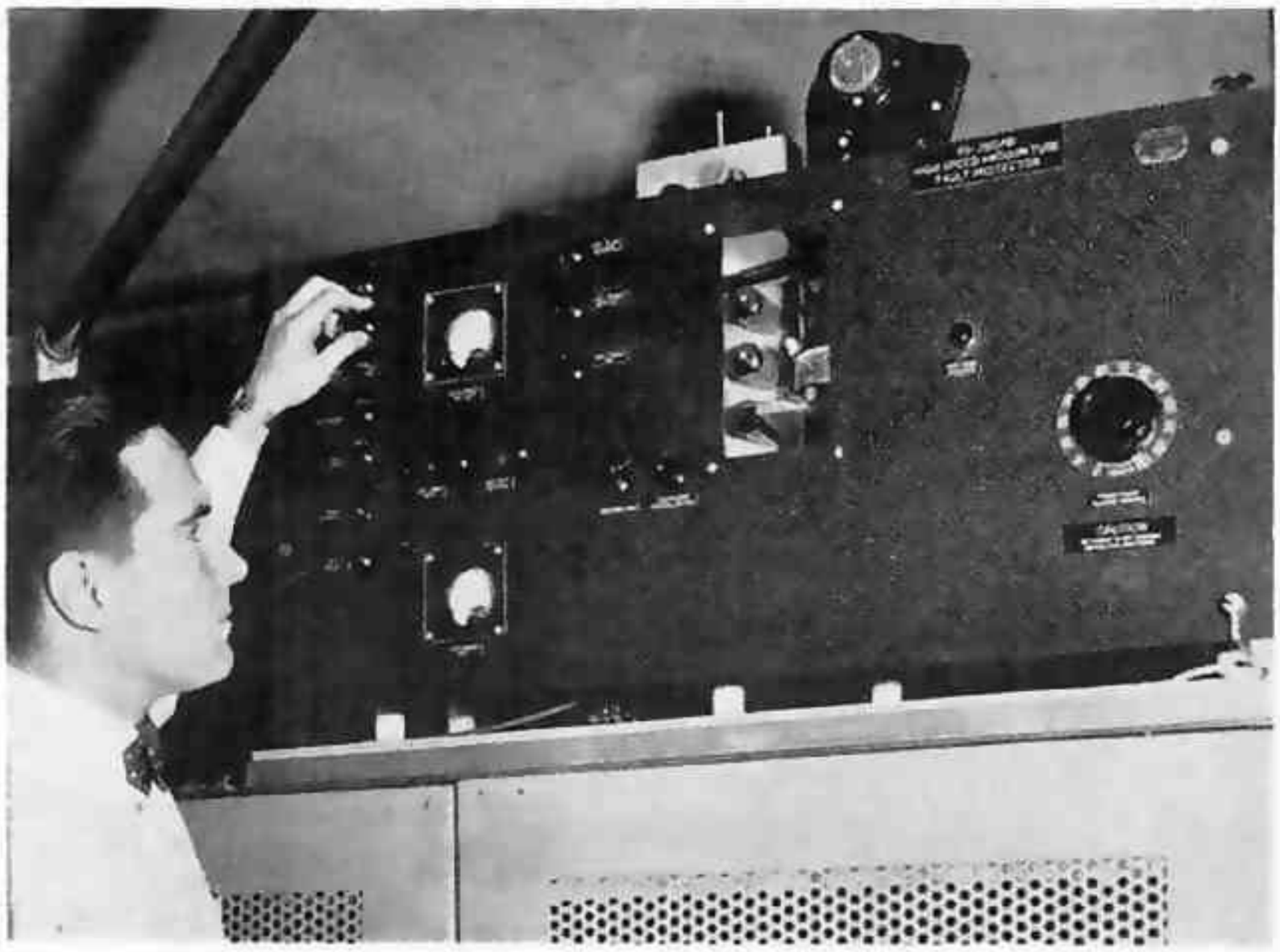


Operator sets fault-protector controls to fix cutoff bias and establish maximum permissible load current. Excess current caused by tube fault is removed from high-voltage circuit rapidly enough to protect tube electrode supports from spontaneous breakdown. The 20-kv chassis-support insulators are visible behind the grounded control panel



Photograph shows the results of a short-circuit at 5,000-volt operation. Here the fault protector was not incorporated as a part of the circuit

ELECTRONIC CROWBAR

SUMMARY —— Electronic switch guards high-power c-w transmitting tubes against flash-arc destruction. Self-protective circuit uses grid-cutoff of power triode to remove excessive voltage within four microseconds after fault occurs. Wide-range time control permits tube recovery and continuity of operation for extended period. Tube-processing use features high-power beam-voltage pulser for gas cleanup as well as high-level beam-voltage modulator for high-power backward-wave oscillator applications

FLASH ARC, commonly called Rocky Point effect, appears to be the result of a spontaneous breakdown of the insulation normally afforded by the high vacuum within an electron tube.

Currents resulting from flash arc may approach several thousand amperes during initial transient conditions and with the available energy inherent in conventional power-supply systems, severe damage may result. In some cases the arc contains sufficient energy to vaporize segments of electrode support members, rendering the tube useless.

Milder effects of flash arc, may manifest themselves in the form of cathode poisoning which will determine the useful life of the tube. Until a better understanding of flash arc and its causes is available, the power tube must be protected.

A circuit known as the electronic crowbar was introduced to provide this protection. Its function, in the event of a fault, was to remove instantly the available energy from the protected tube by short circuiting the power supply with a device, such as a thyratron or ignitron, which would dissipate the power. Installation of this device in high-power transmitter installations has markedly increased the operating life of the power tube and reportedly has reduced out-of-service time.

Protection Circuit

In the event of a fault, the available energy is removed from the protected tube within microseconds. In addition, a wide range of time

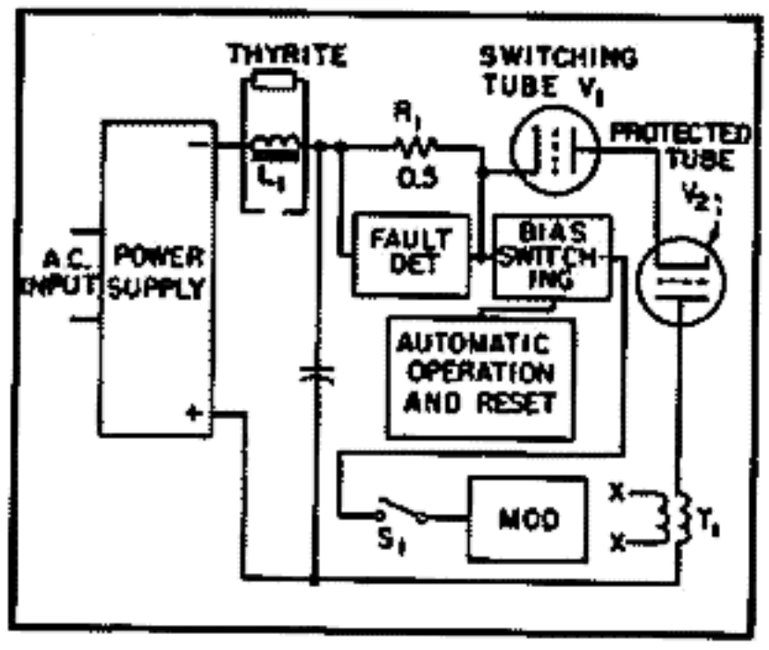


FIG. 1—Incipient breakdown of high-voltage transmitting tube V_2 produces unwanted voltage rise which activates the fault detector. Bias switch drives grid of V_1 beyond cutoff and removes supply voltage from V_2 before irreparable damage occurs. The entire chain of events occurs rapidly enough to prevent damage to the tube

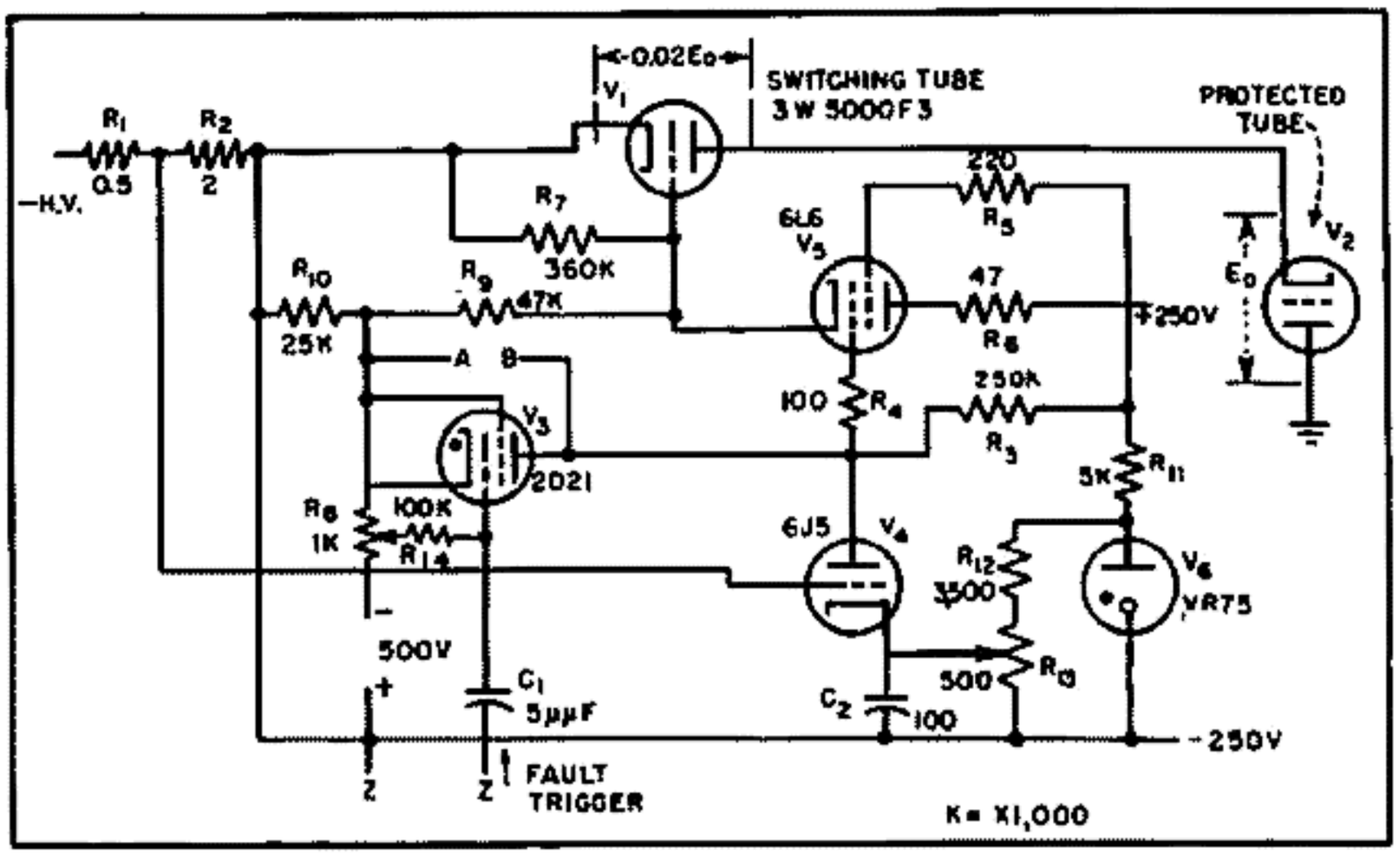


FIG. 2—Bias switching circuit shown with power triode V_1 protecting high-voltage transmitting tube V_2. Resistor R_{13} establishes grid voltage for V_1 and R_8 determines bias

By ROGER G. WENNER

Federal Telecommunication Laboratories
Div. of International Tel. and Tel. Corp.
Nutley, N. J.

PROTECTS TRANSMITTER

control permits tube recovery or provides automatic operation for extended periods during unattended operation.

A high-power beam-voltage pulse, with duty cycles to unify, is used for gas clean-up while the tube is on exhaust. A high level beam-voltage modulator is incorporated for high-power backward-wave oscillator applications.

The modified electronic crowbar is shown in Fig. 1. When a fault occurs, current increase through R_1 produces an undesirable voltage rise which actuates the fault detector. The bias-switching circuit then applies a negative bias to the normally positive grid of switching tube V_1.

The automatic reset and operation circuit shuts the system off in the event of a recurrent fault.

For operation as a beam-voltage pulser switch S_1 is closed.

This allows pulses of predetermined width and repetition rate, produced by the modulator, to control the grid of V_1 through the bias switching circuit.

Although not incorporated in the present working model, a shaped pulse of low magnitude could be applied to the switching circuit to provide large voltage variations across V_2, a valuable feature for backward-wave oscillator applications. The thyrite arc suppressor shown connected across L_1 was not used in the original circuit. No adverse effects were noticed in handling load powers up to 20 kw with average load currents of 2½ amperes.

The entire system operates above ground and is completely isolated from attending personnel. Insulated phenolic shafts are used to make operating adjustments. The system can be operated at ground potential by inserting it between ground and the positive return of the high-voltage supply.

Fault-sensing resistor R_1, can be eliminated by using transformer T_1. The fault may be sensed at the ground return of the protected tube. Tube-current variation appears across the T_1 winding.

Bias Switching

The bias switching circuit, together with switching tube V_1 and protected tube V_2, are shown in Fig. 2.

Switching tube V_1 normally conducts with about 2 percent of the load voltage appearing as a plate-to-cathode voltage drop. This relationship is maintained throughout normal operation by varying the positive grid bias on V_1. As the load supply voltage is raised and more current is required, the positive grid bias increases proportionally.

As the load current through R_8 increases, a larger negative bias voltage is applied to the grid of V_1 which decreases the plate current and causes a reduced voltage drop across the plate load resistor R_8. The control grid voltage of V_2 decreases the voltage drop across V_2

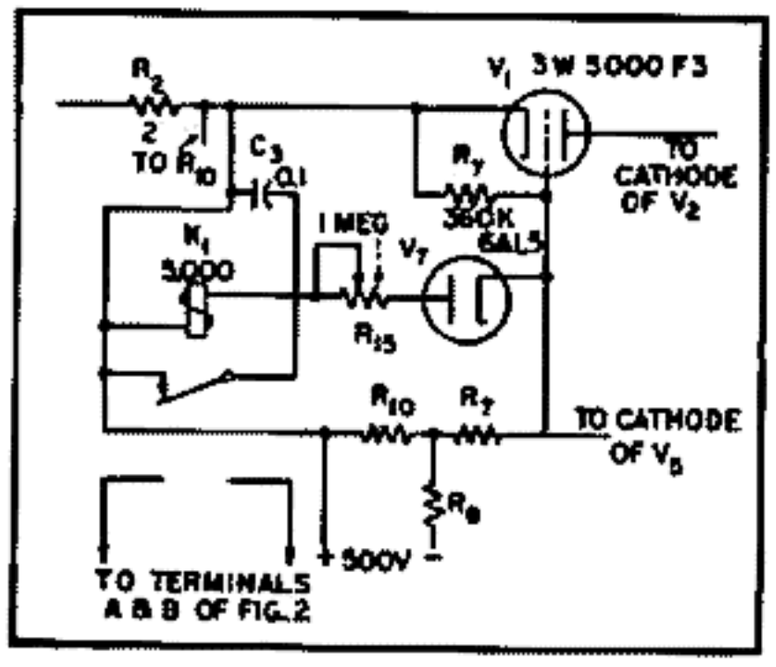


FIG. 3—Reset circuit returns the tube-protection system to normal operation. Relay K_1 shorts terminals A and B, while potentiometer R_{15} establishes the time

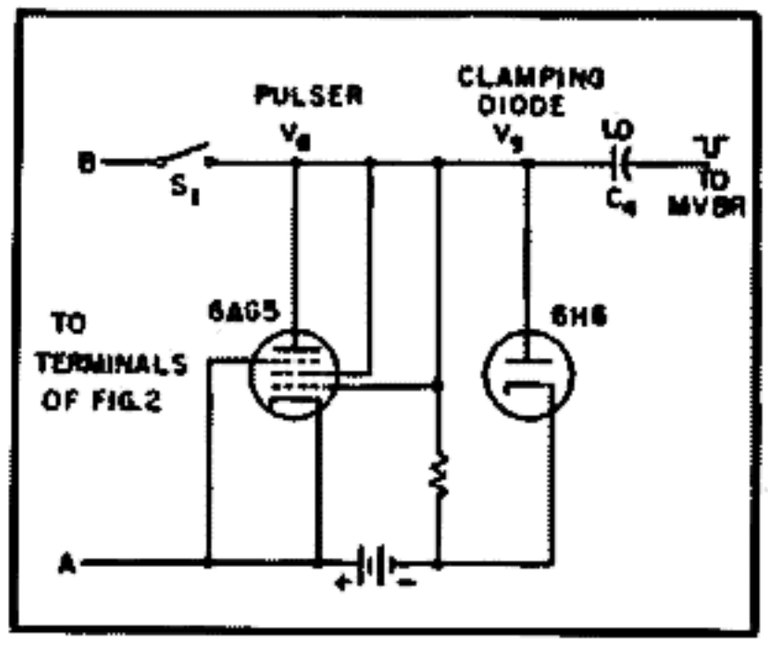


FIG. 4—Modulator allows predetermined pulses to control the grid of switching tube V_1 (shown in Fig. 3) through the bias switching circuit

and places a larger percentage of the available + 250 volts across R_7. Resistors R_{11}, R_8 and R_9 are parasitic suppressors. Potentiometer R_{15} establishes the potential grid voltage for V_1, the value being determined by the grid characteristics of V_1.

Power-handling capabilities of V_1 are determined by the voltage and current of load V_2. For a load of 10 kv at 2 amperes, V_1 dissipates a minimum of 2 percent of the load power, or 400 watts. A safety factor of two or three is used. Switching tube V_1 withstands maximum no-load plate-to-cathode voltage which occurs under cutoff conditions.

When a fault begins, a positive triggering pulse of short duration is applied to the control grid of switching thyratron V_6. This trigger pulse is obtained from the fault detector. Positive triggering overcomes the normally high-negative bias which holds V_6 at cutoff and V_6 conducts. This fixed bias voltage is determined by R_6. When V_6 fires, V_6 is driven to cutoff. A portion of the negative voltages from the — 500-volt supply appears across R_7. Its value is proportional to R_7 divided by $(R_7 + R_8)$. This valve is chosen to drive the grid of V_1 well beyond cutoff, starving the arc.

Reset Relay

The system is returned to normal operation after the fault is removed by momentarily extinguishing V_6, using relay K_1 in Fig. 3 which shorts terminals A and B. The reset time can be adjusted manually to any value greater than the actuation time of the relay. This relay operates in the m-sec range.

Variable potentiometer R_{15} establishes the time required for the voltage to rise exponentially across C_3 to a value sufficient to actuate relay K_1. Tube V_7 conducts only when the grid of V_1 is negative at the incipience of a fault. If the fault is recurrent, V_6 (Fig. 2) conducts immediately and the cycle is repeated.

The fault-counting circuit may shut off the entire system if the fault recurs beyond a predetermined number of cycles.

Modulator

The fault protector operates as a beam-voltage pulser by shorting terminals A and B in Fig. 3. As shown in Fig. 4 the pulse control tube V_6 is normally conducting and E_6 is zero. A negative pulse of predetermined width determines the on time of E_6 and is applied to the control grid of V_6 through C_4 by a multivibrator. The duty cycle is varied by changing the multivibrator frequency, pulse width or both. Clamping diode V_9 establishes a reference level.

The basic fault detector responds to the load current exceeding a predetermined value. The degree of protection this circuit affords is determined by the maximum allowable current and by the time-delay response of the circuit. A typical circuit is shown in Fig. 5.

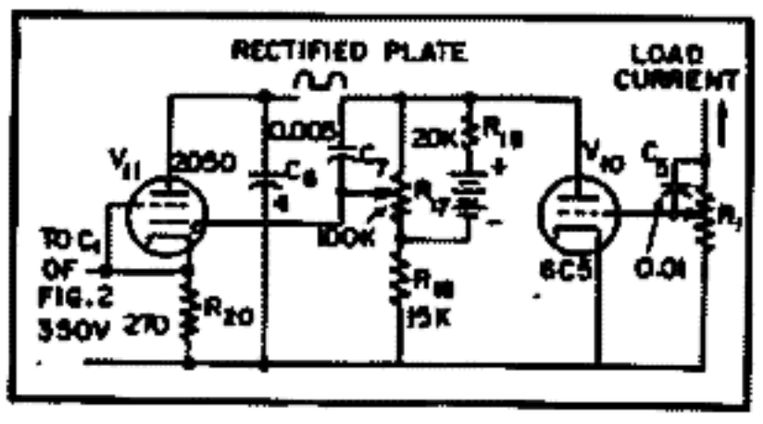


FIG. 5—Thyratron V_{11} in fault detector circuit will fire only above the peak current limit set by R_1. Cutoff bias for thyratron is fixed at R_{17}

Peak Current Limit

As the load current increases, the negative voltage across R_1 increases, causing the current through V_{11} to decrease. Voltage distribution across network R_{17}, R_{16}, R_1, and V_{11} reduce the initial negative bias on the control grid of V_{11} and fires thyratron V^{11}. A large positive pulse is developed across R_{10} which is applied through blocking capacitor C_1 to the switching circuit shown in Figure 2. Potentiometer R_{17} fixes the required cutoff bias for V_{11}. The peak current limit control R_1 establishes maximum permissible load current beyond which V_{11} will fire.

The value of C_4 is sufficiently low so that its discharge time through V_{11} and R_{10} is appreciably less than one-half cycle of the half-wave voltage applied to the plate of V_{11}. This extinguishes V_{11}.

Sensitivity may be increased by employing a slope detector which consists of a high gain a-c amplifier in conjunction with a differentiation network. Network time constants are adjusted so that a gradual variation of load current receives little amplification. However, a low-level excursion having a short rise-time is amplified to a value sufficient to fire V_{11}.

Where the protected tube is to be used at radio-frequencies, a differential fault detector may be used. Here the fault produces a rapid decline in r-f output. A differential amplifier compares a portion of the rectified r-f output voltage with a portion of the load voltage. Voltage unbalance resulting from a decrease in r-f output allows this differential amplifier to fire V_{11}.

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