Aug. 11, 1936. P. O. FARNHAM 2,050,834

FREQUENCY SELECTIVE TRANSMISSION NETWORK

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Fig. 1.

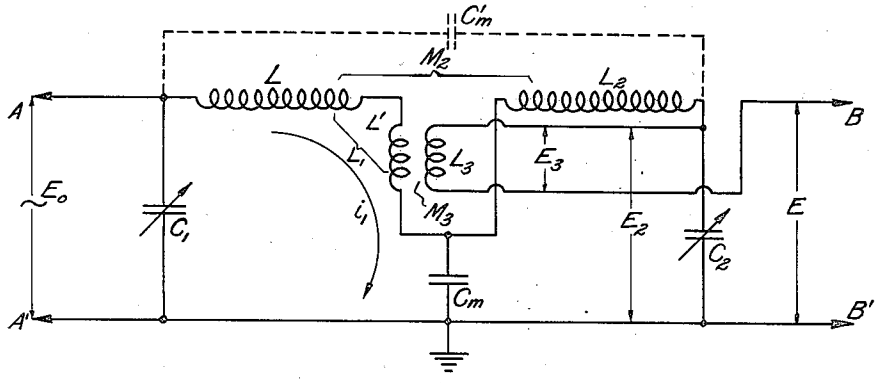
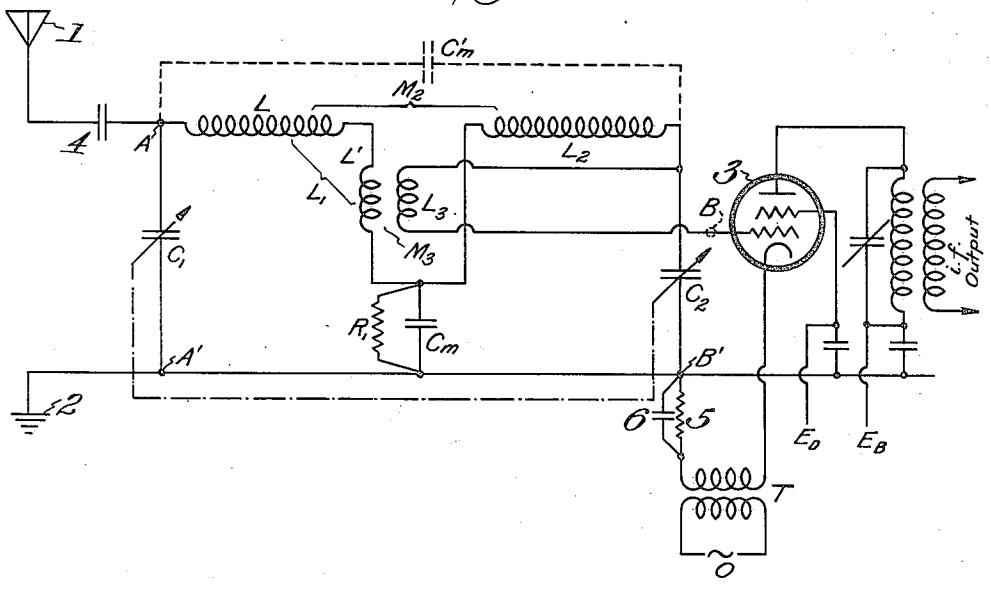


Fig. 2.



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Fig. 3.

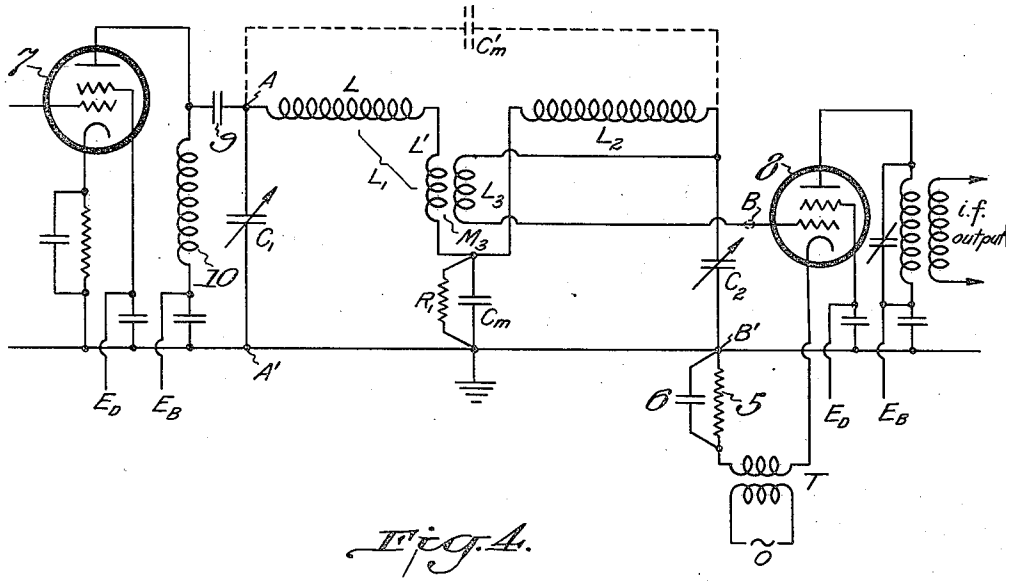
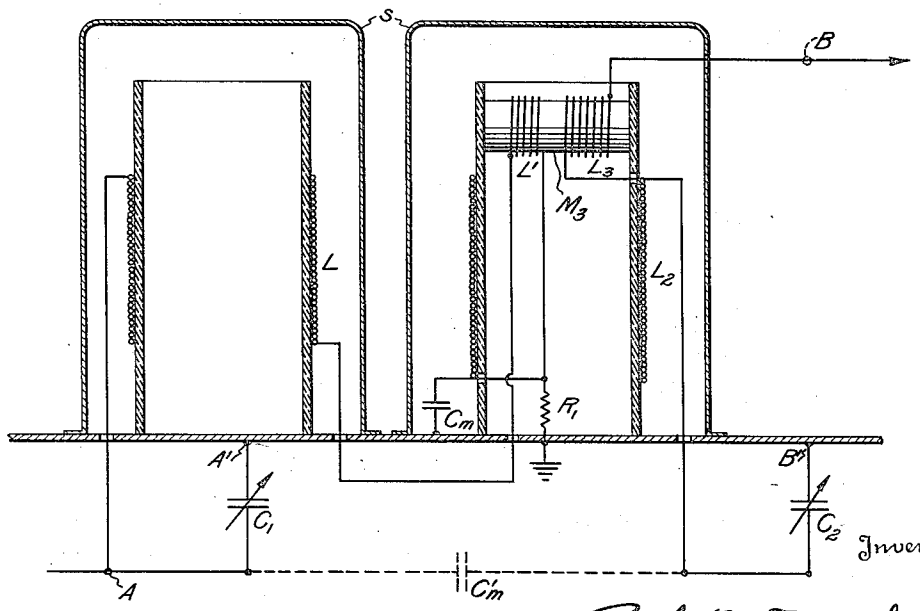


Fig. 4.



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UNITED STATES PATENT OFFICE

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FREQUENCY SELECTIVE TRANSMISSION NETWORK

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Application May 18, 1933, Serial No. 671,770

19 Claims. (Cl. 250—20)

This invention relates to frequency selective transmission networks and more particularly to networks of the type, such as is useful in superheterodyne receivers, in which the maximum transmission at a desired frequency is accompanied by a maximum suppression at another and undesired frequency.

In the superheterodyne reception of carrier waves, the local oscillator will beat with two different carrier frequencies to produce the same beat or intermediate frequency. Satisfactory reception is possible only when the circuits in advance of the first detector suppress the transmission of the undesired carrier or image frequency. It has been proposed to effect such suppression by an increase in the number of tuned radio frequency circuits or by the use of special networks which include circuits tuned to the desired frequency and an additional circuit tuned to the image frequency.

For example, the patent to Stevenson, 1,869,870, granted Aug. 2, 1932, describes a system for image suppression which includes two tuned radio frequency circuits coupled by a tunable link to maintain a substantially constant bandpass characteristic. Systems of this general type are open to the objection that an extra section of a gang tuning condenser is required for tuning the coupling link or other suppressor circuit to resonance at the image frequency.

In my copending application, Serial Number 664,431 filed April 4, 1933, on which Patent No. 1,950,358 was granted on March 6, 1934, I have described and claimed a method of, and circuit arrangements for, effecting a maximum suppression at an undesired frequency, which method and circuit arrangements are characterized by the elimination of the additional tuning condenser previously employed in adjustably tuned suppressor circuits. The method described in that application is not limited to but is particularly adapted for use with sections of transmission networks or coupling systems which include a single tuned radio frequency circuit.

According to the present invention, the same general method of effecting image frequency suppression without the use of an additional tuning condenser may be applied to networks including two tuned radio frequeny circuits which may be so coupled as to exhibit a bandpass characteristic of substantially constant width throughout their tuning range. Although networks constructed in accordance with the invention include only the two tuning condensers of the coupled circuits, the networks yield transmission characteristics at resonance and suppression characteristics at another frequency which are similar to the characteristics obtained in prior networks, for example that of the Stevenson patent, by an additional condenser with plates that must be specially shaped to insure tracking of the suppressed frequency at a constant frequency interval from the desired frequency.

An object of the invention is to provide improved methods of and circuit arrangements for effecting the selective transmission of a desired frequency and the attenuation of an undesired frequency in systems of the type including two coupled tuned radio frequency circuits. Objects are to provide methods of and circuit arrangements for coupling two tuned circuits with substantially fixed coupling elements to obtain a maximum suppression of an undesired frequency.

An object is to provide a wave transmission system tunable over a band of frequencies to yield maximum transmission to a desired and relatively narrow frequency band, and to provide maximum attenuation to a relatively narrow frequency band that bears a predetermined relation to the desired frequency band. Another object is to provide a coupling system involving two tuned coupled circuits possessing a substantially constant bandpass characteristic throughout their tuning range, and including an additional coupling element external to one of the coupled circuits which provides maximum attenuation at frequencies removed from the desired frequencies and of greater degree than would be present without this additional coupling element. Still other objects of the invention include the provision, in a superheterodyne receiving system, of a preselector circuit which for a given number of tunable circuit elements provides greater attenuation to the "image" frequency than would be obtained by the conventional use of the tunable elements. A further object is to provide a selective transmission network in which two tuned circuits are coupled by a plurality of relatively fixed couplings to effect a maximum suppression at a frequency which is spaced from the desired frequency by a substantially constant frequency interval as the circuits are tuned over their frequency range.

These and other objects and advantages of the invention will be apparent from the following specification when taken with the accompanying drawings, in which:

Fig. 1 is a schematic circuit diagram illustrating the coupling system contemplated by the invention;

Fig. 2 is a circuit diagram illustrating the

application of the circuit shown in Fig. 1 to an antenna input system of a receiver;

Fig. 3 illustrates an application of the invention to a typical interstage coupling between cascaded tubes; and

Fig. 4 is a somewhat diagrammatic central section of a convenient arrangement of a coil assembly for the circuits of Figs. 2 and 3.

In the several circuit diagrams, the reference characters A, A' and B, B' identify the respective pairs of terminals of the network or coupling system. For convenience of description, terminals A, A' will be designated as the input terminals but, as noted hereinafter, the characteristics of the network are not affected by the direction of transmission and either pair of terminals may be employed as the input terminals.

The two tuned circuits comprise inductance L_1 and tuning condenser C_1 between terminals A, A', and inductance L_2 and tuning condenser C_2 between terminals B, B'. As shown diagrammatically, the inductance L_1 may be made up of two serially connected coils L, L'. In accordance with the invention, the two tuned circuits are coupled by a mutual inductance M_3 between inductance L_1 and a coil L_3 which is serially connected between the high potential terminal of L_2, C_2 and the network terminal B.

When inductance L_1 has the physical form of two coils, the magnetic coupling M_3 may be provided by coupling coil L_3 to only the coil L' of inductance L_1. Additional couplings may be provided by mutual inductance M_2 between coils L and L_2, by a capacity C_m connecting the junction of inductances L_1 and L_2 to the common, and usually grounded, terminals A' and B' of the network, and/or by a capacitive coupling C'_m between the respective high potential terminals of the tuned circuits, which latter coupling may be either an inherent capacity, as indicated by the dotted lines, and/or a physical condenser.

The method of operation of the system may be analyzed in the following manner. Assume that a current i_1 flowing in inductance L_1 in response to a driving voltage E_0 impressed between input terminals A—A' produces maximum output voltage E at a frequency corresponding to the setting of tuning condenser C_2. This frequency will be known as the desired frequency for which maximum transmission occurs and corresponds closely with the resonant frequency of coil L_2 of the second circuit and condenser C_2. As indicated, the current i_1 will produce a voltage E in the second circuit due to the coupling M_3 and due to any or all of the three couplings represented by C'_m, M_2, and C_m. At resonance in the second circuit the output voltage will be made up mainly of E_2, the voltage across the tuning condenser, while E_3, the voltage due to the auxiliary coupling M_3, will be insignificant in comparison.

As the impressed frequency is shifted away from the desired value, however, the voltage E_2 will decrease rapidly due to the rapid decrease in current in the tuned circuit comprising C_2, whereas the voltage E_3 will change but slightly.

Hence at some frequency differing sufficiently from the resonant or desired frequency the total output voltage E, made up of components E_2 and E_3, may be made to approach zero, i. e., at the frequency for which E_2 has decreased to a value approximately equal to E_3, and provided it is of opposite sign. In superheterodyne receivers, this frequency at which we wish maximum attenuation is usually termed the image frequency and is generally higher than the desired frequency.

The analysis will be continued for purpose of illustration, on the basis of an assumption of superheterodyne operation, by determining the type of coupling from i_1 to the tuned circuit involving C_2, in terms of the auxiliary coupling shown as M_3, in order to make the maximum attenuation of the system occur at a frequency which is always at constant frequency interval higher than the desired frequency by twice the intermediate frequency.

Let

ω=impressed radian frequency

ω_1=desired radian frequency

a=twice intermediate radian frequency

$z_m=\pm j\omega M_3$, the auxiliary coupling impedance

Z_m=total coupling impedance to circuit L_2 C_2 only

$\phi^2{}_2=\omega^2 L_2 C_2$

Then

$E_3=i_1 z_m$ and $E_2=i_1 Z_m/(1-\phi_2{}^2)$ (approx.)

$$\frac{E_3}{E_2}=\frac{z_m(1-\phi_2{}^2)}{Z_m} \qquad (1)$$

For maximum attenuation the expression E_3/E_2 should be equal to minus one. By expressing $\phi_2{}^2$ at the image frequency in terms of the desired and intermediate frequencies, it is possible to determine the type of coupling required for Z_m, in terms of z_m, in order to make $E_3/E_2=-1$ at the image frequency.

$$\phi_2{}^2=\left(\frac{\omega_1+a}{\omega_1}\right)^2 \qquad (2)$$

and

$$\frac{z_m}{Z_m}(1-\phi_2{}^2)=-1 \qquad (3)$$

Hence

$$Z_m=-z_m\left[1-1-\frac{2a}{\omega_1}-\left(\frac{a}{\omega_1}\right)^2\right]$$

$$Z_m=z_m\left[\frac{2a}{\omega_1}+\left(\frac{a}{\omega_1}\right)^2\right] \qquad (4)$$

Thus, if z_m is a pure mutual inductive coupling (M_3 in Fig. 1), Z_m should be made up of two parts which are related to the mutual inductive coupling of z_m by the multiplying factors involving frequency shown in Equation 4. The Equation 4 is general for this type of coupling arrangement and shows how Z_m must be related to z_m if perfect "tracking" of maximum attenuation at the image frequency is to be secured. A consideration of the second multiplying factor, $(a/\omega_1)^2$, Equation 4, indicates that if $z_m=-j\omega M_3$, one part of Z_m should be a capacity coupling of the type indicated by C_m in Fig. 1. The first multiplying factor, $2a/\omega_1$, indicates that the rest of Z_m should be made up of a coupling reactance which is independent of frequency. This latter condition is not readily obtained with exactness but may be approached with sufficient accuracy over a given range of frequency by means of a combination coupling such as provided by C_m and/or M_2 in connection with C_m.

I have found experimentally that the combination of C'_m and C_m, with $M_2=0$, gave a satisfactory compromise for Z_m in the case where Z_m was a negative mutual inductance. In this case, in which the first of the coupled circuits was tunable by condenser C_1 to resonance with the desired frequency over the broadcast frequency range from 550 to 1500 kilocycles, C_m was given the value .02 microfarad, coils L_1 and L_2 each contained approximately 240 microhenries inductance, and couplings M_3 and C'_m were adjusted to give maximum suppression of an image frequency 350 kilo-

cycles higher than the desired frequency. Coupling M_3 was small and of the order of one microhenry.

It will be apparent from the foregoing analysis that the first circuit involving L_1 may or may not be tuned to resonance with the impressed frequency. If it is thus tuned as shown, by condenser C_1, the magnitudes of the couplings comprising Z_m such as C_m, C'_m and/or M_2 may be kept small and a substantially constant band-pass characteristic over the tuning range may be secured. This latter possibility arises due to the fact that with coupled condenser tuned circuits of the conventional type which maintain a nearly constant ratio of reactance to resistance over their tuning range, the coefficent of coupling should decrease with increasing resonant frequency to maintain a substantially constant band width for the significant transmitted frequencies. The required type of coupling Z_m, when Z_m is a mutual inductance, fulfills this condition satisfactorily.

It is furthermore to be noted that, in view of the reciprocal relations existing in passive networks, terminals B, B' may be the input, and A, A' the output terminals of the network. In case the frequency which it is desired to suppress is lower than the desired frequency, it is apparent that Equation 2 will read:

$$\phi_2^2=\left(\frac{\omega_1-a}{\omega_1}\right)^2$$

in which case Equation 4 will become:

$$Z_m=z_m\left[-\frac{2a}{\omega_1}+\left(\frac{a}{\omega_1}\right)^2\right] \qquad (5)$$

If Z_m is, as before, due to a negative mutual inductance M_3 Equation 5 indicates that Z_m is to be made up, as before, of a common coupling capacity C_m and in addition a coupling of opposite sign to C_m, such as a positive mutual inductance M_2.

The circuit of Fig. 2 illustrates an application of the type of coupling circuit just described to the antenna input system of a superheterodyne receiver.

The connections from a collector structure or tube 3 may include the usual series coupling condenser 4 between the antenna 1 and terminal A of the novel network, and a direct connection between ground 2 and terminals A', B'. When the tube 3 is, as illustrated, the first detector of a superheterodyne receiver, the voltage from the local oscillator source O may be impressed on the detector in series with the incoming carrier wave by a transformer T which is connected between terminal B' and the cathode. A resistor R_1 is connected across the coupling condenser C_m to impress upon the grid the direct current bias produced by the plate current in the self-biasing resistor 5 in the cathode circuit, the resistor 5 being shunted by a bypass condenser 6.

When the tube 3 is a radio frequency amplifier, the circuit connections may be substantially the same except that the transformer T will be omitted.

When employed as an interstage coupling between cascaded tubes 7, 8, as illustrated in Fig. 3, the first of the two tuned circuits may be coupled to the plate of tube 7 by a coupling condenser 9 and the direct current voltage for energizing the plate is derived from an appropriate source, indicated as E_B, through a radio frequency choke 10.

The simplicity of an appropriate physical assembly of the several elements of the selective network is indicated by the somewhat diagrammatic sectional view, Fig. 4.

Coils L and L_2 are mounted in separate shielding cans S while L', representing a small part of the total inductance L_1 of the first circuit, is placed in the same can with coil L_2 and coupled to coil L_3 to provide the required magnetic coupling M_3. When coupling M_2 is to be negligible, the coils L', L_3 are mounted at right angles to the coil L_2. The resistance R_1 and coupling condenser C_m may be located within the second coil can and the capacitive coupling C'_m may be given any desired value by proper design of the gang tuning condenser structure by exposing the stator connections of the section C_1 to those of the section C_2, as is indicated by the dotted line showing of C'_m.

In Fig. 2 the tuning condensers C_1 and C_2 are represented, by the dot and dash line in the conventional manner, as ganged for uni-control or simultaneous adjustment and it will be understood that the condensers C_1 and C_2 of Figs. 1, 3 and 4 may be similarly ganged and uni-controlled.

While the invention has been particularly described with reference to the superheterodyne reception of carrier wave signals, it is to be understood that it is applicable to any alternating current transmission system, which is to have the characteristic of effecting a maximum transmission at one frequency and a maximum suppression at an undesired frequency which is spaced therefrom by an appreciable frequency interval.

I claim:

1. In an arrangement for coupling two tuned circuits by means of relatively fixed reactive elements, said arrangement comprising means for coupling said tuned circuits to effect a maximum transmission at a desired frequency band approximately coinciding with the natural resonant frequency of said tuned circuits, a fixed reactive element connected in series with the terminal connection to one of said circuits, and means for coupling said series reactive element to the other tuned circuit, said last-named means comprising an additional fixed reactance of a magnitude effective to neutralize the transmission between said circuits of alternating currents within an undesired frequency band that is spaced from said desired band by a frequency interval.

2. In an arrangement for coupling two tuned circuits by means of reactive elements which remain fixed after said circuits are simultaneously tuned to resonance at a desired frequency within a frequency band, so as to obtain a maximum transmission at a narrow frequency band approximately coinciding with said desired frequency and a maximum suppression at an undesired frequency band spaced from said desired frequency band, said arrangement comprising means for coupling said circuits to effect a maximum transmission at a narrow band of frequencies as said circuits are tuned over the frequency range, a fixed reactive element connected in series with one of said circuits, and means for coupling said series reactive element to the other circuit to transmit at the undesired frequency band alternating currents substantially equal in magnitude but of opposite sign to the currents of said undesired frequency band transmitted by the first coupling.

3. In a frequency selective transmission net-

work, the combination with a pair of circuits each tunable to a desired frequency within a frequency band, of means coupling said circuits to effect a maximum energy transfer between said circuits at a desired frequency, and means for effecting a maximum attentuation of currents of a frequency spaced from and varying with the desired frequency, said attenuation means including a relatively fixed reactive element in series with one circuit and coupled to the other circuit.

4. In a frequency selective transmission network, the invention as claimed in claim 3, wherein said coupling means has a magnitude effective to transmit with substantially equal efficiency all frequencies within a narrow band substantially coinciding with the desired frequency to which said circuits are tuned.

5. In a selective transmission network, a tuned circuit between two terminals, a tuned circuit in series with an inductance between another pair of terminals, a magnetic coupling between said first tuned circuit and the said inductance, and a capacitive coupling between said tuned circuits.

6. In a selective transmission network, the invention as claimed in claim 5, wherein said couplings each comprises a substantially fixed reactive element.

7. In a selective transmission network, the invention as claimed in claim 5, wherein said couplings each comprises a substantially fixed reactive element, the reactances of said elements being of such relative magnitudes that said network has a maximum transmission at a desired frequency and a maximum suppression at an undesired frequency which is spaced from said desired frequency by an interval which remains substantially constant as said circuits are tuned over their frequency band.

8. In a selective transmission system, a tuned circuit between two terminals, a tuned circuit in series with an inductance between a second pair of terminals, means for simultaneously tuning each circuit to resonance at a desired frequency, and means for transmitting the desired frequency ω with maximum efficiency and for suppressing an undesired frequency, $\omega \pm a$, where a is a constant frequency interval; said last means comprising a coupling impedance z_m between the first tuned circuit and said inductance, and means comprising a total coupling impedance Z_m between said circuits, the said impedances consisting of relatively fixed reactive elements and having a ratio substantially equal to

$$Z_m = z_m\left[\pm\frac{2a}{\omega}+\left(\frac{a}{\omega}\right)^2\right]$$

9. An alternating current transmission system of the type including two circuits each tunable to the desired frequency for maximum transmission, and fixed coupling elements between said circuits for effecting a maximum transfer of alternating current energy at a narrow band of frequencies substantially identical with the said desired frequency to which each circuit is tuned, characterized by output terminals between which are serially arranged a reactive element of one of said tuned circuits and an additional reactive element of opposite sign to the first-named reactive element coupled to the other of said tuned circuits for effecting a maximum suppression of alternating current energy available from said output terminals at a frequency band which is spaced from said desired frequency band as the latter is varied over the tuning range.

10. In an alternating current transmission system, the combination with a pair of circuits each including adjustable elements simultaneously variable to resonate said circuits at substantially the same frequency, and a coupling between said circuits for obtaining a maximum transmission over a narrow band of frequencies as said desired frequency is adjusted over a frequency band, of a relatively fixed impedance in series with one circuit, and a coupling between said series impedance and the other circuit for effecting a maximum suppression at a frequency band spaced from said narrow frequency band by a substantially fixed amount as said desired frequency is varied over a frequency band.

11. In a transmission network, the combination with a tuned circuit having a pair of terminals, a second tuned circuit and an inductance serially connected between a second pair of terminals, one terminal of each pair being a high potential terminal and the other terminals being connected to maintain the same at the same low potential with respect to currents of the frequency range over which said circuits may be tuned, a coupling between said circuits, and substantially fixed reactance providing a coupling between said first circuit and said inductance to neutralize the transmission by said first coupling of currents of a frequency spaced from that desired frequency of maximum transmission which is determined by the resonant frequencies of said tuned circuits.

12. A transmission network as claimed in claim 11, wherein said first coupling is a composite coupling comprising a capacitive coupling having a reactance which varies with tuning, and a coupling having a substantially frequency-independent reactance.

13. A transmission network comprising pairs of input and output terminals, one terminal of each pair being a high potential terminal and the others being connected to maintain the same at the same low potential, a pair of tuning condensers each having one side connected to the said common terminals, a pair of inductances serially connected between the other sides of said tuning condensers and cooperating with the respective condensers to form circuits adapted to be tuned to a desired frequency of maximum transmission, the junction of one condenser and its inductance coinciding with a high potential terminal of one of said pairs, an inductance serially connected between the second high potential terminal and junction of the other condenser and its inductance, a magnetic coupling between said last inductance and the inductance to which it is not serially connected, and capacity between the junction of said pair of inductances and the said common terminals.

14. In a coupling network for the suppression of image frequencies in a superheterodyne receiver, the combination of an inductance and a tuning condenser having one junction serving as a high potential terminal of said network, the other terminal of the tuning condenser being grounded for carrier frequencies, a second inductance and tuning condenser, one terminal of said second condenser being similarly grounded, an inductance serially connected between the other terminal of said second condenser and the second high potential terminal of said network, a magnetic coupling between said first and said last inductance, an additional coupling between the

tuned circuits formed by said first two inductances and their respective tuning condensers, and means constituting shields enclosing the said inductances.

15. A coupling network as claimed in claim 14, wherein said first inductance comprises two coils, and said shielding means comprises two shield cans, one coil of said first inductance being inclosed in one can, and the second coil and the remaining inductances being inclosed in the second can.

16. A coupling network as claimed in claim 14, wherein said first inductance comprises two coils, and said shielding means comprises two shield cans, one coil of said first inductance being inclosed in one can, and the second coil and the remaining inductances being inclosed in the second can, and with said second coil and said third inductance arranged to have substantially zero magnetic coupling to said second inductance.

17. In the selective transmission of alternating currents by a network including two circuits adapted to be simultaneously tuned to the desired frequency of maximum transmission, said circuits being serially arranged in the direction of transmission and the second circuit being in series with a fixed reactive element, the method of suppressing the transmission of alternating currents of an undesired frequency spaced from said desired frequency which comprises transferring energy from one of said circuits to the other thereof to effect transmission at the desired frequency with a lesser and undesired transmission at the undesired frequencies, and additionally transferring energy between said two circuits in opposite sense to the first transference of energy to neutralize the first transmission of energy at the undesired frequency.

18. In a selective transmission system of alternating currents, a network including two serially arranged circuits, one circuit including an inductance shunted by a tuning condenser and the other circuit including an untuned inductance in series with an inductance and a shunt tuning condenser, said last mentioned inductance and shunt tuning condenser being substantially identical with those of the first circuit and tunable to the desired frequency of maximum transmission, means for suppressing transmission of alternating currents of an undesired frequency which comprises a coupling between the inductance of the first circuit and the tuned inductance of the second circuit to effect transmission at the desired frequency with a lesser and undesired transmission at the undesired frequency, and means for coupling the first circuit to the untuned inductance of the second circuit in a sense to neutralize the transmission by the first coupling at the undesired frequency.

19. In the selective transmission of alternating currents by a transmission network including two serially arranged circuits adapted to be simultaneously tuned to resonance at a desired frequency within a transmission band, and a relatively fixed reactive circuit element serially connected to one of said tuned circuits, the method which comprises coupling said circuits to effect a desired transmission of alternating currents of the resonant frequency to which said circuits are tuned and an undesired transmission of alternating currents of a frequency spaced from said resonant frequency, and coupling said reactive circuit element to that tuned circuit which is not serially connected to the same to neutralize the undesired transmission of alternating currents of the frequency spaced from the said resonant frequency.

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