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2,407,293

FREQUENCY MODULATION

Filed July 26, 1944

FIG. 1

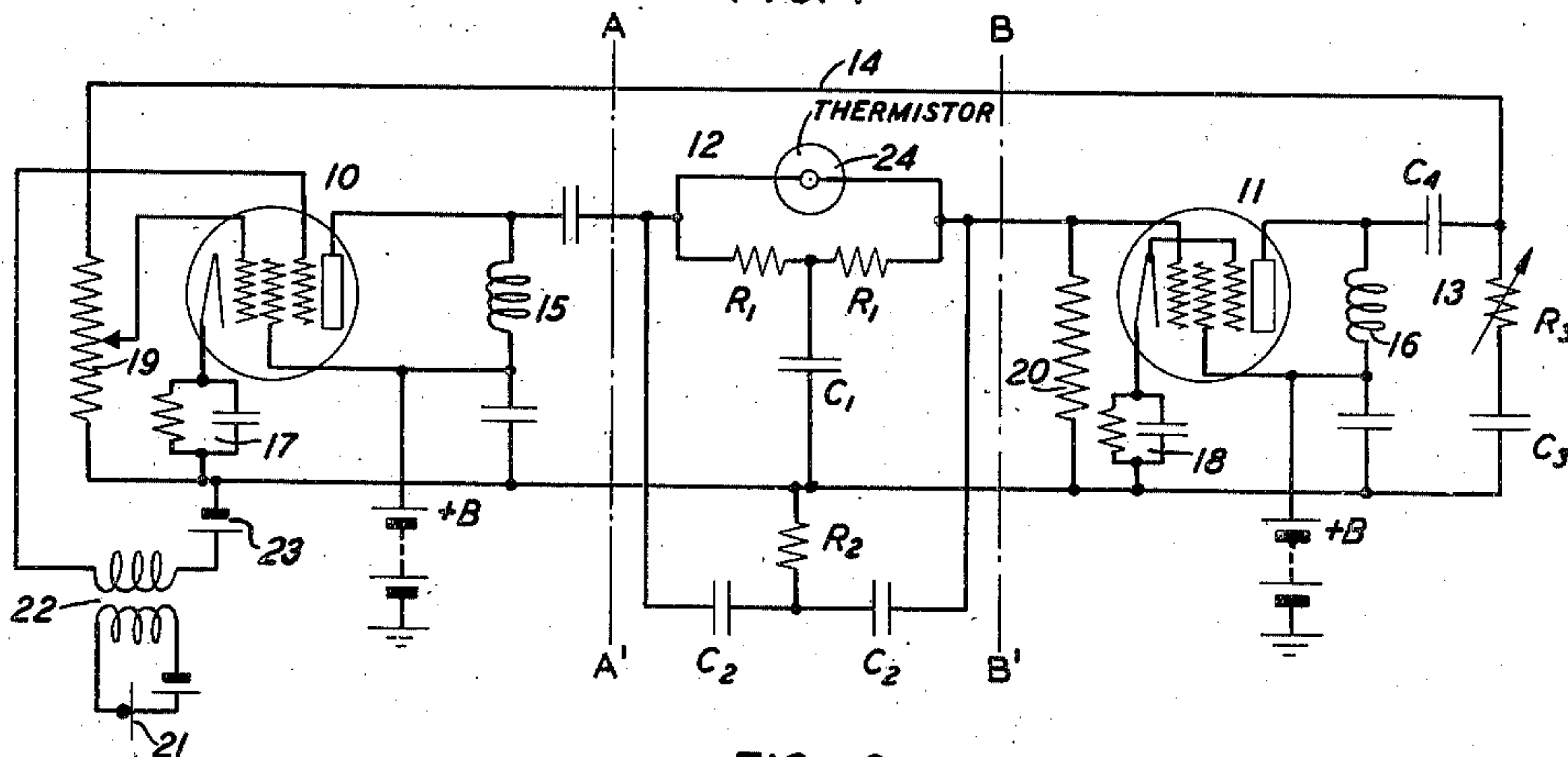


FIG. 2

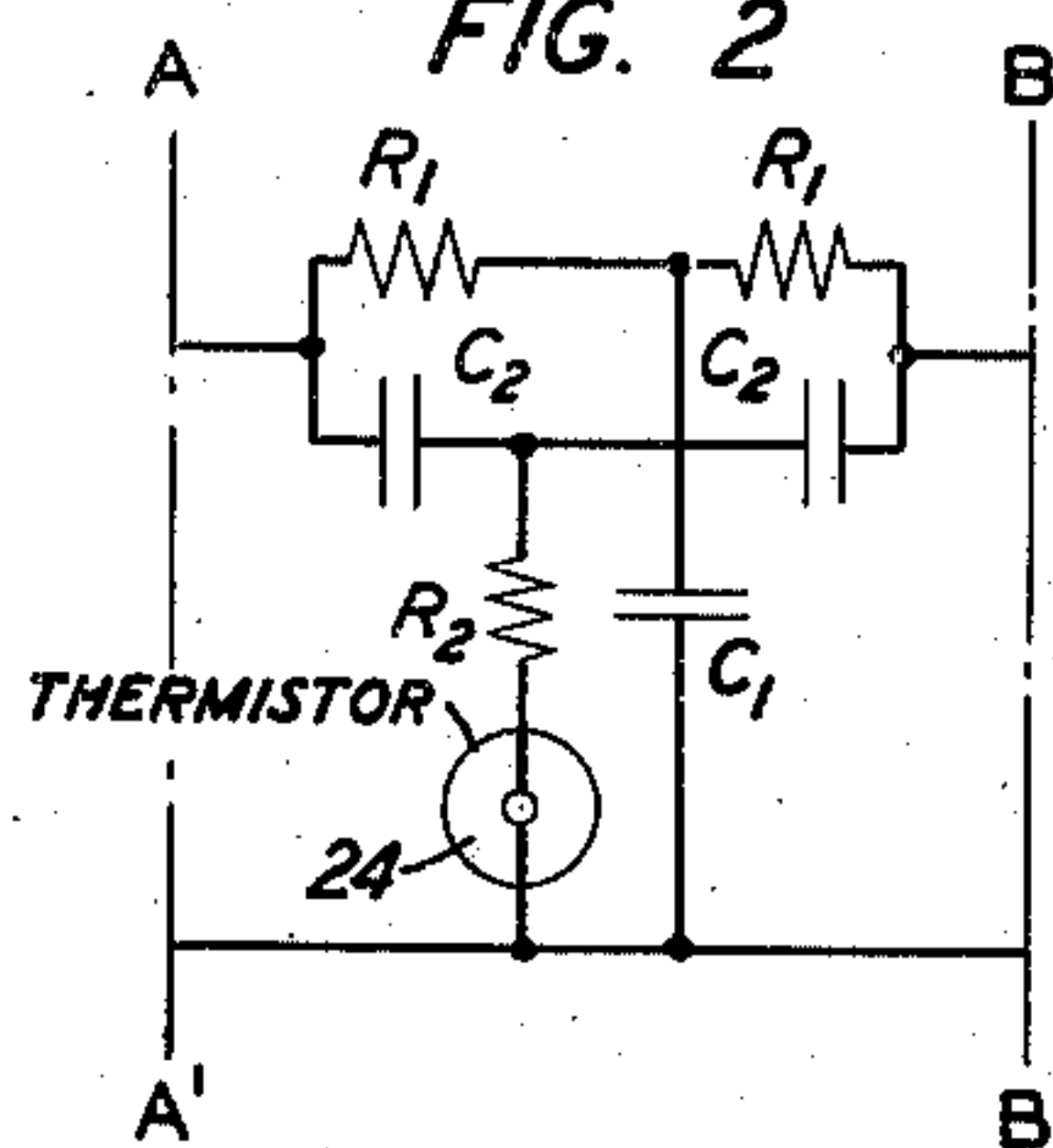


FIG. 4

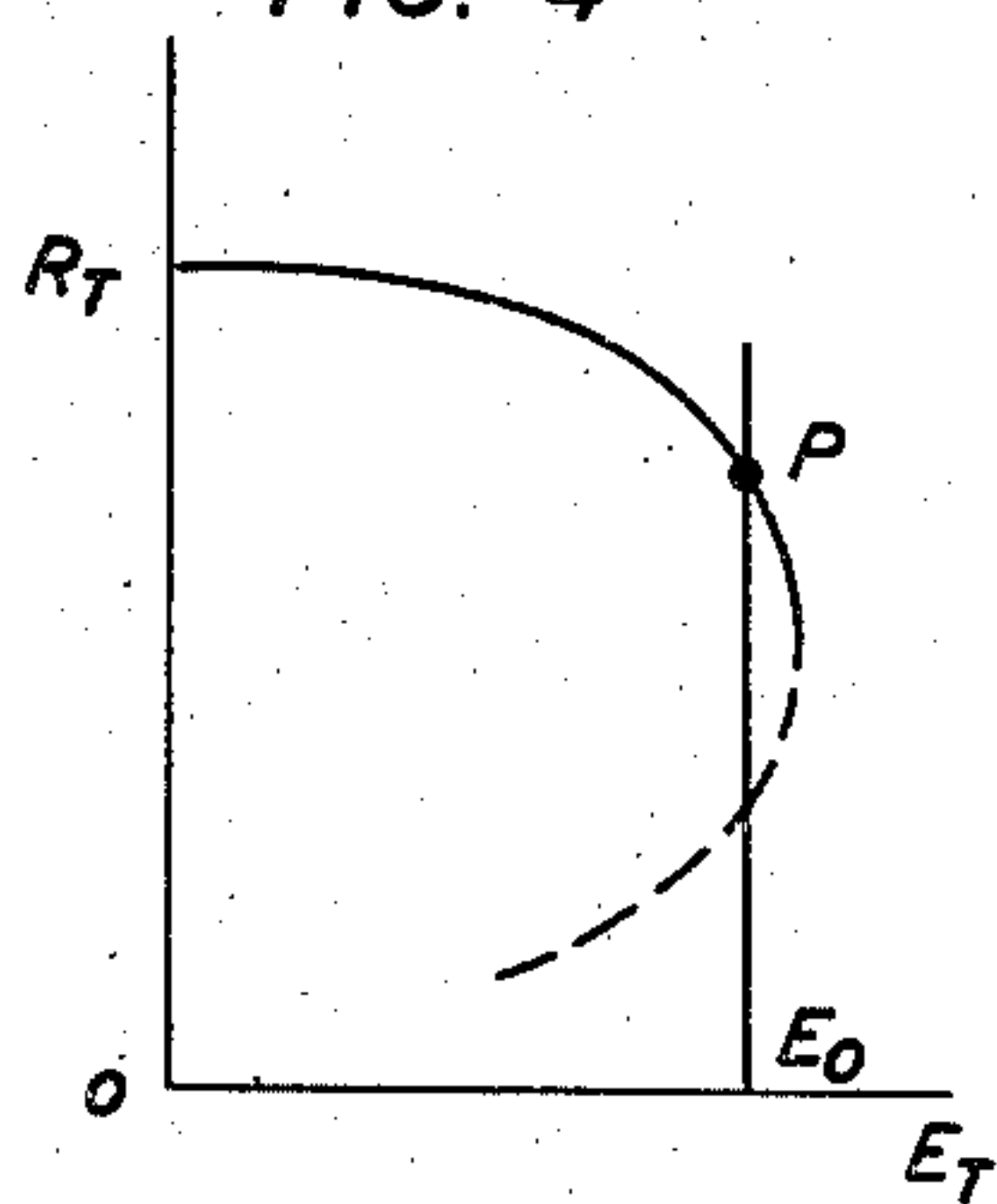
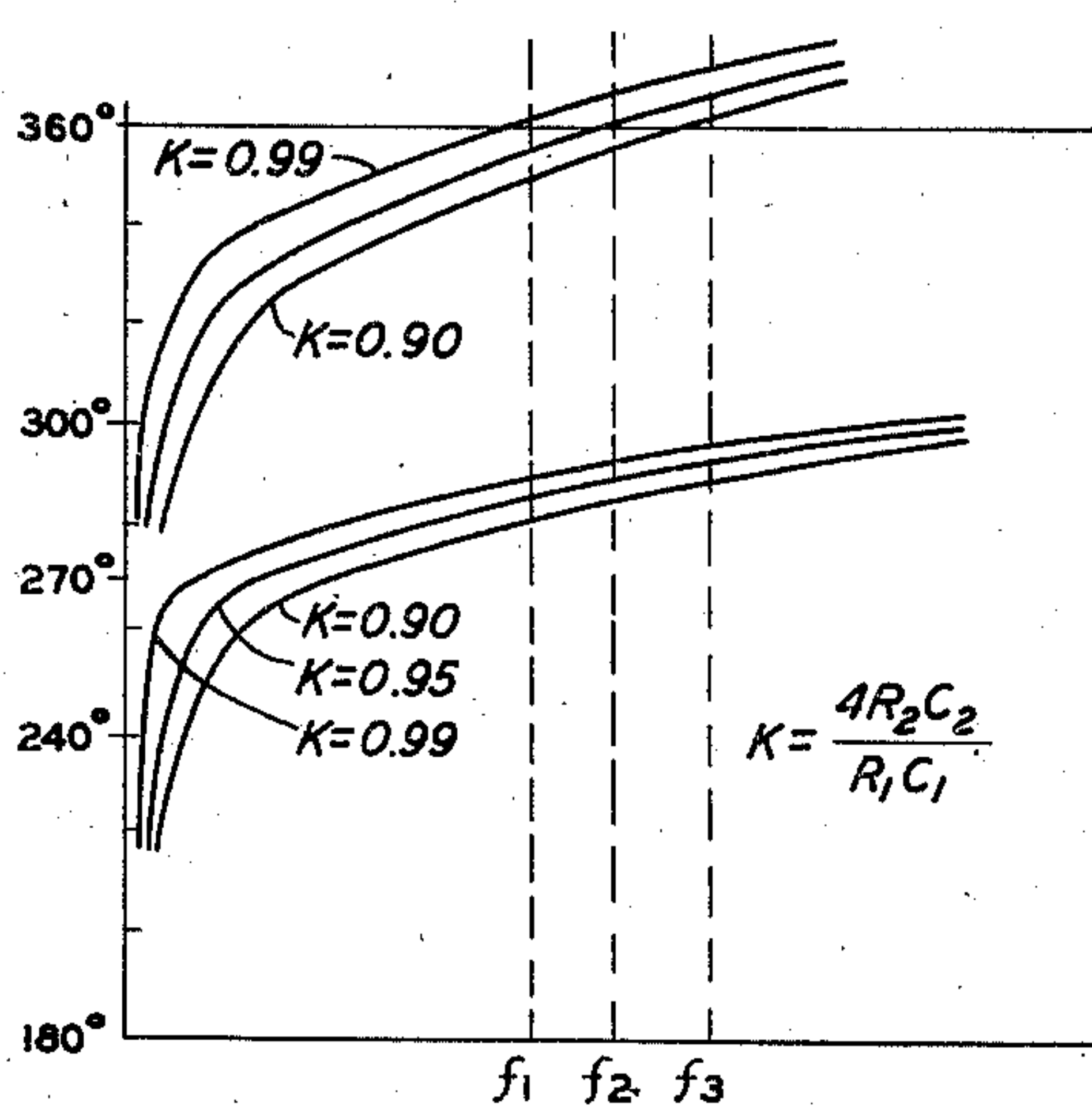


FIG. 3



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FREQUENCY MODULATION

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4 Claims. (Cl. 179—171.5)

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This invention relates to frequency modulation and more particularly to circuits for modulating the frequency of a vacuum tube oscillator in accordance with signals.

The common practice heretofore has been to modulate the frequency of an oscillation generator by varying a reactance element forming part of the frequency determining circuit, the variation being effected under the influence of the modulating signal currents. Where the variation has involved the motion of a mechanical element, such as an air condenser, difficulties have arisen in attempts to secure a large reactance change at the higher frequencies of speech. The use of a reactance tube has made it possible to get uniform modulation at all signal frequencies, but the reactance variations obtainable and the consequent frequency variations are quite small.

An object of the invention is to provide frequency variations of substantial extent in response to speech signals and to accomplish this with relatively simple apparatus and circuits.

In accordance with the invention frequency modulation is effected through the action of a temperature dependent resistance element, or thermistor, included as part of a phase-shifting network in the feedback loop of a vacuum tube oscillator and traversed by the high frequency oscillations. The phase-shifting network, which may represent all or part of the frequency determining circuit is so designed that changes in the thermistor resistance produce substantial changes of the phase shift incurred by oscillations traversing the circuit and hence also in the frequency at which the system oscillates.

A feature of the invention is the manner in which the signal currents are employed to vary the resistance of the thermistor. Instead of being impressed directly upon the thermistor, which would entail the use of separating condensers and chokes, the signal voltage is applied to a control electrode of the vacuum tube in such a way as to bring about small amplitude modulations of the generated oscillations. The varying heating effect of the amplitude modulated waves traversing the thermistor results in the desired changes in its resistance and consequently in corresponding variations of the oscillation frequency.

Thermistor devices capable of following temperature variations occurring at rates corresponding to the highest essential speech frequencies have been constructed, examples of such elements being disclosed in U. S. Patent No. 2,276,864, issued March 17, 1942, to G. L. Pearson.

The nature of the invention and its mode of op-

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eration will be more fully understood from the detailed description which follows and by reference to the accompanying drawing, in which:

Fig. 1 is a circuit diagram of one form of the invention;

Fig. 2 illustrates a modification of the portion of Fig. 1 between the dotted lines AA' and BB'; and

Figs. 3 and 4 are curves illustrating characteristics of certain of the circuit elements.

The modulated oscillator shown in Fig. 1 comprises two pentode vacuum tubes 10 and 11 which are coupled in tandem to form a closed loop through interstage networks 12 and 13 and feedback connection 14. Plate current is supplied to the tubes through chokes 15 and 16 associated with suitable filter condensers. Biasing voltages for the control grids are obtained from resistance-capacity impedances 17 and 18 connected in the cathode leads and are supplied to the grids through potentiometer 19 and leak resistance 20. A source of modulating voltage such as a microphone is connected through signal transformer 22 to the suppressor grid of tube 10. A battery 23 is shown in the suppressor grid circuit the purpose of which is to provide a suitable biasing voltage for that grid. Since the suppressor grid is also subject to the potential drop in impedance 17, the voltage and polarity of battery 23 are chosen to provide the desired net voltage. Other convenient biasing arrangements may, of course, be used. Potentiometer 19 provides an adjustment of the gain around the feedback loop and may be used as described later for adjusting the normal oscillation amplitude.

Network 12 is essentially of the double-T type described in U. S. Patent 2,106,785, issued February 1, 1938, to H. W. Augustadt and disclosed as the frequency determining circuit of a vacuum tube oscillator in U. S. Patent 2,319,965, issued May 25, 1943, to R. O. Wise. The first T comprises equal series resistances R_1 and shunt capacity C_1 and the second T comprises equal series capacities C_2 and shunt resistance R_2 . The network also contains a thermistor element 24 bridged across the series resistances of the first T. This element, which is indicated only conventionally in the drawing, may be constructed in accordance with the disclosures of the above-mentioned Patent No. 2,276,864 to Pearson so that it is responsive to variations occurring at the rates of the essential frequencies of speech. With the connections shown in the figure, variations of the thermistor resistance have a similar effect, al-

though somewhat smaller as simultaneous variations of the two series resistances R_1 .

An alternative connection of the thermistor in the double-T network is shown in Fig. 2, the thermistor here being inserted in series with the shunt resistance R_2 in the second T. Both arrangements provide substantially similar operating characteristics.

Network 13 comprises a shunt branch formed by the series connection of an adjustable resistance R_3 and a condenser C_3 of fixed capacity together with a series branch consisting of a capacity C_4 . This network is designed to produce a phase shift of something less than 90 degrees at the desired frequency of operation, the value of the phase shift being such as to make the total phase shift produced by the two networks equal to 360 degrees. This will be made clearer by a consideration of the characteristics of network 12 and of the operation of the invention.

As pointed out in the above-mentioned patents to Augustadt and Wise, the double-T resistance-capacity network can be so proportioned as to suppress completely the transmission of currents of a chosen frequency. In order that it may do this it is necessary that the resistances and capacities be given values such that

$$\frac{4R_2C_2}{R_1C_1}=1 \quad (1)$$

in which case, the frequency at which complete suppression takes place is given by

$$\omega^2 R_1^2 C_1 C_2 = 2 \quad (2)$$

where ω denotes 2π times frequency.

The phase shift introduced by the network undergoes a very rapid change with frequency in the neighborhood of the suppression frequency. When the network is adjusted for complete suppression there is a complete reversal of phase as the frequency passes through its critical value. If the network is not completely balanced, that is, if the suppression is incomplete, this phase reversal will be completed in a very narrow frequency range, but the course of its variation within this range will depend very greatly on the way in which the unbalance of the network is effected. If the unbalance is brought by making the shunt resistance R_2 less than the value required by Equation 1 or by making the series resistances R_1 greater than this required value, then the phase shift will increase continuously from a value of about 90 degrees to about 270 degrees in the small frequency range and will thereafter increase slowly with increasing frequency. On the other hand, if the unbalance is obtained by increasing R_2 above its critical value or by reducing the series resistances, the phase shift will fall sharply to a negative value of about 90 degrees from which it thereafter increases slowly towards zero.

In the circuits illustrated in Figs. 1 and 2 the network is assumed to be unbalanced in the first of the above-mentioned manners and the remainder of the feedback loop is proportioned so that the frequency of oscillation corresponds to a phase shift of about 290 degrees in the double-T network. Since the loop contains two vacuum tubes each introducing a phase reversal, this requires the network 13 to introduce a supplementary phase shift of about 70 degrees at the oscillation frequency to make the total phase shift in the loop equal to 360 degrees or zero.

The lower set of curves in Fig. 3 are typical phase shift characteristics for the network 12

corresponding to different values of the ratio defined by Equation 1. In the drawing, K is used to denote this ratio. The curves represent only the upper portions of the characteristics corresponding to phase shifts greater than 180 degrees. The upper set of curves represent the total phase shifts in the feedback loop including the contribution of network 13. The latter network has a phase shift characteristic which increases only slowly with frequency, its effect being evident principally as a lifting of the lower set of curves bodily with a slight increase in their upward slopes.

The frequencies at which the circuit oscillates for different values of K are defined by the intersections of the horizontal line at the 360 degree level with the total phase shift curves. In the case illustrated the frequency changes in a substantially linear fashion from a value f_1 to a value f_3 as K changes progressively from 0.99 to 0.90.

To modulate the oscillation frequency, the signal voltage is impressed on the suppressor grid of tube 10, the signal voltage variations resulting in corresponding variations of the tube output voltage and of the voltages across the several branches of network 12. The varying voltage across the thermistor causes its resistance to change, thereby changing the value of the ratio K and producing a corresponding frequency variation in the manner already explained. To avoid excessive amplitude modulation it is desirable that the normal voltage across the thermistor, that is, the oscillation voltage in the absence of signal, be adjusted to bring the thermistor close to its most sensitive operating point. Fig. 4 shows the typical relationship between the voltage E_r across the thermistor terminals and its resistance R_r . For sensitive operation of the modulator the normal voltage should have a value corresponding to the point P on the curve where the rate of change of resistance with voltage is close to its maximum. This may be effected by the adjustment of potentiometer 19 or by other convenient means, for example, by adjusting the voltage of grid biasing source 23. When the normal voltage has been adjusted to bring the thermistor to its sensitive operating point, the voltage across the thermistor varies only slightly as its resistance changes, or, conversely, relatively large resistance changes result from small voltage changes. The voltages at the other points in the circuit likewise remain relatively constant so that amplitude modulation of the wave is slight.

What is claimed is:

1. A frequency modulated oscillator comprising an amplifying vacuum tube, a feedback path coupling the output and the input circuits of said vacuum tube in regenerative relation, a frequency determining network included in said feedback path, a source of signal voltage, circuit means for impressing signal voltage from said source upon said vacuum tube to produce amplitude modulation of the generated oscillations, and means responsive to amplitude variations of the oscillations for producing corresponding variations of substantial magnitude in the oscillation frequency, said frequency varying means comprising a temperature sensitive resistor included in said feedback path and traversed by the oscillation currents therein.

2. A system in accordance with claim 1 in which the gain around the oscillator feedback loop is adjusted to establish a normal oscillation

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amplitude such as to bring the terminal voltage at the temperature-sensitive resistor close to the value corresponding to maximum sensitivity.

3. A system in accordance with claim 1 in which the frequency determining network comprises resistance elements and reactance elements of only one kind, the temperature-sensitive resistor constituting one of the resistance elements.

4. In a frequency modulation system comprising an amplifying vacuum tube the input and output circuits are coupled in regenerative rela-

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tion through frequency determining network to produce self-sustained oscillations, means for producing amplitude modulations of the oscillations in accordance with a signal and means comprising a temperature-sensitive resistor included as part of the frequency determining network for translating the amplitude modulations into corresponding variations of substantial magnitude of the oscillation frequency.

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