

PATENT SPECIFICATION

(11) 1 260 337

DRAWINGS ATTACHED

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- (21) Application No. 26397/69 (22) Filed 23 May 1969
(31) Convention Application No. 733548 (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



(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 *Semiconductor 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, prior systems employing FETs with a capacitor associated with the gate electrode have suffered from leakage of the stored charge on the capacitor with resultant change in level of the conductivity of the device because of the change in voltage at the control electrode. One source of leakage has been through the switching means which couples the storage capacitor and the source of control voltage utilized to charge the capacitor.

According to the present invention there is provided a control circuit for electronic apparatus comprising, a field effect transistor hav-

ing a source electrode, a drain electrode and a gate electrode, with the source and drain electrodes being connected or connectible in an electrical circuit; a capacitor connected to the gate electrode of said transistor; and coupling means for coupling a source of control voltage to said capacitor to establish the conductivity of said transistor in said electrical circuit, said coupling means including a switching tube having a leakage resistance characteristic effective in preventing the leakage of stored charge from said capacitor through the switching tube.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawing.

Referring now to the drawing, an FET control module 10 controls the audio signal processing circuitry 12 of a television receiver. It is to be understood that the FET control module 10 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 10, 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 14. The source and substrate electrodes of the transistor 14 are connected to ground through a module terminal 16. The drain electrode of the transistor 14 is connected by way of the module terminal 18 and a variable resistor 22 to a source of operating potential 20. The takeoff point to the audio processing circuitry 12 is at the junction of the resistor 22 and the module terminal 18.

A storage capacitor 24 is connected from the gate electrode of the transistor 14 through a module terminal 17 to manual adjustment circuitry including a resistor 52 with a slider. The manual adjustment circuitry permits the establishment of a voltage at terminal 17, which, in conjunction with the voltage on the storage capacitor 24, produces a voltage between the gate electrode and the source elec-

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trode of the transistor 14. 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 12. Recharge controlling of capacitor 24 is the main feature of our Patent application 26396/69 (Patent No. 1260336).

The gate electrode of the transistor 14 is also connected to two module terminals 26 and 28 by two neon switching tubes 30 and 32, respectively. These neon tubes connect the storage capacitor 24 to remote control circuitry of a type to be hereinafter described. A reed switch 34 in series with a resistor 36 is connected in parallel with the storage capacitor 24 to provide, when the reed switch contacts are closed, a discharge path for the storage capacitor 24. The reed switch is actuated by energization of the parallel combination of a winding 38 and a resistor 40 which is connected between two module terminals 42 and 44. The terminal 42 is connected by a resistor 46 to a source of potential derived from a transformer diode arrangement 50. The connection to terminal 44 is described below.

A resistor 25 and a capacitor 27 are connected in parallel between the module terminal 17 and the source and substrate electrodes and provide a protective circuit for the transistor 14 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 27 acts as an AC bypass to ground for the tap of the adjustable resistor 52 of the manual adjustment circuitry, to which the module terminal 17 is connected.

Manual adjustment of the gate to source potential of the field-effect transistor 14 and, hence, the conductivity level of the device 14 is achieved by an adjustment of the tap on the variable resistor 52. Movement of the tap on the resistor 52 results in a ganged movement of contacts 54 and 56 which are connected to ground while manual adjustments are made. The contacts 54 and 56 are connected to the module terminal 44 and, hence, their closing results in an energization of the winding 38, and, consequently, a closing of the reeds of the switch 34. This causes the storage capacitor 24 to discharge through resistor 36, such that, when the reed switch opens upon completion of the manual adjustment, the input voltage (gate-to-source) of transistor 14 is equal to the voltage provided at the slide of the adjustable resistor 52. The reed switch 34 thus provides a means for resetting the input voltage of transistor 14 to a desired reference level. A capacitor 58 connected between the module terminals 42 and 44 slows down the rate of collapse of the magnetic field associated with the wind-

ing 38 when the contacts 54 and 56 are open to prevent damage to transistor 14.

The adjustable resistor 52 is connected to a source of negative control voltage 60. The source of negative control voltage includes a diode 62 and a capacitor 64 serially connected between a secondary winding on a transformer 21 and ground, transformer 21 being supplied with AC line voltage. Four serially connected diodes 66, 68, 70 and 72 are connected between ground and a resistor 74 which interconnects the cathode electrode of the diode 72 and the anode electrode of the diode 62. A resistor 76 interconnects the anode of the diode 72 and the anode of the diode 62. A capacitor 78 connected in parallel with the four serially connected diodes bypasses AC signals to ground. The top end of the adjustable resistor 52 of the manual adjustment circuitry is connected at the junction of the diodes 68 and 70, 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 52 is connected to ground, the tap on the resistor 52 can be set at any voltage between 0 and -1.4 volts to establish that same voltage at the module terminal 17.

The control system can also be operated from a remote transmitter 80 which transmits any one of a series of predetermined signals. These transmitted signals are picked up by a microphone 82 and amplified in a pre-amplifier 84. The signals are then coupled to the base electrode of a transistor 86 which is the active device of a driver stage to energize the primary winding 88 of a transformer 90. Operating power to the collector electrode of the transistor 86 is provided through the winding 88 and a resistor 92 which couples the primary winding 88 to the source of operating potential 50. Two serially connected resistors 94 and 96 coupled across the source 50 provide at their junction the bias potential for the base electrode of the transistor 86. Parallel connected resistor 98 and capacitor 101 couple the emitter electrode of the transistor 86 to ground. A capacitor 102 connected between the junction of resistor 92 and the winding 88 with ground provides an AC bypass for the resistor 92. Capacitor 104 coupled across the winding 88 enables the primary winding of the transformer 90 to be tuned.

The transformer 90 also includes two secondary windings 106 and 108. The winding 106 is connected by its left hand terminal to the source of negative control voltage 60 at the cathode electrode of the diode 72 while the secondary winding 108 is connected by its right-hand terminal to the anode electrode of a diode 112 associated with a source of positive control voltage 100. The source 100

includes a diode 114 and a capacitor 116 serially connected between the aforementioned secondary winding of the transformer 21 and ground. The cathode electrode of the diode 114 is connected to the anode electrode of the diode 112 by a resistor 118. The cathode of the diode 112 is connected to the junction of a resistor 120 and the anode electrode of a diode 122, which are serially connected between the cathode electrode of the diode 114 and ground. A capacitor 124 is connected across the diodes 112 and 122 to provide an AC bypass to ground.

Each of the secondary windings 106 and 108 are additionally connected with a capacitor and a variable inductor, the inductors being adjusted for series resonance at specific separate frequencies. The winding 106 is connected in series with an adjustable inductor 130 and a capacitor 132, while the secondary winding 108 is connected in series with an adjustable inductor 134 and a capacitor 136. When the primary winding 88 of the transformer 90 is energized by an appropriate signal from transmitter 80, the corresponding one of the series tuned circuits (that is, one of the circuits including the inductor 130 and capacitor 132 or the inductor 134 and capacitor 136) which is resonant at the transmitted frequency will develop a substantially sinusoidal voltage having a relatively high peak-to-peak value (e.g. 200 volts) at the junction of its inductor and capacitor. This AC voltage is applied to the corresponding one of neon switching tubes 30, 32 by a corresponding one of resistors 138 and 140. The resistor 138 couples the junction of the units 130 and 132 to module terminal 26, and the resistor 140 couples the junction of the units 134 and 136 to module terminal 28.

The peak value of the AC voltage applied to the appropriate neon switching tube 30 or 32 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 (60 or 100) of relatively low unidirectional control voltage to capacitor 24.

If the transmitted signal is at the resonant frequency of the inductor 130-capacitor 132 combination, the neon tube switch 30 will be activated and will permit the flow of direct current between the storage capacitor 24 and the source of negative control voltage 60. The path is from the junction of the resistor 74 and diode 72 through the secondary transformer winding 106, the variable inductor 130, the resistor 138, and the neon tube 30 to the storage capacitor 24. In a like manner, should the transmitted signal be at the resonant frequency of the variable inductor 134-capacitor 136 arrangement, the neon tube switch 32

would be actuated and the storage capacitor 24 would be connected for direct current flow to the source of positive control voltage 100. In this case, the path would be from the junction of the resistor 118 and the diode 112 through the secondary transformer winding 108, the adjustable inductor 134, the resistor 140, and the neon tube 32 to the storage capacitor 24. By selectively actuating the neon tube switches 30 and 32, charge may either be added to or taken off the storage capacitor 24. This results in an adjustable setting, by remote control action, of the voltage on the gate electrode of the field effect transistor 14. Once the proper amount of charge is supplied to the storage capacitor 24, the operating neon switch is open circuited by removing the transmitted signals. The storage capacitor 24 will then be disconnected from the source of control potential 100 or 60 which was employed in adjusting its charge.

The rate of charging of the storage capacitor 24 is determined by the value of the resistor 74 for the source of negative control potential 60 and by the value of the resistor 118 for the source of positive control potential 100. These resistors are selected such that the rate of change of the charge on the storage capacitor 24 is gradual. The diode arrangements in the potential sources 60 and 100 limit the voltage to which the storage capacitor 24 may be charged and confines 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 input impedance of the gate electrode of the transistor 14 is extremely high, the charge on the storage capacitor 24 leaks off at an extremely slow rate (e.g. with a time constant of the order of weeks). The voltage level at the gate electrode of the transistor 14 is thereby maintained and the resultant conductivity level of the device stabilized. It is important that the charge on the storage capacitor 24 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 12. To prevent charge leakage, the module 10 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 30 and 32, because of the high leakage resistance associated with their off condition, provide the desired extremely low charge leakage.

It should be noted that the manual control afforded by variable resistor 52 permits adjustment of a quiescent or initial input voltage to transistor 14 within the range of zero to -1.4 volts while, by virtue of remote control of the charge on capacitor 24, the operating input voltage of transistor 14 may be adjusted

within the wider range of +0.7 volts to -2.1 volts. The latter operating range is set by the voltage supplies 60 and 100 and is selected to accommodate any variations in characteristics of the neon tube switches 30 and 32.

To further prevent any possible change in the charge on the storage capacitor 24 during that period of time when the system is not in operation, means are provided for disconnecting the primary winding of the transformer 21 from its source of power, and, hence, inactivating the source of operating potential 20 for the transistor 14. This means may include a switch 152 which is connected in series with the primary winding of the transformer 21. A winding 154 is also included and is adapted to actuate the switch when energized. The winding 154 interconnects the collector electrode of an added transistor 156 and an additional source of operating potential 50. The base electrode of the transistor 156 is connected to ground by a variable inductor 158 and the emitter electrode of the transistor is connected to ground by a resistor 160. An adjustable inductor 162 is coupled to the winding 158 and is serially connected with a capacitor 164 between the left and right-hand terminal of the secondary winding 108 of transformer 90. The transformer action between the inductors 162 and 158 is necessary to isolate the direct current voltage associated with the transistor 156 from the module charging circuits.

The above-mentioned adjustable inductor 162 and capacitor 164 are adjusted to be series resonant at the desired frequency. When the transmitter transmits signals at this frequency, the transistor 156 is rendered conductive and current flows in its collector to emitter path. The resulting current flow through the winding 154 then opens or closes the relay switch 152, depending on the switch's previous state. A capacitor 166 is connected across the winding 154 to provide filtering of the voltage across the winding 154. A capacitor 168 is connected across the switch of the relay to prevent arcing and the generation of undesired radio frequency signals. A master switch 170 is provided for completely turning off the system. Normally, the switch 170 is closed and the source of operating potential 50 is energized to permit remote turn on of the system. It should be noted that several module 10 arrangements may be used with the windings 106 and 108 by utilizing a parallel arrangement of these modules with the windings 106 and 108. However, the series connected inductor and capacitor associated with each module must be resonant at a unique 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:

20—330Ω
22—2.5KΩ
25—1MΩ
36—100KΩ
40—15KΩ
46—2.2KΩ
74—22MΩ
76—1KΩ
92—4.7KΩ
94—27KΩ
96—4.7KΩ
98—470Ω
118—22MΩ
120—1KΩ
138—150KΩ
140—150KΩ
160—10Ω

The component values in the embodiment drawn are as follows:—

Capacitors:

20—500μf
24—1.5μf
27—.1μf
58—10μf
64—100μf
78—.018μf
101—.1μf
102—.01μf
104—470pf
116—100μf
124—.018μf
132—680pf
136—680pf
164—680pf
166—10μf
168—.01μf

WHAT WE CLAIM IS:—

1. A control circuit for electronic apparatus comprising, a field effect transistor having a source electrode, a drain electrode and a gate electrode, with the source and drain electrodes being connected or connectible in an electrical circuit; a capacitor connected to the gate electrode of said transistor; and coupling means for coupling a source of control voltage to said capacitor to establish the conductivity of said transistor in said electrical circuit, said coupling means including a switching tube having a leakage resistance characteristic effective in preventing the leakage of stored charge from said capacitor through the switching tube. 105
2. A control circuit as defined in Claim 1, wherein said switching tube is a neon gas tube. 110
3. A control circuit as defined in Claim 1, including means for providing a positive voltage as said control voltage, means for providing a negative voltage as a second control voltage, and second coupling means for coupling said second con- 120 125

within the wider range of +0.7 volts to -2.1 volts. The latter operating range is set by the voltage supplies 60 and 100 and is selected to accommodate any variations in characteristics of the neon tube switches 30 and 32.

To further prevent any possible change in the charge on the storage capacitor 24 during that period of time when the system is not in operation, means are provided for disconnecting the primary winding of the transformer 21 from its source of power, and, hence, inactivating the source of operating potential 20 for the transistor 14. This means may include a switch 152 which is connected in series with the primary winding of the transformer 21. A winding 154 is also included and is adapted to actuate the switch when energized. The winding 154 interconnects the collector electrode of an added transistor 156 and an additional source of operating potential 50. The base electrode of the transistor 156 is connected to ground by a variable inductor 158 and the emitter electrode of the transistor is connected to ground by a resistor 160. An adjustable inductor 162 is coupled to the winding 158 and is serially connected with a capacitor 164 between the left and right-hand terminal of the secondary winding 108 of transformer 90. The transformer action between the inductors 162 and 158 is necessary to isolate the direct current voltage associated with the transistor 156 from the module charging circuits.

The above-mentioned adjustable inductor 162 and capacitor 164 are adjusted to be series resonant at the desired frequency. When the transmitter transmits signals at this frequency, the transistor 156 is rendered conductive and current flows in its collector to emitter path. The resulting current flow through the winding 154 then opens or closes the relay switch 152, depending on the switch's previous state. A capacitor 166 is connected across the winding 154 to provide filtering of the voltage across the winding 154. A capacitor 168 is connected across the switch of the relay to prevent arcing and the generation of undesired radio frequency signals. A master switch 170 is provided for completely turning off the system. Normally, the switch 170 is closed and the source of operating potential 50 is energized to permit remote turn on of the system. It should be noted that several module 10 arrangements may be used with the windings 106 and 108 by utilizing a parallel arrangement of these modules with the windings 106 and 108. However, the series connected inductor and capacitor associated with each module must be resonant at a unique frequency. In this manner, additional functions can be added to the receiver, for example, tint and color control.

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94—27KΩ
96—4.7KΩ
98—470Ω
118—22MΩ
120—1KΩ
138—150KΩ
140—150KΩ
160—10Ω

The component values in the embodiment drawn are as follows:—

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101—.1μf
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116—100μf
124—.018μf
132—680pf
136—680pf
164—680pf
166—10μf
168—.01μf

WHAT WE CLAIM IS:—

1. A control circuit for electronic apparatus comprising, a field effect transistor having a source electrode, a drain electrode and a gate electrode, with the source and drain electrodes being connected or connectible in an electrical circuit; a capacitor connected to the gate electrode of said transistor; and coupling means for coupling a source of control voltage to said capacitor to establish the conductivity of said transistor in said electrical circuit, said coupling means including a switching tube having a leakage resistance characteristic effective in preventing the leakage of stored charge from said capacitor through the switching tube. 105
2. A control circuit as defined in Claim 1, wherein said switching tube is a neon gas tube. 110
3. A control circuit as defined in Claim 1, including means for providing a positive voltage as said control voltage, means for providing a negative voltage as a second control voltage, and second coupling means for coupling said second con- 120 125



5 trol voltage to said capacitor, said second coupling means also including a switching tube having a leakage resistance characteristic effective in preventing the leakage of stored charge from said capacitor.

10 4. A control circuit as defined in Claim 3, wherein the coupling means for said positive and negative control voltages include in series with the respective switching tubes respective secondary windings of a transformer.

15 5. A control circuit according to Claim 4, wherein a first inductor is included in series with the connection of one of said secondary windings to its associated switching tube and a second inductor is included in series with the connection of the second secondary winding to its associated switching tube.

20 6. A control circuit according to Claim 5, wherein said first inductor is connected in series with a first capacitor to form a resonant circuit resonant at a first frequency and that said second inductor is connected in series with a second capacitor to form a resonant circuit resonant at a second frequency.

7. A control circuit according to Claim 6, 25 together with means for remotely controlling the energization of the primary winding of said transformer at said first frequency and at said second frequency.

8. A control circuit according to Claim 1, 30 wherein said field effect transistor is of the insulated gate variety.

9. A control circuit substantially as hereinbefore described with reference to that part 35 of the accompanying drawing within the rectangle 10.

10. A control circuit according to any preceding claim embodied substantially as hereinbefore described in a television receiver remote control arrangement. 40

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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.



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