Dec. 16, 1941. J. ROBINSON 2,266,658

ELECTRICAL FREQUENCY-SELECTIVE SYSTEM

Filed Sept. 28, 1938 2 Sheets-Sheet 1

Fig. 1.

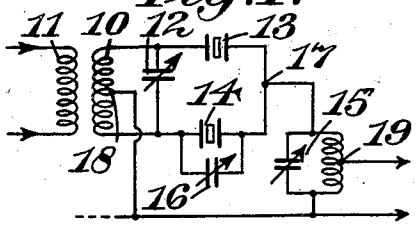


Fig. 2.

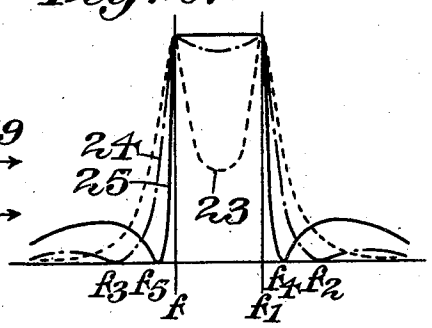


Fig. 3.

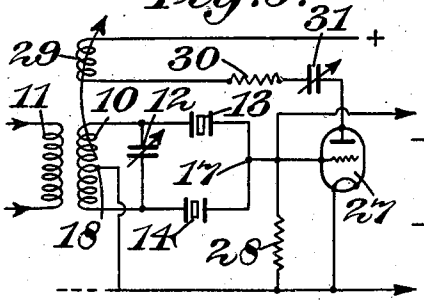


Fig. 4.

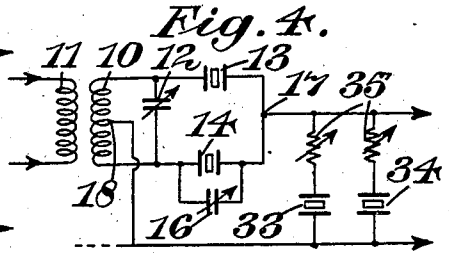


Fig. 5.

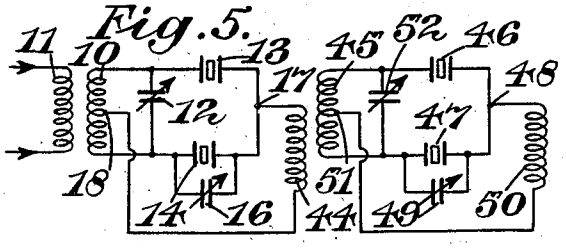
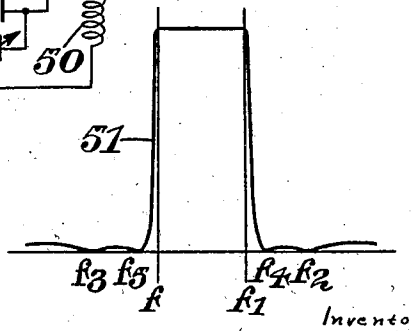


Fig. 6.



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Fig. 8.

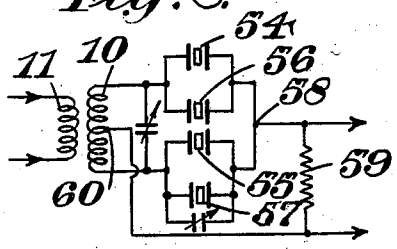


Fig. 7.

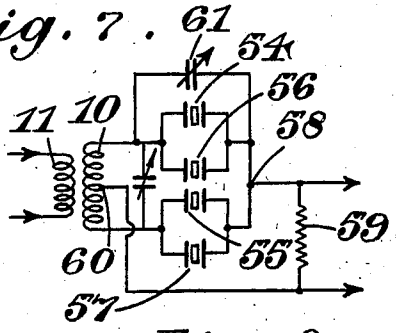


Fig. 10.

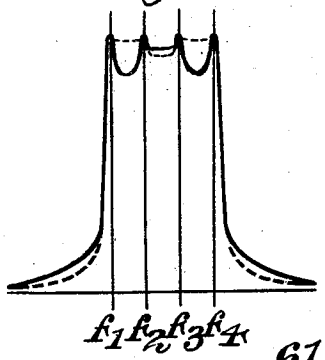


Fig. 9.

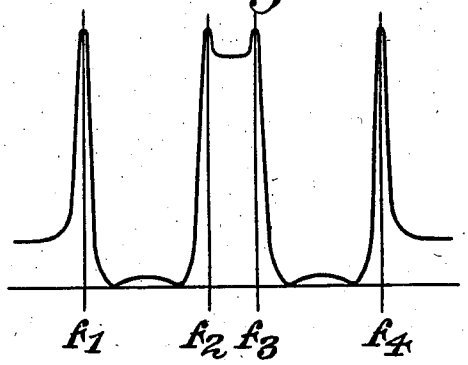


Fig. 11.

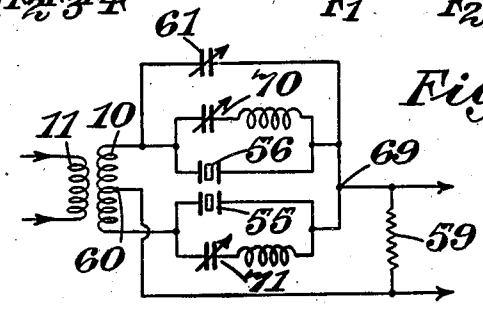
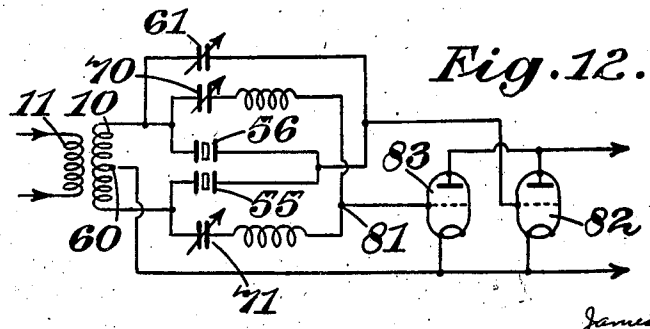


Fig. 12.



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ELECTRICAL FREQUENCY-SELECTIVE SYSTEM

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Application September 28, 1938, Serial No. 232,194
In Great Britain October 6, 1937

16 Claims. (Cl. 178—44)

This invention relates to electrical frequency-selective systems and is primarily though not essentially concerned with such systems employing mechanically resonant selective devices or for example piezo-electric devices.

It is one of the objects of the invention to provide a circuit affording a generally uniform response over a given band of frequencies and abruptly reduced or negligible response to frequencies adjacent such band, the frequency response curve being thus characterized by a generally flat top with unusually sharp cut-off at each side. Various modifications of the circuit are contemplated affording variations of the response at different frequencies as hereinafter more fully described.

According to a feature of the present invention there is provided an electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of these arms which selective devices have different resonant frequencies, means combining the outputs of the two arms in the opposed sense and an additional conductive arm which is substantially non-resonant in parallel with the others. By means of this system there is provided a filter having a band-pass characteristic with a sharp cut-off at the limits of the band determined by the resonant frequencies of the piezo-electric devices.

Further objects and features of the invention will be apparent from the following description, taken in connection with the accompanying drawings in which:

Figure 1 is a diagram of a selective system according to the invention;

Figure 2 shows curves representing the performance of the system illustrated in Figure 1;

Figure 3 shows a modification of Figure 1 employing retroaction;

Figure 4 shows another modification of Figure 1 employing a selective device as an absorber;

Figure 5 shows a modification of Figure 1 employing highly selective devices coupled in series;

Figure 6 shows a curve representing the operation of the system shown in Figure 5;

Figure 7 shows a further modification of the system;

Figure 8 shows another selective system according to the invention;

Figure 9 is a curve representing the operation of the system shown in Figure 7;

Figure 10 is a curve showing the operation of the system shown in Figure 8;

Figure 11 shows another modification of the system shown in Figure 8; and

Figure 12 shows a modification of the system shown in Figure 11.

Like references indicate like parts in the several figures of the drawings.

Referring to Figure 1, signals are applied across inductance 10 from an input inductance 11 coupled thereto. The inductance 10 is preferably tuned by a variable condenser 12 and the ends of the inductance are connected respectively to one terminal of each of two piezo-electric devices 13 and 14. The other terminals of these piezo-electric devices are connected together at 17 and to one side of a tuned circuit 15, the other side of the tuned circuit being connected to a centre tapping 18 on the inductance 10. With this arrangement, the inherent capacities of the piezo-electric devices 13, 14 are normally equal so as to be electrically balanced. In parallel with the conductive arms of the circuit constituted by the piezo-electric devices aforesaid there is the third conductive arm consisting of a variable condenser 16 connected in parallel with the piezo-electric device 14 and thus unbalancing the system.

The piezo-electric devices are selected to have resonant frequencies corresponding to the limit of the band of frequencies which the system is required to pass and thus the resonant frequencies of the two piezo-electric devices may, for example, be 5 kilocycles apart. Since these piezo-electric devices have their outputs combined in opposed phase the total response for frequencies lying between the band is augmented, while the response for frequencies outside the band is diminished, because for frequencies within the band the outputs from the two piezo-electric devices will be substantially in phase, whereas for frequencies above and below the band the outputs will be opposed in phase and therefore reduced.

Referring to Figure 2, the piezo-electric device 14 has a resonant frequency at f_1 and the piezo-electric device 13 has a lower resonant frequency at f. Since their outputs are in opposed phase the total response for frequencies lying within the band defined by their resonant frequencies is augmented, while the response for other frequencies is diminished, so that the overall characteristic for the system if the two piezo-electric devices 13 and 14 are balanced is shown by the dotted line 23 in Figure 2. The system is unbalanced by the condenser 16 providing an alternative path for applied signals. This alternative path being capacitative the phase of signals

passed thereby is advanced through 90° with respect to the signals passed by the piezo-electric devices at resonance so that at some higher frequency than the frequency f_1, the response of the system will have a minimum or zero value, for instance, at f_2 and at some frequency lower than the frequency f the response of the system will have a zero or minimum value as indicated at f_3. At the same time, the signals passed by the condenser **16** at frequencies between the resonant frequencies of the piezo-electric devices will be in substantial phase agreement with the signals of such frequencies passed by both these piezo-electric devices so that the response of the system for frequencies between the resonant frequencies of the piezo-electric devices is raised. The characteristic of the system may thus have the form indicated by the broken line **24** in Figure 3.

By increasing the capacity of the condenser **16** further to unbalance the system, the frequencies at which a minimum or zero response is obtained may be brought closer as indicated at f_4 and f_5 and the response for frequencies between the resonant frequencies of the piezo-electric devices may be made still more uniform so that the system has a response of the form indicated for example by the full line curve **25** in Figure 2.

It will be seen that for frequencies more remote from the required band than those at which zero or minimum values occur, some response may be obtained, especially in the case where the system is considerably unbalanced by the condenser **16** as shown by the curve **25**. In order to overcome any disadvantage arising from this cause the circuit **10**, **12** may be broadly tuned to the mean frequency of the required band so as to raise the response for frequencies within the required band and lower the response for other frequencies. The tuned circuit **15** is also tuned to an intermediate frequency of the required band in order further to assist in obtaining a uniform response throughout the required band and a minimum response outside the band.

Another manner of levelling the response for frequencies within the required band consists in the appropriate selection of the relative impedances of the coupling of the system with associated apparatus. This is exemplified in Figure 1 by the connection of the output line to a tapping **19** on the inductance of the tuned circuit. The coupling is so selected as to favour the transfer of signal frequencies within the required band to associated apparatus.

A further method for correcting the shape of the response curve is shown in Figure 3. In this arrangement the filter of Figure 1 is provided with retroactive means for the purpose of raising the response of the system for frequencies within the required band and also lowering the response for frequencies outside the band. In Figure 3 the terminal **17** is connected to a control electrode of a thermionic valve **27** and the centre tapping **18** on the inductance **10** is connected to the cathode of this valve, a leak resistance **28** being provided between the control electrode and the cathode. The anode circuit of the valve **27** includes a coil **29** retroactively coupled with the inductance **10** and phase adjusting means consisting of a variable resistance **30** and variable condenser **31**. The retroactive coupling is thus adjustable as regards phase to ensure the proper phase relationship for building up the response within the required band and this being the case it necessarily follows that the retroactive effect will be in the opposed sense for frequencies lying to either side of the band.

A still further method for correcting the shape of the response curve of the filter of Figure 1 is shown in Figure 4 in which two additional piezo-electric devices **33** and **34** are connected between the junction point **17** and the centre tapping on the inductance **10**, that is to say, across the output of the system. These piezo-electric devices **33** and **34** have substantially the same resonant frequencies as the piezo-electric devices **13** and **14** and function as absorbers in the system compared with the piezo-electric devices **13** and **14** operating as acceptors. A variable resistance **35** is preferably connected in series with each of the piezo-electric devices **33** and **34**.

By means of the piezo-electric devices **33** and **34** the two peaks in the output of the system due to the piezo-electric devices **13** and **14** are reduced and may be controlled to have any desired value with respect to the response of the system for frequencies within the band by adjustment of the resistances **35**. The piezo-electric devices **33** and **34** operating as absorbers reduce the response of the system at the resonant frequencies of the piezo-electric devices **13** and **14** and immediately adjacent frequencies, but have substantially no effect on other frequencies more widely removed, with the result that the final output of the system more closely approaches a uniform response for frequencies within the band without effecting the sharpness of the cut-off at the limits of the band.

It will be appreciated that the impedance matching method described with reference to Figure 1, the retroaction method of Figure 3 and the absorption method of Figure 4 provide alternative methods of adjusting the characteristic of the filter to any desired shape. They are particularly useful when it is desired to limit the action of the condenser **16** in order to prevent a too great rise in the transmission outside the desired pass band. In some cases it may be desirable to use two or more of these methods simultaneously.

It will also be appreciated that although the above described arrangements all relate to band pass filters, the same configurations may be used to obtain band absorption filters. Thus if the piezo-electric device **14** across which the condenser **16** is connected has the lower frequency, the response above f_1 and below f will be increased while the response between f_1 and f will be decreased. The methods of Figures 1, 3, and 4 may be similarly applied to obtain any desired shape of characteristic.

Figure 5 shows a filter network in which two of the filters of Figure 1 are connected in series to provide an improved response curve. The output of the fist filter which comprises inductance **10**, condenser **12**, two piezo-electric devices **13** and **14**, and the condenser **16** in shunt with the device **14** is developed across the inductance **44** which is coupled with inductance **45**. This inductance **45** together with condenser **52**, piezo-electric devices **46** and **47** and the condenser **49** comprise the second filter, the output from which is developed across the inductance **50**.

The piezo-electric device **46** has substantially the same resonant frequency as the piezo-electric device **13**, and the resonant frequencies of the piezo-electric devices **14** and **47** are also substantially the same. By adjustment of the condenser **49** the second filter comprising the

piezo-electric device 46 and 47 is unbalanced to a different degree from that of the first filter comprising the piezo-electric devices 13 and 14. For example the first filter may have a response as represented by curve 24 of Figure 2 while the second filter may have a response as represented by curve 25 of Figure 2. In this manner the overall response of the system of Figure 5 will be of the form indicated by the curve 51 in Figure 6, in which there are minimum or zero values f_3 and f_5 at one side of the required band and at f_2 and f_4 at the other side, thus further decreasing the response for frequencies outside the required band. The inductance 45 is tuned by a condenser 52 to the mean frequency of the required band and the response of the system for frequencies within the band may be made still more uniform by employing any of the measures for this purpose hereinbefore described.

Instead of employing piezo-electric devices 46 and 47 having substantially the same resonant frequencies as the piezo-electric devices 13 and 14 respectively, they may have different frequencies, for example, such that one piezo-electric device of each series pair 13, 46 and 14, 47 has a resonant frequency corresponding to the minimum or zero value of the response of the other.

In another form of frequency selective system according to this invention comprising two conductive arms, as aforesaid, a plurality of selective devices is employed in each arm, these selective devices having different resonant frequencies and being arranged alternately in the two arms as regards the order of their resonant frequencies.

In Figure 7, there is employed an inductance 10 to which signals are applied by means of the input coil 11 coupled thereto. One end of the inductance 10 is connected to terminals of two piezo-electric devices 54 and 56 and the other end of the inductance 10 is connected to terminals of two other piezo-electric devices 55 and 57 connected in parallel. The other terminals of these piezo-electric devices are connected together at 58 and the output of the system is developed across an impedance 59 connected between the junction point 58 and a centre tapping 60 on the inductance 10. The piezo-electric devices 54 to 57 have resonant frequencies of progressively increasing value so that the piezo-electric device 54 has the lowest frequency and the piezo-electric device 57 has the highest frequency. Additional piezo-electric devices may be employed if desired, and arranged in the same manner as regards their resonant frequencies so as to be distributed over the required band. A third non-resonant conductive arm consisting of a condenser 61 in parallel with the piezo-electric devices 54 and 56 may be employed if desired, in which case the signals passing the condenser will be advanced in phase with respect to signals passing each of the piezo-electric devices in resonance therewith.

It will be understood that due to the resonant characteristics of the piezo-electric devices there will be a change of phase of the applied signals passed by these devices which is of the same sign through the range of frequencies between the resonant frequencies of the piezo-electric crystals which are adjacent as regards frequency, and that the change of phase will be of opposite sign for frequencies at the other sides of the resonant frequencies of these piezo-electric devices. Thus, in employing four selective devices, of which the resonant frequencies are indicated at f_1, f_2, f_3 and f_4 in Figure 9, the change of phase for frequencies between f_2 and f_3 will be of opposite sign to the change of phase for frequencies between f_1 and f_2 and frequencies between f_3 and f_4. The signals passed by the condenser 61, which is connected in parallel with the piezo-electric devices 54 and 56, will be opposed in phase with regard to signals at frequencies between f_1 and f_2 and between f_3 and f_4. Thus, by appropriate adjustment of the condenser 61 a zero response is obtained at a frequency between the frequencies f_1 and f_2 and at a frequency between the frequencies f_3 and f_4. By increasing the capacity of the condenser 61 a zero response will be obtained at two different frequencies between f_1 and f_2 and between f_3 and f_4 as shown in Figure 9. Thus, there is obtained a sharply defined band-pass characteristic as indicated in Figure 9 with substantial zero response for a range of frequencies immediately each side of the band. The peaks at the frequencies f_1 and f_4 may be reduced by employing a broadly tuned circuit tuned to the mean frequency of the band defined by the frequencies f_2 and f_3, for example by tuning the inductance 10 by means of the parallel condenser 12, by employing a tuned circuit as the impedance 59, or by means of absorbers as described with reference to Figure 4. It will be appreciated that if a plurality of piezo-electric devices are provided in each parallel arm, this arrangement will enable a plurality of alternating band pass and band absorption channels to be obtained.

The system shown in Figure 7 may be modified to give a single band pass characteristic by connecting the condenser 61 in parallel with the piezo-electric devices 55 and 57 instead of the piezo-electric devices 54 and 56, as shown in Figure 8. In this case a minimum response is obtained at a frequency lower than the frequency f_1 and higher than the frequency f_4. The response for frequencies between f_1 and f_2 and between f_3 and f_4 are raised in this case and although the response for frequencies between f_2 and f_3 is reduced, by selecting the piezo-electric devices to have resonant frequencies f_2 and f_3 comparatively close together, the total response may be substantially uniform throughout the range f_1 to f_4. This is illustrated in Figure 10 of the drawing in which the response of the circuit of Figure 8 with condenser 61 omitted is shown in full lines, the effect of shunting the condenser 61 about the piezo-electric devices 55 and 57 being indicated by the dotted line curve.

In Figure 11 there is shown a modification of the system shown in Figure 7 in which the piezo-electric devices 54 and 57 of lowest and highest frequencies respectively are replaced by series tuned circuits 70 and 71. In this case the final characteristic of the system will have the same general form as that shown in Figure 9 except that the peaks at frequencies f_1 and f_4 will be broader due to the use of the tuned circuits.

It will be appreciated that instead of employing the two piezo-electric devices to define the band, tuned circuits may be tuned for this purpose and the piezo-electric devices may have resonant frequencies, one higher and the other lower than the required band.

In another modification of the system shown in Figure 11, the piezo-electric device 55 may have the same order of frequency as the tuned circuit 70 and similarly the piezo-electric device 56 may have the same order of frequency

as the tuned circuit 71, in which case a band-pass characteristic is also obtained. A similar modification may be made in the system shown in Figure 7.

Another modification of Figure 11 is shown in Figure 12 in which the piezo-electric devices are joined at 80 and this junction point is connected to the input electrode of a valve 82. The tuned circuits 70 and 71 are joined at an independent junction point 81 which is connected to the input electrode of a valve 83. The output is derived from the anodes of the valves connected together, the cathodes being connected to the tapping 60 on the inductance 10. In this case the condenser 61 providing the additional conductive path of the system is connected in parallel with the piezo-electric device 56 and therefore the tuning of the circuits 70 and 71 is independent of the capacity of this condenser.

It is convenient in some circumstances to employ a signal response which is higher for the two outer selective devices than for the inner ones and this result may be obtained by discriminate amplification or, for example, in the case of piezo-electric devices, by supplementing these piezo-electric devices with other piezo-electric crystals of the same order of frequency in parallel therewith.

It will be understood that the piezo-electric devices hereinbefore referred to may each consist of a single crystal or a plurality of crystals of substantially the same resonant frequncy connected in series or parallel.

Furthermore the use of one or more broadly tuned circuits tuned to an intermediate frequency of the required band, as described for example with reference to Figure 1, or retroaction as described with reference to Figure 3, or absorbers as described with reference to Figure 4, may be applied to any other of the selective systems described herein. Alternatively or in addition one or more absorption circuits may be in the system and tuned to a frequency or frequencies beyond the limits of the required band in order to still further reduce the total response of system for frequencies outside the required band.

Whereas a tapped coil 10 has been shown as a convenient means of feeding applied frequencies along two conductive arms for their ultimate combination in opposition, any other means for this purpose may be employed.

It will also be understood that any of the circuits hereinbefore described may be reversed as to their input and output in operation.

I claim:

1. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and means increasing the output of one of said arms for signals having a frequency lower than the frequency of the associated selective device, and reducing the output of such arm for signals having a frequency higher than the frequency of the associated selective device, said means comprising, in parallel with such arm, an additional conductive arm which is substantially non-resonant.

2. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and means for altering the relative amplitude of the combined output for signals having frequencies falling within and without the said band, said means comprising an additional conductive arm which is substantially non-resonant connected in parallel with one of said first named arms.

3. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and means increasing the combined output of said arms for signals having frequencies falling within the said band, said means comprising an additional conductive arm which is substantially non-resonant connected in parallel with one of said first named arms.

4. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and a non-resonant conductive device connected in parallel with that one of said selective devices which has the higher resonant frequency for increasing the combined output of said arms for signals having frequencies falling within the said band.

5. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and capacitative means in parallel with one of said devices for unbalancing the capacitative value of the two arms to alter the relative amplitude of the output for signal frequencies falling within and without the said band.

6. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, means increasing the output of one of said arms for signals having a frequency lower than the frequency of the associated selective device, and reducing the output of such arms for signals having a frequency higher than the frequency of the associated selective device, said means comprising, in parallel with such arm, an additional conductive arm which is substantially non-resonant, and at least one broadly tuned circuit which is tuned to a frequency intermediate the resonant frequency of said selective devices, said last named circuit being associated with said conductive arms and arranged in advance thereof in said system.

7. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device in each of said arms, said selective devices having different resonant frequencies within a band of frequencies, means combining the out-

puts of the two arms in phase opposition, a third conductive arm which is substantially non-resonant in parallel with one of said first named arms, and phase changing means in said third conductive arm to change the phase of frequencies passing said third conductive arm into opposition with the frequencies passing said selective device and falling outside of the said band of frequencies.

8. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a piezo-electric device in each of said arms, said devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and means increasing the output of one of said arms for signals having a frequency lower than the frequency of the associated piezo-electric device and reducing the output of such arm for signals having a frequency higher than the frequency of the associated piezo-electric device, said means comprising, in parallel with such arm, an additional conductive arm which is substantially non-resonant.

9. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a piezo-electric device in each of said arms, said piezo-electric devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and capacitative means in parallel with one of said devices for unbalancing the capacitative value of the two arms to alter the relative amplitude of the output for signal frequencies falling within and without the said band.

10. An electrical frequency-selective system comprising two conductive arms constituting parallel paths for applied frequencies, a piezo-electric device in each of said arms, said piezo-electric devices having different resonant frequencies within a band of frequencies, means combining the outputs of the two arms in phase opposition, and a non-resonant conductive device connected in parallel with that one of said piezo-electric devices which has the higher resonant frequency for increasing the combined output of said arms for signals having frequencies falling within the said band.

11. An electrical frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, a plurality of piezo-electric devices in each of said arms, said piezo-electric devices having different resonant frequencies and being arranged in the two arms alternately as regards the order of their resonant frequencies, means for combining the outputs of the two arms in opposed phase, and non-resonant phase changing means connected in parallel with one of said conductive arms to increase the output of the system in bands of frequencies defined by alternate pairs of the said piezo-electric devices of adjacent frequency and to reduce the output of the system between the said bands such that a plurality of spaced band pass channels are provided.

12. An electrical frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, a plurality of piezo-electric devices in each of said arms, said piezo-electric devices having different resonant frequencies and being arranged in the two arms alternately as regards the order of their resonant frequencies, means for combining the outputs of the two arms in opposed phase, and non-resonant phase changing means connected in parallel with one of the said arms to reduce the output of the system for frequencies above the frequency of the piezo-electric device having the highest resonant frequency and below the frequency of the device having the lowest resonant frequency.

13. A frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, a plurality of selective devices in each of said arms which selective devices have different resonant frequencies and are arranged in the said two arms alternately as regards the order of their resonant frequencies, the selective devices having the highest and the lowest resonant frequency being constituted by piezo-electric crystals, the other of said devices being constituted by series tuned circuits, means for combining the outputs of the two arms in opposed phase, and a non-resonant phase changing device connected in parallel with one of said conductive arms.

14. A frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, two selective devices consisting of a piezo-electric device and a series tuned circuit in each of said arms, said selective devices having different resonant frequencies and being arranged in the said two arms alternately as regards the order of their resonant frequencies, the devices of highest and lowest frequency being constituted by the piezo-electric devices, means for combining the outputs of the two arms in opposed phase and a condenser, shunting that one of the said arms including the device of highest frequency, of such magnitude as to provide a substantially uniform response over a band of frequencies defined by the resonant frequencies of the piezo-electric devices.

15. A band pass frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, a selective device consisting of a piezo-electric device and a series tuned circuit having the same resonant frequency in each of said arms, the said selective devices having different resonant frequencies within the pass band, means for combining the outputs of the two arms in opposed phase and a condenser connected in shunt with one of said arms to increase the response of the system for frequencies within the pass band.

16. A frequency selective system comprising two conductive arms constituting parallel paths for applied frequencies, a piezo-electric device in each of said arms, said piezo-electric devices having different resonant frequencies corresponding to the limits of a band of frequencies to be selected, means for combining the outputs of the two arms in opposed phase, non-resonant phase changing means connected in shunt with the piezo-electric device of the higher resonant frequency, and a parallel circuit tuned to a frequency intermediate the limits of the said band of frequencies and connected in shunt with the output of the selective system.

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