-