

PATENT SPECIFICATION

(11)

1 260 336

DRAWINGS ATTACHED

- (21) Application No. 26396/69 (22) Filed 23 May 1969
 (31) Convention Application No. 733640 (32) Filed 31 May 1968 in
 (33) United States of America (US)
 (45) Complete Specification published 12 Jan. 1972
 (51) International Classification G 11 c 27/00 H 03 g 1/02
 (52) Index at acceptance

H3T 1CX 2E 2F5 2J 2S 2T2X 2T2Z 2T3F 2T3J 2V
 2W2 2W3 3F1 3J 3VX 3X
 H3Q 2C



(54) CAPACITOR STORAGE CIRCUITS USING FIELD-EFFECT TRANSISTORS

(71) We, RCA CORPORATION, (formerly known as Radio Corporation of America) a corporation organized under the laws of the State of Delaware, United States of America, of 30 Rockefeller Plaza, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention pertains to control systems, and more particularly to a control system utilizing field-effect transistors (FET) for controlling various functions in electronic apparatus.

The use of field-effect transistors in conjunction with a storage capacitor associated with the gate electrode of the device as a memory or control unit is known. For example, a thesis prepared by T. D. Martin entitled "Circuit Applications of the Field-Effect Transistor", deposited with the University of Pennsylvania Library in April 1960 and later published as an article in *Semi-conductor Products* in February 1962, pages 33 to 39, discloses the use of a field-effect transistor as an analog memory. The basic concept is to charge the capacitor associated with the FET control electrode to a set level and due to the high input impedance of FET devices, the charge remains on the capacitor and establishes a level of conductivity in the device. Nevertheless, due to leakage of the storage charge on the capacitor over a period of time, there is a change in level of the conductivity of the device because of change in voltage at the control electrode. If, under these conditions, the control system is operated, the system may begin to operate with the controlled function far from its normal operating range. It is, therefore, desirable to be able to preset the level of conductivity in the device so that the controlled function will remain within its normal operating range.

Moreover, once preset conditions have been established for the device, it is also desirable to be able to reset the level of conductivity to the preset conditions after the system has been in operation.

A control circuit embodying the present invention includes; an insulated-gate field-effect transistor having a gate electrode, a source electrode and a drain electrode; said source and drain electrodes interconnected with circuit means to form an electrical circuit operable to control functions in an electric apparatus by changes in the conductivity of the source to drain conductivity of said transistor, a capacitor connected to said gate electrode to control the source to drain conductivity of said transistor according to the charge on said capacitor, means including a first switch for connecting a reference potential to said gate electrode which can be adjusted to a particular potential within a predetermined potential range relative to the source electrode when said switch is closed; and a charge controlling circuit including additional switching means for changing the charge on said capacitor either above or below said reference potential when said additional switching means is closed to control the source of drain conductivity of said transistor so that the controlled function is adjusted to a desired condition.

A complete understanding of the invention may be obtained from the following detailed description of a specific embodiment thereof, when taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a schematic circuit diagram of a control system embodying the present invention; and

FIGURE 2 is a schematic circuit diagram of a control system embodying the present invention and adapted for use with a radio receiver.

Referring now to Figure 1, a field-effect transistor 10 which may be of the metal

[Price 25p]

oxide semiconductor (MOS) type controls signal processing circuitry 11. For example, the transistor 10 may be an N channel enhancement device which has a high source-drain resistance for zero gate-to-source voltage and a decreasing source-drain resistance as the gate is made positive relative to the source. Control is achieved by varying the conductivity of the drain-to-source electrode path of the transistor 10. By way of example, the transistor 10 is shown as a variable shunt attenuator for the signal processing circuitry 11, but may also be used as a series attenuator. Typical functions which may be controlled by the transistor 10 are the audio, color and tint signal processing circuitry of a television receiver. The gate electrode of the transistor 10 is coupled to the slide of a resistor 12 by a capacitor 14. The resistor 12 is connected between a terminal 16, adapted to be energized by a source of potential and ground.

The gate side of the capacitor 14 is connected by a resistor 18 to a series of switches 20, 22, 24 and 26. The switches 20 and 24, when closed, connect the gate electrode of the transistor 10 through the resistor 18 to a terminal 28 which is adapted to be energized by a source of control voltage. The switches 22 and 26, when closed, connect the gate electrode of the transistor 10 through the resistor 18 to ground. The switches 20 and 22 may be positioned adjacent the apparatus for local control thereof, while the remaining switches 24 and 26 may be positioned remote from the apparatus to be controlled, or alternatively positioned locally and arranged for control from a remote location.

The setting of the slide on the variable resistor 12 establishes a reference, or preset, condition for the gate electrode of the transistor 10. This adjustment is made so that the signal processing circuitry 11 is adjusted to be within its normal operating range.

The preset of the gate electrode enables the signal processing circuitry to remain within its normal operating range even after a charge setting on the capacitor 14, as hereinafter described, leaks off after a period of time. Adjustment of the signal processing circuitry within its operating range is achieved by changing the voltage at the gate electrode of the transistor 10 through the use of the switches 20, 22, 24 and 26. By connecting the capacitor to the source of control voltage at terminal 28 or to ground, charge may be added or subtracted from the capacitor 14. This adjustment of charge on the capacitor changes the voltage at the gate electrode of the transistor 10 and, thus, the conductivity of the drain-to-source electrode path.

After the system has been in operation and charge has been added or subtracted from the capacitor 14, it may be desirable to reset the level of conductivity of the drain-to-source

electrode path of the transistor 10 to the preset conditions determined by the slide adjustment on the variable resistor 12. This is achieved by a discharge path for the capacitor 14 which includes the switch 30. By closing the switch 30, the capacitor is discharged and, when the switch is opened, the voltage at the gate electrode of transistor 10 will be reset to the voltage at the slider of resistor 12.

Referring now to FIGURE 2, an FET control module 100 controls the audio signal processing circuitry 112 of a television receiver. It is to be understood that the FET control module 100 may be adapted to control other signal processing circuitry, and may, for example, be used in the color and tint control circuitry of the receiver.

The module 100, which is an encapsulated unit to prevent a deterioration of the module components due to environmental conditions, includes a metal oxide semiconductor (MOS) type insulated-gate field-effect transistor 114. In this case, the transistor 114 is an N channel depletion device. Such a device exhibits moderate source-to-drain resistance for zero gate-to-source bias voltage, and increasing source-to-drain resistance as the gate is made negative relative to the source, but decreasing resistance as the gate is made positive relative to the source. The source and substrate electrodes of the transistor 114 are connected to ground through a module terminal 116. The drain electrode of the transistor 114 is connected by way of the module terminal 118 and a variable resistor 122 to a source of operating potential 120. The takeoff point to the audio processing circuitry 112 is at the junction of the resistor 122 and the module terminal 118.

A storage capacitor 124 is connected from the gate electrode of the transistor 114 through a module terminal 117 to manual adjustment circuitry including a resistor 152 with a slider. The manual adjustment circuitry permits the establishment of a voltage at terminal 117, which, in conjunction with the voltage on the storage capacitor 124, produces a voltage between the gate electrode and the source electrode of the transistor 114. This establishes a conductivity level in the device, or, put another way, establishes the impedance of the source-to-drain electrode path which is utilized to control the audio processing circuitry 112. It will be understood that the audio circuits receive an appropriate audio signal, from a source not shown, and the transistor 114 is shown as a shunt attenuator at some appropriate point in the audio channel.

The gate electrode of the transistor 114 is also connected to two module terminals 126 and 128 by two neon switching tubes 130 and 132, respectively. Their preference as the coupling media is a prominent feature of our Application 26397/69 (Serial No. 1260337). These neon tubes connect the stor-

age capacity 124 to remote control circuitry of a type to be hereinafter described. A reed switch 134 in series with a resistor 136 is connected in parallel with the storage capacitor 124 to provide, when the reed switch contacts are closed, a discharge path for the storage capacitor 124. The reed switch is actuated by energization of the parallel combination of a winding 138 and a resistor 140 which is connected between two module terminals 142 and 144. The terminal 142 is connected by a resistor 146 to a source of potential derived from a transformer diode arrangement 150. The connection to terminal 144 is described below.

A resistor 125 and a capacitor 127 are connected in parallel between the module terminal 117 and the source and substrate electrodes and provide a protective circuit for the transistor 114 when it is not a part of the system. This protective circuit insures that a static charge will not build up which may destroy the device. In addition, the capacitor 127 acts as an AC bypass to ground for the tap of the adjustable resistor 152 of the manual adjustment circuitry, to which the module terminal 117 is connected.

Manual adjustment of the gate-to-source potential of the field-effect transistor 114 and, hence, the conductivity level of the device 114 is achieved by an adjustment of the tap on the variable resistor 152. Movement of the tap on the resistor 152 results in a ganged movement of contacts 154 and 156 which are connected to ground while manual adjustments are made. The contacts 154 and 156 are connected to the module terminal 144 and, hence, their closing results in an energization of the winding 138 and, consequently, a closing of the reed contacts of the switch 134. This causes the storage capacitor 124 to discharge through resistor 136, such that, when the reed switch opens upon completion of the manual adjustment, the input voltage (gate-to-source) of transistor 114 is equal to the voltage provided at the slider of the adjustable resistor 152. The reed switch 134 thus provides a means for resetting the input voltage of transistor 114 to a desired reference level. A capacitor 158 connected between the module terminals 142 and 144 slows down the rate of collapse of the magnetic field associated with the winding 138 when the contacts 154 and 156 are open to prevent damage to the transistor 114.

The adjustable resistor 152 is connected to a source of negative control voltage 160. The source of negative control voltage includes a diode 162 and capacitor 164 serially connected between a secondary winding on a transformer 121 and ground; transformer 121 being supplied with AC line voltage. Four serially connected diodes 166, 168, 170 and 172 are connected between ground and a resistor 174 which interconnects the cathode

electrode of the diode 172 and the anode electrode of the diode 162. A resistor 176 interconnects the anode of the diode 172 and the anode of the diode 162. A capacitor 178 connected in parallel with the four serially connected diodes, bypasses AC signals to ground. The top end of the adjustable resistor 152 of the manual adjustment circuitry is connected at the junction of the diodes 168 and 170, as shown, and, hence, to a voltage twice the diode anode-cathode voltage drop above ground—typically twice 0.7 volts, or a total of 1.4 volts for silicon diodes. Since the bottom end of the variable resistor 152 is connected to ground, the slide on the resistor 152 can establish at the module terminal 117 any voltage between 0 and -1.4 volts.

The control system can also be operated from a remote transmitter 180 which transmits any one of a series of predetermined signals. These transmitted signals are picked up by a microphone 182 and amplified in a pre-amplifier 184. The signals are then coupled to the base electrode of a transistor 186 which is the active device of a driver stage to energize the primary winding 188 of a transformer 190. Operating power for the collector electrode of the transistor 186 is provided through a winding 188 and a resistor 192 which couples the primary winding 188 to the source of operating potential 150. Two serially connected resistors 194 and 196 coupled across the source 150 provide at their junction the bias potential for the base electrode of the transistor 186. Parallel connected resistor 198 and capacitor 201 couple the emitter electrode of the transistor 186 to ground. A capacitor 202 connected between the junction of resistor 192 with the winding 188 and ground provides an AC bypass for the resistor 192. Capacitor 204 tunes the winding 188 of the transformer 190 to the received control signal frequency band.

The transformer 190 also includes two secondary windings 206 and 208. The winding 206 is connected by its left-hand terminal to the source of negative control voltage 160 at the cathode electrode of the diode 172 while the secondary 208 is connected by its right-hand terminal to the anode electrode of a diode 212 associated with a source of positive control voltage 200.

The source 200 includes a diode 214 and a capacitor 216 serially connected between the aforementioned secondary winding of the transformer 121 and ground. The cathode electrode of the diode 214 is connected to the anode electrode of the diode 212 by a resistor 218. The cathode of the diode 212 is connected to the junction of a resistor 220 and the anode electrode of a diode 222, which are serially connected between the cathode electrode of the diode 214 and ground. A capacitor 224 is connected across the diodes 212 and 222 to provide an AC bypass to ground.

Each of the secondary windings 206 and 208 are additionally connected with a capacitor and a variable inductor, the inductor being adjusted to series resonate with its associated capacitor at different frequencies. The winding 206 drives an adjustable inductor 230 and a capacitor 232, while the secondary winding 208 drives an adjustable inductor 234 and a capacitor 236. When the primary winding 188 of the transformer 190 is energized by an appropriate signal from transmitter 180, the corresponding one of the series tuned circuits (that is, one of the circuits including the inductor 230 and capacitor 232 or the inductor 234 and capacitor 236) which is resonant at the transmitted frequency will develop a substantially sinusoidal voltage having a relatively high peak-to-peak value (for example, 200 volts) at the junction of its inductor and capacitor. This AC voltage is applied to the corresponding one of neon switching tubes 130, 132 by a corresponding one of resistors 238 and 240. The resistor 238 couples the junction of the units 230 and 232 to module terminal 126, and the resistor 240 couples the junction of the units 234 and 236 to module terminal 128.

The peak value of the AC voltage applied to the appropriate neon switching tube 130, or 132 exceeds the ionizing voltage of that tube and, furthermore, is at a frequency (for example, in the typical television receiver remote control frequency range of 34 to 45 KHz) sufficiently high that ionization (activation) of the neon tube is maintained continuously. The ionized neon tube connects its associated source (160 or 200) of relatively low unidirectional control voltage to capacitor 124.

If the transmitted signal is at the resonant frequency of the inductor 230-capacitor 232 combination, the neon tube switch 130 will be activated and will permit the flow of direct current between the storage capacitor 124 and the source of negative control voltage 160. The path is from the junction of the resistor 174 and diode 172 through the secondary transformer winding 206, the variable inductor 230, the resistor 238, and the neon tube 130 to the storage capacitor 124. In a like manner, should the transmitted signal be at the resonant frequency of the variable inductor 234-capacitor 236 arrangement, the neon tube switch 132 would be actuated and the storage capacitor 124 would be connected for direct current flow to the source of positive control voltage 200. In this case, the path would be from the junction of the resistor 218 and the diode 212 through the secondary transformer winding 208, the adjustable inductor 234, the resistor 240, and the neon tube 132 to the storage capacitor 124. By selectively actuating the neon tube switches 130 and 132, charge may either be added to or subtracted from the storage capacitor 124.

This results in an adjustable setting, by remote control action, of the voltage on the gate electrode of the field effect transistor 114. Once the proper amount of charge is supplied to the storage capacitor 124, the operating neon switch is open circuited by removing the transmitted signals. The storage capacitor 124 will then be disconnected from the source of potential 200 or 160 which was employed in adjusting its charge.

The rate of charging of the storage capacitor 124 is determined by the value of the resistor 174 for the source of negative control potential 160 and the value of the resistor 218 for the source of positive control potential 200. These resistors are selected such that the rate of change of the charge on the storage capacitor 124 is relatively slow. The diode arrangements in the potential sources 160 and 200 limit the voltage to which the storage capacitor 124 may be charged and confine the charging to a linear portion of the exponential charge curve. By making the change of charge gradual and linear, accurate remote control adjustment is enhanced.

Since the output impedance of the gate electrode of the transistor 114 is extremely high, the charge on the storage capacitor 124 leaks off at an extremely slow rate (for example, with a time constant in the order of weeks). The voltage level at the gate electrode of the transistor 114 is thereby maintained and the resultant conductivity level of the device stabilized. It is important that the charge on the storage capacitor 124 not be permitted to leak off, else the voltage at the gate electrode of the device would change to produce a change in the control of the audio processing circuitry 112. To insure against charge leakage, the module 100 is encapsulated. It is also desired that there be no leakage of charge through the switching means which connects and disconnects the storage capacitor to the source of control potential employed. The neon tube switches 130 and 132, because of the high leakage resistance associated with their off condition, provide the desired extremely low charge leakage. This feature forms the subject of our co-pending Application 26397/69 (Serial No. 1260337). It should be noted that the manual control afforded by variable resistor 152 permits adjustment of a quiescent or initial input voltage to transistor 114 with the range between zero and -1.4 volts, while by virtue of the remote control of the charge on capacitor 124, the operating input voltage of transistor 114 may be adjusted within the wider range of $+0.7$ volts to -2.1 volts. This latter operating range is set by the voltage supplies 160 and 200 and is selected to accommodate any variation in the neon tube switches 130 and 132.

When the system (audio processing circuitry 130

11) is not in operation, means are provided for disconnecting the primary winding of the transformer 121 from its source of power and, hence, inactivating the source of operating potential 120 for the transistor 114. This means may include a switch 252 which is connected in series with the primary winding of the transformer 121. A winding 254 is also included and is adapted to actuate the switch when energized. The winding 254 interconnects the collector electrode of a transistor 456 and the source of operating potential 150. The base electrode of the transistor 256 is connected to ground by a variable inductor 258 and the emitter electrode of the transistor is connected to ground by a resistor 260. An adjustable inductor 262 is coupled to the winding 258 and is serially connected with a capacitor 264 between the left and right-hand terminal of the secondary winding 208 of transformer 190. The transformer action between the inductors 262 and 258 isolates the direct current voltages associated with the transistor 256 from the module charging circuits.

The above-mentioned adjustable inductor 262 and capacitor 264 are adjusted to be series resonant at a desired frequency different from the control frequencies mentioned previously. When the transmitter signals at this frequency, the transistor 256 is rendered conductive and current flows in its collector-to-emitter path. The resulting current flows through the winding 254, then opens or closes the relay switch 252, depending on the switch's previous state. A capacitor 266 is connected across the winding 254 to provide filtering of the voltage across the winding 254. A capacitor 268 is connected across the switch of the relay to prevent arcing and the generation of undesired radio frequency signals. A master switch 270 is provided for completely turning off the system. Normally, the switch 270 is closed and the source of operating potential 150 is energized to permit remote turn on of the system.

It should be noted that several module 100 arrangements may be used with the windings 206 and 208 by utilizing a parallel arrangement of these modules with the windings 206 and 208. However, the series connected inductor and capacitor associated with each module must be resonant at a different frequency. In this manner, additional functions can be added to the receiver, for example, tint and color control.

The component values in the embodiment drawn are as follows:

Resistors:—

120—330 Ω
122—2.5K Ω
125—1M Ω
136—100K Ω
140—15K Ω

146—2.2K Ω
174—22M Ω
176—1K Ω
192—4.7K Ω
194—27K Ω
196—4.7K Ω
198—470 Ω
218—22M Ω
220—1K Ω
238—150K Ω
240—150K Ω
260—10 Ω

The component values in the embodiment drawn are as follows:

Capacitors:—

120—500 μ f
124—1.5 μ f
127—.1 μ f
158—10 μ f
164—100 μ f
178—.018 μ f
201—.1 μ f
202—.01 μ f
204—470pf
216—100 μ f
224—.018 μ f
232—680pf
236—680pf
266—10 μ f
268—.01 μ f
264—680pf

WHAT WE CLAIM IS:—

1. A control circuit comprising: an insulated-gate field-effect transistor having a gate electrode, a source electrode and a drain electrode; said source and drain electrodes interconnected with circuit means to form an electrical circuit operable to control functions in an electric apparatus by changes in the conductivity of the source to drain conductivity of said transistor, a capacitor connected to said gate electrode to control the source to drain conductivity of said transistor according to the charge on said capacitor, means including a first switch for connecting a reference potential to said gate electrode which can be adjusted to a particular potential within a predetermined potential range relative to the source electrode when said switch is closed; and a charge controlling circuit including additional switching means for charging the charge on said capacitor either above or below said reference potential when said additional switching means is closed to control the source to drain conductivity of said transistor so that the controlled function is adjusted to a desired condition.

2. A control circuit according to Claim 1 wherein said first switch comprises a reed switch and affords a discharge path for said capacitor for resetting said capacitor to zero potential.



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2. A control circuit according to Claim 1 wherein said first switch comprises a reed switch and affords a discharge path for said capacitor for resetting said capacitor to zero potential.



3. A control circuit substantially as herein described with reference to FIGURE 1 of the accompanying drawing.
4. A control circuit according to any preceding claim embodied in a television receiver remote control arrangement.
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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1972.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.