April 18, 1939. L. KAMENAROVIC 2,154,849

CRYSTAL-STABILIZED RESONATING CIRCUITS

Filed Aug. 7, 1937

Fig. 1

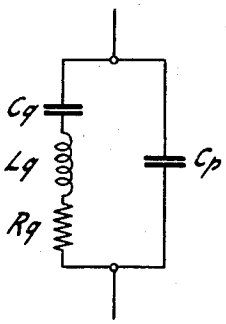


Fig. 2a

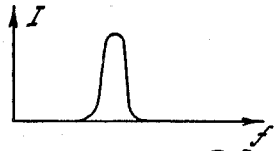


Fig. 2b

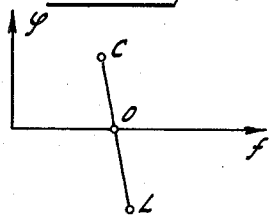


Fig. 3

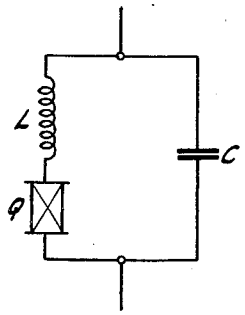


Fig. 4

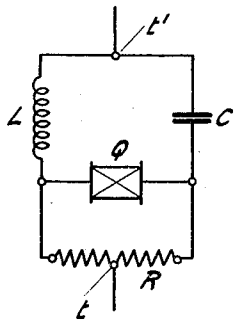


Fig. 5

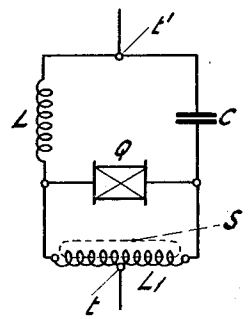


Fig. 6

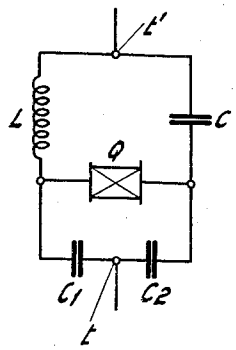


Fig. 7

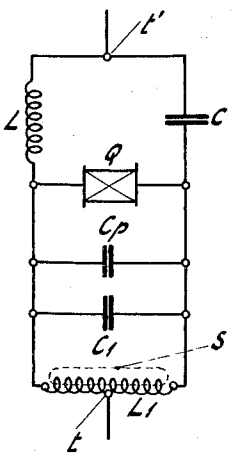
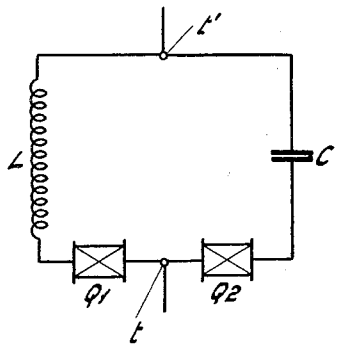


Fig. 8



Inventor:
L. Kamenarović,
By E. F. Hendroth
Atty

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CRYSTAL-STABILIZED RESONATING CIRCUITS

Leone Kamenarovic, Milan, Italy, assignor to Fabbrica Italiana Magneti Marelli Societa Anonima, Milan, Italy, a corporation of Italy

Application August 7, 1937, Serial No. 157,993
In Italy August 11, 1936

10 Claims. (Cl. 178—44)

It is known that a piezo-electric crystal may be considered, in respect of frequencies adjacent to its resonance frequency, as equivalent to a resonating network consisting of a capacitor, an inductor and a resistor arranged in series with each other; this fact means that such a crystal develops a current resonance.

On the other hand crystal-stabilized networks showing a voltage resonance are often required in the art of piezo-oscillators and of piezo-electric filters.

The present invention is directed to provide a class of networks which may be easily built up and in which, by taking advantage of the current resonance of a crystal, a voltage resonance may be obtained at a frequency exactly corresponding with the natural frequency of said crystal.

On the annexed drawing:

Figure 1 shows a network equivalent to a crystal in proximity of its natural frequency;

Figs. 2*a* and 2*b* are the resonance curves of a quartz crystal in proximity of the natural frequency of said crystal and more particularly Fig. 2*a* shows the progression of the current amplitude in terms of frequency the voltage applied to the quartz crystal electrodes being held constant, and Fig. 2*b* shows the progression of the phase angle between the current and voltage in terms of frequency;

Fig. 3 is a diagram of a known network of the involved class;

Fig. 4 is a diagram of a network of this invention including a resistor shunted across a crystal;

Fig. 5 is a diagram similar to Fig. 4 including an inductor shunted across a crystal;

Fig. 6 is a diagram of a network of this invention including two capacitors in a series circuit shunted across a crystal;

Fig. 7 is a diagram of a network of this invention including a resonating circuit shunted across a crystal, and

Fig. 8 is a diagram of a network of this invention including two crystals with a tap intermediate them.

As illustrated in Fig. 1, C*q*, L*q* and R*q* show conventionally a network including a capacitor, an inductor and a resistor which in their whole are equivalent to the oscillatory system provided by a crystal; C*p* shows the interelectrode capacity of the crystal which usually has very reduced value and may be ignored in most cases.

Considering Figs. 2*a* and 2*b* which are the associate resonance curves of a quartz crystal in proximity of the natural frequency of the crystal and show respectively the progression of the current amplitude (I) in terms of frequency (*f*) when the voltage applied to the quartz crystal electrodes is held constant, and the progression of the phase angle (φ) between the current and the voltage in terms of frequency (*f*), it derives that the phase difference (φ) between the current and the voltage is zero when the maximum current amplitude is reached; this means that the crystal acts as a pure ohmic resistance (R*q*).

To obtain a voltage resonance in a crystal-stabilized network it is known to insert a crystal Q in series with one of the two paths of a resonating network including a capacitor C and an inductor L arranged in parallel, as shown in Fig. 3. However the networks of this kind are subject to the objection that the crystal, instead of keeping itself exactly at the point O of zero phase angle (Fig. 2), tends to act as an inductor or as a capacitor respectively according to the inductive or capacitive character of the network path in which it is inserted; in other words, having in mind the diagrams of Figs. 2*a* and 2*b* said point will shift towards L or towards C, respectively. It derives that the frequency of operation will not longer be the resonance frequency of the crystal but a somewhat higher or lower frequency.

The present invention provides for removing said objection by connecting one of the taps of the oscillatory network at a point of the network having the average or medium potential of the piezo-oscillator.

Fig. 4 shows diagrammatically an embodiment in which a resistor R is shunted across a crystal Q and one (*t*) of the two taps of the network is connected with the centre of said resistor while the other tap (*t'*) is connected with the ends of said crystal by paths including a capacitor C and an inductor L respectively.

It has been found that in such a network the resonance frequency of the stabilized oscillatory network corresponds exactly with the natural frequency of the crystal and is entirely independent of the resistance value of the resistor

R. Further the two bands of the resonance curve of the network are symmetrical with respect to the resonance frequency.

It has also been found that the amplitude of the resonance voltage of such a network or, in other words, its aptitude to be piloted by the crystal, varies with the variation of the resistance value of the resistor R and reaches an optimum when said resistor has a resistance value

$$R=\sqrt{\frac{L}{C}}$$

L and C being the resistance and capacity values of the inductor L and capacitor C in Fig. 4, respectively.

In the embodiment of Fig. 5 an inductor L_1 is substituted for the resistor R and in Fig. 6 two capacitors C_1 and C_2 having equal capacities are substituted for said resistor R, the tap *t* being at the centre of inductor L_1 and between capacitors C_1 and C_2 respectively.

Both the networks of Figs. 5 and 6 have a resonance frequency corresponding exactly with that of the crystal Q; of course when tuning said networks the values of L_1 and of C_1, C_2 must be considered, respectively.

Figure 7 shows a network in which a tuned circuit consisting of a capacitor C_1 and an inductor L_1 is substituted for the resistor R. This arrangement is of particular advantage when the value of the interelectrode capacity *Cp* cannot be neglected. Then the network elements will be adjusted in such a manner that the resonance frequency of the network portion including the inductor L and capacitor C is equal to that of the portion thereof including the inductor L_1 and the capacitor C_1 and capacity *Cp* in parallel. Then the effect of capacity *Cp* will be entirely nullified and the resonance frequency of the network will exactly have the value depending upon the values *Lq*, *Cq* and *Rq* equivalent to the crystal Q.

In connection with the networks of Fig. 5 and Fig. 7 it is particularly useful to closely intercouple the two sections of the inductor L_1 at the sides of the central tap thereof, as shown at S. It is thus obtained that said inductor shows no impedance against the voltage impressed at the ends of the network in that the fluxes in said two inductor sections will cancel each other they being interlinked and in opposition. Thus undue voltage drops are avoided.

Fig. 8 illustrates a network equivalent to that of Fig. 5; in said network the assembly consisting of the crystal and the impedance element with central tap is substituted by two crystals Q_1 and Q_2 having identical features, one of them being inserted in the inductive path of the resonant network while the other one is inserted in the capacitive path thereof.

What I claim as my invention and desire to secure by United States Letters Patent is:

1. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network provided between one end of said inductive and capacitive elements, piezo-electric crystal means connected between the other end of said inductive and capacitive elements, the second tap of said network being provided at a point having the average or medium potential of said crystal means.

2. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, an impedance element shunted across said piezo-electric crystal, the second tap of said network being connected with the central point of said impedance element.

3. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, a resistor shunted across said piezo-electric crystal, the second tap of said network being connected with the central point of said resistor.

4. An oscillatory network of the two terminal type comprising two paths, an inductive element in one of said paths and a capacitive element in the other path, a tap of said network provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, a resistor shunted across said piezo-electric crystal, said resistor having a resistance value

$$R=\sqrt{\frac{L}{C}}$$

in which L and C are the total inductance value and the total capacitive value of the two respective paths of said network, the second tap of said network being connected to the central point of said resistor.

5. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network being provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, and a capacitive reactance element shunted across said piezo-electric crystal, the second tap of said network being connected with the central point of said capacitive reactance element.

6. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network being provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, and an inductive reactance element shunted across said piezo-electric crystal, the second tap of said network being connected with the central point of said inductive reactance element.

7. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network being provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, and a capacitive and an inductive reactance element shunted across said piezo-electric crystal, the second tap of said network bing connected with the central point of said inductive reactance element.

8. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network being provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, and an inductive reactance element shunted

across said piezo-electric crystal, the second tap of said network being connected with the central point of said inductive reactance element and the sections of said inductive reactance element at the sides of said central tap being closely intercoupled with each other.

9. An oscillatory network of the two terminal type comprising an inductive element and a capactive element, a tap of said network being provided between one end of said inductive and capacitive elements, a piezo-electric crystal connected between the other end of said inductive and capacitive elements, an impedance element shunted across said piezo-electric crystal, said impedance element forming with the interelectrode capacity of said crystal an antiresonant circuit at the resonance frequency of said network, the second tap of said network being connected with the central point of said impedance element.

10. An oscillatory network of the two terminal type comprising an inductive element and a capacitive element, a tap of said network being provided between one end of said inductive and capacitive elements, two piezo-electric crystals connected between the other end of said inductive and capacitive elements, the second tap being provided between said two crystals.

LEONE KAMENAROVIC.