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(54) FILM CIRCUIT FOR INTRODUCING A LARGE TIME CONSTANT

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, 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 invention relates to a film circuit which provides a large time constant.

A film circuit consists of a substrate of an insulating material, for example glass or ceramic, on which conductor tracks are disposed using appropriate techniques, which tracks interconnect the various elements of a circuit. Said elements are integrated circuits and elements which for technical or economic reasons cannot be incorporated in the integrated circuits. A number of said elements which cannot be incorporated in the integrated circuits can be mounted on the substrate using the appropriate techniques. Resistors, inductances and capacitors can be realized within certain limits by means of said techniques. For capacitors the practical upper limit may be assumed to be approx. 10,000 pF.

Film circuits may be divided into two groups, *viz.* the so-called thin-film circuits and the thick-film circuits. The difference between the two said types is mainly the manner in which the various structures and conductor tracks are deposited on the substrate. In the case of thin-film circuits this is effected *inter alia* by evaporation or sputter techniques, whilst in the case of thick-film circuits the structures and conductor tracks are applied *inter alia* by means of various pastes, after the substrate has been partly covered in a suitable manner.

If a circuit in which a large time constant is to be realized is manufactured with conventional techniques, the circuit will mainly consist of one or more integrated circuits which, as the case may be, together with non-integrated elements made by film-techniques and a capacitor for obtaining a large time constant are disposed on a substrate which is provided with conductor tracks. The spatial dimensions of the necessary capacitor may be such that these amply exceed the dimensions of the other circuit components at least in one dimension, so that a significant advantage of the integrated circuit which is used is eliminated. For example, if such a capacitor is mounted on the substrate of a film circuit, the thickness dimension of the substrate and capacitor together will be substantially greater than that of the substrate alone.

It is an object of the invention to realize a large RC time constant in a film circuit without the use of such capacitors.

According to the invention there is provided a film circuit which provides a large time constant between a change in an input voltage on an input terminal and a resulting corresponding change in an output voltage on an output terminal of the circuit by employing the heat capacity of at least one resistance layer, through which resistance layer a heating current flows, which circuit includes at least one temperature-sensitive resistance layer which is in direct thermal contact with the heating resistance layer and which determines by its resistance values the output voltage of the circuit, and means for determining, in use, the difference between the input and output voltages of the circuit and for providing said heating current as a function of said difference, such function being such that the polarity of said resulting corresponding change in output voltage corresponds to the polarity of said difference, with the proviso that the heating current in the event that the output voltage equals the input voltage just suffices

to compensate for the loss of heat of the heating resistance layer, so that by analogy with an RC circuit at a constant input voltage output voltage substantially equal thereto is obtained, whilst the output voltage does not follow rapid voltage fluctuations of the input signal. The means for determining the difference between the input and output voltages may for example be a transistorised differential amplifier.

It is obvious that the resistance layers required for the circuit according to the invention can simply be deposited on the substrate by film techniques.

Although the use of the delaying properties of heated temperature-sensitive resistors is known *per se*, the use according to the invention is to be regarded as novel. The known circuits are mainly divided into two categories, *viz.*: on the one hand circuits in which a heating current is fed through the temperature-sensitive resistance, in which in contradistinction to the invention the a.c. components of the heating current causes an alternating voltage instead of a direct voltage to develop across the temperature-sensitive element, and on the other hand circuits in which use is made of an indirectly heated temperature-sensitive resistance, the delaying properties being derived from the delaying action of a heat-conducting medium between the heating element and the temperature-sensitive element, which heat-conducting element electrically behaves as a long line.

The invention is based on the insight that a heat capacity as an equivalent for an electrical capacitance can simply be used to realise an 'RC' time constant in a film circuit.

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

Fig. 1 shows a circuit diagram of an arrangement according to the invention,

Fig. 1*a* being a basic layout of the circuit of Fig. 1 in a film-technique embodiment, and

Fig. 1*b* being a cross-section of the configuration of Fig. 1*a*,

Fig. 2 shows the step response of the circuit of Fig. 1.,

Fig. 3 shows a circuit diagram of an arrangement according to the invention, in which the charge and the discharge time constant are the same, and

Figs. 4, 5 and 6 are some applications of the arrangement according to the invention.

Fig. 1 shows a first transistor T_1 and a second transistor T_2, both of the *npn*-type with a common-emitter circuit, which *via* a resistor 8 is connected to a negative supply terminal 13. The base of the transistor T_1 is connected to an input terminal 1 and the base of the transistor T_2 is connected to an output terminal 2. The collector of T_1 is connected to a positive supply terminal 12, whilst the collectors of T_2 is connected to the positive supply terminal 12 *via* a heating resistance layer 11. The resistance layer 11 is in thermal contact with a resistance 10 having a negative temperature coefficient, called NTC hereinafter, in such a way that said NTC resistor 10 is at the same temperature as the resistance layer 11. The NTC resistor 10 connects the base of T_2 to the negative supply terminal 13, whilst said base *via* the resistance 9 is connected to the positive supply terminal, so that the resistance 9 and the NTC resistor 10 constitute a temperature-dependent voltage divider between the supply terminals 12 and 13.

Fig. 1*a* shows the basic arrangement of the circuit of Fig. 1 on a substrate and by no means represents a realized embodiment to scale. The block 16 is the schematic representation of all elements of the circuit of Fig. 1 except for the NTC resistor 10 and the resistance layer 11. Said block may include an integrated circuit of which the circuit of Fig. 1 forms part and may consist of separate elements which are disposed on the substrate 17 and which are not shown in detail. The resistance layer 11, which is disposed on the substrate 17, is connected to the positive supply terminal 12 and to the collector of the transistor T_2 (not further shown) in block 16 *via* the conductor tracks 18 and 19 respectively. NTC resistor 10 is disposed on the resistance layer 11, is isolated therefrom by an electrically insulating layer 20, and is connected by the conductor tracks 21 and 22 to the negative supply terminal 13 and to the base of the transistor T_2, not shown, respectively.

Fig. 1*b* shows the cross-section at the line A-A′ of Fig. 1*a*.

The insulating layer 20 is so thin that it constitutes a neglible heat resistance, so that the resistance layer 11 and the NTC resistor 10 may be assumed to be at substantially the same temperature.

The behaviour of the circuit of Fig 1 will now be discussed with reference to Fig. 2. When at a given instant t_1 a negative voltage transient appears at the input, the base-emitter voltage of T_1 will decrease, so that the emitter current of T_1 and thus the voltage drop across the resistor 8 will decrease. As a result, the base-emitter voltage of T_2 at the instant t_1 will exhibit a positive transient, so that the collecor current of T_2 increases. The temperature of the resistance layer 11 in the collector circuit T_2 gradually increases owing to the heat capacity and at the same time the tem-

perature of NTC resistor 10 also increases. If said NTC resistor 10 is to follow the temperature of the heating resistance layer directly, the heat capacity of said NTC resistor 10 should be small relative to the heat capacity of the heating resistance layer 11 and, as stated previously, the electrical insulation between the resistance layer 11 and the NTC resistor 10 should have a low heat resistance.

The resistance of the NTC resistor 10 decreases with increasing temperature and owing to the voltage divider consisting of the NTC 10 and the resistor 9, the base potential of the transistor T_2 decreases, as a result of which the base-emitter voltage of T_2 decreases and thus the collector current of T_2 the resistance layer 11 is heated less rapidly. Said process continues until the output voltage V_u has reached such a value that the collector current of T_2 provides just sufficient power to the resistance layer 10 to compensate for the loss of heat of said resistance as a result of cooling. The circuit should be designed so that this equilibrium is attained when V_u substantially equals input voltage V_i, which is also determined by the values of the resistors and the supply voltage. By analogy with the time constant of an RC circuit, the time τ_1 which elapses between the instant t_i and the instant at which the output voltage V_u has performed a part (1-1/e) of the total variation of the input voltage V_i is referred to as the time constant of the circuit when e is the base of Naperien logarithms.

The said time constant determines the frequency of that input signal whose amplitude can just be followed by the output signal. If a non-negligible heat resistance were present between the heating resistance layer 11 and the NTC resistor 10, the temperature variations of the NTC resistor 10 would lag the temperature variations of the heating resistance layer 11. In the case of an input signal with a frequency which is substantially lower than the said frequency, the temperature of the heating resistance layer 11 will follow said input signal, whilst the signal at the output terminal, and thus at the base of the transistor T_2, will follow the temperature of the NTC resistor 10, so that an undesired phase shift exists between the input signal and the output signal. Said phase shift may become so great for certain frequencies that instabilities may result. This is because a heat resistance electrically behaves as a long line which, in contradistinction to an RC network, causes a continually increasing phase shift between input signal and output signal.

At the instant t_i a positive voltage transient appears at the input, so that said process takes place in the reverse sequence, except that the decrease of the temperature of the resistance layer 11 is caused by loss of heat to the environment. As a result of this the time constant τ_2 of the positive voltage-transient response is not the same as the time constant τ_1 of the negative voltage-transient response. The thermal insulation of the resistance layer may be selected so that $\tau_1=\tau_2$. If the two time constants must be equal with a high accuracy, the circuit of Fig. 1 is not satisfactory, because the cooling of the resistance layer cannot readily be predicted and controlled. The circuit of Fig. 3 does not have said drawbacks.

In the circuit of Fig. 3 the resistor 9 in the circuit of Fig. 1 has been replaced by an NTC resistor 14, which is heated by a resistance layer 15 and which connects the collector circuit of transistor T_1 to the positive supply terminal 12.

When a positive voltage transient occurs at terminal 1, the base-emitter voltage of T_1 increases and the base-emitter voltage of T_2 decreases. Accordingly, the collector current of T_1 increases and the collector current of T_2 decreases, so that the temperature of the resistance layer 15 rises and the temperature of the resistance layer 11 decreases. The resistance of the NTC resistor 10 consequently increases and the resistance of the NTC resistor 14 decreases, so that V_u will increase. Conversely, in the case of a negative voltage transient at the input the reverse will happen and V_u will decrease. When the various resistances are suitably selected, the obtaining time constants will be equal.

The circuit of Fig. 3, moreover, has the advantage that an alternating voltage with a frequency which is substantially higher than $1/\tau$ at the input terminals will cause a temperature rise of both NTC resistor 10 and NTC resistor 14, which when the circuit is correctly balanced will not affect the output voltage V_u, in contradistinction to the circuit of Fig. 1 where the output direct voltage decreases slightly when an alternating voltage is applied to the input.

The circuit according to the invention may be used in all circuits which employ large RC time constants and in which capacitors of large physical dimensions and not desired.

Fig. 4 schematically shows a circuit in which a control voltage Vi is remotely adjustable and which voltage *via* a conductor is fed to a control circuit 27. Owing to capacitive and inductive influences interference signals are produced in the line which have an adverse effect on the control means. By including a circuit according to the invention between the long line and the control circuit 27, a d.c. control voltage V_u is obtained at the input of the control cir-

cuit which equals the d.c. level of V_i.

Fig. 5 represents an amplifier consisting of three stages with the transistors T_3, T_4 and T_5. The collector circuits of said transistors include the resistors 16, 17 and 18 respectively, whilst the collector of transistor T_3 *via* a coupling element which couples the d.c. level of the base of transistor T_4 to the d.c. level of the collector of transistor T_3, is connected to the base of transistor T_4. Such a coupling element may for example consist of a Zener diode or, as is shown in the Figure, of the series connection of some diodes (D_1 and D_2), in forward direction. Similarly, the collector of transistor T_4 is connected to the base of transistor T_5 *via* such a coupling element which consists of the series-connection of the diodes D_3 and D_4. The collector of transistor T_5 is connected to the output terminal 25 and *via* the circuit of Fig. 3 it also provides feedback to the input terminal 24. The fed-back voltage in series with an input signal is available at the base of transistor T_3.

Each amplifier stage of the circuit causes a 180° phase shift for low-frequency signals. When the base voltage of the transistor of the relevant amplifier stage increases, the collector current of said transistor increases and, as a result of this, the collector voltage decreases. As the voltage at terminal 2 of the circuit of Fig. 3 follows the low-frequency voltage at terminal 1 of said circuit, said low-frequency voltage is subject to full negative feedback. Said low-frequency negative feedback stabilizes the settings of the various transistors. The circuit of Fig. 3 when included in the negative-feedback path prevents feedback of high-frequency signals, thus preventing the circuit from ringing.

When the circuit of Fig. 3 is used as described in this example, it is obvious that a heat resistance between the heating resistance layer and the temperature-sensitive resistance layer is undesirable. The heat resistance gives rise to an additional phase shift in the negative-feedback loop, which at a high loop-gain may give rise to an unstable circuit arrangement.

Fig. 6 shows a third example using the circuit according to the invention. The resistor 8 in Fig. 3 has now been replaced by a current source, which draws a direct current 2I from the common emitter circuit of the transistors T_1 and T_2. Since the base potential of the transistor T_2 equals the d.c. component of the signal which is applied to the input terminal 1 of the circuit, the d.c. components of the collector currents of the transistors T_1 and T_2 are the same and equal I when the base currents are neglected. The a.c. components of the collector currents are proportional to the a.c. component of the input signal and are mutually in phase opposition. When the voltage which is caused across the resistor 15 by the collector current of transistor T_1 is applied to a terminal 26, the terminal voltage of terminal 26 consists of a d.c. component which is independent of the input signal, and an a.c. component which is proportional to and in phase opposition with the a.c. component of the input signal.

It is obvious that for the differential amplifier constituted by the transistors T_1 and T_2 any other type of differential amplifier may be employed. Neither is the scope of the invention limited to a specific transistor type. Instead of resistance layers with a negative temperature co-efficient it is alternatively possible to employ resistance layers with a positive temperature co-efficient, called PTC resistors hereinafter, with the proviso that either the temperature-sensitive resistance layer in the voltage divider is interchanged with the other element of the voltage divider, or that the associated heating resistance layers are included in the other output circuit of the differential amplifier. With respect to the circuit of Fig. 1, this yields *inter alia* the following possibilities, *viz.*;

- the heating resistance layer 11 in the collector circuit of transistor T_2, whilst the resistance layer 11 heats a PTC resistor which is included between the base of transistor T_2 and the positive supply terminal 12, the resistor 9 being included between the base of transistor T_2 and the negative supply terminal 13,
- the heating resistance layer 11 in the collector circuit of the transistor T_1, whilst the resistance layer 11 heats a PTC resistor which is included between the base of transistor T_2 and the negative supply terminal 13, the resistor 9 being included in the circuit of Fig. 1.
- the heating resistance layer 11 in the collector circuit of transistor T_1, whilst the resistance layer 11 heats an NTC which is included between the base of transistor T_2 and the positive supply terminal 12, the resistor 9 being included between the base of transistor T_2 and the negative supply terminal 13,
- the heating resistance layer 11 in the collector circuit of transistor T_2, whilst the resistance layer 11 heats the NTC resistor 10 as well as a PTC resistor, which replaces resistor 9, and
- the heating resistance layer 11 in the collector circuit of transistor T_1, whilst the resistance layer 11 heats an NTC resistor which takes the place of the resistor 9, as well as a PTC resistor which replaces the NTC resistor 10.

As regards the circuit of Fig. 3 the NTC resistors 14 and 10 may be replaced by

PTC resistors, the heating resistance layers 11 and 15 being interchanged.

WHAT WE CLAIM IS:—

1. A film circuit which provides a large time constant between a change in an input voltage on an input terminal and a resulting corresponding change in an output voltage on an output terminal of the circuit by employing the heat capacity of at least one resistance layer through which a heating current flows, which circuit includes at least one temperature sensitive resistance layer which is in direct thermal contact with the heating resistance layer and which determines, by its resistance value the output voltage of the circuit, and means for determining, in use, the difference between the input and output voltages of the circuit and for providing said heating current as a function of said difference, such function being such that the polarity of said resulting corresponding change in output voltage corresponds to the polarity of said difference, with the proviso that the heating current in the case that the output voltage equals the input voltage just suffices to compensate for the loss of heat of the heating resistance layer; so that, by analogy with an RC circuit, at a constant input voltage output voltage does not follow rapid fluctuations of the input signal.

2. A circuit as claimed in Claim 1, wherein the said means comprises a differential amplifier, the input voltage being applied to a first input of the differential amplifier and the output voltage being produced at a second input of the differential amplifier, whilst in at least one of the two outputs of the differential amplifier the heating resistance layer is incorporated which is in direct thermal contact with the temperature-sensitive resistance layer, which temperature sensitive resistance layer forms part of a voltage divider which thus provides the output voltage which appears at said second input, which voltage depends on the temperature of the resistance layer to be heated, said resistance layer being included in the voltage divider in such a way that the voltage realized by the voltage divider follows the d.c. component of the input voltage.

3. A circuit as claimed in Claim 1 or 2, wherein the differential amplifier forms part of an integrated circuit which is disposed on an insulating substrate, on which by the appropriate techniques a double layer is deposited which consists of a resistance layer to be heated and a temperature sensitive resistance layer in direct thermal contact therewith.

4. A circuit as claimed in Claim 1, 2 or 3, wherein the input voltage is a d.c. control voltage which is applied *via* a long line and that the output is connected to the input terminal of a control circuit, to which the said d.c. control voltage is to be applied.

5. A circuit as claimed in Claim 1, 2 or 3, included in the negative-feedback loop of a low-frequency negative feedback amplifier.

6. A circuit as claimed in Claim 2 or 3, wherein a signal is taken from at least one of the outputs of the differential amplifier.

7. A film circuit, for introducing a large time constant, substantially as hereinbefore described with reference to Figures 1 1*a*, 1*b*, and 2, or to Figure 3, Figure 4, Figure 5, or Figure 6, of the accompanying drawings.

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