June 16, 1942. M. P. ODELL 2,286,436

PIEZOELECTRIC TEMPERATURE COMPENSATING CIRCUIT

Filed Aug. 2, 1940

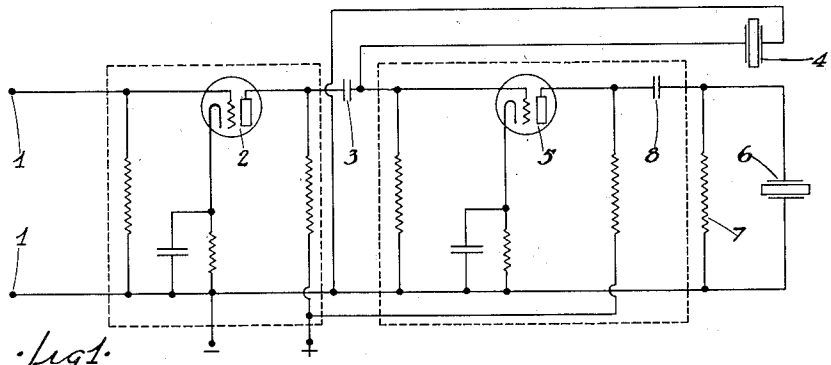


fig 1.

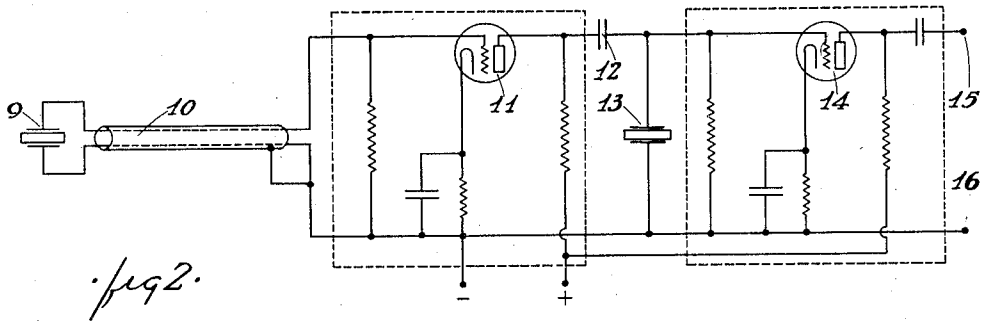


fig 2.

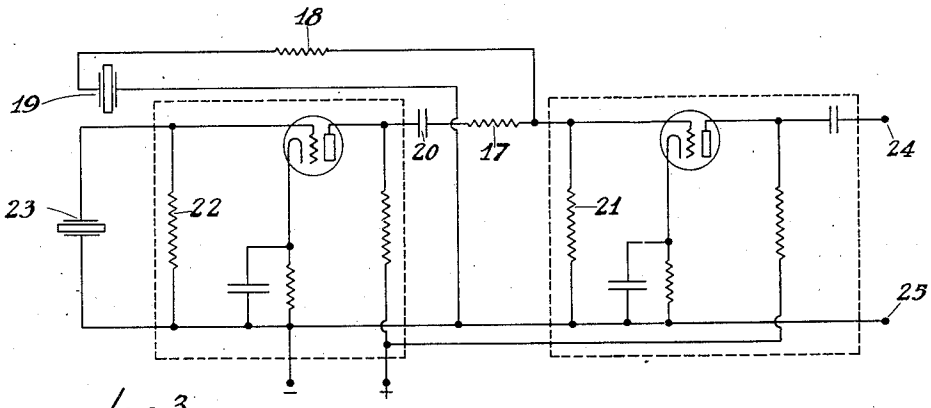


fig 3.

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Patented June 16, 1942 2,286,436

UNITED STATES PATENT OFFICE

2,286,436

PIEZOELECTRIC TEMPERATURE COMPENSATING CIRCUIT

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Application August 2, 1940, Serial No. 349,738

9 Claims. (Cl. 178—44)

This invention relates in general to the reduction of the effects of temperature on the characteristics of energy transforming systems which embody piezoelectric devices, and it relates more particularly to automatic means for reducing the effect of temperature on the sensitivity of systems which embody piezoelectric transducers.

The principal object of this invention is to provide automatic means for reducing the effect of temperature on the sensitivity of a system which embodies a temperature-sensitive piezoelectric transducer of the Rochelle salt type.

Another object of the invention is to provide automatic means for reducing the possibility of damaging a piezoelectric motor device by the application of excessive signal voltage when the temperature is of such a value that the sensitivity of the device is high.

Other objects and features of the invention will be apparent from the following specification and accompanying drawing in which:

Fig. 1 is a schematic wiring diagram of a transmission path which is connected to a piezoelectric motor unit, the diagram illustrating one mode in which the invention may be applied to an amplifier transmission path which transmits signal to the motor unit.

Fig. 2 is a schematic wiring diagram of a transmission path which is connected to a piezoelectric generating unit, the diagram illustrating one mode in which the invention may be applied to the amplifier transmission path which receives signal from the generator unit.

Fig. 3 is a schematic wiring diagram of a piezoelectric generating device which has an amplifier system coupled thereto and illustrates the way in which a modification of the invention may be applied to the amplifier system.

Within recent years, Rochelle salt piezoelectric crystal units have come into general use in various types of electro-acoustical and electro-mechanical devices such as microphones, earphones, phonograph pickups, loud-speakers, and vibration pickups. Such units offer many advantages such as simplicity, low cost, and uniform sensitivity for a wide range of frequencies. It has been found, however, that when these devices are introduced into many of the circuit arrangements which are generally used, they frequently exhibit an undesirable temperature-induced variation in sensitivity. When a piezoelectric generator device utilizing a Rochelle salt crystal unit is connected to a circuit whose input impedance is high in comparison with the impedance of the crystal unit itself throughout the useful frequency range, the terminal voltage does not vary appreciably with changes in temperature. Likewise, there may be little variation when a motor unit is supplied with signal from a high impedance source, as explained hereafter. However, the impedance of a Rochelle salt crystal unit used in either a motor or a generator device increases as the temperature rises above or falls somewhat below about 23° C. Consequently the voltage sensitivity of a generator device that is connected to a low impedance circuit decreases with such temperature changes. Likewise, when a piezoelectric motor device is driven by a signal derived from a constant voltage source, such as an ordinary triode amplifier circuit having a low internal output impedance, the amplitude of motion decreases as the temperature increases above about 23° C. and in most cases also decreases as the temperature falls below this value. While this latter decrease in sensitivity at the lower temperatures is caused at least partly by the increased stiffness of the mounting pads and the damping materials that are commonly used, the effect of temperature on the sensitivity is frequently the predominant cause.

It will be noted that the sensitivity versus temperature variations are substantially the reverse of the impedance versus temperature variations both in the case of a generator device feeding a low impedance circuit and in the case of a motor device driven from a low impedance source. This fact has been utilized by prior workers in temperature-compensating circuits; for example, it has been proposed that a motor unit be supplied with driving voltage obtained from an amplifier which has a high internal output resistance. When this is done, a larger percentage of the available output voltage of the amplifier is applied to the crystal unit as the temperature rises above or falls somewhat below about 23° C., because there is a concurrent temperature-induced change in the impedance match between crystal unit and amplifier. This larger voltage offsets to some extent the loss of sensitivity. However, such an expedient is usually not practical because the frequency characteristic of the unit is adversely affected. Moreover, the signal handling capacity of the output stage of the amplifier is reduced because the load impedance presented to it by the unit decreases as the frequency increases.

The effect of temperature on sensitivity can also be reduced by connecting a small condenser in series with the crystal motor unit and supplying the driving voltage from an amplifier having

a comparatively low internal output resistance. The voltage applied to the crystal unit then varies with changes in temperature so that the sensitivity is maintained substantially constant. The frequency characteristic is not affected because the impedance of both the crystal unit and the condenser is essentially capacitive reactance. However, if this type of circuit is used, a large percentage of the available output voltage of the amplifier is wasted because of the voltage drop in the series condenser. Consequently, neither of these methods of compensating is practical except when the required driving voltage is small.

The present invention is based on my observation that the disadvantages and limitations of the foregoing methods of compensating for temperature-induced variations in sensitivity may be avoided by using a pilot piezoelectric unit in conjunction with the primary piezoelectric unit and with a suitable transmission network. When the pilot and primary units are both subjected to substantially the same temperature variations, the impedance versus temperature characteristic of the pilot unit may be employed to vary the transmission factor of the network so as to compensate the sensitivity versus temperature variations resulting from changes in the temperature of the primary unit. In such a system the pilot unit is included in the main transmission network as part of an attenuator. The system accordingly is quite simple. Furthermore, the system functions automatically to control the compensation.

The essential feature of this new circuit resides in the use of an attenuator which consists of the pilot unit with one or more fixed impedance elements the impedance of which does not vary with temperature. The voltage drop appearing across the output terminals of this attenuator is applied to the succeeding amplifier stage. The impedance elements may be resistive, capacitive, or inductive in nature and may be connected in various ways. In most applications of the invention, however, a single capacitive element is suitable. In the latter instance, the attenuator takes the form of a simple capacitive voltage divider which consists of a fixed condenser in series with the pilot unit, and the voltage drop across the pilot unit is applied to the following section of the main transmission network. Although this type of compensating circuit is particularly useful in amplifiers which feed piezoelectric motor devices, it is also applicable to amplifiers which are fed by generating devices. It is particularly useful in conjunction with a generating device which is loaded by the capacity of its connecting cable. A microphone or phonograph pickup located at a considerable distance from the amplifier is an example of such a device.

Another important application is in amplifiers used in conjunction with low frequency crystal vibration pickups and other similar generating devices whose low frequency response is limited by the loading effect of the input resistance of the first amplifier stage. Since the impedance of piezoelectric crystalline material is predominantly capacitive, the impedance of piezoelectric crystal units increases as the frequency decreases. Because of this, a high input resistance is required in order to obtain good low frequency response. If this resistance is not sufficiently high, temperature-induced variations occurring in the capacity of the unit produce an effect on the response in the low frequency range. However, it is difficult to construct an amplifier having a high input resistance without introducing instability, and therefore it is desirable to use a compensating network that provides the necessary amount of low frequency correction for any temperature. The present invention provides such correction.

The invention is also applicable to other types of circuits and can be used in various types of amplifiers, but since the essential feature is a pilot piezoelectric unit contained in an attenuator network which is connected between successive sections of a transmission network, the description of a simple amplifier circuit arrangement will illustrate the invention.

The application of the invention to an amplifier feeding a Rochelle salt crystal motor device is illustrated in the wiring diagram shown in Fig. 1. A signal source **1** is connected to the first amplifying tube **2**, and the output of this tube is applied to the gain regulating attenuator which characterizes the invention. This attenuator, or voltage divider, consists of a fixed condenser **3** in series with a pilot crystal unit **4**, which is preferably constructed similar to the motor unit and located in a position adjacent to it. The voltage appearing across the pilot unit is applied to the input circuit of the final triode amplifier tube **5** which preferably has a low output impedance, and the output of this tube is connected to the piezoelectric motor device **6**. The condenser **3** of the voltage divider also serves to prevent the positive potential on the plate of the first tube **2** from being applied to the grid of the second tube **5**. In order to prevent direct current voltage from being applied to the motor crystal unit, a filter consisting of resistor **7** and condenser **8** is used. The use of resistor **7** is desirable because the leakage resistance of the condenser **8** may be less than that of the crystal unit. The two amplifier stages are both of conventional design and may be operated from either batteries or a rectifier power supply circuit.

The wiring diagram shown in Fig. 2 illustrates the application of the invention to an amplifier used in conjunction with a piezoelectric generating device, such as a microphone or phonograph pickup. This circuit is particularly useful when the microphone or pickup is connected to the input terminals of the amplifier through a long cable whose shunt capacitive reactance is low enough to reduce the terminal voltage of the primary crystal unit when its impedance rises because of a change in temperature. A piezo electric generating device **9** is connected to the input amplifier tube **11** by means of the connecting cable **10**. The output circuit of this first amplifier stage is connected to the gain regulating attenuator which consists of the fixed condenser **12** and the pilot piezoelectric unit **13**. The voltage developed across the pilot unit is applied to the grid circuit of the second amplifier tube **14**, and the plate circuit of this tube is connected to the output terminals **15**, **16** of the amplifier. The circuit arrangement of the voltage divider and the amplifier stages is the same as that illustrated in Fig. 1. Since the pilot piezoelectric unit should preferably be exposed to substantially the same temperature as the primary unit, this application of the invention may not always be useful. However, this type of circuit can also be used with a piezoelectric generator device that is shunted by a condenser in order to extend the useful frequency range to a lower frequency. By choosing a shunting condenser whose reactance is low in comparison with the input resistance of the

amplifier for all frequencies through the desired range, the input voltage is reduced but the low frequency response is made relatively greater. The variation in the impedance of the pilot unit, due to a change in temperature, varies the gain of the amplifier in such a manner as to compensate for the variation in input voltage due to the change in the impedance of the generator crystal.

Compensation for the effect of temperature is obtained in the same manner in both of these circuits. When the temperature rises above or decreases below approximately 23° C., the impedance of the pilot unit increases, and so a larger percentage of the output signal voltage of the first amplifier tube is applied to the grid circuit of the succeeding amplifier tube. The output of the latter tube is accordingly increased proportionately, so that the gain of the amplifier as a whole is increased. This increase in the gain of the amplifier compensates for the loss in sensitivity of the crystal motor device in the circuit shown in Fig. 1, and compensates for the loss in input voltage in the circuit of Fig. 2. Since the gain of the amplifier is reduced at temperatures for which the sensitivity is high, the possibility of damaging a crystal motor device by the application of excessive signal voltage is minimized.

In Fig. 3 is shown a modified form of the invention used in conjunction with a piezoelectric generator device. This circuit compensates for the effect of the shunt resistance of the input circuit on the low frequency response of the device at various temperatures. The two amplifier stages illustrated in this diagram are the same as in Figs. 1 and 2, but the gain-regulating attenuator, or voltage divider, which consists of two resistors **17**, **18** connected in series with the pilot crystal unit **19**, is designed to control the gain at only the lower frequencies. This is accomplished by applying the sum of the voltages appearing across resistor **18** and the pilot unit to the succeeding amplifier stage. At medium and high frequencies the impedance of the pilot crystal unit is low in comparison with the resistance of this arm or branch of the attenuator, and so variations in the impedance of the pilot unit due to changes in temperature have a negligible effect on the gain of the amplifier. The coupling condenser **20** should have a large capacity so that its reactance is small in comparison with the input impedance of the attenuator for all frequencies throughout the desired range. The resistance of the grid leak **21** of the second amplifier stage should be high in comparison with the impedance of the pilot crystal unit at all useful frequencies, and the resistance of resistor **17** plus the effective internal impedance of the first amplifier stage should be large compared with the resistance of resistor **18**. The ratio of the resistance of resistor **18** to the impedance of the pilot unit **19** must be approximately equal to the ratio of the resistance of grid leak **22** to the impedance of the piezoelectric generator crystal unit **23** at any given frequency and temperature. If these conditions are satisfied, this voltage divider network will substantially compensate for the variation in the input voltage applied to the first stage at low frequencies with changes in temperature. The output terminals **24** and **25** may be connected to an indicating device, another amplifier, or any other suitable circuit.

It will be understood from these examples that the invention can be applied to various types of circuits for the purpose of introducing temperature-compensating effects. For example, a transmission system having no amplification could embody this invention, additional amplifying stages could be used, or the circuit could be of the push-pull amplifier type, in which case two pilot units might be desirable, or the circuit could be arranged to use only one. Also, the invention may be applied to transducer devices which use crystalline Rochelle salt units or which use other types of piezoelectric crystalline material. The pilot unit may also be constructed of some other type of piezoelectric material, but throughout the working temperature range its impedance versus temperature characteristic must either complement the sensitivity versus temperature characteristic of the transducer device, or be similar thereto. In this latter case the voltage across the fixed impedance element of the attenuator is applied to the succeeding amplifier stage. In view thereof, it will be understood that the above description is to be considered as illustrative, and the scope of the invention is to be limited only by the following claims.

In the foregoing discussion it has been pointed out that the impedance versus temperature characteristics of the pilot unit complement the sensitivity versus temperature charasteristics of the main or primary transducer unit. This language has been used heretofore and is used in the following claims to mean that when the temperature change is such as to decrease the sensitivity of the primary unit, the voltage drop applied by the attenuator to the following section of the transmission path is increased; and conversely, when the temperature change is such as to increase the sensitivity of the primary unit, the voltage drop applied by the attenuator to the following section of the transmission path is decreased.

Having now disclosed the invention, what I claim is:

1. A piezoelectric system comprising the combination of: a transmission path which includes an input circuit and an electronic amplifying output circuit, each of said circuits having a pair of input terminals and a pair of output terminals; a temperature sensitive primary piezoelectric unit connected to said transmission path so as to be in shunt with the output terminals of the output circuit; a pilot piezoelectric unit having impedance versus temperature characteristics which complement in some measure the sensitivity versus temperature characteristics of said connected primary piezoelectric unit, said pilot and primary units being physically disposed relative to each other so as to be subjected at substantially the same time to substantially the same temperature conditions; and an attenuator which combines a relatively-fixed temperature-insensitive impedance element in series circuit with a corrective impedance branch which includes said pilot piezoelectric unit, said attenuator being connected to the output terminals of the input circuit with at least the pilot piezoelectric unit thereof in shunt with the input terminals of the output circuit.

2. In combination, a primary piezoelectric transducer whose sensitivity varies with temperature and which is subjected to temperature changes when in use; and corrective transmission means for transmitting signal voltages to said transducer, and for automatically altering

the amplitude of the signal voltage so transmitted to increase the amplitude when the temperature change is such as to reduce the sensitivity of the transducer, and conversely to decrease the amplitude when the temperature change is such as to increase the sensitivity of the transducer, whereby the effects of temperature induced changes in the sensitivity of the transducer are compensated at least in part, said corrective means comprising: (A) a signal-voltage attenuator having its input in shunt with said signal voltage and including a pilot piezoelectric unit whose impedance varies with temperature and is thereby effective in producing temperature-induced variations in the output of the attenuator relative to its input, said pilot unit being disposed relative to said primary transducer so as to be subjected to substantially the same temperature variations as the latter at substantially the same time; and (B) an amplifier having its input circuit operatively connected in shunt with the output of said attenuator to amplify said output.

3. The combination as claimed in claim 2 wherein said signal voltage attenuator consists of said pilot unit in series circuit with a substantially temperature-insensitive impedance, and wherein the output of the attenuator is the signal voltage drop across said pilot unit.

4. The combination as claimed in claim 2 wherein said signal voltage attenuator consists of said pilot unit in series circuit with a condenser, and wherein the output of the attenuator is the signal voltage drop across said pilot unit.

5. The combination as claimed in claim 2 wherein said amplifier has an input circuit whose impedance is high relative to the output impedance of the attenuator measured at frequencies within the useful frequency range of the said primary transducer.

6. An improved piezoelectric system as claimed in claim 1 wherein said fixed impedance element is a fixed capacity.

7. An improved piezoelectric system as claimed in claim 1 wherein said fixed impedance element is a fixed capacity, and wherein said corrective impedance branch consists solely of said pilot unit.

8. An improved piezoelectric system for compensating the effects of temperature-induced variations in the sensitivity of a piezoelectric motor unit, said system comprising the combination of: a piezoelectric motor unit subject to temperature-induced variations in sensitivity; a source of signal; an attenuator having a ratio of output to input which varies with temperature and which complements in some measure the sensitivity - versus - temperature characteristics exhibited by said motor unit when in operation in said system, said attenuator including a pilot piezoelectric unit which is physically disposed relative to said motor unit so as to be subjected to substantially the same temperature variations as said motor unit; circuit means for transmitting signal from said source to the input of said attenuator; and means for amplifying the output signal of said attenuator while transmitting said signal to said piezoelectric motor unit.

9. An improved system as claimed in claim 8 wherein said attenuator consists of a fixed capacity in series with said pilot unit, and wherein the output of the attenuator is the signal voltage drop across the said pilot unit.

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