RESERVE COPY.

# PATENT SPECIFICATION

DRAWINGS ATTACHED

**982,942**

*Date of Application and filing Complete Specification: May 1, 1961.*
*No. 3123/62.*
*Application made in United States of America (No. 26136) on May 2, 1960.*
*(Divided out of No. 982,941).*
*Complete Specification Published: Feb. 10, 1965.*
*© Crown Copyright 1965.*

**Index at acceptance:—H1 K1C1; H3 U(2A1, 10B1, 12B2, 12B3)**
**Int. Cl.:—H 01 l // H 03 h**

COMPLETE SPECIFICATION

## Low Pass Filters

We, TEXAS INSTRUMENTS INCORPORATED, of 13500 N. Central Expressway, Dallas, Texas, United States of America, a corporation organized and existing under the Laws of the State of Delaware, 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:—

This invention relates to low pass filters incorporating the channels of field effect transistors as high impedance elements, which filters are particularly suited for incorporation in semiconductor circuits or networks.

Our co-pending British Patent Application No. 15,722/61 (Serial No. 982,941), the disclosure of which is incorporated herein by reference in so far as it is applicable to the present invention, discloses an amplifier circuit suitable for use in the audio frequency range and further suitable for incorporation into semiconductor circuits or networks. When such audio frequency amplifier circuits are incorporated into semiconductor circuits or networks, there may be instability of the DC bias voltages of the amplifier circuit due to the temperature dependance of the parameters of the circuit elements and the semiconductor material. In order to compensate such instability of the bias voltages, a negative feedback means from the output to the input of the amplifier circuit may be employed. The negative feedback may be accomplished through the use of a low pass filter designed in accordance with the present invention.

The present invention is a low pass filter comprising a plurality of field effect transistors having their channels connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

The present invention is also a low pass filter comprising a semiconductor wafer having therein or thereon a plurality of field effect transistors each having a channel comprising a surface portion of one major wafer face and each having a gate electrode adjacent said major wafer face overlying a respective channel, said channels being connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Fig. 1 is a schematic diagram of a low pass filter circuit;

Fig. 2 is a schematic diagram of a low pass filter circuit according to the invention;

Fig. 3*a* is a perspective view of a semiconductor network embodying a low pass filter device according to the present invention; and

Fig. 3*b* is a circuit diagram for the network of Fig. 3*a*.

An example of a low pass filter typical of the prior art is given in Fig. 1. It consists of two resistors 40 and 41 in series, with a capacitor 42 connected between the two resistors and ground 45.

The resistors of the low pass filters must be reasonably large, in the order of $10^7$ ohms. First, this is to match the impedance of an input device and, secondly, to allow a small capacitor 42 to be used between terminal 46 and ground 45.

It must be noted that large resistors cannot easily be incorporated in a semiconductor network and retain the concept of smallness. Fig. 2 shows two field effect trnsistors 60 and 61 having their channels connected in series, and in combination with capacitor 62 to form a low-pass filter. The characteristics of the channel of the field effect transistors is such that with a reasonably large gate voltage the field effect device is "pinched off" and the resistance of the channel circuit becomes very high, requiring a large voltage across the channel circuit of the field effect transistor in order to produce an appreciable current. With high

[*Price 4s. 6d.*]

enough voltage on the gates of the field effect transistors, the resistance of the channel circuits can be made in the order of $10^7$ ohms. In Fig. 2, the source of one transistor 60 and the drain of the other transistor 61 are connected to a common terminal 66. The gates of the transistors are connected together by lead 68 and to a battery 65. These field-effect transistors are in effect used as voltage variable resistors. They lend themselves to semiconductor circuitry as they can be incorporated as high resistances, and allow the use of a small capacitor 62 which may be in the order of 0.001 microfarad. The battery 65 can be replaced by another potential source. For example, lead 68 can be connected to a tap on the load resistor to provide a high enough gate voltage to make the channel portions of the field effect transistors of sufficiently high resistance to be usable in a low pass filter device.

Materials as germanium, gallium arsenide, indium antimonide, and other semiconductor materials can be employed, silicon, however, is believed to produce superior results as it lends itself more readily to the fabricating technique required.

Figs. 3*a* and 3*b* describe a semiconductor network in accordance with co-pending patent application No. 15,722/61 (Serial No. 982,941) and embody a low pass filter device according to the present invention. As shown, an input terminal 160 connects with a coupling capacitor 162, which is connected to the gate region of a field-effect coupling transistor generally designated by the reference numeral 164. The channel of the field-effect transistor 164 connects with the base region of a bipolar transistor, generally designated by the reference numeral 166. The load resistance for the bipolar transistor 166 is constituted by the bulk resistance of the region of the semiconductor body 168 contiguous with the collector region of the bipolar transistor 166. A suitable lead 170 interconnects the source end of the field-effect transistor 164 with the collector region of the bipolar transistor 166. A suitable voltage supply is attached to the end of the region 168 remote from the bipolar transistor 166. This attachment is indicated generally by the reference numeral 172. At the opposite end of the semiconductor body, there is located a second stage consisting of a bipolar transistor, designated generally by the reference numeral 174. A Zener diode 176 connects with the base region of the transistor 174. A lead 178 connects the other side of the diode 176 with the collector of the transistor 166. The method of manufacturing this semiconductor network includes starting with an n-type wafer of silicon into which is diffused a suitable p-type impurity to produce the base regions of the bipolar transistors and the channel of the field-effect transistor. Thereafter, the emitter regions of the bipolar transistors, as well as the gate region of the field-effect transistor, are produced by a subsequent diffusion of an n-type impurity. It will be appreciated that in some cases it will be possible to utilize an alloying technique to establish the emitter regions of the bipolar transistors in the p-diffused layer. Conceivably, an alloy technique can be utilized to establish the gate region for the field-effect transistors. Alloy techniques, however, are not the equivalent of diffusion processes for the reason that they are more difficult to control, and less susceptible of reproducible results. The region between the collector of the transistor 174 and the attachment or contact 172 is generally designated by the numeral 180, and functions as the load resistor for the bipolar transistor 174. In this regard, the bulk resistance of the semiconductor body furnishes the load resistance. An output terminal 182 is attached to the collector region of the transistor 174 by means of a lead 184.

Formed on the semiconductor body above the region 180 are two field-effect transistors joined together and in combination with a capacitor 186 for the purpose of providing a low pass filter between the output of the transistor 174 and the input to the gate of the field-effect transistor 164. The two field-effect transistors are formed by a p-diffused layer 188 into which has been further diffused two n-type regions 190. Each n-type region defines beneath it the channel for its respective field-effect transistor. The two n-type regions 190 constitute the gates for the field-effect devices, and are connected together by means of a lead 191 and to an intermediate portion of the region 180 by means of lead 192. To stabilize the bias on the gates 190, a Zener diode is formed on the region 180 intermediate the output 182 and supply terminal 172 and connected by lead 199 to the output 182. Lead 193 connects the output lead 184 with one end of the field-effect devices at contact 194. The other end of the field-effect devices at contact 195 is connected by means of lead 196 back to the gate of field-effect transistor 164. The region intermediate the two n-type diffused regions 190 is connected by means of a contact 197 and lead 198 to capacitor 186, the other side of which is grounded. The emitter region of transistor 174 is connected to ground. The emitter region of transistor 166 is also connected to ground. By connected to ground is meant that a suitable terminal or tab is provided to which the emitter regions are connected either by leads or other means for the purpose of grounding these areas. The circuit diagram for the semiconductor network shown in Fig. 3*a* is illustrated in Fig. 3*b*.

It will be appreciated that the problem of d-c bias stability is overcome to a large extent in this semiconductor network by means of the large amount of d-c negative feedback that

is furnished from the output lead 184 to the gate of the field-effect transistor 164 via the low pass filter constituted by the field-effect devices located above the region 180 and the capacitor 186. In this connection, the field-effect devices function as voltage-variable resistors and provide resistances in the order of meg-ohms for attenuation whereas the capacitor 186 functions as an a-c shunt or bypass. Thus, the d.c. is fed back without difficulty, whereas the a-c component of the output signal is shunted out of the feedback loop.

In the semiconductor network of Fig. 3*a*, capacitors 162 and 186 have not been included. It is possible to fabricate these capacitors from the same wafer used for the device of Fig. 3*a* simply by widening the wafer and using the additional space for the fabrication of capacitors 162 and 186.

By this means, the capacitors can be fabricated at the same time as the semiconductor device. After completion, the wafer can be etched through or otherwise divided to separate the device and the capacitors. The three semiconductor parts can then be mounted on a ceramic wafer using tabs and appropriate interconnections.

Advantages of this invention are that it imparts greater versatility in the design of low pass filter circuits suitable for incorporation into semiconductor circuits or networks; and it extends the frequency range over which semiconductor networks of minimum size can be effectively operated.

A further advantage is the integration of field effect transistors in semiconductor network form with an associated capacitor to form a low pass filter suitable for providing d-c feedback to stabilize the bias conditions of an audio amplifier circuit.

WHAT WE CLAIM IS:—

1. A low pass filter comprising a plurality of field effect transistors having their channels connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

2. A low pass filter according to claim 1, wherein the gate electrodes of the field effect transistors are directly connected together.

3. A low pass filter according to claim 1 or 2, wherein the reversed bias applied to said gate electrodes includes one terminal of a bias source connected to the gate electrodes and the other terminal of said bias source connected to the source electrode of one of said channels.

4. A low pass filter according to any preceding claim, including a diode having one of its electrodes connected to the gate electrode of each of said field effect transistors and the other of its electrodes connected to the source electrode of one of said channels.

5. A low pass filter according to claim 4, wherein said diode is a Zener diode.

6. A low pass filter comprising a semiconductor wafer having therein or thereon a plurality of field effect transistors each having a channel comprising a surface portion of one major wafer face and each having a gate electrode adjacent said major wafer face overlying a respective channel, said channels being connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

7. A low pass filter according to claim 6, wherein each surface portion is separated from the opposite major wafer face by a P—N junction.

8. A low pass filter according to claim 6 or 7, wherein at least one plate of said capacitor constitutes a portion of said wafer, which portion is separated from said surface portions on said major wafer face.

9. A low pass filter according to claim 6, 7 or 8, including a diode having one of its electrodes connected to each of said gate electrodes and the other of its electrodes connected to one of the source electrodes of said channels and wherein said diode constitutes a portion of said wafer.

10. A low pass filter substantially as hereinbefore described with reference to Fig. 2 of the accompanying drawings.

11. A low pass filter substantially as hereinbefore described with reference to Figs. 3A and 3B of the accompanying drawings.

H. D. FITZPATRICK & CO.,
Chartered Patent Agents,
3, Gray's Inn Square, London, W.C.1, and
94, Hope Street, Glasgow.

Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press (Leamington) Ltd.—1965. Published by The Patent Office, 25 Southampton Buildings, London, W.C.2, from which copies may be obtained.

is furnished from the output lead 184 to the gate of the field-effect transistor 164 via the low pass filter constituted by the field-effect devices located above the region 180 and the capacitor 186. In this connection, the field-effect devices function as voltage-variable resistors and provide resistances in the order of meg-ohms for attenuation whereas the capacitor 186 functions as an a-c shunt or bypass. Thus, the d.c. is fed back without difficulty, whereas the a-c component of the output signal is shunted out of the feedback loop.

In the semiconductor network of Fig. 3*a*, capacitors 162 and 186 have not been included. It is possible to fabricate these capacitors from the same wafer used for the device of Fig. 3*a* simply by widening the wafer and using the additional space for the fabrication of capacitors 162 and 186.

By this means, the capacitors can be fabricated at the same time as the semiconductor device. After completion, the wafer can be etched through or otherwise divided to separate the device and the capacitors. The three semiconductor parts can then be mounted on a ceramic wafer using tabs and appropriate interconnections.

Advantages of this invention are that it imparts greater versatility in the design of low pass filter circuits suitable for incorporation into semiconductor circuits or networks; and it extends the frequency range over which semiconductor networks of minimum size can be effectively operated.

A further advantage is the integration of field effect transistors in semiconductor network form with an associated capacitor to form a low pass filter suitable for providing d-c feedback to stabilize the bias conditions of an audio amplifier circuit.

WHAT WE CLAIM IS:—

1. A low pass filter comprising a plurality of field effect transistors having their channels connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

2. A low pass filter according to claim 1, wherein the gate electrodes of the field effect transistors are directly connected together.

3. A low pass filter according to claim 1 or 2, wherein the reversed bias applied to said gate electrodes includes one terminal of a bias source connected to the gate electrodes and the other terminal of said bias source connected to the source electrode of one of said channels.

4. A low pass filter according to any preceding claim, including a diode having one of its electrodes connected to the gate electrode of each of said field effect transistors and the other of its electrodes connected to the source electrode of one of said channels.

5. A low pass filter according to claim 4, wherein said diode is a Zener diode.

6. A low pass filter comprising a semiconductor wafer having therein or thereon a plurality of field effect transistors each having a channel comprising a surface portion of one major wafer face and each having a gate electrode adjacent said major wafer face overlying a respective channel, said channels being connected in series between the input and output terminals of said filter, and a capacitor having one of its plates connected to a junction of the channels.

7. A low pass filter according to claim 6, wherein each surface portion is separated from the opposite major wafer face by a P—N junction.

8. A low pass filter according to claim 6 or 7, wherein at least one plate of said capacitor constitutes a portion of said wafer, which portion is separated from said surface portions on said major wafer face.

9. A low pass filter according to claim 6, 7 or 8, including a diode having one of its electrodes connected to each of said gate electrodes and the other of its electrodes connected to one of the source electrodes of said channels and wherein said diode constitutes a portion of said wafer.

10. A low pass filter substantially as hereinbefore described with reference to Fig. 2 of the accompanying drawings.

11. A low pass filter substantially as hereinbefore described with reference to Figs. 3A and 3B of the accompanying drawings.

H. D. FITZPATRICK & CO.,
Chartered Patent Agents,
3, Gray's Inn Square, London, W.C.1, and
94, Hope Street, Glasgow.

Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press (Leamington) Ltd.—1965. Published by The Patent Office, 25 Southampton Buildings, London, W.C.2, from which copies may be obtained.

