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PATENT SPECIFICATION

DRAWINGS ATTACHED

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Semiconductor device.

COMPLETE SPECIFICATION

We, TEXAS INSTRUMENTS INCORPORATED, of 6000 Lemmon Avenue, 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 means for extending the temperature range of satisfactory operation of transistor circuits in such a way that the power handling capabilities of the transistor are also increased. More particularly, the present invention relates to means for compensating temperature induced shifts of transistor d-c bias currents from optimum operating levels.

It is well-known that nearly every parameter of semi-conductor amplifier devices, called transistors, is temperature sensitive. Thus, increases in the operating temperature of a transistor will effect a decrease in the internal impedances of the unit resulting in bias current increases, impedance mismatches in the external circuit, lower gain and lower power handling capabilities of the unit. Also, a transistor unit may be permanently damaged if the circuit in which it is used is so critical as to allow a cumulative action wherein the increase in bias current produces further heating of the bar resulting in an even greater increase in the bias current and more heating until the unit has exceeded its maximum temperature causing permanent parameter changes.

Many temperature compensation schemes have been evolved using temperature sensitive elements in the external circuit. However, such schemes provide a counteraction for ambient temperature changes only and the effects of temperature changes in the semiconductor material itself, i.e. the

junction temperature changes, which affect all transistors and particularly power transistors, remain uncompensated. The present invention, in order to overcome this deficiency, provides a diode element for use in temperature compensation of transistor circuits which is part of the transistor itself and which, consequently, is sensitive to the unit temperature as well as ambient temperature. The element has the further advantage of possessing a resistance-temperature characteristic almost identical to the transistor unit to be compensated.

An object of the invention is to provide a temperature compensated transistor circuit which includes a non-ohmic rectifying junction which has a resistance-temperature characteristic substantially identical with that of the transistor.

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

Figure 1 is a schematic diagram illustrating a common method for applying d-c bias currents to one type of transistor circuit;

Figure 2 illustrates the preferred embodiment of the semiconductor device of the present invention; and

Figure 3 is a schematic diagram illustrating the use of the device of the present invention in a circuit to provide temperature compensation of the d-c bias currents in a transistor amplifier;

Although the n-p-n transistor configuration is used throughout the following description in the specific examples of the several embodiments of the present invention, it is to be understood that the present invention is in no way limited to the n-p-n configuration, for the principles disclosed herein may be applied as well to p-n-p transistor configurations.

With reference now to Figure 1, there is shown schematically a grounded emitter

(Price 3s. 6d.)

transistor circuit illustrating a typical biasing arrangement for an n-p-n junction transistor. Circuits of this type commonly use a single bias battery 1 with its positive terminal connected to the collector of the transistor 2 and the negative terminal connected to the emitter. The base bias voltage is obtained from a voltage divider network of series resistors 3 and 4 between B+ voltage and ground. The resistor 3 is normally of a much lower value than the resistor 4. Therefore, changes in the base bias current flowing through resistor 3 have very little effect on the voltage at the base of the transistor and this voltage remains substantially constant. Temperature difficulties arise in such a circuit because the collector current and the amplification characteristics of this circuit are a function of the base-emitter current which, with a constant voltage applied, depends solely on the emitter-base resistance of the transistor unit. Each change in the junction temperature of the transistor, then, causes a change in the resistance of the junction and results in a shift of the base-emitter bias current from optimum value and a corresponding change in the characteristics of the circuit. Successful temperature compensation therefore must provide a means of maintaining a constant bias current through an emitter-base resistance varying with temperature.

One method of decreasing the effects of temperature on the bias current would be to shunt or replace the resistor 4 with a rectifying diode whose forward resistance temperature characteristic is similar or identical to that of the base-emitter junction of the transistor. However, if such an arrangement is to compensate for changes in the temperature of the semiconductor material of the transistor itself, the diode element must be maintained at the same temperature as that material. The device of the present invention provides a means of maintaining a diode element and a transistor element at exactly the same temperature.

Such a device is shown in Figure 2 illustrating a grown junction transistor of the conventional type having two relatively thick layers 5 and 6 of one conductivity type semiconductor material separated by a relatively thin layer 7 of an opposite type conductivity semiconductor material. In addition to the usual ohmic contacts 8, 9 and 10 for the collector, base and emitter layer leads respectively, a fourth contact 11 is provided to one of the layers, in this case the emitter. The contact 11 is formed as a rectifying contact by any of the several means to be described below and produces a diode whose temperature-resistance characteristic is nearly identical to that of the emitter-base diode of the transistor

element of the device. This triode-diode transistor provides an excellent temperature compensated amplifier when connected as shown in Figure 3.

In the circuit of Figure 3, the collector of the transistor triode-diode 16 is connected to B+ voltage and the emitter, which is also the cathode of the diode element, is connected to ground exactly as in the circuit of Figure 1. However, in the voltage divider network of resistors 12, 13 and 14, the resistors 12 and 13 providing the base bias voltage are shunted by the diode element of the triode-diode. In such an arrangement, the voltage developed across the resistors 12 and 13 to ground is always identical to the voltage developed across the diode element shunting them. If the resistance of resistor 14 is high compared to that of the resistors 12 and 13 and the diode element, the current in the circuit will be determined almost solely by resistor 14 and will remain substantially constant. The voltage developed across the resistors 12 and 13 and across the diode element will be a function of the resistance of the diode and therefore a function of the temperature of the semi-conductor material of the unit. Thus, the base bias voltage developed across the resistor 12 is an inverse function of the temperature of the material and the tendency of the base-emitter current to increase with temperature is counteracted by a decrease in the base bias voltage.

The circuit illustrated in Figure 3 presents merely one example of temperature compensation in transistor circuits using the device of the present invention. However, the triode-diode transistor disclosed herein can be used to improve the performance of many other well-known temperature compensated transistor circuits by merely substituting the triode-diode transistor of the present invention in the circuit and using the diode portion of the device as the temperature sensitive element of the circuit. In the manufacture of the device of the present invention, the rectifying contact may be produced by any of the several methods now well-known in the art. By way of specific example, a rectifying contact to n-type conductivity semiconductor material can be produced by placing a 99% gold-1% gallium alloy wire against the n-type material and heating the material until the tip of the wire melts and combines with the adjacent semiconductor material. Such is the preferred method when the semiconductor material is germanium. For n-type silicon, the preferred technique is the same, substituting an aluminum wire for the gold-gallium wire. It is to be understood that the present invention is by no means limited to the above described techniques but contemplates providing a transistor with an

additional junction or junctions acting as a diode element of the types generally referred to as grown junctions, alloyed junctions, diffused junctions, point contacts, and others.

It is to be realized that the diode element of the triode-diode transistor of the present invention may be formed as a part of the collector layer instead of as a part of the emitter layer. The applicable methods of forming the contact are exactly the same in either case.

A further modification of the present invention provides a dual diode-triode transistor wherein two diode elements may be formed as part of the amplifier device by the same methods described above. Depending on the requirements of the circuit in which the unit is to be used, both of the diode elements may be formed on the emitter layer of the bar of both on the collector layer or one on the emitter layer and one on the collector layer.

The use of the diode-triode transistor of the present invention in the circuit specifically described above and, of course, in a great many others is advantageous in that the same circuit performance is achieved at a lower cost than is possible using separate diode and amplifier devices. For example, the combined unit uses less semiconductor material than the two separate units and, since only a single can or enclosure is used, other material requirements are also reduced. Further, only one item of two need be stocked by equipment manufacturers.

Thus, there has been disclosed a new transistor device combining in a single unit the functions which previously required two or more separate units and in addition provides a new function of temperature compensation in transistor circuits according to the temperature of the semiconductor material of the transistor itself.

WHAT WE CLAIM IS:—

1. A temperature compensated transistor circuit which comprises a body of semiconductive material having a plurality of adjacent layers of alternating opposite con-

ductivity types, a first ohmic connection to a zone of one type conductivity to provide an emitter electrode, a second ohmic connection to another zone of said one type conductivity to provide a collector electrode, a third ohmic connection to a zone intermediate said last mentioned zones to provide a base electrode, a non-ohmic rectifying electrical connection to a zone other than said intermediate zone at a spacing remote enough therefrom to produce a diode which responds to temperature variation substantially in accordance with the emitter-base resistance-temperature characteristic of the transistor and which produces diode action electrically unaffected by the transistor action of said material.

2. A temperature compensated transistor circuit as defined in Claim 1, wherein said rectifying connection is positioned intermediate two of said ohmic connections.

3. A temperature compensated transistor circuit as defined in Claim 1, wherein said rectifying connection is a point contact bearing against one of said zones of one conductivity type.

4. A temperature compensated transistor circuit as defined in Claim 1, wherein said rectifying connection is produced by alloying into said zone other than said intermediate zone a wire containing material producing a conductivity opposite to that of said zone.

5. A temperature compensated transistor circuit substantially as described and as shown in Figures 2 and 3 of the accompanying drawings.

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