Aug. 25, 1936. H. T. BUDENBOM 2,052,338

FILTERING CIRCUIT

Filed June 29, 1929 2 Sheets-Sheet 1

FIG. 1

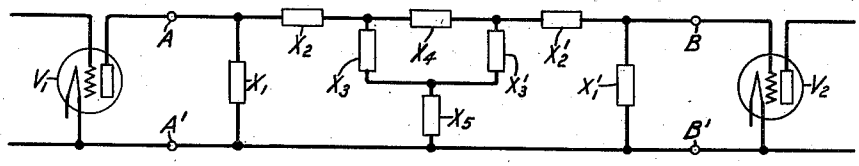

FIG. 2

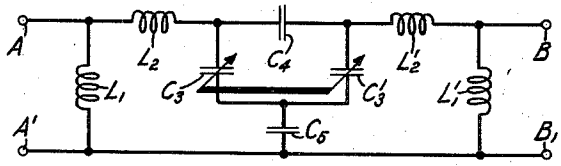

FIG. 3

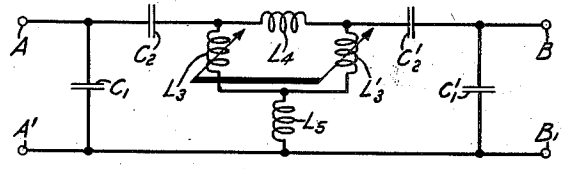

FIG. 4

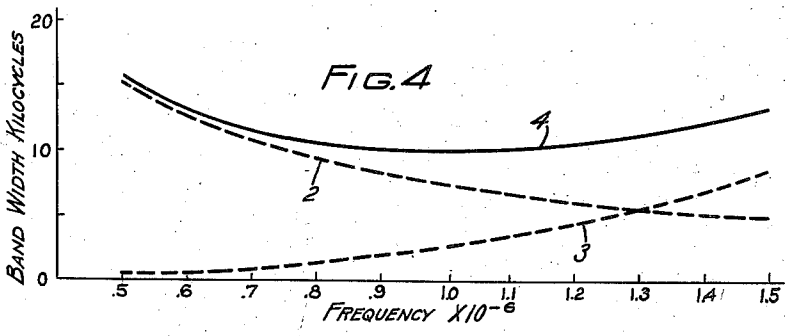

FIG. 5

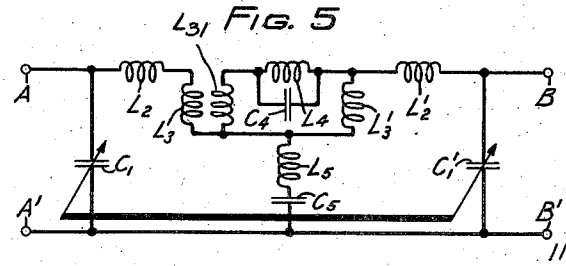

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Fig. 6

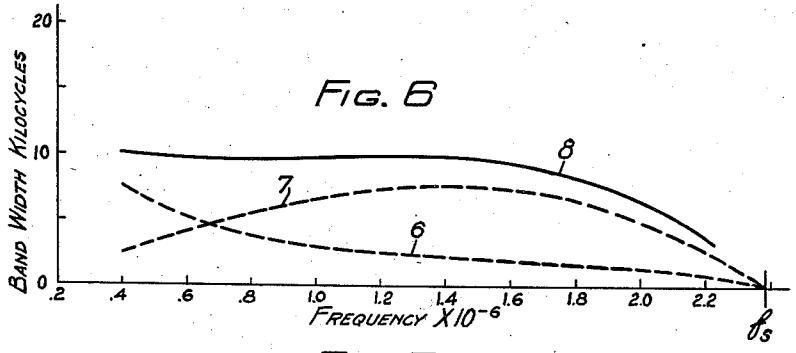


Fig. 7

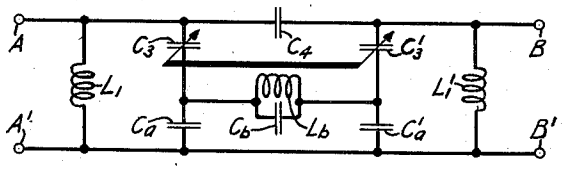


Fig. 8

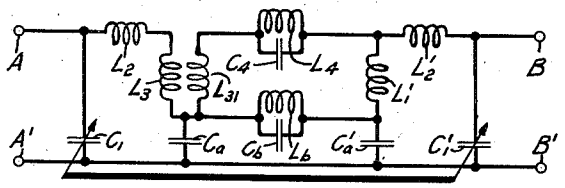


Fig. 9

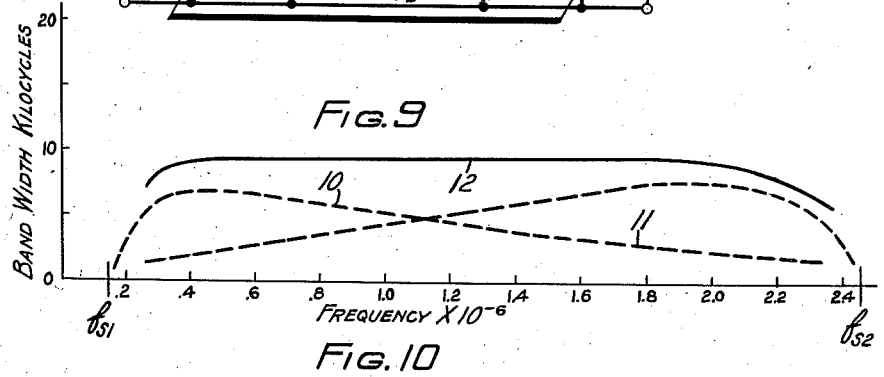
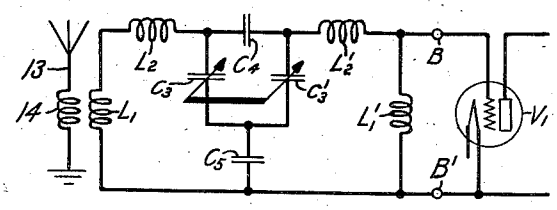


Fig. 10



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Patented Aug. 25, 1936 2,052,338

UNITED STATES PATENT OFFICE

2,052,338

FILTERING CIRCUIT

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Application June 29, 1929, Serial No. 374,741

14 Claims. (Cl. 178—44)

This invention relates to frequency selective circuits and more particularly to systems of coupled tuned circuits having band selective properties.

The principal object of the invention is to maintain constant the width of a selected band of frequencies as the mean frequency of the band is varied.

Another object is the improvement of the selective characteristics of radio receivers and of high frequency amplifiers used in connection with radio or other carrier wave receivers.

A further object is the improvement of the coupling of adjustable tuned circuits whereby a constant width band selectivity is provided by the impedance properties of the coupling means.

In the reception of speech or music transmitted by radio it is necessary for good quality reproduction that the selective circuits of the receiver should be responsive to a band of frequencies about 10,000 c. p. s. wide. For proper discrimination between stations, particularly when the carrier waves are closely spaced in the frequency scale, it is also necessary that the band width should not greatly exceed this value at any tuning adjustment. To meet both of these requirements it is therefore desirable that the selective circuits should be adapted to transmit a substantially constant width band of frequencies at all points in the tuning range.

It is well known that when two syntonous tuned circuits are coupled together electrically the system exhibits the property of double resonance, the two resonance frequencies being separated by an interval depending on the degree of coupling. When such a system is used as a frequency selective transmission network it may be made to exhibit the properties of a band-pass wave filter by the proper proportioning of the connected terminal impedances, the limits of the band coinciding with the two resonance frequencies. If the degree of coupling is small so that the resonance frequencies are close together, the band character of the transmission is maintained in part by the resistances of the circuit elements, and is to some extent independent of the values of the connected terminal impedances. The location of the band in the frequency scale may be varied in the well known manner by simultaneously changing the tuning of the individual circuits, but when this is done, unless the degree of coupling is also adjusted by an appropriate amount, the width of the band will not remain constant. Thus, in the case of two tuned circuits coupled inductively with a fixed degree of coupling, changing the tuning by adjustment of the capacities causes the band width to increase proportionately to frequency of resonance.

In accordance with this invention the coupling between a pair of syntonous tuned circuits is so arranged that, as the tuning of the circuits is varied, the degree of coupling also varies by the amount necessary to maintain a substantially constant band width. The variation of the coupling is effected by the use of a plurality of fixed impedance elements in the coupling system the effects of which are substantially complementary over a wide frequency range. Preferably the coupling system comprises a combination of series and shunt impedances connecting the two tuned circuits, but other arrangements may also be used in which, for example, the several coupling elements disposed in a single branch, form a complex impedance the value of which varies with frequency in the desired manner. By the use of fixed coupling elements having complementary effects upon the band width, the shifting of the band, while maintaining its width constant, is effected with a minimum number of adjustments, the only adjustments necessary being those for changing the tuning of the syntonous circuits.

Of the attached drawings:

Fig. 1 is a schematic showing the general type of circuit of the invention;

Figs. 2 and 3 represent specific circuits of the invention corresponding to Fig. 1;

Fig. 4 is a representation of the band width variation in the circuits of Figs. 2 and 3;

Fig. 5 illustrates a modified form of the invention;

Fig. 6 shows the band variation for the circuit of Fig. 5;

Figs. 7 and 8 show additional forms of the invention;

Fig. 9 illustrates the band variation corresponding to Figs. 7 and 8; and

Fig. 10 illustrates one form of the invention applied to a radio receiver input circuit.

Referring to Fig. 1 the selective circuit, which is represented in a generalized schematic form, is included between the terminals AA' and BB' and is illustrated as an interstage coupling circuit between two vacuum tube amplifiers V_1 and V_2. The circuit is symmetrical in its arrangement and is made up of substantially pure reactance elements. It comprises two equal shunt reactances X_1, X_1', located adjacent the terminals AA' and BB', respectively, series reactances X_2, X_2', also equal, and a symmetrical bridged-T structure in the center of the circuit comprising a bridging reactance X_4, a shunt reactance X_5 and two equal connecting reactances X_3 and X_3'. These reactances constitute two similar tuned circuits together with a compound coupling system comprising the shunt reactance X_5 and the bridging reactance X_4. Reactances X_1, X_2, X_3 and X_1', X_2', X_3' constitute the principal elements of the tuned circuits, but in certain cases the reactances X_3 and X_3' may be considered as

part of the coupling system together with X_4 and X_5. Due to the coupling, the circuit is resonant at two frequencies and if the coupling is loose these frequencies fall close together giving the circuit a band transmission characteristic. A three-mesh circuit such as shown in Fig. 1 would in general have three resonances but by the proper selection of the reactances and by the use of proper proportions one of the resonances can be eliminated or else placed well outside of the operating range of frequencies.

The resonance frequencies may be ascertained in the usual manner by equating the discriminant of the network to zero. Assuming the circuit to be symmetrical, the discriminant is equal to

$$\begin{vmatrix} (X_1+X_2+X_3+X_5), & -X_3, & -X_5 \\ -X_3, & (X_4+2X_3), & -X_3 \\ -X_5, & -X_3, & (X_1+X_2+X_3+X_5) \end{vmatrix}$$

which simplifies to

$$(X_1+X_2+X_3+2X_5)[X_4(X_1+X_2+X_3)+2X_3(X_1+X_2)] \quad (1)$$

Equating this expression to zero gives the following equations for the determination of the resonance frequencies:

$$X_1+X_2+X_3+2X_5=0 \quad (2)$$

and

$$X_4+2\frac{X_3(X_1+X_2)}{X_1+X_2+X_3}=0 \quad (3)$$

The resonance defined by Equation 2 is that of the series circuit X_1, X_2, X_3, plus twice the shunt coupling reactance X_5 and the resonance defined by Equation 3 is that of the combination constituted by the series coupling reactance X_4 plus twice the impedance of X_3 in parallel with X_1+X_2. If these combinations are each singly resonant the network will have only two resonances one of which can be independently controlled by the shunt coupling X_5 and the other by the series coupling X_4. Further, if X_5 is very small the first resonance will be close to the frequency defined by

$$X_1+X_2+X_3=0$$

and if X_4 is very large the second resonance will likewise be close to this frequency. From this it follows that, with the composite coupling system described, loose coupling of the tuned circuits requires the use of a small shunt coupling impedance and a large series coupling impedance.

In the circuit of Fig. 2 the first, or primary tuned circuit comprises an inductance made up of two portions L_1 and L_2, corresponding to X_1 and X_2 of Fig. 1, and a variable condenser C_3 corresponding to X_3. The secondary tuned circuit comprises similar elements L_1', L_2' and C_3'. The shunt coupling is provided by a condenser C_4 and the series coupling by another condenser C_5. The circuit is symmetrical as in the case of Fig. 1, that is, $L_1=L_1'$ etc., the equality of the tuned circuits being maintained by having the variable condensers C_3 and C_3' mechanically coupled so that their capacities are equal for all tuning adjustments. Fig. 2 corresponds to the portion of Fig. 1 between the terminals AA' and BB'.

Applying Equations 2 and 3 to the circuit the resonance frequencies, denoted by f_1 and f_2 are found to be as follows:

$$4\pi^2 f_1^2=\frac{1+\frac{2C_3}{C_5}}{(L_1+L_2)C_3}$$

and

$$4\pi^2 f_2^2=\frac{1}{(L_1+L_2)C_3\left(1+\frac{2C_4}{C_3}\right)}$$

If the coupling is loose the resonance frequencies will be relatively close together and the circuit will have a band selective characteristic, the limits of the transmission range being defined by the resonance frequencies. The useful range will, of course, be wider than the band lying between the resonances but its width will be substantially proportional to the band so defined. The requirement for loose coupling is that the capacity C_5 should be large compared with C_3 and the capacity C_4 should be small relatively to C_3. Under this condition the resonance frequencies are closely approximated by the equations

$$2\pi f_1=\frac{1}{\sqrt{C_3(L_1+L_2)}}\left(1+\frac{C_3}{C_5}\right) \quad (4)$$

and

$$2\pi f_2=\frac{1}{\sqrt{C_3(L_1+L_2)}}\left(1-\frac{C_4}{C_3}\right) \quad (5)$$

The resonance frequencies lie close to the tuning frequency f_0 defined by

$$2\pi f_0=\frac{1}{\sqrt{C_3(L_1+L_2)}}$$

f_1 being slightly higher and f_2 being slightly lower. The departure of the frequency f_1 from f_0 is controlled by the shunt coupling capacity C_5 and the deviation of f_2 by the series capacity C_4. The band width is given by

$$2\pi(f_1-f_2)=2\pi f_0\left(\frac{C_3}{C_5}+\frac{C_4}{C_3}\right)$$

or

$$\omega_1-\omega_2=\frac{1}{\omega_0 C_5(L_1+L_2)}+\omega_0^3 C_4(L_1+L_2) \quad (6)$$

where ω denotes 2π times the frequency.

The variation of the band width with the tuning frequency is shown by the curves of Fig. 4, which relate to a particular circuit designed to maintain a band width of about 10,000 c. p. s. throughout a tuning range from 500 k. c. per second to 1500 k. c. per second. Dotted curve 2 corresponds to the first term on the right of Equation 6, this component of the band width being inversely proportional to the frequency. The contribution of the series capacity C_4 to the band width is represented by curve 3 corresponding to the second term of Equation 6, which varies as the cube of the frequency. The total band width is shown by the full line curve 4. The value diminishes at first with frequency, but reaches a minimum and then increases again. For a wide range of frequencies, in the ratio of one to three, the width is nearly constant the variation from the average value being only ±20 per cent. The minimum band width occurs when the frequency f_0 has the value f_m given by

$$4\pi^2 f_m^2=\frac{1}{\sqrt{3C_4C_5(L_1+L_2)}} \quad (7)$$

and is equal to

$$\frac{4}{\sqrt{3}}\sqrt{\frac{C_5}{C_4}}f_m \quad (8)$$

Formulae 7 and 8 suffice for the design of the coupling system when the values of the tuning elements are given. The minimum band width may be given any desired value, preferably between 5000 and 10,000 c. p. s. for speech reception, and may be placed at any desired point in the frequency scale. Usually it is preferable to have

the minimum band width occur at a frequency somewhere above the middle of the range since the effect of resistance in the impedance elements is to increase the band width somewhat at the higher frequencies.

At the resonance frequencies the impedance of the circuit at the terminals AA' becomes infinite and at frequencies above and below the resonances the impedance falls off rapidly to a small value. When the circuit is used in the output of a vacuum tube amplifier, as in Fig. 1, it is desirable that the impedance, at frequencies between the resonances, should be at least as great as the internal impedance of the vacuum tube and, at other frequencies, should be relatively low. In this way the effect of the tube impedance upon the selective characteristic is made negligibly small. To this end the tuning inductance is divided into two parts, the part L_1 between the input terminals AA' being relatively small and the total inductance being adjusted to provide the desired range of tuning with a convenient size of condenser. The divided inductance also acts as a step-up transformer, but if the secondary tuning inductance L_1', L_2', is divided in the same manner there is no over-all voltage transformation in the circuit. When an over-all voltage transformation is desired it can be obtained by suitably changing the relative values of the secondary inductances L_1', L_2', a maximum step-up being obtained when all of the tuning inductance is included between the terminals BB'.

The circuit of Fig. 3 is of a converse type to that of Fig. 2. Here the variable elements of the tuned circuits are inductances L_3 and L_3' and the coupling is effected by a small shunt inductance L_5 and a large series inductance L_4. Capacities C_1 in shunt and C_2 in series constitute the other elements of the primary tuned circuit and corresponding capacities C_1' and C_2' complete the secondary tuned circuit. The tuning inductances L_3 and L_3' are mechanically coupled to maintain syntony of the primary and secondary circuits. The band width in this case is given by

$$2\pi(f_2-f_1)=2\pi f_0\left(\frac{L_3}{L_4}+\frac{L_5}{L_3}\right) \qquad (9)$$

or

$$\omega_2-\omega_1=\frac{1}{\omega_0 L_4}\,\frac{C_1+C_2}{C_1C_2}+\omega_0{}^3L_5\,\frac{C_1C_2}{C_1+C_2} \qquad (10)$$

where

$$\omega_0{}^2=\frac{1}{L_3}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)$$

and ω denotes 2π times frequency as before. The band width variation is the same as for the circuit of Fig. 2. Also, as in the case of Fig. 2, the fixed tuning elements are divided to provide a control of the input impedance and of the voltage transformation.

In Figs. 2 and 3 the series and shunt elements of the compound coupling are of the same character, both capacities or both inductances. Fig. 5 illustrates a circuit in which the coupling is of a more complex character, the series coupling impedance comprising an anti-resonant combination, L_4, C_4, and the shunt coupling impedance a series resonant combination L_5, C_5. The primary circuit comprises a variable capacity C_1 and inductances L_2 and L_3. The secondary circuit comprises similar elements C_1', L_2', and L_3' of equal magnitudes to the corresponding elements of the primary circuit. The series coupling impedance is connected at one end directly to the junction of L_2' and L_3' and at the other end is coupled to L_3 by an inductive winding L_{31}. Coils L_3 and L_{31} are of equal inductance and have substantially perfect coupling, the direction of winding of L_{31} being reversed to give a reversal of the E. M. F. applied to the coupling impedance. The tuning condensers C_1 and C_1' are mechanically coupled to maintain the syntony of the primary and secondary circuits.

The band width characteristic may be determined by following the procedure outlined in connection with Fig. 1, but due to the resonant character of the coupling impedances, the equations for the resonances of the system are rather complicated and it is therefore simpler to make use of a modified method of analysis. Consider first the case where capacity C_4 and inductance L_5 are omitted, the coupling being effected by means of series inductance L_4 and shunt capacity C_5 alone. For this case, assuming symmetry of the circuit, the resonance frequencies are limited to two and are determined by simple equations. Their values are found to be

$$f_1=\frac{1}{2\pi\sqrt{C_1L_2\left(1+\frac{L_3}{L_2}\right)}} \qquad (11)$$

and

$$f_2=\frac{1}{2\pi\sqrt{L_2C_1}}\left(1+\frac{C_1}{C_5}\right)\left(1-\frac{L_3L_4}{2L_2(2L_3+L_4)}\right) \qquad (12)$$

and the band width to be given by

$$f_2-f_1=\frac{1}{2\pi\sqrt{L_2C_1}}\left[\frac{C_1}{C_5}+\frac{L_3}{L_2}\left(\frac{L_3}{2L_3+L_4}\right)\right] \qquad (13)$$

Since capacity C_1 is the variable by which tuning is effected its value is inversely proportional to $f_1{}^2$. The first component of the band width, represented by the first term on the right of Equation 12 is therefore inversely proportional to the tuning frequency and the second component,

$$\frac{1}{2\pi\sqrt{L_2C_1}}\,\frac{L_3}{L_2}\left(\frac{L_3}{2L_3+L_4}\right)$$

is directly proportional to the tuning frequency. The sum of the components has a variation of the same general character as that illustrated by curve 4 of Fig. 4, but modified slightly due to the fact that the increasing component has a linear instead of a cubic variation. The minimum band width occurs when

$$\frac{C_1}{C_5}=\frac{L_3}{L_2}\left(\frac{L_3}{2L_3+L_4}\right).$$

The effect of coupling the series inductance L_4 to inductance L_3 by a reversed transformer winding is the equivalent to substituting for the transformer a negative inductance of magnitude L_3 and changing the sign of L_4 and of the other coupling inductance L_3.

The increasing value of the band width at frequencies above the value corresponding to the minimum is disadvantageous on account of the natural tendency of resistance in the elements to flatten the resonance peaks and so widen the effective band. This effect may be counteracted by the addition of the capacity C_4 in parallel with the series coupling inductance and, if desired, by the addition of inductance L_5 in series with C_5. At the resonance of L_5 and C_5 the shunt coupling is reduced to zero and at the anti-resonance of L_4 and C_4 the series coupling is reduced to zero. If these resonances occur at some common frequency above the tuning range, the total coupling of the tuned circuits will be zero at this frequency making the band width also zero. Let the com-

mon frequency of resonance of the coupling branches be denoted by f_s, then at lower frequencies the series branch has an effective inductance equal to

$$\frac{L_4}{1-\left(\frac{f}{f_s}\right)^2}$$

and the shunt coupling branch has an effective capacity equal to

$$\frac{C_5}{1-\left(\frac{f}{f_s}\right)^2}$$

Since the band is assumed to be relatively narrow these values hold substantially at all frequencies in the band, the frequency f being assumed constant and equal to either f_1 or f_2. Substituting the effective values for L_4 and C_5 in Equation 10 the formula for the band width for the complete circuit of Fig. 5 is obtained

$$f_2-f_1=\frac{1}{2\pi\sqrt{L_2C_1}}\left(1-\frac{f_1^2}{f_s^2}\right)\left[\frac{C_1}{C_5}+\frac{L_3}{L_2}\left(\frac{L_3}{L_4+2L_3\left(1-\frac{f_1^2}{f_s^2}\right)}\right)\right] \quad (14)$$

The band variation expressed by Equation 14 is illustrated by the curves of Fig. 6, which refer to a circuit designed to maintain a 10,000 cycle band through a range from 400 k. c. to 1800 k. c. per second. Curve 7 corresponds to the component due to the series coupling L_4, C_4, curve 6 to the component due to L_5, C_5, and curve 8 shows the variation of the total band width. The suppression freqency f_s is placed at 2400 k. c. which is fairly well above the operating range. Since the effect of the shunt coupling is small at the higher operating frequencies, the resonating inductance L_5 may be omitted without much effect upon the band width characteristic.

Fig. 7 illustrates another type of circuit in which the band width characteristic is modified by suppressing the coupling at a frequency outside the useful tuning range, the suppression in this case occurring at a frequency below the useful range. The circuit corresponds to Fig. 2, but is modified in that the coupling capacity C_5 is replaced by a Π-network comprising equal shunt capacities C_a and C_a' and a series impedance constituted by an inductance L_b in parallel with a shunt capacity C_b. At the anti-resonant frequency of L_b and C_b the coupling through the Π-network is zero and, except for the effect of the series coupling capacity C_4 the resonances of the system coincide. At frequencies above this value the combination L_b C_b is effectively capacitive and the Π-network therefore acts substantially like a single shunt coupling capacity the value of which decreases progressively with frequency. The band variation due to the Π-network alone is illustrated by curve 10 of Fig. 9. The band width is zero at the frequency f_{s1} corresponding to anti-resonance of L_b and C_b, increases to a maximum at a higher frequency, and then falls off approximately inversely with the frequency. The series capacity C_4 produces an increasing band as the frequency increases and may be adjusted to compensate, in part or in whole, the falling off of the band width due to the shunt coupling capacity.

The circuit of Fig. 8 is a combination of the circuits of Figs. 5 and 7, the shunt coupling being the same as that of Fig. 7 and the series coupling corresponding to the series coupling of Fig. 5. The symbols have the same significance as in Figs. 5 and 7 respectively. In this case the band width falls to zero at two frequencies, one below the operating range, due to suppression of the shunt coupling, and the other above the operating range, due to suppression of the series coupling. The band width variation is illustrated by the curves of Fig. 9, curve 10 representing the component due to the shunt coupling, curve 11 representing the component due to the series coupling, and curve 12 representing the total band width. By appropriate adjustments of the coupling impedances curve 12 may be made to slope in either direction or may be made substantially flat. The suppression frequencies f_{s1} and f_{s2} should be located well outside the operating range.

The circuits of the invention are not necessarily confined in their use to the interstage coupling of amplifiers, but may be applied to all purposes for which tuned circuits or wave filters are used. Fig. 10 shows the application to the input circuit of a radio receiver. The tuned circuit is of the type shown in Fig. 2, the primary inductance L_1 being coupled to an antenna 13 through a small coupling coil 14. Preferably the antenna should be aperiodic or else should have its natural periods well outside the tuning range of the selective circuit, and, in addition, should be loosely coupled to the selective circuit so that its impedance will have a minimum effect upon the circuit resonances. In this case the band width is defined by the resonance frequencies and the formulae given above may be used for the design of the circuits.

What is claimed is:

1. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits simultaneously, and a coupling impedance connecting said circuits serially, said coupling impedance comprising an anti-resonant circuit tuned to a fixed frequency outside the tuning range of said syntonous circuits.

2. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits simultaneously, coupling means for said circuits comprising an impedance common to both circuits and an additional coupling circuit connecting said tuned circuits serially, said additional coupling circuit including an inductance element and being inductively coupled to said tuned circuits in opposite senses respectively.

3. A band selective transmission network comprising a pair of syntonous tuned circuits, each comprising an inductance and a variable tuning capacity, means for varying the tuning of said circuits simultaneously, coupling means comprising a capacity common to both of said circuits and additional coupling means comprising a loop circuit coupling said circuits serially, said loop circuit including an anti-resonant combination of inductance and capacity and being inductively coupled to said tuned circuits in opposite senses respectively.

4. A band selective transmission network comprising a pair of syntonous tuned circuits including variable tuning condensers of equal capacity, said capacities being mechanically coupled for simultaneous tuning of said circuits, coupling means for said circuits comprising an impedance common to both circuits which is capacitive throughout the tuning range of the network and

additional inductive coupling means comprising coupled windings phased to aid the capacitive coupling throughout the tuning range, said capacitive coupling and said inductive coupling being proportioned to provide a substantially constant width transmission band throughout the range of frequencies to which the network can be tuned, and said inductive coupling means including an anti-resonant circuit tuned to a frequency outside and above the tuning range of the network whereby the degree of the inductive coupling is reduced substantially to zero at said frequency and the tendency of the inductive coupling to increase the band width at the higher tuning frequencies is counteracted.

5. A network in accordance with claim 4 in which the capacitive coupling impedance includes tuning means for reducing its coupling effect to zero at a frequency outside the tuning range of the network.

6. A band selective transmission network comprising a pair of syntonous tuned circuits means for varying the resonance of said circuits simultaneously, capacitive coupling means for said circuits adapted to produce a band width which decreases as the frequency of tuning increases and tuning means included in said capacitive coupling means adapted to reduce the degree of coupling substantially to zero at a frequency outside and below the tuning range of the network.

7. A band selective network in accordance with claim 6 and additional coupling means comprising a loop circuit inductively coupled to the tuned circuits to aid the capacitive coupling throughout the tuning range, said loop circuit including a circuit anti-resonant at a frequency outside and above the tuning range of the network.

8. A band selective transmission network comprising a pair of syntonous tuned circuits, means for ranging the resonance of said circuits simultaneously, capacitive coupling means and inductive coupling means for coupling said circuits, said coupling means being arranged to transfer energy in aiding relation throughout the tuning range of the network and to provide equal degrees of coupling at a frequency within the tuning range, means for reducing the capacitive coupling to zero at a frequency outside and below the tuning range of the network and means for reducing the inductive coupling to zero at a frequency outside and above the tuning range.

9. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits, and a coupling impedance connecting said circuits serially, said coupling impedance comprising an anti-resonant circuit tuned to a fixed frequency outside the tuning range of said syntonous circuits.

10. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits, and a selective link circuit coupling the variable tuned circuits and tuned to a frequency outside the tuning range of the networks, whereby the coupling effect of the link circuit is reduced substantially to zero at the frequency to which the link circuit is tuned.

11. A network in accordance with claim 10 in which the selective link circuit is composed of fixed impedance elements.

12. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits, and a fixed coupling impedance common to said circuits, said coupling impedance being tuned to a frequency outside the tuning range of the network for reducing the coupling effect substantially to zero at the frequency to which the coupling impedance is tuned.

13. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits and a fixed shunt coupling impedance connecting said circuits, said coupling impedance being tuned to a frequency outside the tuning range of the network for reducing the coupling effect substantially to zero at the frequency to which the coupling impedance is tuned.

14. A band selective transmission network comprising a pair of syntonous tuned circuits, means for varying the tuning of said circuits and a series resonant branch common to said syntonous tuned circuits said series resonant branch being composed of fixed elements and resonant to a frequency outside the tuning range of the network.

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