

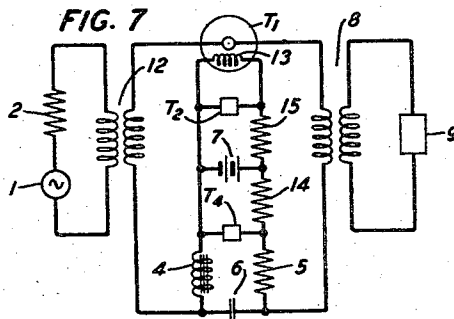
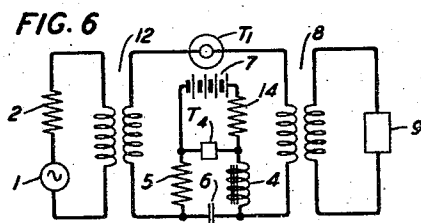
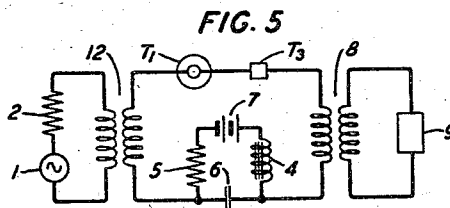
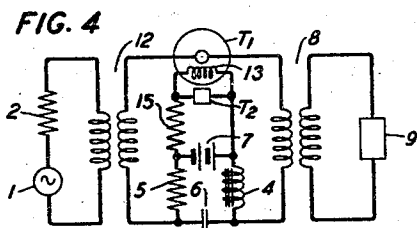
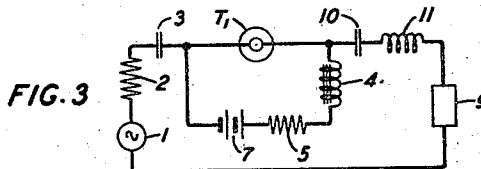
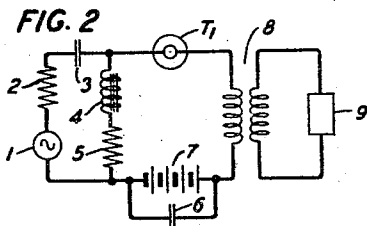
Oct. 10, 1944.

L. W. HUSSEY

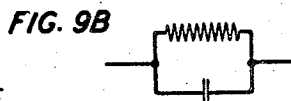
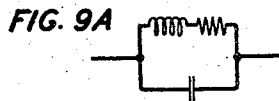
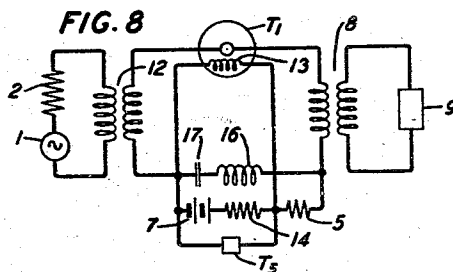
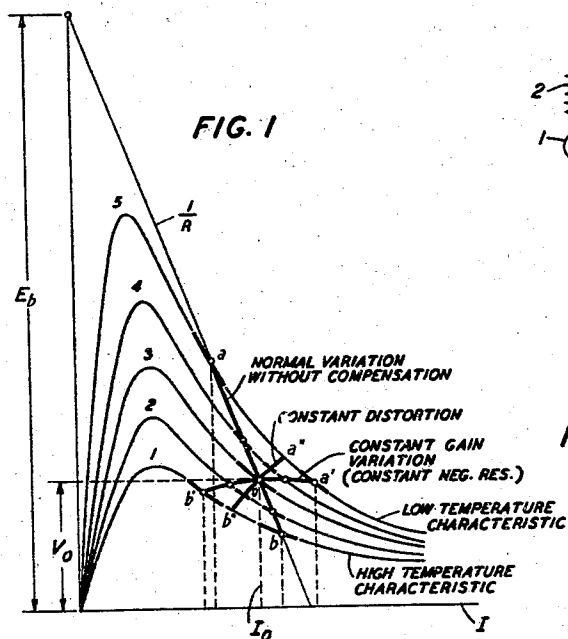
2,360,233

THERMISTOR AS AMPLIFIER FOR LOW FREQUENCY SIGNALS

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ALL FIGURES, T_1 'S ARE THERMISTORS



INVENTOR
L. W. HUSSEY
BY
H. A. Burgess
ATTORNEY

UNITED STATES PATENT OFFICE

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THERMISTOR AS AMPLIFIER FOR LOW
FREQUENCY SIGNALS

Luther W. Hussey, Madison, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

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7 Claims. (Cl. 179-171)

This invention relates to amplifying systems and particularly amplifying systems operative over a band of frequencies. More particularly it relates to the use of semiconductors such as silver sulphide as amplifying elements in such systems and as elements to control the behavior of these amplifying elements as the ambient temperature varies.

It is known that certain compounds which are ordinarily classed as semiconductors exhibit two very useful phenomena—negative temperature coefficient of resistance and a voltage-current characteristic that rises to a voltage maximum after which the voltage falls off as the current increases thus achieving a negative slope which is practically linear over a part of its range. It is in this latter range that these elements function as negative resistances to facilitate amplification in the manner well-known in the art. Also it is because of the negative temperature coefficient they display that they are often used as temperature controls especially to regulate electrical devices in accordance with variations in ambient temperature. Both of these desirable properties are made use of in the operation of this invention.

In using semiconductors for amplification a direct current potential is applied to bias the element into operation over the most linear portion of its negative resistance region so that when it is inserted in a suitable alternating current circuit maximum undistorted amplification is realized. Also, in order to increase the frequency range of the amplification band and the amount of amplification realizable both of which factors are limited by the thermal inertia of the semiconductor, it is desirable to keep the elements small in volume in order that they may be sensitively responsive to rapid changes in current and temperature.

In using semiconductors as temperature controls each is chosen to have the proper dimensions and temperature coefficient to regulate the particular variable feature of the amplifier semiconductor that it is designed to control in a prescribed manner. Most of these have been discussed in the prior art. Throughout this description the word semiconductor and its commercial synonym, thermistor, will be used interchangeably.

For a detailed description of this invention and of the component embodiments thereof, reference is made to the drawing, in which:

Fig. 1 shows graphically the variable behavior of a thermistor unit operated in the negative

resistance region of its voltage-current characteristic;

Figs. 2 and 3 show circuits with thermistors used to effect amplification as in the prior art;

Figs. 4 to 8 inclusive are circuit diagrams showing various ways of using one or more additional thermistors to modify the action of the amplifier thermistor in accordance with this invention; and

Figs. 9a and 9b show types of impedance used to compensate the variation with frequency of amplifier thermistors.

Referring, now, more particularly to Fig. 1 curves 1, 2, 3, 4, and 5 represent a family of thermistor voltage-current characteristics, curve 3 representing the mean, curves 1 and 2 representing the effect of high ambient temperature and curves 4 and 5 representing the effect of low ambient temperature. The curve marked 1/R represents the normal variation of the bias without compensation. It is the E-I characteristic of a fixed resistance inserted in series with the thermistor to stabilize its bias. I_0 is the direct current bias, E_b is the battery voltage, and V_0 is the direct current voltage across the thermistor. This type of construction using a line with a slope equal to the reciprocal of the bias stabilizing resistance is a familiar one and is valid for any kind of resistive device in series with a linear resistance and a battery. In the case of the thermistor it is necessary that the bias stabilizing resistance and the battery voltage be sufficiently large so that the straight line with slope equal to the reciprocal of the bias stabilizing resistance intersects the thermistor direct current voltage characteristic at one point only. Otherwise the bias will slide to a positive resistance intersection. Curve $a'ob'$ represents the locus to be followed by the shifting bias if the gain is to remain constant. $a''ob''$ represents the locus of the bias shift if the distortion is to remain constant.

Fig. 2 shows T_1 as a negative resistance thermistor for amplifying the signals generated by source 1 after which they are impressed upon the windings of transformer 3 from which they are passed along to load 2. The energy for heating and biasing T_1 to its negative resistance condition is derived from direct current source 7. Its path is from direct current source 7 through the primary winding of transformer 3 through T_1 , through retard coil 4, stabilizing resistance 5 (which was discussed with reference to Fig. 1) and back to source 7. The path of the signals starts from source 1, goes through source im-

pedance 2, condenser 3, T_1 , through the primary winding of transformer 8 (and by induction to the secondary and on to load 9) through condenser 6 (very little going through direct current source 7) and back to signal source 1, very little passing through resistance 5 on account of retard coil 4. Condenser 3 is merely a blocking condenser to prevent direct current energy from entering the signal source circuit. Its impedance is made sufficiently low so as not to affect transmission.

Fig. 3 shows a single frequency amplifier without a transformer. Like numbered elements perform similar functions to those of Fig. 2. The tuned circuit composed of condenser 10 and inductance 11 could obviously be replaced by a band-pass network. In this circuit the thermistor amplifier direct current supply is prevented from entering any part of the signal circuit by condenser 3.

With circuits such as those shown in Figs. 2 and 3 the thermistor T_1 would be initially biased to operate about point 0 on voltage-current characteristic 3 of Fig. 1. This operating point is determined by the negative resistance desired and the required freedom from distortion. This is accomplished by adjusting the direct current source 7, which has a battery voltage E_b , to produce a drop V_0 across T_1 causing current I_0 to flow through thermistor T_1 which will then have its optimum bias for maximum undistorted amplification. When signals from the source 1 are applied to T_1 , in its biased condition, they will cause the voltage across and current through T_1 to oscillate along the tangential direction at point 0 on curve 3 provided the frequency of the signals does not exceed a limiting maximum. By operating over the negative resistance portion of the characteristic in this manner more alternating current power is transferred to the load than is received from the signal source, the excess being absorbed from the source of direct current supply in a manner somewhat similar to that of a vacuum tube amplifier. T_1 thus provides the negative resistance necessary for very satisfactory amplification over a frequency range limited only by its thermal lag which can be reduced by reducing the mass of T_1 . But if the ambient temperature rises, the direct current voltage characteristic shifts toward curve 1 and if the ambient temperature falls the characteristic shifts toward curve 5 the bias shifting with it along the line aob .

If a circuit such as that shown in Fig. 4 is used, the shift in locus of the voltage-current characteristic of the negative resistance thermistor with ambient temperature change can be held to within closer limits such as curve 4 for low values and curve 2 for high values. In this circuit all elements similarly numbered perform the same functions as in Figs. 2 and 3. A heater winding 13 shunted by an ambient temperature control thermistor T_2 is connected across the battery 7 in series with resistance 15. Heater winding 13 is wound around thermistor T_1 , being electrically but not thermally insulated from it to elevate its temperature to a level somewhat above ambient temperature to effect closer temperature regulation. Now, if the ambient temperature changes, the resistance of T_2 changes with it thereby changing the current through the heater winding which reduces the tendency of the temperature of T_1 to change, thus diminishing the shift in locus of its voltage-current characteristic. An input transformer 12 couples the input circuit and

signal source voltage to the amplifying portion of the circuit.

Fig. 5 illustrates another method of reducing gain change with variable ambient temperature. It has a thermistor T_3 operated over the positive region of its characteristic in series with T_1 . If the series positive resistance of T_3 is smaller than the negative resistance of T_1 and changes magnitude in the same way as the negative resistance of T_1 with ambient temperature variations the series combination will tend to produce a resultant negative resistance that is substantially constant. Referring to Fig. 1 this means that although the bias operating point shifts along line aob , the sum of the resistances of thermistors T_1 and T_3 remains nearly constant even though the slope of the voltage-current characteristic changes appreciably.

Fig. 6 illustrates a circuit whereby the bias may be controlled in such a way that the operating point will follow a locus that intersects the shifting voltage-current characteristics at points at which the slope is very nearly the same. Referring again to Fig. 1, if the bias is made to vary as the ambient temperature varies in such a way that the operating point shifts along $a'ob'$ instead of aob the negative resistance of T_1 and hence the gain will remain constant. T_4 is a slow acting thermistor operating as an ohmic resistance to adjust the bias. It has a negative coefficient of resistance and decreases the bias when the temperature increases or increases it when the temperature decreases. Resistance 14 is inserted to properly proportion the relationship between the bias and the resistance of the positive thermistor.

Any two or even all three of these methods of controlling the negative resistance of T_1 may be combined to realize the close regulation obtainable by their concurrent action. For example the heater may be used to decrease the ambient temperature variation (say to a range of curves 2 to 4 instead of 1 to 5) and then one or both of the other methods may be used for more accurate compensation. Also in case the gain compensated device of Fig. 5 has excessive distortion at some point, the bias variation control of Fig. 6 can be used to make the operating point vary over that locus of points on the voltage-current characteristics whereat the distortion is the same (such as $a'ob'$ of Fig. 1) and either of the other methods used to further minimize the gain variations.

Fig. 7 shows a circuit which uses both heater and bias control thermistors to produce closer regulation. In this figure and in Fig. 4, additional resistance 15 is a voltage proportioning resistance to facilitate the controlling effect of thermistor T_2 .

Also one thermistor may be designed to perform the function of both heater control and bias control as illustrated in Fig. 8. In this figure T_5 is the thermistor that performs both functions. If the ambient temperature changes, the resistance of T_5 changes thereby changing the current through the heater which reduces the tendency of the temperature of T_1 to change, thus diminishing the shift in locus of the voltage-current characteristic. The change in the resistance of T_5 also changes the bias of the thermistor by the proper amount and in the proper direction to compensate for whatever shift in locus does occur. As a precautionary measure against the possibility of oscillation at some very low frequency due to the low impedance looking into the output transformer at low frequencies, the by-pass condenser 6 may be

replaced with a series resonant circuit such as condenser 17 in series with inductance 16, tuned to the midband frequency, in order to pass frequencies in the amplifier band but keep the impedance facing the thermistor high at low frequencies. In this particular circuit the amplifier thermistor direct current is allowed to pass through the high impedance winding of both transformers.

To facilitate band-pass operation an electrical network such as those shown in Figs. 9a and 9b designed to take account of the effective reactive component of the amplifier thermistor (due to its thermal inertia) may be put in series with it. A resistance shunted by a condenser in series with the thermistor gives a fair compensation for a flat gain over a band of frequencies. If an impedance consisting of an inductance and resistance in series and a capacitance in parallel is connected in series with the thermistor a considerably better compensation is obtained.

Self-oscillation will not occur in a negative resistance thermistor circuit used for amplification purposes if the sum of the thermistor impedance and the total impedance facing it has a positive resistance component at all frequencies. Sufficient positive coefficient resistance should, therefore, be provided in the loop containing the thermistor for all embodiments of this invention.

The fact that all the amplifier circuits embodying the invention have been described with reference to transformer coupled load and source circuits in no way limits its application to such circuits. Resistance, capacitance and network coupling may be used, the complexity of such coupling depending in each instance on the particular circuit application.

These specific and preferred embodiments illustrate the utility of my invention which is defined by the following claims.

What is claimed is:

1. A semiconductor operated in its negative resistance region, electrically biased for optimum amplification and a thermistor connected in said biasing circuit to tend to cause said bias to be always optimum as the ambient temperature changes.

2. A thermistor having a negative resistance that varies with ambient temperature and means for operating it in the negative resistance part of its range including electrical biasing means and means for controlling said negative resistance by changing the bias, said means so operating that the change in negative resistance it introduces is equal and opposite to the change introduced by the change in ambient temperature.

3. In an amplifying system, a source of waves to be amplified, a load circuit, and a negative temperature coefficient thermistor included in circuit with said source and said load circuit, means to supply a bias current to said thermistor of such value as to bias the thermistor into the negative resistance region of its volt-ampere characteristic, said thermistor having a sufficiently small temperature lag to enable its temperature to vary at the frequency of said waves to be amplified, and means to reduce the effect of ambient temperature variations upon the amplifying action of said system comprising a sec-

ond negative temperature coefficient thermistor connected in said system and responsive to ambient temperature variations but substantially unresponsive to temperature variations of the frequency of said waves to be amplified, said second thermistor being connected in circuit with said bias current supply and reducing the bias applied to said first thermistor as the ambient temperature increases.

4. In an amplifying circuit for amplifying signals, a negative temperature coefficient thermistor that is temperature responsive at the frequencies of said signals, a source of steady bias current for biasing said thermistor into the negative resistance region of its characteristic, and means to compensate for variable amplification with varying ambient temperature comprising a relatively slow-speed thermistor connected in circuit with said first thermistor and said source to change the bias current in response to change in ambient temperature.

5. In combination, an amplifier comprising a thermistor having a speed of temperature response sufficiently high to follow variations to be amplified, means to bias said thermistor into the negative resistance region of its voltage-current characteristic, said characteristic having different slopes at different operating temperatures and the same value of bias and means to compensate for the effect on the amplifying properties of the thermistor of changes in ambient temperature comprising means responsive to ambient temperature variations for changing the amount of bias on said thermistor in the direction to tend to maintain at constant value the slope of the portion of the characteristic over which the thermistor is operated by said variations to be amplified.

6. In an amplifier for electrical waves a negative temperature coefficient thermistor capable of having its temperature changed at the frequency of said waves, means to bias said thermistor into the negative resistance region of its voltage-current characteristic, and means responsive to changes in ambient temperature for decreasing the value of bias as the ambient temperature increases and vice versa by the amount necessary to maintain the slope of the operating portion of the characteristic substantially constant.

7. In an amplifying circuit, a source of waves to be amplified, a thermistor in circuit with said source having a sufficiently high speed of temperature response to heating current to have its temperature and therefore its resistance changed at the frequency of said waves, a source of bias current connected to pass a current through said thermistor of such magnitude as to enable the thermistor to exhibit a negative resistance effect to said waves, and a slow speed thermistor connected in circuit between said source of bias current and said first thermistor and responsive to relatively slow changes in ambient temperatures affecting said first thermistor and, in response to such changes in ambient temperature, changing the amount of bias current and thereby maintaining the negative resistance effect exhibited by said first thermistor substantially constant.

LUTHER W. HUSSEY.