Fail-Safe Operation of
Electronic Control Circuits

In equipment employing thyratron tubes, circuits shown here protect equipment and prevent unwanted operation in event of tube or component failure.

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Fail-Safe Operation of Electronic Control Circuits

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As ELECTRONIC control circuits are finding increased application in industry, it is becoming more evident that ability to perform a specific task is not all that is required of an electronic device. In many cases it is highly important that, in addition to performing its assigned function, an electronic device must also protect the associated equipment in case of operational failure. Furthermore, it is often required that the device make some positive indication of its inoperative condition when it fails. Fail-safe circuit design, consequently, is receiving ever-increasing attention because of both economic and personnel safety considerations. The methods outlined here for the design of a fail-safe thyratron relay-control circuit are also adaptable to many other types of electronic control circuits.

Conventional circuit in which a thyratron, an RCA-2D21 in this case, is connected as a switching tube to control a relay or contactor is shown in Fig. 1. In this circuit anode voltage is supplied by the high voltage winding of a power transformer. The relay or contactor is usually of the shaded pole or double coil type and is connected in series with the thyratron anode. The tube is kept from conducting by applying to the control grid either a negative d-c signal or an a-c signal that is 180 deg out of phase with the anode voltage. Although this simple circuit works satisfactorily, it is far from fail safe. Its outstanding fault, of course, is that loss of signal will result in relay operation.

Another arrangement of this circuit which does provide protection for loss of signal is shown in Fig. 2. In this circuit, a grid bias 180 deg out of phase with the anode voltage is used and the signal is then required to overcome the bias in order to cause relay operation. Although this circuit is an improvement over the circuit of Fig. 1, undesirable features remain. The most likely source of failure in this circuit is an open circuit in the potentiometer or in the signal source. Either eventuality would cause the tube to conduct continuously.

Operating Grid With Positive Voltage

To eliminate these faults, it is advisable to rearrange the circuit so that the thyratron is operated with its grid positive. In this arrangement, as shown in Fig. 3, the tube is kept from conducting by operating the No. 2 or shield grid slightly negative while the anode is positive. The shield grid of the thyratron is connected to the center tap of the filament winding and the voltage is phased so that the shield grid is negative when the anode is positive. Dynamic characteristic curves of the RCA-2D21 thyratron used as a positive grid tube are

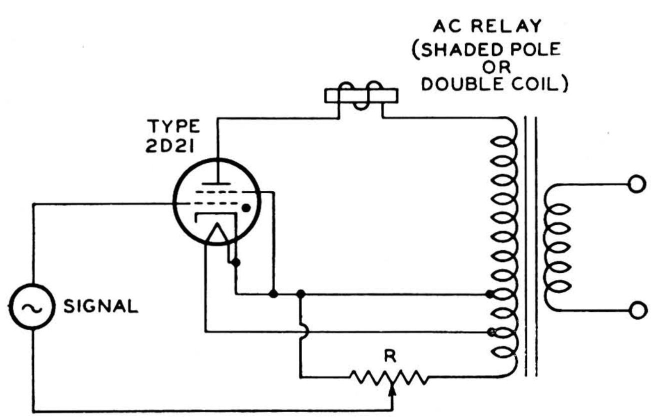

Fig. 1—*In conventional thyratron circuit with negative grid bias, loss of signal will result in relay operation.*

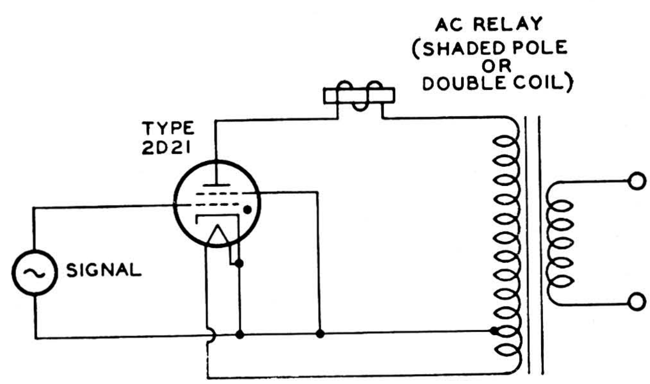

Fig. 2—*Applying grid bias 180 deg out of phase with anode voltage, relay will not operate with loss of signal, but an open circuit in the signal source causes operation.*

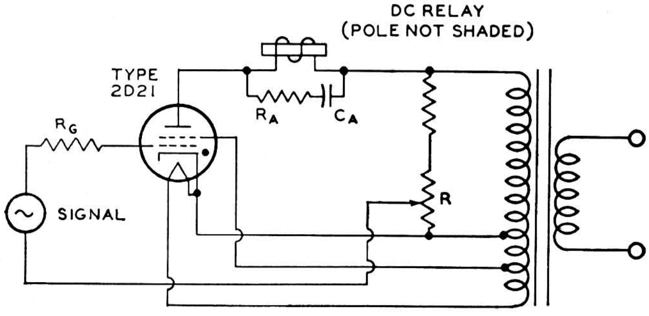

Fig. 3—*Operating the tube with positive grid prevents operation in event of loss of signal. Bias voltage is critical, however, and must be adjustable.*

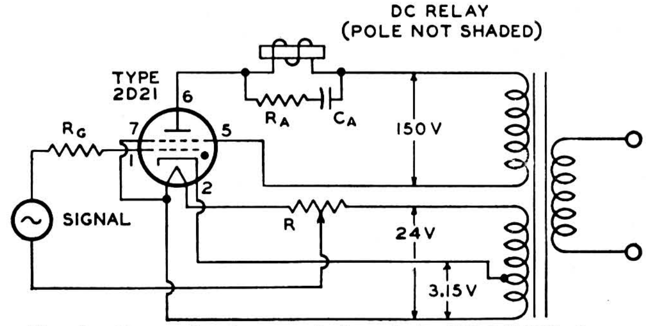

Fig. 4—*Dynamic characteristics of the RCA-2D21 thyratron used in a positive grid circuit. Loss of a positive signal will not cause the tube to fire.*

given in Fig. 4. These curves show that loss of signal will *not* cause the tube to fire and operate the relay.

In the circuit of Fig. 3, a shield grid voltage in the order of 3 to 6 volts rms should be used. With a value of shield grid voltage less than 3 volts rms, the tube will conduct at the beginning of the cycle as indicated in Fig. 5 by the sharp drop in the dynamic characteristic curve. With a shield grid voltage in excess of 6 volts rms, the tube is likely to conduct during the half cycle that the shield grid goes positive. Because no limiting resistor is provided in the shield grid circuit, damage to the thyratron would result.

If signal voltages of large magnitude were available, in-phase control grid bias would not be required. In most cases, however, it is desirable to obtain maximum sensitivity. In order to operate the thyratron at maximum sensitivity, an in-phase bias control resistor *R* is utilized. This resistor provides sufficient bias voltage so that a signal of a volt or two will be ample for the thyratron throughout its life. The potentiometer for controlling the in-phase bias on the control grid also provides bias adjustment when a new tube is placed in service.

As a thyratron ages, the critical grid voltage advances in the positive direction. Therefore, with a positive-grid

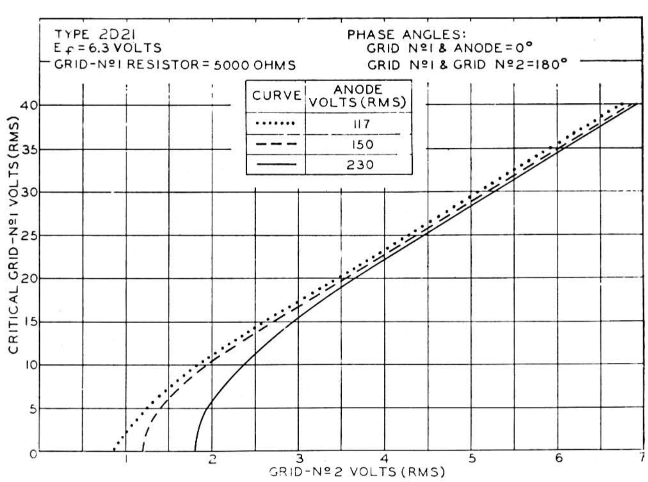

Fig. 5—*When the anode return is made through the shield grid, a short occurring in the shield grid circuit will burn through the cathode lead and cause the circuit to fail safe.*

circuit the advance causes the tube to require more signal for conduction and, of course, eventually when the signal used is not sufficient to fire the tube, the circuit will fail safe.

In the circuit of Fig. 3, the relay or contactor in the anode circuit has no shaded pole and is shunted with an *RC* filter. This filter is another fail-safe feature. If the inverse impedance of the thyratron becomes low because of inverse breakdown or a short circuit, an a-c component of voltage would appear across the relay but the current would be shunted through the *RC* filter and the relay would, therefore, remain de-energized.

Even though the circuit of Fig. 3 provides protection against failure of signal voltage, it has other features that are not desirable for fail-safe operation. For instance, if a short occurs in the shield grid circuit, the shield grid bias is lost and the relay closes whether or not the signal is present. A circuit which is protected against this type of fault is shown in Fig. 5. In this circuit, the anode return is made through the shield grid of the thyratron. This arrangement is possible because the RCA-2D21 has two shield grid leads. With this arrangement, a short-circuit between shield grid pin 5 or 7 and cathode pin 2 would result in a safe condition because the connection between the cathode and base pin inside the thyratron is a thin nickel strip which would burn out when connected directly across the 3.15-volt section of the filament winding. If the transformer is designed so that under short-circuit conditions at least 10 amp will flow, enough current is available to burn out the thin nickel between base pin and cathode and thereby open the cathode circuit. In addition, a heater-cathode short between pins 2 and 4 would also result in fail-safe operation, although in this case the heater would probably burn open. Heater-cathode leakage, on the other hand, will have little or no effect upon the operation of the circuit until the condition is so severe that the heater actually burns out. Any open element in the thyratron circuit will cause the circuit to fail safe because each tube element must carry current for proper operation.

If either end of the potentiometer *R* were to open, the circuit would fail safe because an open heater circuit would result and the thyratron would lose its emission. In order to make sure that the in-phase a-c control grid bias is present, the heater current is passed through the potentiometer control. Opening of the potentiometer arm would, therefore, remove the a-c in-phase bias voltage from the control grid. Because this grid voltage must be positive in order to obtain tube conduction, its removal results in fail-safe operation.

When the value of the grid resistor can be less than about 5000 ohms, a fail-safe condition results when the grid is shorted to the anode because a low impedance shunts the thyratron and insufficient d-c current is available to operate the relay. The occurrence of this particular fault, however, is not very likely since the anode lead of the RCA-2D21 tube is shielded with a small ceramic sleeve which insulates the anode from other elements outside of the tube structure. Within the tube structure, it is impossible for the control grid to touch the anode without first touching the shield grid.

If it is desirable to have a higher impedance in the control grid circuit and still retain a fail-safe condition in case of a short-circuit between control grid and anode, a cathode-follower type of circuit should be utilized between the input source and the thyratron. When any extra components are added to a simple circuit such as that of Fig. 5, it is necessary, of course, to be sure that the added items do not alter the circuit in such a way that its fail-safe features are cancelled.

Although it is possible to protect circuits for single faults, a double combination of faults will in some cases prevent fail-safe operation. However, if good design principles are utilized and high quality components used, two or more faults occurring at precisely the same instant are very unlikely. Because complete fail-safe conditions may not be required for many applications, the designer should first determine what degree of fail-safe operation is necessary. There are many simple arrangements which cause no additional expense that can be used to protect a circuit. These, of course, should be given first consideration. They include, first, the use of positive grid operation and, second, the technique of returning the anode circuit through the shield grid.

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