

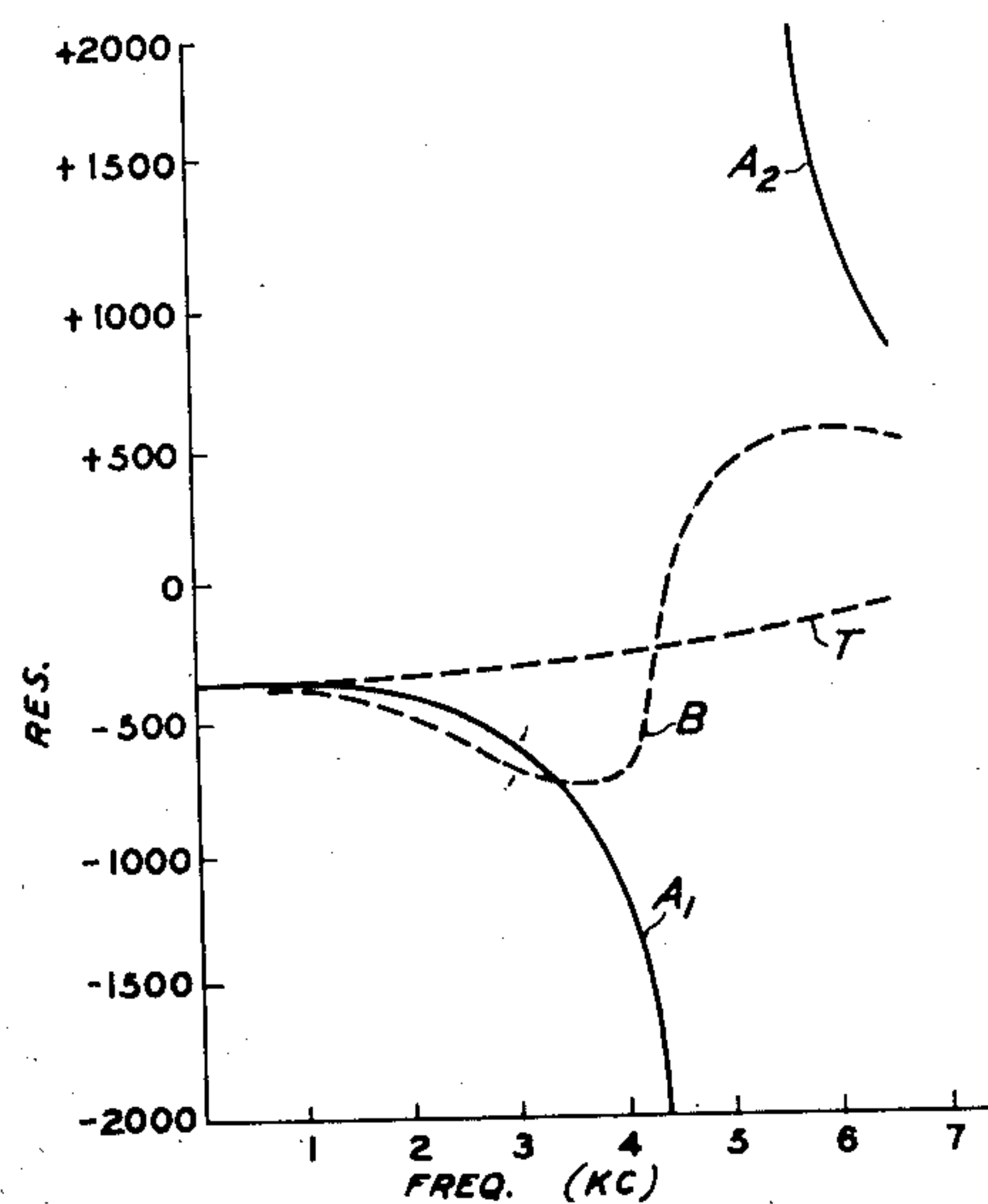
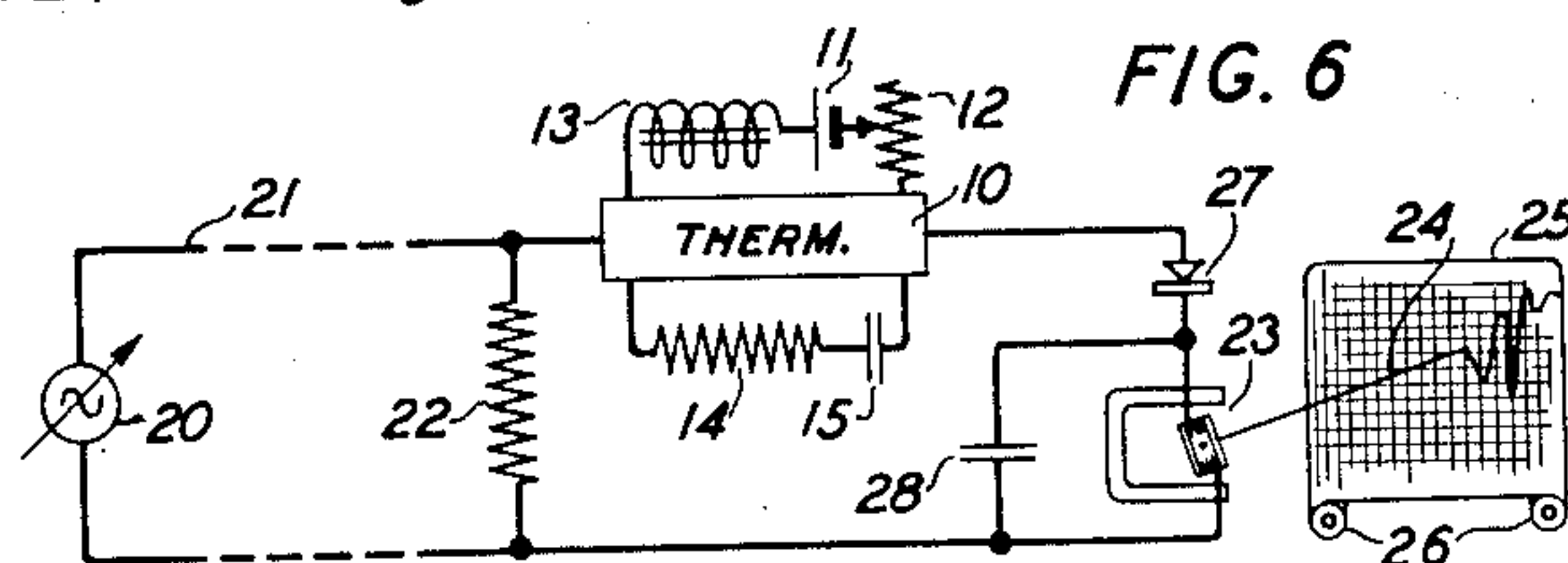
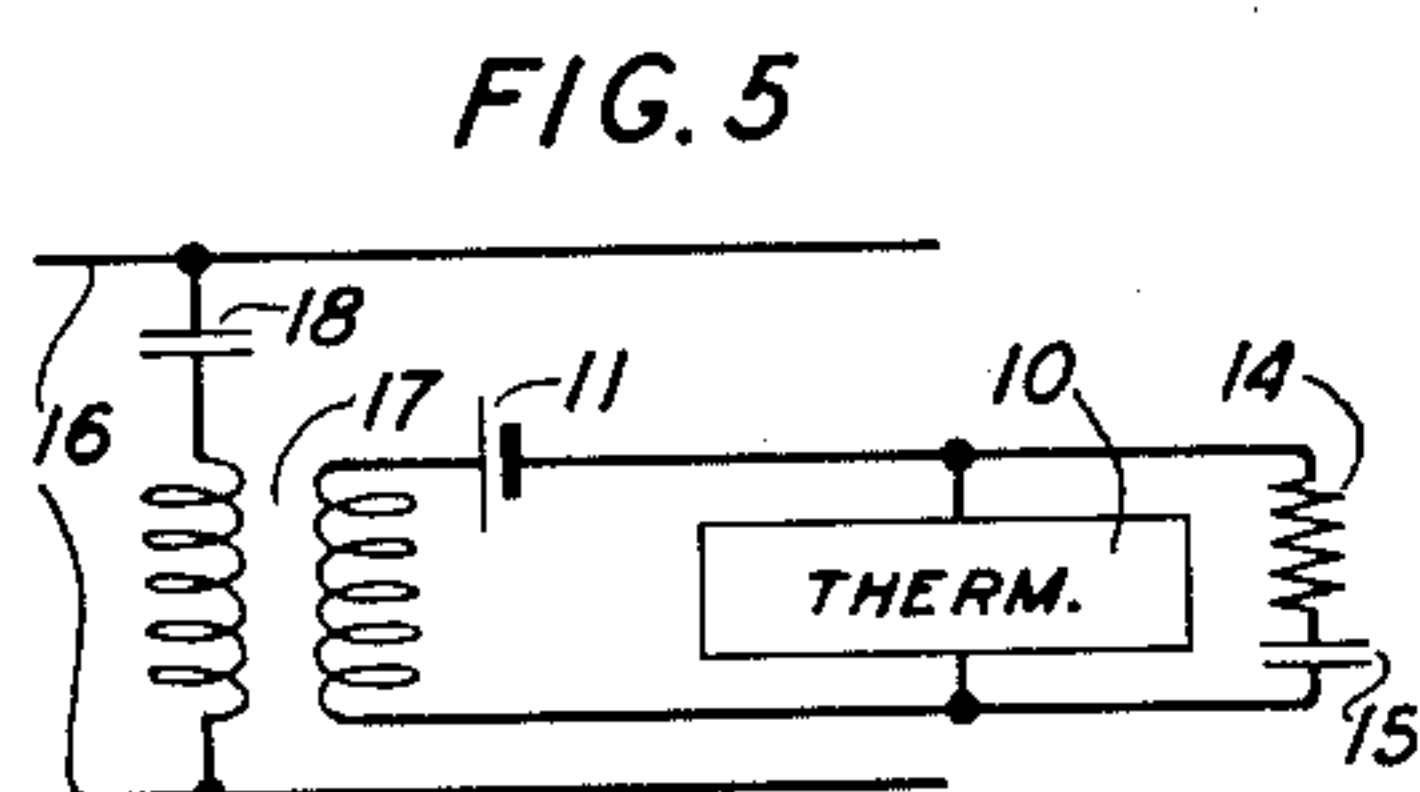
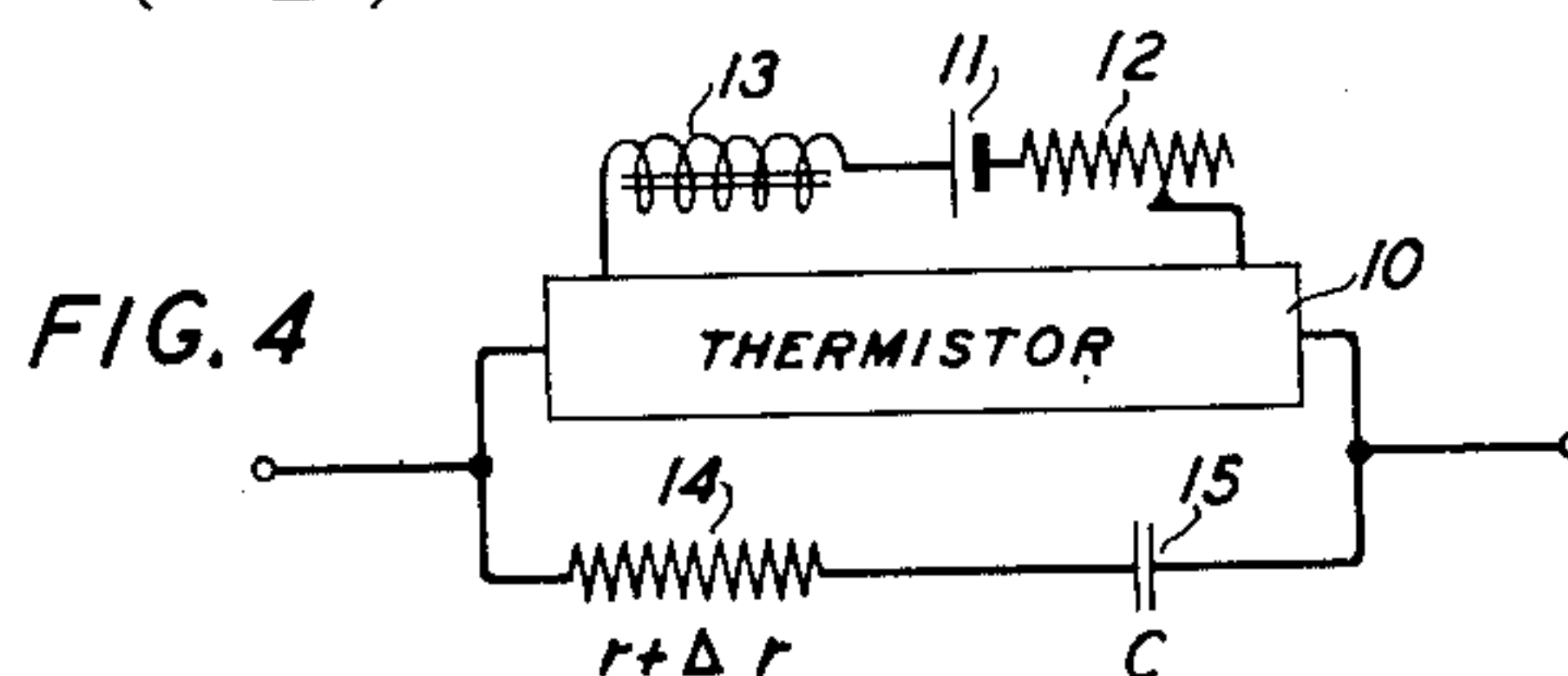
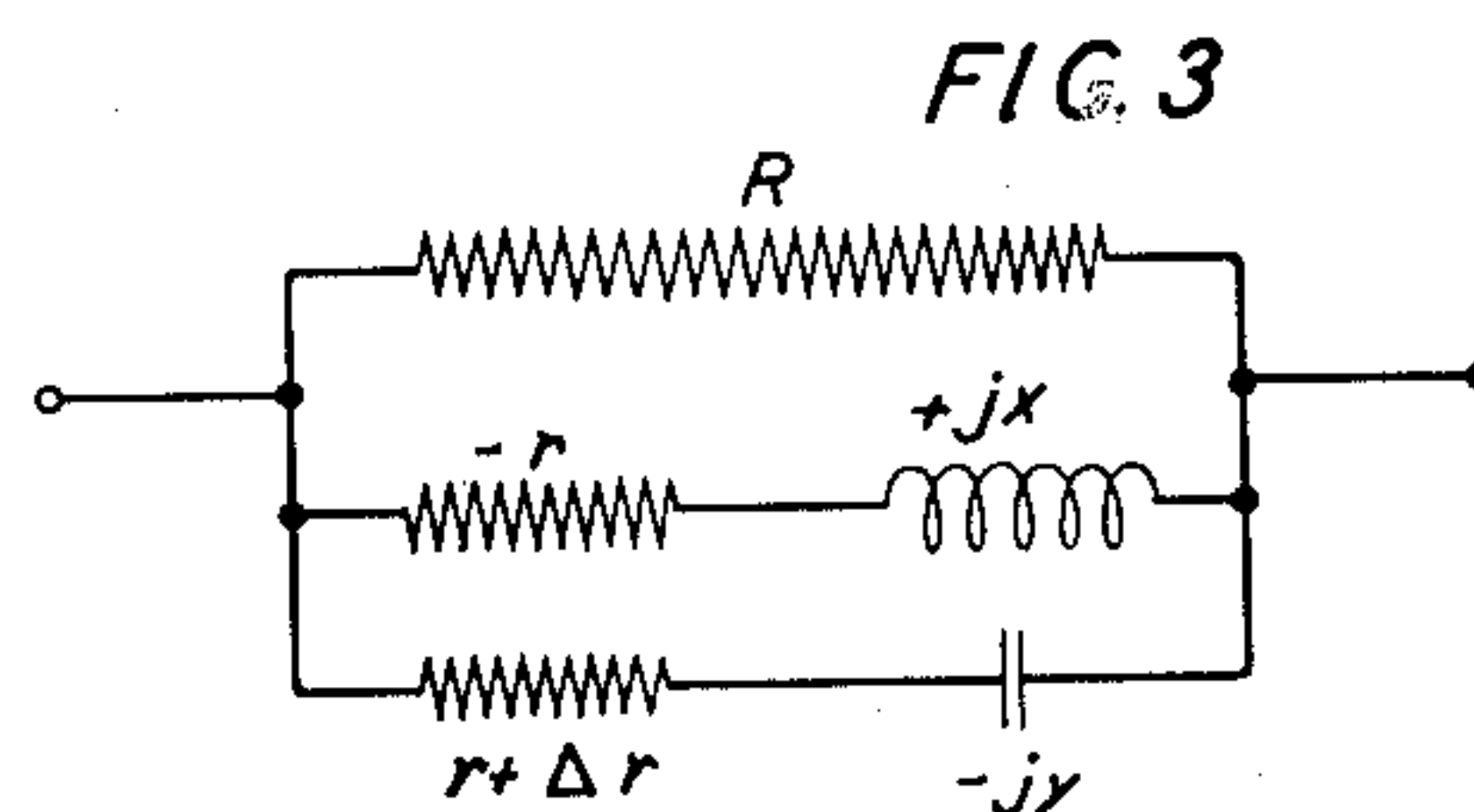
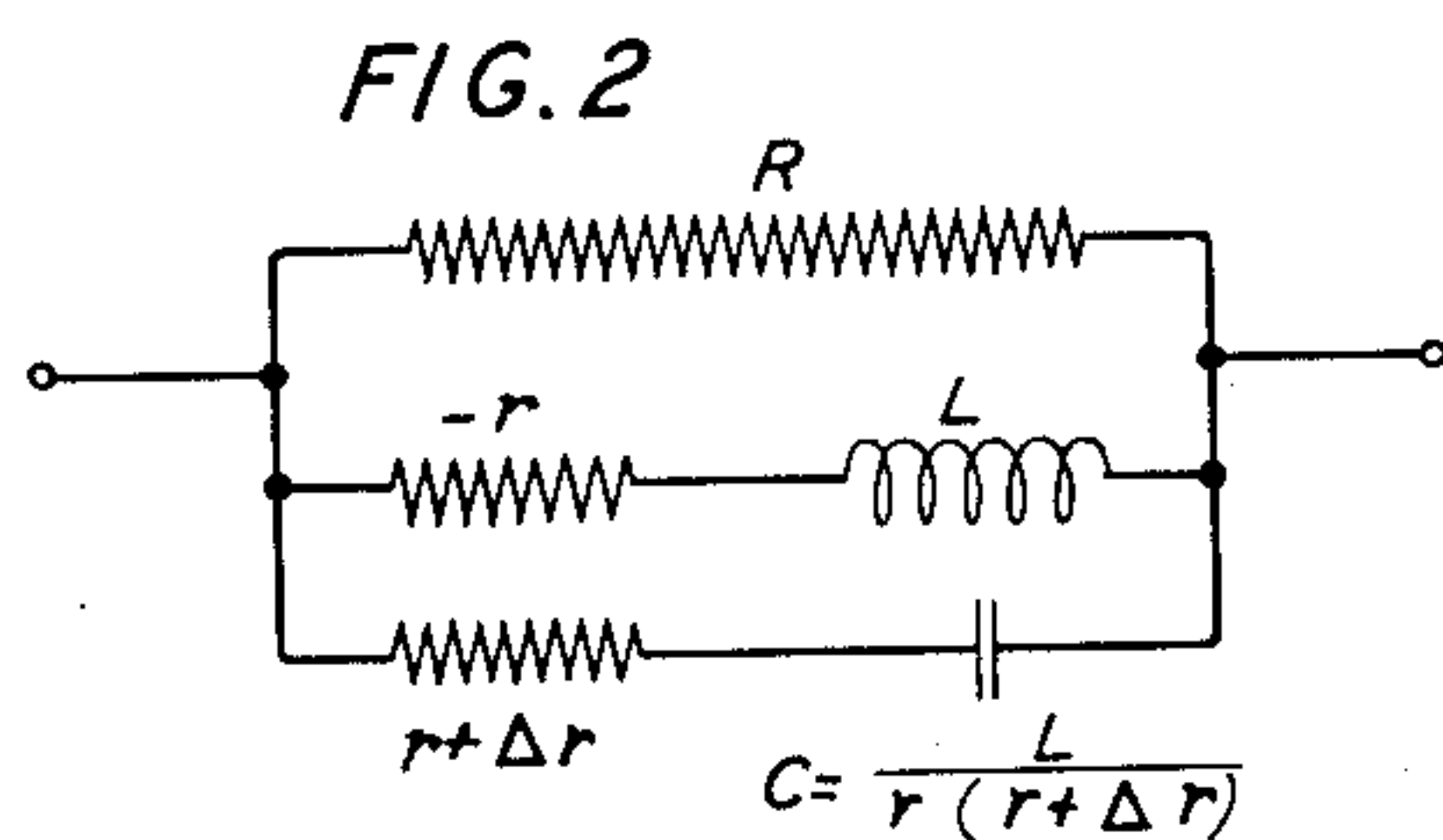
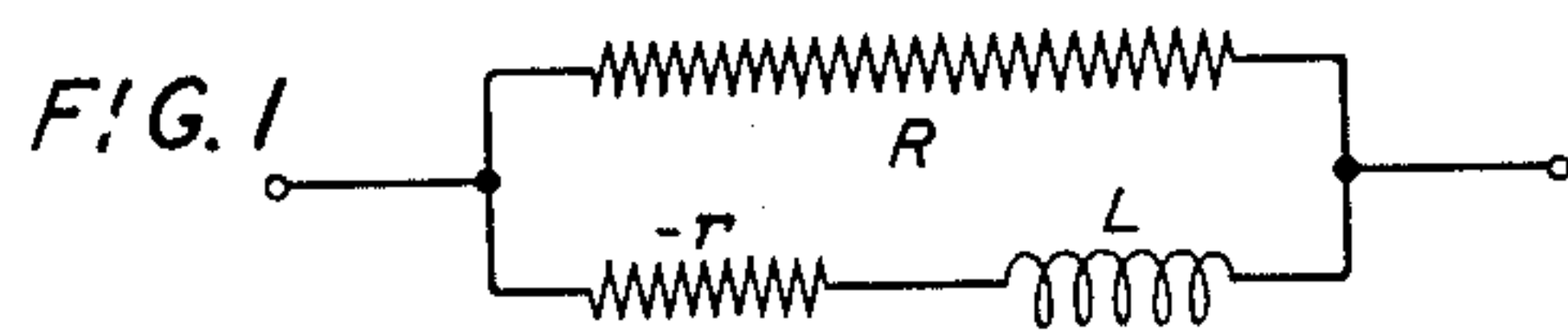
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2,410,076

NEGATIVE IMPEDANCE CIRCUIT

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2,410,076

NEGATIVE IMPEDANCE CIRCUIT

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8 Claims. (Cl. 178—44)

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The present invention relates to circuits using negative impedance and more especially to the provision of auxiliary impedance, which may comprise a network of impedances, for modifying the characteristic of the negative impedance.

One known type of negative impedance device consists of a substance having a negative temperature coefficient of resistance connected in circuit with a source of biasing current which raises the temperature of the substance to such a point that its resistance changes in response to small impressed current fluctuations in such manner that the terminal voltage across the substance decreases as the current through the device increases. In other words, the device operates on a falling portion of its volt-ampere characteristic. This type of negative impedance device has been termed thermistor because its resistance changes as a function of its temperature. This and other types of devices that exhibit a characteristic with a region in which the slope is downward are referred to as negative resistance devices since the derivative of voltage with respect to current variation is negative in sign.

It has been shown that the time lag of heating inherent in a thermistor is equivalent to an inductance in the equivalent electrical network. For some purposes this time lag is undesirable and what is desired is a negative resistance with substantially no reactance.

It is an object of the present invention to compensate or neutralize to a material degree the reactive component of impedance of a negative resistance device such as a thermistor.

A further object of the invention is to provide a negative resistance whose magnitude varies with frequency.

Thermistors that are suitable for carrying out the objects of this invention may comprise any of a number of known substances including particularly semiconductors, such as silver sulphide, boron, oxides of uranium or other substances having negative temperature coefficients of resistance. Such thermistors have been constructed having a frequency response range covering the range of commercial speech and even extending to many kilocycles per second. One type of thermistor construction capable of responding to frequencies of this order of band width is disclosed in United States patent to G. L. Pearson 2,276,864, granted March 17, 1942.

The nature and objects of the present invention will appear more fully from the following detailed description together with the accompanying drawing in which:

Figs. 1 to 4, inclusive, are impedance network diagrams to illustrate how the equivalent circuit of a thermistor may be combined with a compensating network according to the invention;

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Fig. 5 shows one method of coupling a thermistor to a line according to the invention;

Fig. 6 shows a circuit for utilizing a thermistor in accordance with the invention; and

Fig. 7 shows curves to be referred to in the description.

Fig. 1 is the approximate circuit equivalent of a thermistor. The thermistor when suitably biased to its negative resistance region behaves like a series positive resistance R shunted by a negative resistance $-r$ and inductance L in series with each other. As stated, it is the temperature time lag which imparts to the thermistor the reactance effect represented in the equivalent circuit by the inductance L . As the frequency increases, the negative resistance effect eventually disappears and the thermistor behaves as an ohmic resistance R . In terms of the thermistor this occurs when the frequency exceeds the highest frequency which the temperature variations can follow. In terms of the equivalent circuit, this occurs at the frequency at which the impedance of the inductance L becomes so great that substantially no current can traverse the path through $-r$ and all of the current must take the path through R .

In accordance with the invention, this time lag of the thermistor is reduced or substantially neutralized by connecting in shunt across the thermistor terminals a circuit comprising a positive resistance of numerical value nearly equal to r in series with a capacity C of proper size, as indicated in Figs. 2 and 3. It can be shown that the impedance Z of the circuit of Fig. 2 (which is identical to the circuit of Fig. 3 but uses a different notation) is

$$Z = j \frac{[(L\omega)^2 + r^2](r + \Delta r)}{(L\omega)\Delta r + j[(L\omega)^2 - r(r + \Delta r)]}$$

where

$$C = \frac{L}{r(r + \Delta r)}$$

or, using the notation of Fig. 3,

$$Z = j \frac{(r + \Delta r)x + ry}{\Delta r + j(x - y)}$$

where

$$xy = r(r + \Delta r)$$

As Δr approaches 0, Z approaches the value

$$\frac{(L\omega)^2 + r^2}{r(L\omega)^2 - r^2}$$

which, since it contains no reactance term, represents a pure resistance whose magnitude varies with frequency. Moreover, the resistance can be positive or negative depending upon the frequency. This effect is illustrated by the graphs in Fig. 7.

Curve T is the measured curve of a boron ther-

mistor without the compensating shunt circuit of the invention. Its resistance is negative at all of the frequencies plotted but the value is decreasing with increasing frequency so that at some frequency in the neighborhood of 7 kilocycles its resistance will turn positive. Solid line curve A is in two parts (A_1 , A_2) and represents the ideal case in which Δr is zero and, therefore, r is numerically exactly equal to $-r$. This curve passes from minus infinity to plus infinity in going through a frequency of about 5 kilocycles. This curve represents an unstable case and cannot be actually realized in practice but can be approached. Dotted curve B is a curve calculated for the case where Δr has a small positive value large enough to give stable operation. This curve is interesting in exhibiting increasing negative resistance effect with rising frequency over a considerable range below 4 kilocycles and a steeply rising characteristic between 4 and 5 kilocycles, this steep portion being entirely in the negative resistance range for several hundred cycles. This offers the possibility of a circuit with net gain and with its gain varying rapidly as a function of frequency. The computations for these curves assumed values as follows:

$$\begin{aligned} R &= 600 \text{ ohms} \\ L &= 0.00577 \text{ henry} \\ C &= 0.096 \text{ microfarad} \\ -r &= -240 \text{ ohms} \end{aligned}$$

The curve A was computed for $r=240$ ohms and curve B was computed for $r=250$ ohms.

In the case of curve B since the neutralization of the inductive reactance L is incomplete, the impedance Z is not a pure resistance but has a phase angle varying with frequency. The real or resistance component is plotted in curve B.

The invention provides what is believed to be a highly novel circuit combination or unit capable of general application. This unit is illustrated in Fig. 4 as comprising a thermistor 10 having a battery 11 and variable resistance 12 for applying an adjustable bias to the thermistor to bias it to the desired point along its negative resistance characteristic. The current may be passed through the thermistor by a conductive path or applied to a heating winding surrounding the thermistor. Choke coil 13 is for preventing current variations representing signals or other waves to be amplified from being shunted through the bias current circuit. The compensating or neutralizing circuit already described comprises a resistance 14 and capacity 15 proportioned in magnitude with relation to the negative resistance and positive inductance effects inherent in the thermistor operation as already set forth.

Fig. 5 shows a circuit for introducing into a line or circuit represented by the fragment of line 16 a resistance or a gain varying with frequency over a definite range. The thermistor is coupled to the line 16 through transformer 17 inserted between the thermistor and a bridge across line 16, including condenser 18 which may be a stopping condenser or a tuning condenser for tuning the shunt branch. The transformer 17 may serve to step the impedance up or down as between the line and the thermistor circuit. The resistance 14 may be partly or wholly a resistance having a highly positive temperature coefficient of resistance to insure stability if high local circulatory currents should tend to exist.

Fig. 6 shows a circuit for using the compensated thermistor of the invention for converting

frequency variations into amplitude variations. A source of variable frequency is shown at 20 which may in practice comprise a vacuum tube oscillator with a movable condenser plate for varying the frequency. The output of source 20 is sent over a circuit or line 21 to the point at which the variations in frequency are to be indicated. Resistance 22 (which could be replaced by transformer 17 and condenser 18 of Fig. 5, if desired) is for coupling the line 21 to the indicator circuit comprising thermistor unit 10 to 15 (Fig. 4) and a suitable current responsive element shown for illustration as a moving coil instrument 23 having a pen 24 movable across a paper 25 fed along by rollers 26 to make a record of the frequency variations.

The frequency of source 20 may be varied by hand to transmit signs or signals or may be varied by a meter, float, steering wheel or any other movable member whose position or movement is to be indicated at a distance. The resulting changes in frequency are translated by the thermistor circuit into amplitude variations which are rectified by any suitable type rectifier 27 shown as a solid element rectifier, such as copper oxide. The rectifier current flows through the coil of the instrument 23 and the alternating current component flows through shunting condenser 28. If operation is desired in accordance with curve B of Fig. 7, the source 20 may have a mean frequency slightly above 4 kilocycles (e. g. 4,200 cycles) and the maximum range of variation may be between 4,000 cycles and 4,400 cycles. Over this entire range the resistance is negative and varying at a steep rate so that the thermistor acts as an amplifier and at the same time as a very effective conversion circuit for changing frequency modulated waves to amplitude modulated waves. By using two channels like the one in Fig. 6 and suitably coordinating them, a telautograph system may be provided. Other applications of the invention will occur to persons skilled in the art, from the illustrative examples that have been given showing the principle of operation.

The invention is not to be construed as limited to the specific forms that have been disclosed but the scope is defined in the claims, which follow.

What is claimed is:

1. A circuit comprising a thermistor and a bias current supply circuit for causing said thermistor to develop an impedance effect having a negative resistance component and an inductive component, and a circuit connected in shunt relation to said thermistor and comprising positive resistance and capacitive reactance proportioned to substantially neutralize the inductive reactance of said thermistor impedance.
2. A circuit comprising a thermistor and a bias current supply circuit for causing said thermistor to develop an impedance effect having a negative resistance component and a reactive component, and a circuit connected in shunt relation to said thermistor and comprising positive resistance and a reactive impedance proportioned to substantially neutralize the reactive component of said thermistor impedance.
3. In combination a thermistor, means to bias said thermistor to the negative resistance region of its volt-ampere characteristic whereby said thermistor exhibits negative resistance over a given frequency range with an inductive reactance, and a passive network connected in shunt across said thermistor of such character-

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istic that the combination thermistor and network has a resultant impedance closely approaching a pure negative resistance whose magnitude varies with frequency over said frequency range.

4. In combination, a negative resistance device whose impedance includes an inductive component and means comprising a positive resistance and a capacitance in series with each other in shunt across said device, said positive resistance being nearly equal in magnitude to the negative resistance of said device and said capacitance being of such value that said inductive component is substantially neutralized.

5. A frequency-amplitude conversion circuit comprising a negative resistance device having inherent reactance and a compensating network having resistance and reactance shunted across said negative resistance device for giving a resultant impedance approaching a pure resistance whose magnitude varies with frequency.

6. A circuit for converting frequency variations to amplitude variations comprising a thermistor of sufficiently high response speed to permit its temperature to follow said frequency variations, said thermistor exhibiting an inductive reactive effect, and means to reduce said inductive effect

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comprising a compensating network in shunt relation to said thermistor comprising positive resistance and capacitance.

7. In combination with a circuit carrying currents of different frequency, a circuit unequally responsive to currents of different frequencies comprising a thermistor shunted by resistance and capacitance of such value as to give a resultant impedance approaching a pure resistance whose magnitude varies markedly at said different frequencies.

8. A circuit comprising a pair of terminals and two parallel branches connected between said terminals, the first branch comprising a negative resistance device which is electrically equivalent in impedance to a pure resistance connected between said terminals, shunted by a negative resistance of value $-r$ and an inductance L in series with each other, and the second branch consisting of a resistance $r + \Delta r$ in series with a capacitance C of magnitude given by

$$C = \frac{L}{r(r + \Delta r)}$$

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