July 15, 1941.

R. A. SYKES

2,249,440

WAVE FILTER

Filed June 2, 1939

FIG. 1

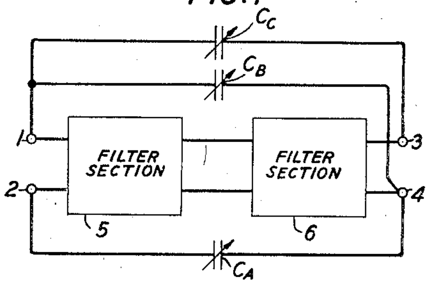


FIG. 2

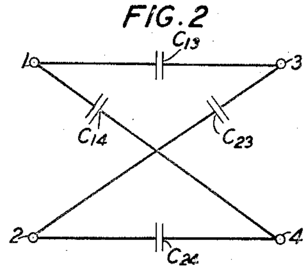


FIG. 3

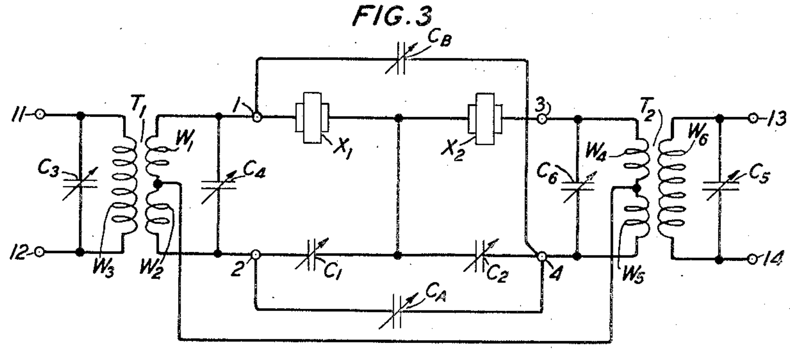


FIG. 4

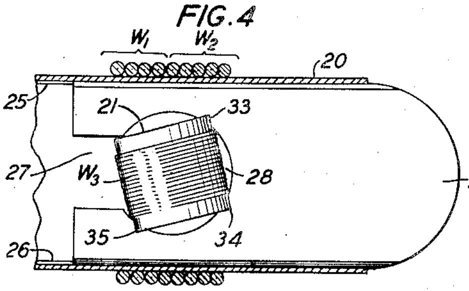
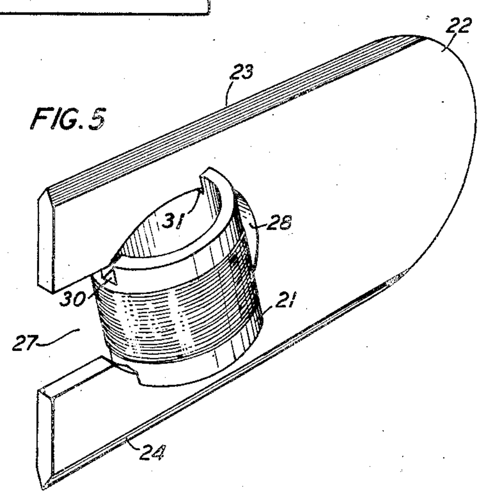


FIG. 5



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Patented July 15, 1941 2,249,440

UNITED STATES PATENT OFFICE

2,249,440

WAVE FILTER

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Application June 2, 1939, Serial No. 276,981

20 Claims. (Cl. 178—44)

This invention relates to wave filters and more particularly to composite filters made up of more than one section.

The object of the invention is to increase the attenuation outside of the transmission band in a composite wave filter.

In a wave filter of the balanced type comprising two or more tandem sections the overall attenuation outside of the transmission band may be materially reduced by capacitive unbalance due to uncompensated stray capacitances and by inductive unbalance due to the inequality of nominally equal inductances. In accordance with the present invention the capacitive unbalance is reduced by the addition of a properly chosen capacitor connected between an input terminal and either the corresponding output terminal or the diagonally opposite output terminal of the filter. A further improvement in the attenuation characteristic may, in general, be obtained by employing two added capacitors, one connected between an input terminal and the corresponding output terminal, and the other connected either between the remaining input and output terminals or between an input terminal and the diagonally opposite output terminal. The capacitors are preferably made adjustable to facilitate selection of the proper values.

Also in accordance with the invention the inductive unbalance is reduced by providing at each end of the filter a balanced three-winding transformer having an adjustment by means of which the coupling between the single winding and one of the two balanced windings may be increased while at the same time the coupling between the single winding and the other balanced winding is decreased. The transformer is preferably provided with a further adjustment for varying the coupling between the single winding and the two balanced windings in series so that the transformer may be adjusted to transmit the required band of frequencies. A suitable embodiment of the transformer is disclosed in which the two balanced windings are wound upon a hollow cylinder and the single winding is supported within the cylinder. Provision is made for adjusting the position of the inner coil longitudinally with respect to the outer windings and for adjusting the angle between the axes of the inner and the outer coils.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, of which—

Fig. 1 is a schematic showing of a two-section wave filter with balancing capacitors in accordance with the invention;

Fig. 2 is an equivalent lattice network representing the stray capacitances effective between the input and output terminals of the filter of Fig. 1;

Fig. 3 shows the circuit of a specific embodiment of the invention including balancing capacitors and end transformers with adjustments for balance;

Fig. 4 is a cross-section of a suitable three-winding transformer having special adjustments; and

Fig. 5 is a perspective view of the sliding member and inner coil of the transformer of Fig. 4.

Fig. 1 shows diagrammatically a composite wave filter comprising a plurality of sections, such as **5** and **6**, connected in tandem between a pair of input terminals **1**, **2** and a pair of output terminals **3**, **4**. The individual sections may be of any type but it is assumed that the filter as viewed at either end is a balanced structure. The capacitors C_A and C_B, each connected between an input terminal and an output terminal, are added in accordance with the invention to balance the stray capacitances associated with the component filter elements and thereby increase the attenuation of the filter outside of the transmission band. For a perfect balance to a common ground at both ends of the filter a third capacitor, such as C_C, is required. The capacitors are preferably made adjustable, as indicated by the arrows.

The considerations involved in choosing the location and magnitude of the balancing capacitors are best explained by reference to Fig. 2 which shows the equivalent lattice network representing the stray capacitances effective between the terminals of the filter of Fig. 1. The capacitances C_{13} and C_{24} forming the series branches of the lattice represent, respectively, the stray capacitances effective between each input terminal **1**, **2** and the corresponding output terminals **3**, **4**. The capacitances C_{14} and C_{23} in the diagonal branches represent, respectively, the stray capacitances effective between each input terminal **1**, **2** and the diagonally opposite output terminals **4**, **3**. In general, all of the four capacitances forming the lattice will have different values and there is thus provided, in effect, a second transmission path in parallel with the normal path through the filter sections.

In accordance with the invention the stray capacitances represented by the lattice of Fig. 2

may be so balanced by the addition of a single capacitor that an electromotive force impressed upon the input terminals 1 and 2 in Fig. 2 will produce no current in a load connected to the output terminals 3 and 4. The relationship to be satisfied is that the product of the capacitances in the series branches must be equal to the product of the capacitances in the diagonal branches. In equation form,

$$C_{13}C_{24}=C_{14}C_{23} \qquad (1)$$

It is apparent, therefore, that if the product of the series capacitances is smaller than the product of the diagonal capacitances, an added capacitor such as C_A or C_C of Fig. 1 is connected in parallel with one of the series branches. On the other hand, if the product of the diagonal capacitances is smaller than the product of the series capacitances, the added capacitor is connected between either of the input terminals and the diagonally opposite output terminal, as illustrated in Fig. 1 by the capacitor C_B. In either case the added capacitor is given such a value that Equation 1 is satisfied.

The equivalent lattice of Fig. 2 even when balanced by the addition of a single capacitor, as explained above, will still permit the flow of longitudinal currents. That is to say, an electromotive force effective between ground and the two input terminals will cause a current to flow to ground through a load impedance connected across the output terminals. This current may be eliminated by making all of the branches in the lattice equal. This can be done by the addition of three capacitors, such, for example, as C_A, C_B and C_C in Fig. 1. A capacitor is connected in parallel with each of the branches except the one having the largest stray capacitance and these capacitors are given the proper values to make all of the branches of the lattice equal.

The effects of the longitudinal current in the output load may also be eliminated by the addition of only two capacitors so proportioned and so placed that the unbalance voltage to ground at the input end of the filter is made equal in magnitude to, but 180 degrees out of phase with, the unbalance voltage to ground at the output end. To accomplish this, Equation 1 must be satisfied and in addition the two series capacitances must be made equal. The latter condition in equation form is

$$C_{13}=C_{24} \qquad (2)$$

The choice of the branches to which the capacitors are to be added is based upon the following considerations. Since the two series branches are to be equal it is seen from Equation 1 that each series capacitance must be equal to the geometric mean of the two diagonal capacitances. That is,

$$C_{12}=C_{24}=\sqrt{C_{14}C_{23}} \qquad (3)$$

Therefore, if each series capacitance is smaller than the geometric mean of the diagonal capacitances, a capacitor is added to each series branch and its value is so chosen that the total capacitance of each series branch is equal to this mean. Under these conditions the capacitors C_A and C_C of Fig. 1 are used. On the other hand, if either or both of the series capacitances are larger than the geometric mean of the diagonal capacitances, the smaller series capacitance is built out to the value of the larger by the addition of a capacitor and either of the diagonal capacitances is built out by the addition of a second capacitor of such a value that the product of the series branches is equal to the product of the diagonal branches. In this case the capacitors C_A and C_B may, for example, be used.

Fig. 3 shows an embodiment of the invention in a two-section filter which includes balancing capacitors to reduce the capacitive unbalance and balanced three-winding transformers with special adjustments to reduce the inductive unbalance. The two sections have similar circuit configurations and are designed to pass the same band of frequencies. Each section is of the differential transformer type in which the transmission through a piezoelectric crystal impedance is balanced against the transmission through an impedance of different character, for example, a capacitor. The two impedances are so proportioned that substantially complete balance is obtained at all frequencies except those falling in the transmission band.

One section of the filter comprises a three-winding transformer T_1, a piezoelectric crystal X_1 and a balancing capacitor C_1, and the other section includes the corresponding elements T_2, X_2 and C_2. The two sections are connected in tandem back-to-back, with the transformers at the outer ends, so that the composite filter is symmetrical and is seen as a balanced structure at the input terminals 1, 2 and also at the output terminals 3, 4. As explained above the capacitors C_A and C_B are added to reduce the capacitive unbalance caused by the stray capacitances shown in Fig. 2 which are effective between the various filter termonals.

On the assumptions that the stray capacitance C_{13} is larger than C_{24} and also larger than the geometric mean of C_{14} and C_{23}, the capacitance C_A is connected between terminals 2 and 4 and is given a value equal to the difference between C_{13} and C_{24}. The capacitance C_B is now added to a diagonal branch, for example, between terminals 1 and 4, as shown. and given such a value that the product of the series branch capacitances is equal to the product of the diagonal branch capacitances. Alternatively, the capacitance C_B may be connected between terminals 2 and 3. Under other circumstances the capacitance C_A may be connected between terminals 1 and 3, and C_B may be connected either between terminals 1 and 4, as shown, or between terminals 2 and 3. On the other hand, if each stray series capacitance is smaller than the geometric mean of the diagonal capacitances, the capacitance C_A may be connected as shown between terminals 2 and 4 and C_B connected between terminals 1 and 3, and their values so chosen that the total capacitance of each series branch is equal to this mean. Also, as explained above, considerable improvement may be obtained by the use of a single balancing capacitor.

In the input transformer T_1 the two balanced windings W_1 and W_2 are equal in inductance and are closely coupled. The third inductance W_3 is inductively coupled to the balanced windings. The two variable capacitors C_3 and C_4 are connected in shunt at the respective ends of the transformer and adjusted to resonate with the associated inductances at the mid-band frequency of the filter in order to decrease the transmission loss introduced by the transformer. In order to reduce the inductive unbalance in the filter due to an inequality in the windings W_1, W_2 or to other causes, an adjustment is provided by means of which the coupling between W_3 and W_1 can be increased or decreased while at the same time the coupling between W_3 and W_2 is decreased or increased. A further adjustment is provided to vary the coupling between W_3 and the windings W_1 and W_2 in series so that the proper coupling can be provided to make the transformer a band-pass network. The output transformer T_2 is of similar construction and comprises the windings W_4, W_5 and W_6 and the capacitors C_5 and C_6.

If the filter is to be used between balanced circuits and the adjustment for inductive balance is not required, the loads may be connected directly to the input terminals **1**, **2** and the output terminals **3**, **4**, in which case the windings W_3, W_6 and the associated tuning capacitors C_3, C_5 may be omitted. When these elements are included, however, the loads are connected to the input terminals **11**, **12** and the output terminals **13**, **14** and the filter may be used in either balanced or unbalanced circuits. By a proper adjustment of the differential coupling between the single winding and the balanced windings the inductive unbalance may be substantially eliminated and the attenuation of the filter outside of the transmission band materially increased. The addition of balancing capacitors and the proper adjustment of the differential coupling have increased the attenuation by as much as 30 decibels in actual cases.

A suitable structure for the three-winding transformer T_1 is shown in cross-section in Fig. 4. The balanced windings W_1 and W_2 are wound on the tube **20**, and the third winding W_3 is placed on a smaller tube **21** which is supported within the tube **20** by the sliding member **22**. As is shown more clearly in the perspective view of Fig. 5 the slide **22** has beveled edges **23**, **24**, which fit into the oppositely disposed longitudinal grooves **25**, **26** in the inner surface of the tube **20**. One end of the slide has a slot **27** leading to a circular hole **28** which has a diameter somewhat larger than the width of the slot. Each end of the tube **21** has a pair of notches **30**, **31** which permit the tube to be slid through the slot **27** into the hole **28**. The distance between diagonally opposite notches is equal to the diameter of the hole and therefore the tube is supported at at least three points, such as **33**, **34** and **35**.

By turning the tube **21** around in the hole the angle between the axis of the inner coil W_3 and axis of the outer windings W_1 and W_2 can be adjusted, and therefore the inductive coupling between these coils can be set at the required value. Furthermore, by moving the slide **22** to the left or to the right the inner coil W_3 may be displaced to one side or the other of a central position, and in this way the coupling between the single winding W_3 and one of the balanced windings, say W_1, may be increased while at the same time the coupling between W_3 and the other balanced winding is decreased. This latter adjustment does not affect appreciably the coupling between W_3 and the two balanced windings in series, as this is dependent primarily upon the angle between the axes of the coils.

What is claimed is:

1. A balanced wave filter comprising a pair of input terminals, a pair of output terminals, a plurality of sections connected in tandem between said pairs of terminals, and means for reducing the capacitive unbalance due to stray capacitance comprising an added capacitor connected between an input terminal and an output terminal whereby the attenuation of the filter outside of the transmission band is increased.

2. A wave filter in accordance with claim 1 in which said capacitor is connected between an input terminal and the corresponding output terminal.

3. A wave filter in accordance with claim 1 in which said capacitor is connected between an input terminal and a diagonally opposite output terminal.

4. A wave filter in accordance with claim 1 in which said capacitor is adjustable.

5. A balanced wave filter comprising a pair of input terminals, a pair of output terminals, a plurality of sections connected in tandem between said pairs of terminals, and means for reducing the capacitive unbalance due to stray capacitance comprising a plurality of added capacitors, each of said capacitors being connected between an input terminal and an output terminal, whereby the attenuation of the filter outside of the transmission band is increased.

6. A wave filter in accordance with claim 5 in which two of said capacitors are connected respectively between each of the input terminals and the corresponding output terminal.

7. A wave filter in accordance with claim 5 in which one of said capacitors is connected between an input terminal and the corresponding output terminal and another of said capacitors is connected between an input terminal and the diagonally opposite output terminal.

8. A wave filter in accordance with claim 5 in which two of said capacitors are connected respectively between each of the input terminals and the corresponding output terminal and another of said capacitors is connected between an input terminal and the diagonally opposite output terminal.

9. A wave filter in accordance with claim 5 in which said capacitors are adjustable.

10. In a balanced wave filter comprising a plurality of sections connected in tandem between a pair of input terminals and a pair of output terminals, means for reducing the capacitive unbalance due to unequal stray capacitances effective between said terminals comprising an added capacitor connected between an input terminal and an output terminal, the capacitance of said capacitor being so proportioned with respect to said stray capacitances that the product of the capacitances effective between each input terminal and the corresponding output terminal is substantially equal to the product of the capacitances effective between each input terminal and the diagonally opposite output terminal.

11. In a balanced wave filter comprising a plurality of sections connected in tandem between a pair of input terminals and a pair of output terminals, means for reducing the capacitive unbalance due to unequal stray capacitances effective between said terminals comprising a plurality of added capacitors, each of said capacitors being connected between an input terminal and an output terminal, and the capacitances of said capacitors being so proportioned with respect to said stray capacitances that the capacitances effective between each input terminal and the corresponding output terminal are substantially equal and their product is substantially equal to the product of the capacitances effective between each input terminal and the diagonally opposite output terminal.

12. A balanced wave filter comprising means for reducing inductive unbalance including a three-winding transformer comprising a single winding and two substantially balanced wind-

ings, said transformer having an adjustment for increasing the coupling between said single winding and one of said balanced windings while at the same time decreasing the coupling between said single winding and the other of said balanced windings.

13. A wave filter in accordance with claim 12 in which said transformer has an additional adjustment for increasing or decreasing the coupling between said single winding and both of said balanced windings.

14. A balanced wave filter comprising a pair of input terminals, a pair of output terminals and a plurality of sections connected in tandem between said pairs of terminals, each end section of said filter including a three-winding transformer for connecting said filter with one of its terminal loads, each of said transformers comprising two substantially equal windings connected in series between one of said pairs of terminals, a third winding, and means for increasing the coupling between said third winding and one of said equal windings while decreasing the coupling between said third winding and the other of said equal windings.

15. A wave filter in accordance with claim 14 which includes a capacitor connected between an input terminal and an output terminal to reduce the capacitive unbalance.

16. A wave filter in accordance with claim 14 which includes a plurality of added capacitors for reducing the capacitive unbalance, each of said capacitors being connected between an input terminal and an output terminal.

17. A wave filter in accordance with claim 14 in which each of said transformers includes additional means for adjusting in the same direction the coupling between said third winding and both of said equal windings.

18. A balanced wave filter comprising a pair of input terminals, a pair of output terminals, a plurality of sections connected in tandem between said terminals, and an added capacitor connected between an input terminal and an output terminal and adjusted to decrease the capacitive unbalance due to stray capacitance, each end section of sail filter including a three-winding transformer for connecting the filter to a terminal load and each of said transformers comprising a single winding and two balanced windings and including means for increasing the coupling between said third winding and one of said balanced windings while decreasing the coupling between said third winding and the other of said balanced windings.

19. A wave filter in accordance with claim 18 in which each of said transformers includes additional means for adjusting in the same direction the coupling between said third winding and both of said balanced windings.

20. A wave filter in accordance with claim 18 which includes a second added capacitor connected between an input terminal and an output terminal and adjusted to further decrease the capacitive unbalance.

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