

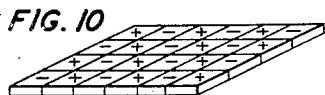
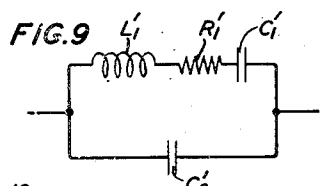
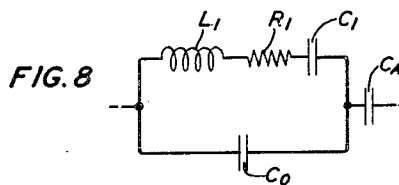
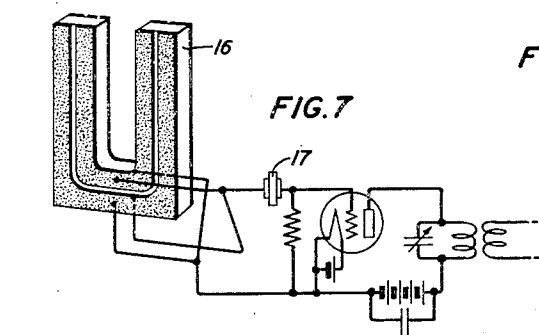
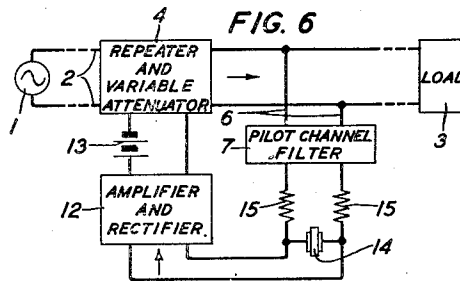
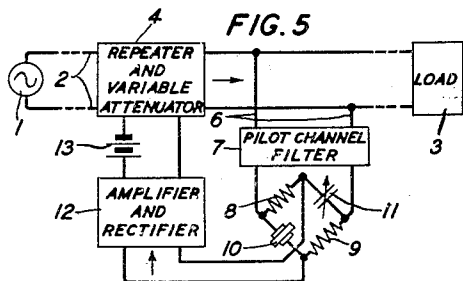
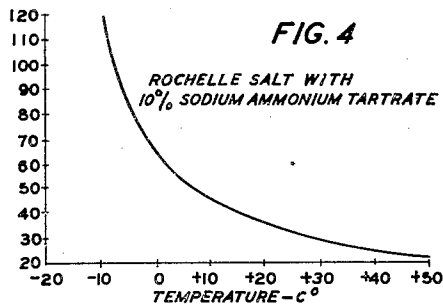
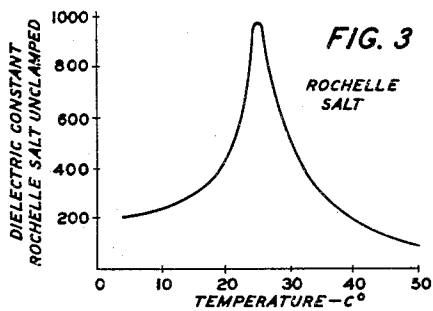
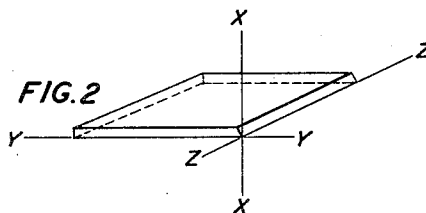
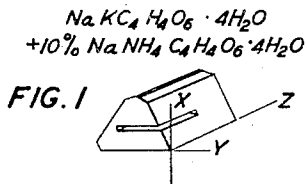
Feb. 4, 1941.

W. P. MASON

2,230,649

VARIABLE ELECTRIC CAPACITY DEVICE

Original Filed March 5, 1938



INVENTOR
W. P. MASON
BY
E. V. Griggs
ATTORNEY

UNITED STATES PATENT OFFICE

2,230,649

VARIABLE ELECTRIC CAPACITY DEVICE

Warren P. Mason, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Continuation of application Serial No. 194,049,
March 5, 1938. This application September 3,
1938, Serial No. 228,351

6 Claims. (Cl. 175-41)

This invention relates to electric capacity devices, the magnitude of which varies with temperature.

5 An object of the invention is an electrical regulating element, the magnitude of the capacity of which varies in substantially uniform manner throughout a wide range of temperatures normally encountered in industrial applications.

10 An additional object of the invention is to provide a capacity element having a dielectric of piezoelectric character in which the piezoelectric effect may be annulled.

15 Another object of the invention is to compensate for the variable reactance of certain piezoelectric substances such as Rochelle salt which occurs with change in temperature.

20 A further object of the invention is to provide a Rochelle salt piezoelectric frequency control device for vacuum tube oscillators which may maintain the frequency within a relatively narrow range throughout a considerable change in temperature.

25 It has been found experimentally that the dielectric constant of isomorphous crystals of Rochelle salt containing some other ingredient is, in general, notably different from that of pure Rochelle salt. The dielectric constant of a clamped crystal of Rochelle salt as measured with an alternating current increases from 0° C. as the temperature is raised and at about 20° C. begins a very rapid rise to a maximum in the region of the Curie point at 24° C. From that point the dielectric constant rapidly falls. The dielectric constant of an unclamped crystal of 35 Rochelle salt including about 10 per cent of sodium ammonium tartrate is found to fall in a fairly uniform manner as the temperature rises throughout the range from -10° C. to +50° C. In accordance with the invention a capacity device is constructed with a dielectric of such an isomorphous crystalline substance and the variability of its dielectric constant with temperature is utilized to regulate or control other characteristics which vary with temperature such as attenuation of a transmission line or the frequency of a vacuum tube oscillator having a Rochelle salt piezoelectric frequency control device.

40 Other objects and aspects of the invention will become apparent upon consideration of the following specification in connection with the accompanying drawing in which:

45 Fig. 1 illustrates a crystal consisting of sodium potassium tartrate (Rochelle salt) in which is included a considerable percentage as, for example, 10 per cent by weight of sodium ammonium tartrate;

50 Fig. 2 indicates a plate of material cut from the crystal of Fig. 1 with its principal faces perpendicular to the X axis as indicated in Fig. 1;

Fig. 3 is a graph illustrating the variation of the dielectric constant of Rochelle salt with temperature;

Fig. 4 is a graph showing the variation of the dielectric constant of the isomorphous crystal of Figs. 1 and 2 with variation in temperature;

Fig. 5 shows diagrammatically an attenuation regulating system for transmission lines according to the invention;

Fig. 6 shows a modification of the circuit of Fig. 5;

Fig. 7 shows a Rochelle salt piezoelectric device for controlling the frequency of a vacuum tube oscillator in accordance with the invention;

Figs. 8 and 9 are equivalent electrical circuit diagrams of a portion of the structure of Fig. 7;

Figs. 10 and 11 illustrate expedients for reducing or eliminating piezoelectric reactance of a variable capacity element constructed in accordance with the invention.

20 Fig. 1 illustrates a crystal of Rochelle salt including as an ingredient approximately 10 per cent by weight of sodium ammonium tartrate. As indicated in the figure a plate may be cut therefrom with its principal faces perpendicular to the X axis in the manner of the ordinary A or X cut utilized in the Rochelle salt piezoelectric art. Such a plate is illustrated in Fig. 2.

25 Figs. 3 and 4 show respectively the graph of the dielectric constant of pure Rochelle salt and of the X cut plate of the isomorphous Rochelle salt sodium ammonium tartrate crystal of Fig. 2 each plotted with respect to variations in temperature. As will be readily apparent from Fig. 3, the dielectric constant of the pure Rochelle salt crystal attains a maximum in the neighborhood of the Curie point at about 24° C. which corresponds to approximately 75° F. or normal room temperature. Such a characteristic is of little use in any temperature regulating system since it experiences like variations for both rise and fall of temperature from the maximum point. As will be seen from Fig. 4, the dielectric constant of the plate of Fig. 2 continuously diminishes throughout the range from -10° C. to +50° C. Although not linear the characteristic is reasonably uniform over a fairly wide range of temperatures.

30 The attenuation of long transmission systems and particularly those subjected to wide variations in temperature as, for example, open wire or elevated cable circuits is found to vary considerably from time to time. Devices known in the art as variable attenuators are utilized with such systems to compensate for the variations in attenuation which occur upon change in temperature.

35 Fig. 5 illustrates a long transmission system or other circuit, the attenuation of which undergoes wide variation with temperature. In that figure

a source 1 which may represent the various transmitters associated with a communication line is connected by the long transmission conductors 2 to a remote load or terminal circuit 3. At an intermediate point in the circuit which may be a repeater station including a broad band repeater capable of amplifying all of the currents transmitted over the transmission conductor line there is introduced the variable attenuator 4 of a type to cooperate with the repeater in such manner that the output level of the energy transmitted from the unit 4 remains substantially constant. This is preferably effected by transmitting from the station of source 1 along with the desired currents a so-called pilot channel wave having a constant amplitude at station 1 and a frequency within or closely adjacent to the frequency range of the communication wave frequencies so that the pilot channel wave may be similarly affected by the variations of attenuation of the transmission line. After amplification by repeater 4 the pilot channel wave is diverted from the output of the repeater by a controlling path 5 including a pilot channel filter 7 in series with a Wheatstone bridge in which are the equal magnitude resistance arms 8 and 9 and the normally equal magnitude capacity arms 10 and 11. Connected across the bridge or control points are the input terminals of an amplifier and rectifier 12 which supplies a unidirectional controlling electromotive force to the variable attenuator 4 to control its magnitude in well-known manner. The capacitance 10 of the bridge is constructed with a dielectric similar to the plate of Fig. 2 and the capacity element 11 which may be of any type, preferably little subject to temperature variations, is adjusted to balance the bridge at some temperature. As the surrounding temperature rises or falls the dielectric constant and hence capacity of the element 10 will vary in a manner indicated by the graph of Fig. 4. The bridge will therefore be unbalanced in such manner as to supply to the amplifier and rectifier 12 an electromotive force which after amplification and rectification will be impressed upon the variable attenuator 4 to vary its attenuation in a manner complementary to that of the transmission circuit 2. Preferably the bridge is balanced at a temperature lower than any that may occur in practice. This will result in an unbalance with a consequent electromotive force of pilot channel frequency applied from the bridge path to amplifier and rectifier 12 to tend to produce a correcting bias electromotive force in the output circuit of the amplifier-rectifier 12. To counteract such a bias a source 13 of opposing electromotive force is introduced into the circuit and the electromotive force of source 13 is of such magnitude as to introduce the correct amount of attenuation at the outdoor temperature to which the transmission line and the capacity element 10 are simultaneously exposed it being understood that the Wheatstone bridge, or preferably bridge arm 10, is located outdoors in such manner as to be exposed to the same general fluctuations in temperature to which the transmission line is exposed. With the adjustments described the Wheatstone bridge is always unbalanced, in the same direction, the degree of unbalance and the consequent attenuation correcting force depending upon the temperature. The attenuator and attenuation correction are of the well-known type in which attenuation is increased by an increase of the correcting electro-

motive force derived from the control path and applied to the attenuator.

Fig. 6 illustrates a modification of the circuit of Fig. 5 in which in lieu of the Wheatstone bridge a shunt path including a variable capacity element 14 similar to element 10 of Fig. 5 is employed. The input terminals of the amplifier and rectifier 12 are connected across element 14 and resistances 15 are connected in series with it. When the temperature and attenuation of the transmission line are low the dielectric capacity and shunting effect of element 14 are large so that a large portion of the output electromotive force of the pilot channel filter 7 is expended across resistances 15 leaving a small potential across the capacity element 14. As the temperature and attenuation of the transmission line rise, the output electromotive force of the pilot channel filter decreases. However, the impedance of the element 14 rises rapidly with increase in temperature so that the resultant potential thereacross is materially higher than before. Under these circumstances the electromotive force of pilot channel frequency applied to the amplifier and detector 12 rises with increase in temperature and attenuation of the line 2 as in the case of Fig. 5 to increase the over-all gain of the device 4.

Fig. 7 illustrates a piezoelectric frequency control for a vacuum tube oscillator in which a Rochelle salt composite tuning fork reactance element 16 of the type illustrated in Fig. 3 of the patent to W. P. Mason 2,081,405, May 25, 1937 may be connected between the grid and cathode of an electron discharge tube of any well-known type. In series with the device 16 in the grid cathode circuit is a variable capacity element 17 similar to the element 10 of Fig. 5. The equivalent network of the piezoelectric tuning fork 16 is as shown in Fig. 8 in which the mesh $L_1 R_1 C_1 C_0$ represents the resistance and reactance of the piezoelectric tuning fork 16 and the series capacitance C_A is that of the element 17. This network is equivalent to that of Fig. 9 with the element values,

$$C_0' = \frac{C_0 C_A}{C_0 + C_A}; C_1' = \frac{C_A^2 C_1}{(C_0 + C_A)(C_0 + C_A + C_1)}; \\ R' = \left(\frac{C_0 + C_A}{C_A} \right)^2; L_1' = L_1 \left(\frac{C_0 + C_A}{C_A} \right)^2 \quad (1)$$

The resonant frequency of the combination is given by

$$f_R = \frac{1}{2\pi\sqrt{L_1' C_1'}} = f_{R_0} \left(1 + \frac{C_1}{2(C_0 + C_A)} \right) \quad (2)$$

where f_{R_0} is the resonance frequency when C_A is infinite. The temperature coefficient of frequency of the combination T_R , when f_{R_0} and C_A both vary with temperature, is

$$T_R = T_{R_0} + \frac{C_1 C_A T_{C_A}}{2(C_0 + C_A)^2} \quad (3)$$

where T_{R_0} is the temperature coefficient of frequency when C_A is infinite. The maximum effect occurs when $C_A = C_0$ and for this case

$$T_R = T_{R_0} - \frac{T_{C_A}}{8r}$$

where r is the ratio of capacities of the crystal, C_0/C_1 . At about 20° C. the isomorphous Rochelle salt including sodium ammonium tartrate has a temperature coefficient of capacity T_{C_A} of 20,000 parts per million per degree centigrade. Hence, for a ratio r equal to about 300 for the tuning

fork 16, the variable capacity 17 will reduce substantially to zero the temperature coefficient of the combination if the temperature coefficient of the tuning fork 16 alone, that is, T_{R_0} is -8.3 parts per million per degree centigrade.

In the foregoing discussion it has been assumed that the devices 10, 14 and 17 may be treated simply as capacitances having dielectric constants varying with temperature. However, depending upon the orientation and the dimension of the dielectric, the variable capacitance element will also exhibit a piezoelectric reaction. This may become important if the system in which the device is operated involves transmission of frequencies in the neighborhood of any of its piezoelectric resonances. In order to reduce or annul the effect of this piezoelectric characteristic the plate employed as the dielectric of the elements 10, 14 and 17 may be made of such a small piece of material that all its resonances are considerably above the frequencies encountered in the system in which it is to be employed. However, where this is not possible either because of the very high transmission frequencies involved or the very small dimensions imposed upon the dielectric element, the plate may be divided into small squares, the alternate squares being reversed as shown in Fig. 10. With such a structure the individual squares of the dielectric will, from a piezoelectric standpoint, be directed against each other and their individual piezoelectric effects will be largely annulled.

An alternative to the structure of Fig. 10 is that of Fig. 11 in which the dielectric material of variable dielectric constant is glued or otherwise firmly attached to metal backing plates 18 in such a way that its vibrations are damped out. It is to be understood that in the variable dielectric capacity elements 10, 14 and 17 of Figs. 5, 6 and 7 either or both of these expedients of Figs. 10 and 11 may be employed. In other words, the dielectric may be divided into individual squares, alternate ones of which are reversed as indicated in Fig. 10 or it may be damped by heavy backing plates as indicated in Fig. 11 or it may be divided into squares as indicated in Fig. 10 and then provided with the backing plates.

Although a specific substance has been disclosed for the dielectric material of the variable capacitance, it is to be understood that the invention is not to be so limited but that any natural material or artificially prepared dielectric substance, the dielectric constant of which varies in approximately uniform manner throughout the range of operating temperatures normally encountered in industrial applications of electric transmission circuits may be employed.

This application is a continuation of application Serial No. 194,049, filed March 5, 1938.

What is claimed is:

1. A capacity reactance element having a dielectric of piezoelectric material the dielectric

capacity of which varies with temperature, the piezoelectric material consisting of a crystalline substance having a point of maximum dielectric capacity within ordinary room temperature range and a component of an isomorphous substance mixed therewith in an amount sufficient to cause the point of maximum dielectric capacity to fall outside the normal room temperature range.

2. A variable capacitance device comprising a pair of conducting surfaces, a plate of an artificially prepared dielectric substance in crystalline form placed between the conducting surfaces, the dielectric substance comprising Rochelle salt and an isomorphous substance mixed therewith and having a dielectric constant which rapidly decreases in magnitude throughout the range of -10° C. to $+50^{\circ}$ C. whereby the capacitance device may be employed as a regulating element in systems, the characteristics of which are subjected to change with changing temperature.

3. An electrical capacity device having a dielectric, the dielectric constant of which is variable with temperature, the dielectric consisting of crystalline sodium potassium tartrate including a percentage of another material sufficient to cause the dielectric constant to change its magnitude in one direction only throughout the range of 10° C. to 30° C.

4. A capacity element having a dielectric of crystalline sodium potassium tartrate with a substantial portion of sodium ammonium tartrate such that throughout the range of 0° to 40° C. the reactance of the element continuously varies in one direction with variation of temperature.

5. A device exhibiting variable reactance with temperature having a dielectric consisting of crystalline sodium potassium tartrate including a percentage of another material sufficient to cause the dielectric constant to change its magnitude in one direction only throughout the range of 10° C. to 23° C., the reactance of the variable reactance device increasing throughout the specified temperature range, the variable reactance device having a dielectric consisting of unitary elements of similar type, alternate ones of which are reversed in position with respect to the electrodes of the device in order to neutralize any piezoelectric reactance developed.

6. A reactance element, the reactance of which varies with temperature, comprising a pair of separated electrical conducting plates and an interposed dielectric consisting of a plurality of similar elements of solid dielectric material of piezoelectric character alternately reversed with respect to the conducting plates and the plates having considerable thickness and mass and being adherently attached to the dielectric to suppress any piezoelectric tendencies of the capacitance element.

WARREN P. MASON.