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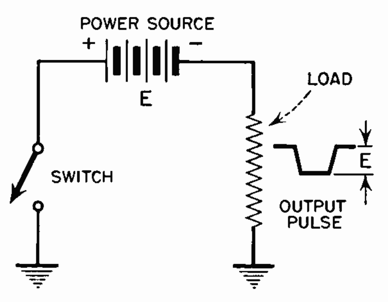
Introduction to Radar Techniques

Part 3. The Pulse Modulator

By the Engineering Department, Aerovox Corporation

THIS series of RESEARCH WORKER articles is devoted to a discussion of the specialized components which comprise the basic radar system. Part 1 consists of a description of the overall equipment used for radio detection and ranging while Part 2 dealt with the principles of the magnetron transmitting tube. The present article discusses the means employed to generate the high voltage d. c. pulses which are applied to the magnetron. This equipment is variously known as the "pulse modulator", "pulser", or "keyer". The techniques used in this equipment to generate pulses which may be as much as 60 kilovolts in peak amplitude and yet only *one-millionth* of a second in duration are typical of radar practices, and so are of interest here.

The basic function of the modulator in a radar set can be illustrated by the elementary circuit of Fig. 1. In this circuit, a source of e.m.f. such as a battery is periodically connected to the load circuit for short intervals by a switch or key. The pulse of voltage which appears across the load circuit will be essentially rectangular if the distributed inductance and capacitance of the circuit is low and this pulse will have a duration equal to the time the switch is closed. For reasons explained in Part 2, most radar modulators are designed to give a negative pulse.



ELEMENTARY PULSE MODULATOR CIRCUIT

FIG.1

In actual practice, the circuit of Fig. 1 is not practical because of the high internal impedance of the battery or other power supply and the difficulty of forming very short pulses mechanically. For these reasons, the circuit is usually modified as in Fig. 2. Here the energy from a d.c. power supply is used to charge a storage device such as a capacitor or *pulse network.* This stored energy is then recurrently connected to the magnetron load circuit for short intervals of time by an electronic switching device. This switching device may take the form of a high vacuum tube or a gas thyratron. Which form of switch tube is used determines the general category into which any particular modulator design falls. Since the characteristics of these two types differ considerably, they will be considered separately.

The "Hard Tube" Modulator

Any form of pulser or modulator which utilizes high vacuum tubes for the function of switching the high pulse currents required by the magnetron is classed as a "hard tube" modulator. The simplified circuit of a pulser of this type is shown in Fig. 3. In this type, the grid of the vacuum tube, which is normally biased to cut-off, is driven positive by a pulse from a "driver" circuit. The

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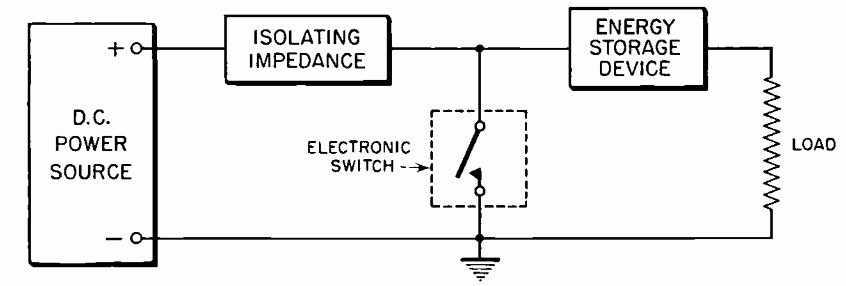


GENERALIZED PULSER CIRCUIT

FIG. 2

storage device is thus connected to the load circuit for the duration of the positive driver pulse, and a negative pulse appears across the load. The storage device is usually a large capacitor which is capable of supplying the energy needed by the load during the pulse with only a small drop in voltage. This voltage drop is frequently only a few percent.

The storage capacitor recharges from the d.c. source in the interval between pulses. This *interpulse interval* is usually very long compared to the duration of the pulses. This makes it possible to isolate the d.c. recharging circuit (shown in light lines in Fig. 3) from the pulse circuit (heavy lines) during the pulses by means of isolating elements such as L1 and R1, which have very high impedances for short pulses. The average current drawn by the magnetron is measured by the meter (M) indirectly, since this meter indicates the current from the d.c. source required to replenish the charge on the storage condenser. This current is equal to the magnetron average current since the condenser discharges only through the magnetron.

The tube or tubes in the output stage of a hard tube modulator must be capable of withstanding an anode voltage equal to the voltage of the required output pulses. They must also be capable of conducting the peak pulse current required by the magnetron. In radar practice, large transmitting-type triodes or tetrodes are usually employed. Type having tungsten or thoriated-tungsten filaments are the most practical for this application because the high voltages involved make the use of oxide coated emitters somewhat marginal. The pulser tubes are usually biased to cut-off or beyond, so that plate current flows only during pulses.

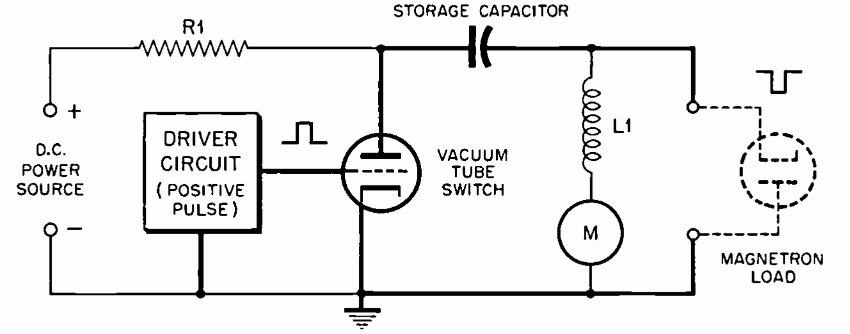
The driver circuit used to drive the modulator tubes to conduction during pulses may be one of several types. In one system the rectangular pulses are formed at low level by a small gas tube or blocking oscillator and amplified to the required driving level by several hard tube stages biased to cut-off. Another method utilizes a medium power hard tube in a special blocking oscillator circuit to form the drived pulses. A third approach makes use of a small thyratron pulser, of the type to be discussed later, to drive the hard tube final stage. In any of these driver systems, the pulse repetition rate is determined by a "trigger" pulse which is introduced into the first driver stage to insure that the transmitter pulse is synchronized with the range sweep on the oscilloscope. This synchronizing pulse is usually generated in the display section of the radar system.

The Thyratron Modulator

Radar pulsers which use gas-filled tubes for the purpose of pulse switching are known as "thyratron" or "line type" modulators. The gas most frequently employed is hydrogen. Relatively small tubes are capable of conducting peak pulse currents of hundreds of amperes with small voltage drop. In addition, only a small trigger pulse is required to drive thyratrons to heavy conduction. The thyratron differs from the hard tube, however, in that the grid loses control after conduction has been initiated. This characteristic results in the basic circuit of the thyratron-type modulator differing considerably from that of the vacuum tube modulator, as is illustrated in Fig. 4.

Since the grid of the thyratron is incapable of interrupting the plate current at the end of the driver pulse, the storage device must be of a type which discharges entirely during each pulse. Otherwise, the gas in the thyratron would remain ionized as long as a voltage existed across the tube. A simple capacitor like that used for energy storage in the hard tube modulator cannot be employed, since the discharge pulse would be exponential in shape rather than rectangular. However, if a length of open-circuited transmission line is charged to a high voltage and suddenly connected to a load impedance equal to its characteristic impedance, an essentially rectangular current pulse flows through the load. The duration of the pulse so formed is equal to twice the time required for an electrical impulse to travel the length of the line. This time is determined by the *propagation constant* for the type of transmission line used. In actual practice, the transmission line is usually replaced by an *artificial line* made up of lumped inductances and capacitors for all but very short pulses. This is because an actual line is inconveniently long for the pulse lengths most frequently employed, whereas the simulated delay line, or *pulse forming network* as it is sometimes called, is quite compact even for 10 microsecond pulses. Fig. 5 shows one of the possible connections for a pulse network and some of the design constants involved.

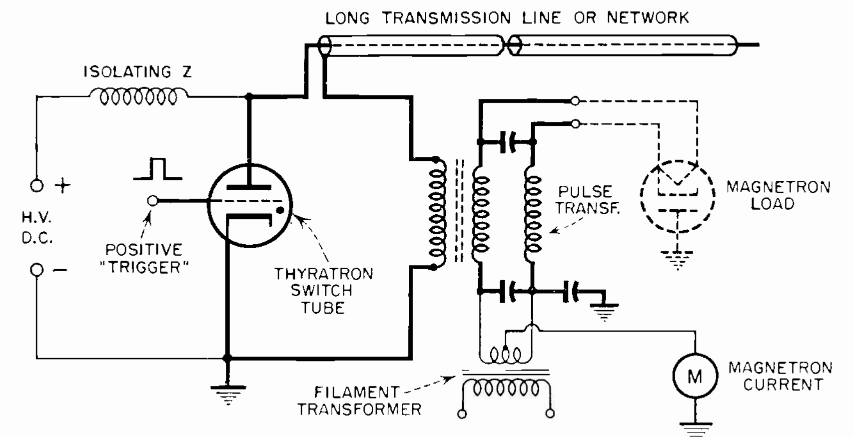
The pulse forming network will deliver maximum energy to the magnetron only if its impedance matches that of the magnetron. Since the usual magnetron impedance is between 500 and 1000 ohms, while the design of the pulse line is most practical for low impedances of 25 or 50 ohms, an impedance matching device



BASIC "HARD TUBE" PULSER

FIG. 3

must be used between the line and the load. This requirement has led to the development of the *pulse transformer,* which transforms the impedance of the magnetron load to that of the source. The transformer is specially designed to pass the square pulses. It is carefully designed to minimize leakage inductance while maintaining shunt inductance at a maximum. A special core material having very thin laminations is used to obtain sufficient permeability to pass frequency components up to several megacycles present in pulses having fast rise time. Pulse transformers which faithfully reproduce pulses ranging from a few hundredths of a microsecond to about 10 microseconds are available, although individual designs are satisfactory over a much smaller range. Turns ratios from about 2:1 up to something like 6:1 are practical. The physical appearance of a typical pulse transformer is shown in Fig. 6. As indicated in Fig. 4, the secondary of the transformer is usually *bifilar* wound. This means that the secondary consists of two wires wound as one. This permits the magnetron heater current to be sent through the secondary windings of the pulse transformer from a filament transformer having low voltage insulation. Otherwise, a specially built low capacity filament transformer, insulated for the full pulse voltage, would be required.



BASIC THYRATRON RADAR MODULATOR

FIG. 4

Comparison of Modulator Types

Because of the differences in basic circuits, the performances of the two general modulator types differ considerably. Each has certain disadvantages not inherent in the other. The important characteristics may be compared as follows:

(a) *Efficiency.* The thyratron type is inherently the most efficient. It requires fewer stages and consequently less drain from power source. The voltage drop in the switch tube is less than in the hard tube case, resulting in less power dissipation.

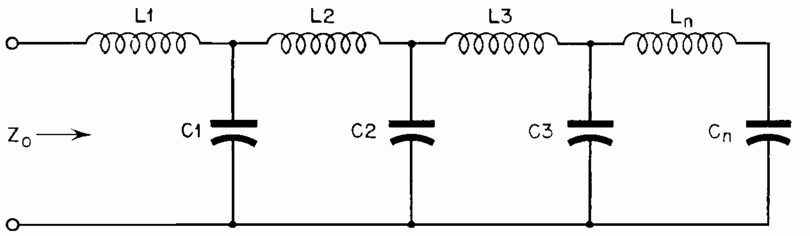
(b) *Impedance Sensitivity.* The hard tube modulator has the advantage in this respect since it can operate fairly efficiently into load impedances varying over a wide range. For good efficiency and satisfactory pulse shape, the line type pulser must match the load impedance to within about ±30%. Thus, the line modulator has a disadvantage in applications where many magnetron types are encountered, such as laboratory testing.

(c) *Adaptability.* The hard tube modulator is the most adaptable to different pulse durations and repetition rates. Since the pulses are formed at low level small components can be switched for varying pulse durations. In the line pulser the pulse forming network and, in some instances, the pulse transformer, must be changed to effect a change in pulse duration. In addition, the pulse line is usually designed for operation only over a small range of repetition rates.

(d) *Voltage Requirements.* The thyratron modulator requires a lower voltage d.c. supply since the pulse transformer steps the pulse voltage up to the required level. In the hard tube system, the d.c. source must furnish a d.c. voltage equal to the required pulse voltage.

(e) *Arcing Behaviour.* In case of internal magnetron arcing, the hard tube modulator is more severe than the thyratron type since the entire charge of the storage capacitor can discharge through the magnetron, with damaging effects on the magnetron cathode. The energy stored in the pulse forming network, on the other hand, is only the amount required for each pulse.

As a result of these characteristics, the thyratron pulser is usually favored for field radar applications where its greater efficiency simplicity, and light weight give it the advantage. The hard tube modulator is useful in laboratory applications because of its versatility and in instances where very high repetition rates make the gas tube type inapplicable.



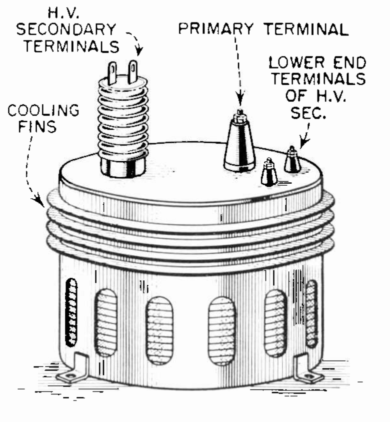
$Z_0 = \sqrt{L/C}$ $t = 2_n\sqrt{LC}$ = pulse length

$L = L1 = L2 = L3 = L_n$

$C = C1 = C2 = C3 = C_n$

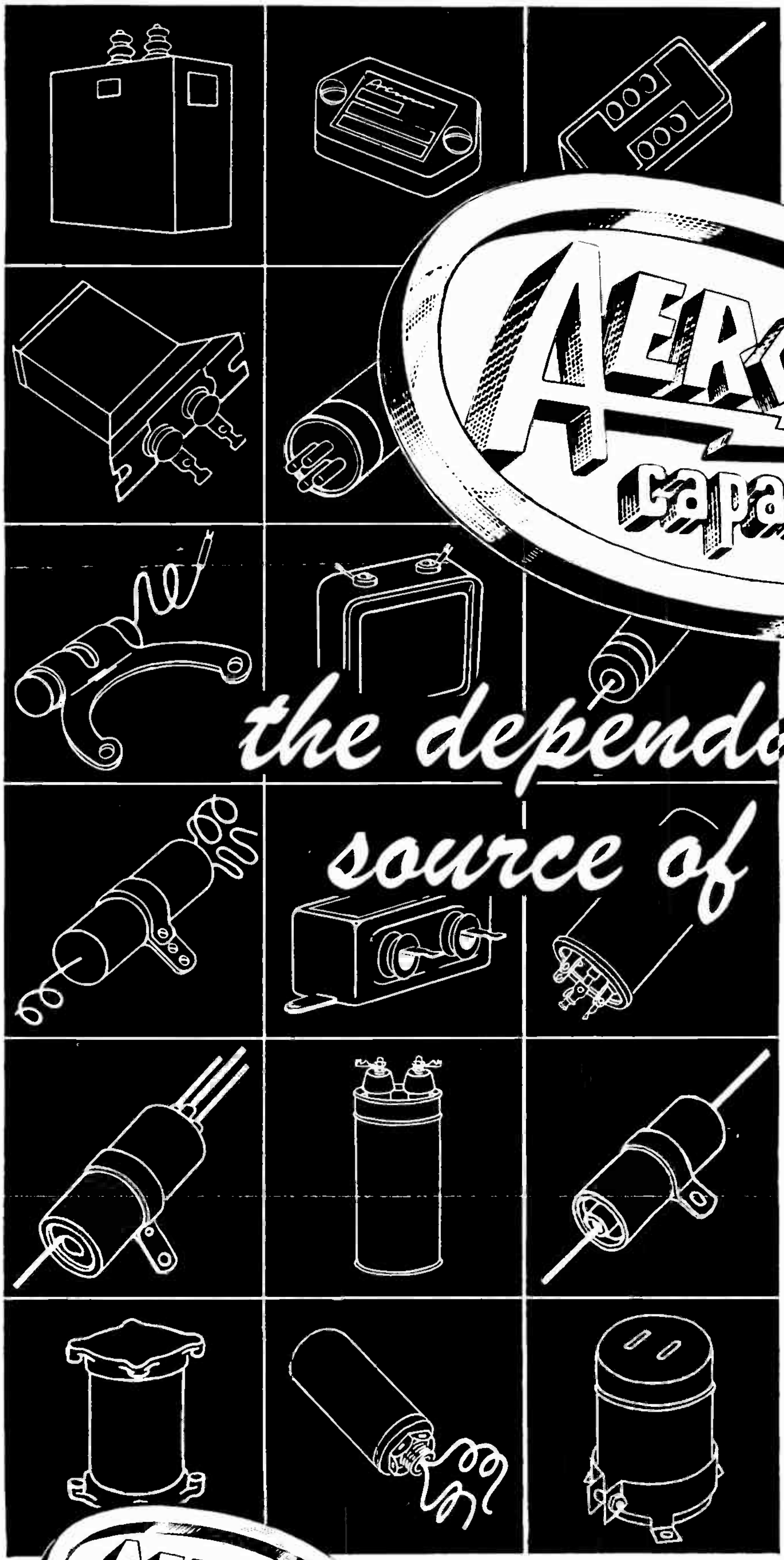
SIMPLE LUMPED CONSTANT PULSE NETWORK

FIG. 5



TYPICAL PULSE TRANSFORMER

FIG. 6



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