Jan. 29, 1952 L. G. BOSTWICK 2,583,542

VIBRATORY REED-CONTROLLED OSCILLATOR

Original Filed July 10, 1948 2 SHEETS—SHEET 1

FIG. 1

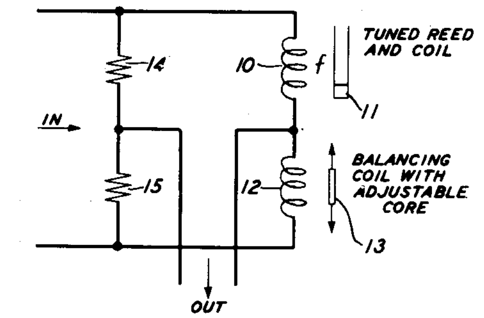


FIG. 1A

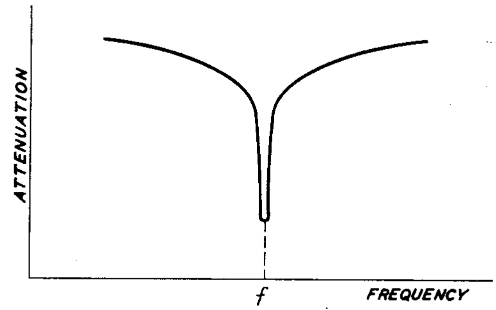


FIG. 2

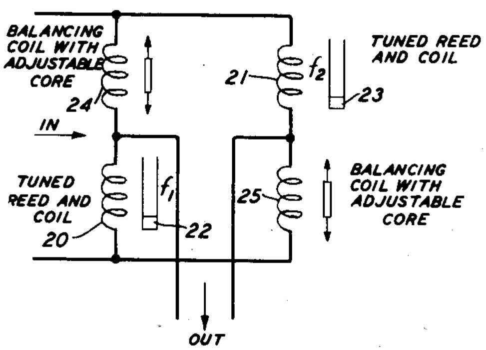
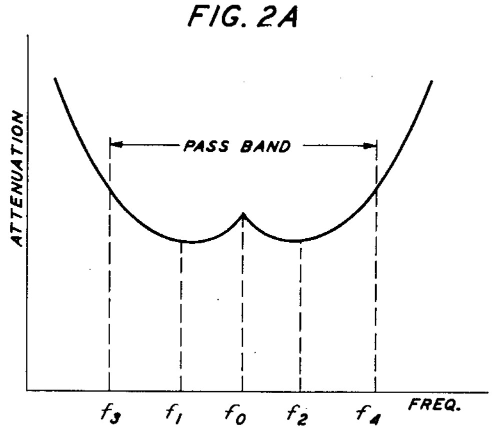


FIG. 2A



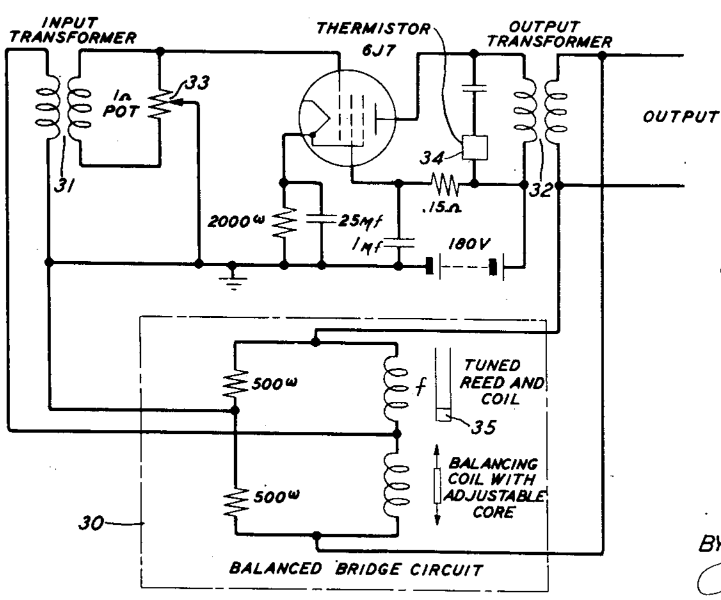


FIG. 3

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VIBRATORY REED-CONTROLLED OSCILLATOR

Original Filed July 10, 1948 2 SHEETS—SHEET 2

FIG. 4

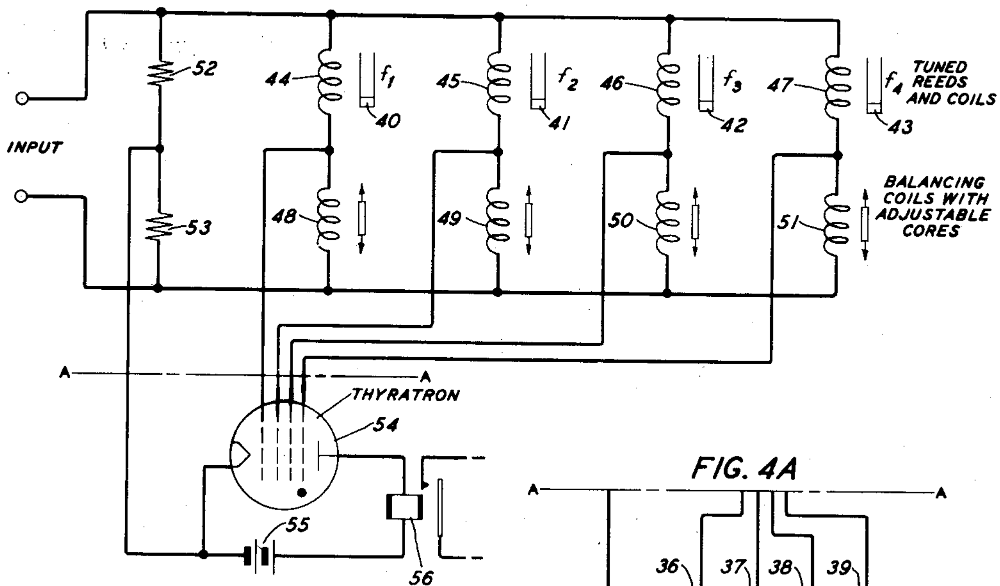


FIG. 4A

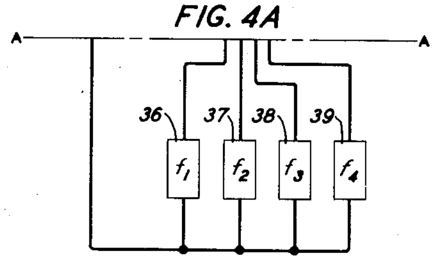
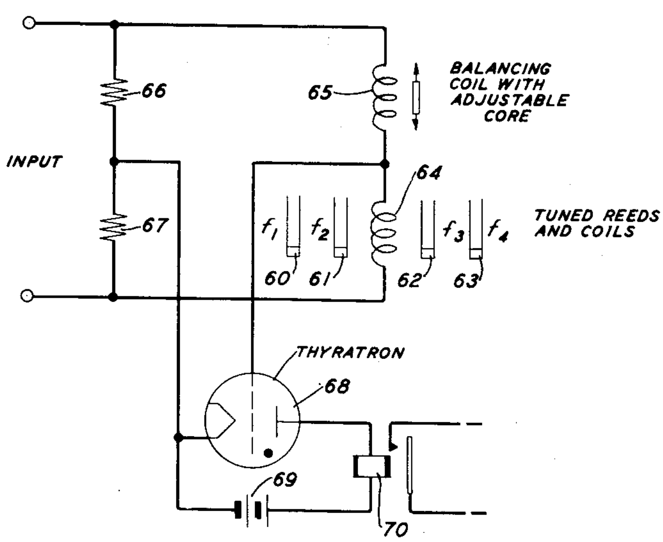


FIG. 5



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VIBRATORY REED-CONTROLLED OSCILLATOR

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2 Claims. (Cl. 250—36)

1

This is a division of L. G. Bostwick application Serial No. 38,130, filed July 10, 1948, for Tuned Vibrating Reed Selective Circuit.

This invention relates to frequency selective circuits and more particularly to those using a tuned vibratile reed or fork for the selective element.

Although in nowise limited thereto, the invention will be disclosed in a form suitable for use, by way of example in a mobile radio communication system, as a simple, compact and reliable frequency selective means suitable for selective signaling purposes. Such signaling is generally accomplished at audio frequencies and in order to supply a sufficient number of tones to provide a large number of selective signaling tone combinations, the tones must be spaced close to each other in the frequency spectrum. This requires that the selective means used to differentiate and separate one tone from another must possess a relatively high Q value. Such high values of Q are not readily obtained at the lower audio frequencies using conventional coil and condenser resonant circuits. However, mechanically resonant systems are known to have very high values of Q. Accordingly a selective relay has been developed which utilizes an electrically driven tuning fork which is provided with contacts located on the tines for making or breaking a circuit when the electric current drive frequency is equal to the resonant frequency of the tuning fork and is described in copending United States patent application, Serial No. 776,252, H. C. Harrison, but now abandoned. This arrangement, however, involves the use of contacts and therefore presents a maintenance problem which, if possible, should be avoided.

One means of avoiding the use of contacts is to employ the tuning fork or reed as a coupling element between two coils; one a drive coil and the other a pick-up coil. Such an arrangement is shown in United States Patent 1,906,985 to W. A. Marrison dated May 2, 1933, wherein a tuning fork is used as the frequency determining element and is provided with both a drive coil and a pick-up coil. The present invention differs from previously used tuning fork frequency selective means known to applicant in that but one coil is used in association with the tuning fork or reed and that coil serves the dual functions of driving the fork and acting as a variable impedance element.

An object of this invention is to provide an electrical circuit, or filter, having sharply selective frequency characteristics by making use of

2

the electrical motional impedance characteristic of an electromagnetically driven tuning fork.

One feature of this invention is that very high values of Q may be obtained from mechanically vibrating reeds or tuning forks. Another feature is that the filter circuit used is of the bridge type which is simple and inexpensive. A very useful feature is that the frequency at which the filter is selective may be readily changed by simply changing the tuning fork or reed to one which resonates at a different frequency. Another feature is that no contacts are required to be associated with the reeds, imposing a maintenance and replacement burden. A further feature of the invention lies in the ability to provide band-pass filters utilizing two reeds each tuned to a different frequency. Still another feature of the invention is the ability to utilize any number of these simple filters in a multiple arrangement whereby the simultaneous presence of a plurality of frequencies may be recognized.

In accordance with the invention the driving coil of a tuning fork is placed in one arm of an impedance bridge, which is unbalanced near the resonance frequency of the fork by the increase in the coil's impedance due to the motional impedance effect. Because of this unbalance the bridge will pass the frequency to which the tuning fork is tuned. A high degree of selectivity is obtained because of the high mechanical Q of a tuning fork.

In accordance with the invention in one application a plurality of driving coils for a plurality of tuning forks, each of which is tuned to a different frequency, are placed in a multiple arrangement which in effect comprises a multiplicity of impedance bridges in tandem in which two of the arms are common to all the bridges. This arrangement therefore functions as a multi-frequency selective circuit with high degrees of selectivity at each of the tuning fork frequencies.

A more complete understanding of this invention, its objects, features and mode of operation, will be derived from the detailed description that follows, read with reference to the appended drawings wherein:

Fig. 1 shows the basic circuit of the impedance bridge selective filter utilizing the electrical motional impedance characteristic of an electromagnetically driven tuning fork;

Fig. 1A is the selectivity curve for the circuit of Fig. 1;

Fig. 2 shows a modification of the basic circuit of Fig. 1 using two tuning forks to provide a band-pass selective characteristic;

Fig. 2A illustrates the pass-band frequency characteristic obtained with the circuit of Fig. 2;

Fig. 3 shows the circuit of an oscillator in which the frequency of oscillation is controlled by a frequency selective bridge of the type shown in Fig. 1;

Fig. 4 illustrates a multifrequency tandem multiple bridge arrangement wherein the presence of several frequencies is required to operate a multigrid gas discharge device;

Fig. 4A shows a modification of Fig. 4 where the several frequencies selected are applied to individual load circuits; and

Fig. 5 illustrates another multifrequency selective circuit using a single bridge arrangement in which several forks are electromagnetically coupled to one driving coil.

The invention herein disclosed involves the application of the electrical motional impedance characteristic of an electro-magnetically driven tuning fork to provide an electrical circuit, or filter, having sharply selective frequency characteristics. A tuning fork like that described in copending patent application Serial No. 776,252, H. C. Harrison, except with the contacting elements omitted, may be used or any similar form of electrically driven mechanical system having suitable motional impedance characteristics.

When a tuning fork like that referred to above is placed in a driving coil through which is passed a sinusoidal current, the electrical impedance of the coil may be considered as composed of two parts; namely, a damped impedance and a motional impedance. The damped impedance is the impedance of the coil when the fork is either blocked or does not vibrate due to the frequency of the current in the driving coil being different from that of the resonance frequency of the fork. The motional impedance z_m is a change in the impedance of the coil caused by vibration of the fork. Its magnitude is proportional to the square of the force factor or coupling constant M of the electromechanical system and inversely proportional to the mechanical impedance Z_m, of the vibrating system at the point of application of the driving force. This relation is expressed by the following equation:

$$z_m = \frac{M^2}{Z_m \times 10^9} \qquad (1)$$

where M is expressed in dynes per abampere, Z_m in mechanical ohms and z_m in electrical ohms.

The mechanical impedance at the end of a tine of a tuning fork varies like that of a simple series resonant circuit consisting of inductance, capacitance and resistance. At resonance the impedance goes through a minimum and increases as the frequency departs from resonance. The shape of the impedance frequency curve, or the rapidity with which the impedance changes as the frequency departs from resonance, depends upon the phase constant Q of the circuit. With a mechanical vibrating system like a tuning fork the Q can be made large and therefore the impedance made to change rapidly with frequency. If the fork is electromagnetically driven, this rapidly changing mechanical impedance is reflected into the electrical system as indicated by Equation 1, to give an electrical motional impedance that varies in a reciprocal manner, but at the same rate or with effectively the same Q.

This electrical motional impedence characteristic is used to obtain a sharply selective network as shown in Fig. 1. This network is in the

form of an electrical bridge with the drive coil **10** of the tuning fork or reed **11** serving as one arm and a similar coil **12** with an adjustable core **13** serving as another arm. This latter balancing coil **12** preferably (although not necessarily) should have the same resistance and the same number of turns as the driving coil **10** and the core **13** should be capable of giving about the same effective magnetic reluctance as the fork **11**. The other two arms of the bridge are shown as resistances **14** and **15**, although these could as well be capacitors, inductors or a tapped coil or transformer. In operation the core **13** of the balancing coil **12** is adjusted so that its impedance is equal to the damped impedance of the coil **10** with the fork **11**. Consequently, for voltages at frequencies that cause negligible vibration of the fork **11** there is a large transmission loss, or attenuation between the "in" and "out" terminals in accordance with the usual properties of a balanced bridge. However, if the input voltage to the bridge has a frequency that is near the resonance frequency of the fork **11**, vibration of the fork **11** will result in a motional impedance that will unbalance the bridge and the transmission loss will be reduced by an amount depending upon the degree of unbalance. Since the motional impedance is appreciable compared to the damped impedance only near the resonance frequency of the fork and as the same phase constant Q as the fork, the result is a sharply selective frequency attenuation characteristic like that shown in Fig. 1A.

Several coil driven forks of different frequencies may be used in a bridge at the same time to give a multiplicity of pass-bands corresponding to the resonance frequencies of the forks. For example, several forks with individual coils connected in series or several forks in a common coil may serve as one arm of a bridge and be balanced by another coil having an impedance equal to the combined damped impedance of the coil or coils with all the forks. Then for frequencies that are not near the resonance frequencies of the forks the bridge will be balanced but for frequencies near the resonance frequencies the bridge will be unbalanced and these latter frequencies will be relatively less attenuated.

Coil driven forks may also be placed in the different arms of the bridge where they balance each other at frequencies away from resonance, but individually unbalance the bridge at their resonance frequencies. If these resonance frequencies are close together the unbalance of one fork may be made to complement that of another, to pass a wider band of frequencies than that obtained with either fork alone. Such a band-pass arrangement is shown in Fig. 2. This bridge consists of two coils **20**, **21** with tuned reeds **22**, **23** of frequencies f_1 and f_2 and two balancing coils **24**, **25**. The two reed coils **20**, **21** are placed in opposite branches of the bridge so that their motional impedances unbalance the bridge in the same or aiding direction. If f_1 and f_2 are the same frequency the effect of the unbalance due to one reed is increased by that due to the other reed and the transmission loss or attenuation is less than that when using a single reed as in Fig. 1. If f_1 and f_2 are slightly different, it is evident that the maximum unbalance of one reed will occur at a different frequency from that of the other. The degree of unbalance will be less than when both frequencies are alike, but the unbalance will occur over a wider frequency range.

The pass-band characteristic obtained is shown in Fig. 2A and depends upon the Q values of the two electromechanical resonant reeds. The term pass-band is restricted to mean the frequency band in which the transmission loss is constant within certain definite limits. For example, suppose the transmission is to be kept constant within 3 decibels throughout the pass-band. Assuming a given value of Q for both reeds, f_1 and f_2 are spaced so that at f_0, mid-way between them, the response is down 3 decibels; and f_3 and f_4 represent the 3-decibel points at the lower and upper ends of the pass-band. Then suppose that the value of Q is increased so that the selectivity curves are sharper. This requires that f_1 and f_2 be spaced closer together so that the loss at f_0 will not exceed 3 decibels and also means that f_3 and f_4 will be closer to f_1 and f_2, respectively. This means that to maintain response within 3 decibels, the pass-band and the spacing between f_1 and f_2 must be reduced when the Q is increased. Only a narrow range of frequencies near the pass-band is depicted in Fig. 2A.

Figs. 3, 4 and 5 show circuit schematics in which use is made of the principle above-described to obtain sharply discriminating frequency control. Fig. 3 shows the balanced bridge circuit **30** of Fig. 1 used as the frequency control of regenerative feedback oscillator. This oscillator consists of an amplifier with input and output transformers **31**, **32**, a gain control potentiometer **33** on the secondary of the input transformer, and a thermistor **34** in the plate circuit to limit the amplitude as oscillation is built up. Thermistor **34** is of the general type of thermally sensitive element in which current flow through the device causes internal heating, which in turn causes a sharp reduction in the resistance of the device. The transformers and circuit elements are chosen so that the phase shift or transmission time through the amplifier is small over a substantial frequency range encompassing the resonance frequency of the tuned reed or fork **35**. The tuned reed selective circuit **30** is connected between the output and input terminals of the amplifier so that transmission through the bridge circuit **30** near the resonance frequency of the fork **35** causes regenerative feedback or singing in a well-known manner. The gain of the amplifier is adjusted to be slightly larger than the loss through the bridge near the resonance frequency where the loss is minimum and the phase shift is proper to permit singing. The loss and phase shift through the bridge varies rapidly with frequency near resonance of the fork and consequently the conditions necessary to permit sustained feedback oscillations are sharply defined by the fork **35**.

Figs. 4 and 5 show two arrangements of four reeds in multifrequency selective circuits that may be used in a system for selectively signaling substations from a central station by sending out from the central station signaling currents of a plurality of different predetermined frequencies. The central station may be provided with a plurality of tuned reed controlled oscillators like those shown in Fig. 3 and each substation may be provided with a multifrequency receiving circuit with several reeds such as shown in Fig. 4. This latter circuit consists of four forks **40**, **41**, **42**, **43** of frequencies f_1, f_2, f_3 and f_4, each in a driving coil **44**, **45**, **46**, **47** in series with a balancing coil **48**, **49**, **50**, **51** and these in turn bridged across the line from the central office. Likewise bridged across the line are resistors **52** and **53** which, with each driving coil **44**, **45**, **46**, **47** and its associated balancing coil **48**, **49**, **50**, **51**, form a bridge like that in Fig. 1. The output of each bridge thus formed is individually connected to the cathode and one grid of a multigrid gas discharge device **54** which is designed to break down and cause plate current to flow when a suitable positive potential appears simultaneously between all four grids and the cathode. When four oscillators having frequencies f_1, f_2, f_3 and f_4 are connected to the line at the central office the corresponding four reeds **40**, **41**, **42**, **43** in the receiving circuit at the substation vibrate and their motional impedances unbalance the normally balanced bridges. Voltages at each of these four frequencies are then transmitted through the corresponding bridges and appear at the grids of the device **54** which breaks down and allows current to flow in the plate circuit from battery **55** through relay winding **56** to operate a signal bell or other device. All four frequencies must be present at the same time because, otherwise, the device **54** will not break down. If one or more of the four frequencies applied at the central office differs from that of the resonance frequencies of the forks, the frequencies will be attenuated by the bridge circuits sufficiently to be ineffective at the grids. Other substations connected to the same line may have similar receiving circuits, except with forks tuned to different frequencies in order to permit each substation to be signaled individually.

Instead of connecting the output of each bridge between cathode and one of the grids of a gas discharge device, these individual outputs may be connected to a like number of separate loads. In this manner the circuit of Fig. 4 minus the gas discharge device and associated relay could be used to select particular frequencies from among a large number of frequencies present at the input to the circuit, and to actuate a different load device in response to each frequency. Such an arrangement is shown in Fig. 4A which may be substituted for that part of Fig. 4 shown below section A—A. The different load devices **36**, **37**, **38** and **39** will respond to the respective frequencies f_1, f_2, f_3, and f_4. These load devices may be mere resistors or any other types of load impedances across which it is desired to develop voltages of the respective frequencies; or they may be alternating current relays or trigger devices responsive to voltages of reed frequency which may be applied to them.

Fig. 5 shows a similar substation receiving circuit except here all four reeds **60**, **61**, **62**, **63** are located in a common drive coil **64** and the balancing coil **65** is adjusted to balance the combined damped impedance of this common drive coil **64**. Two resistors **66**, **67** complete the bridge circuit. When the four frequencies f_1, f_2 f_3, f_4 of the forks **60**, **61**, **62**, **63** are received from the central office each of the four frequencies f_1, f_2, f_3, f_4 is passed to the control grid of a gas discharge device **68** which requires a definite value of grid-cathode potential to operate. Since all four frequencies f_1, f_2, f_3, f_4 are different the voltages are continuously changing in relative phase and within a short period of time the resulant voltage at the grid will be momentarily equal to the sum of the individual peak voltages at each frequency. This resultant voltage is chosen to be adequate to operate the device **68** causing current from battery **69** to flow through and operate relay **70**. If one or more frequencies are absent then the resultant voltage is below the just operate voltage of the device **68** which will not break down and under this condition relay **70** will not operate.

It will be apparent to those skilled in the art that there are many variations and modifications of the arrangements described herein. For example, several forks or reeds with individual driving coils connected in series may be placed in one arm of the bridge and be balanced by a coil having an impedance equal to the combined damped impedance of all the driving coils. In addition, the band-pass arrangement may be modified to provide a wider pass-band by the use of more than two forks or reeds in the bridge arms.

Although the disclosure is in reference to tuning forks or reeds, it is obvious that any similar form of electrically driven mechanical system having suitable motional impedance characteristics may be used.

What is claimed is:

1. In an oscillatory circuit having an input and an output circuit, frequency determining means comprising a reactance coil including a vibratile reed tuned to a given frequency in series with a second reactance coil having an impedance substantially equal to the impedance of said first coil at frequencies removed from the reed frequency, connected across said output circuit, a pair of series-connected substantially equal impedances connected across said output circuit, and connections from the junctions of the series-connected coils and series-connected impedances to said input circuit, said means being in substantial electrical balance in the absence of output energy in said output circuit including the frequency to which the reed is tuned, the presence of such frequency producing vibrations of said reed at that frequency thereby to alter the effective impedance of said first-mentioned reactance coil to produce a substantial electrical unbalance in said means and transfer of output energy to said input circuit, whereby the oscillations produced have their frequency determined by the frequency of the reed.

2. An oscillation generating circuit comprising an input circuit, an output circuit, amplifying means included between said input and output circuits, and a feedback circuit interconnecting said output circuit and said input circuit for introducing output circuit energy into said input circuit, said feedback circuit including frequency determining means comprising a bridge circuit having reactive impedance devices in one pair of adjacent arms and resistive impedance devices in the other pair of adjacent arms, the junction of the reactive impedance devices and the junction of the resistive impedance devices being connected with said input circuit, and each of the junctions of a reactive impedance device and a resistive impedance device being connected with said output circuit, one of said reactive impedance devices having an impedance characteristic with frequency such that its impedance at the desired frequency of oscillation is sharply different from its impedance at frequencies removed from said desired frequency, said one reactive impedance device comprising a vibratile magnetic reed tuned to resonate at the desired frequency of oscillations and a reactance coil, and the other of said reactive impedance devices having an impedance characteristic with frequency such that it substantially balances said first impedance device at all frequencies removed from said desired frequency, said other reactive impedance device comprising a reactance coil and a magnetically responsive core adjustably positionable for varying the effective impedance of the latter coil.

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