Aug. 2, 1932. G. H. STEVENSON 1,869,870

FILTERING CIRCUITS

Filed April 17, 1930

FIG. 1

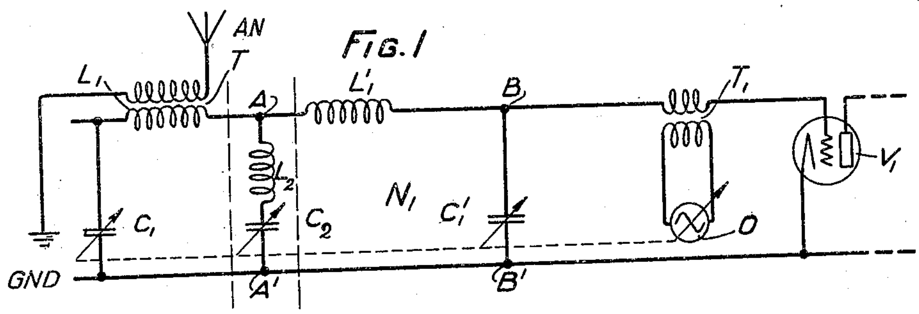


FIG. 1A

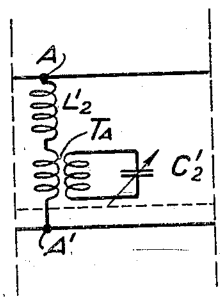


FIG. 3

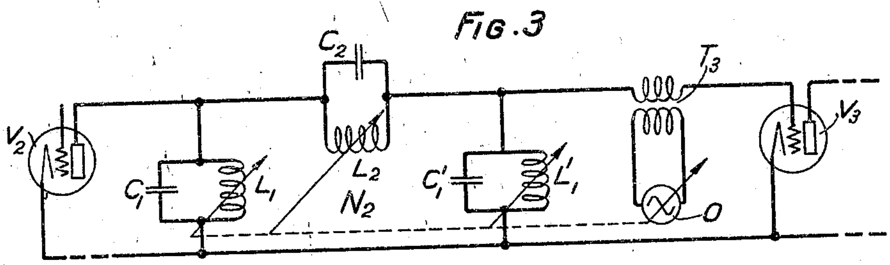


FIG. 2

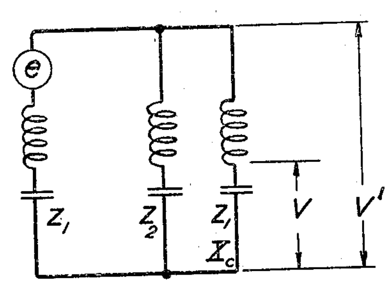
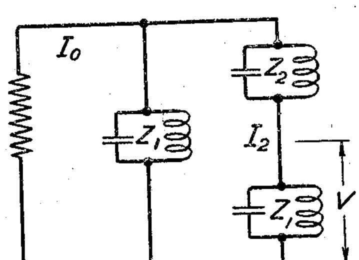


FIG. 4



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1,869,870

UNITED STATES PATENT OFFICE

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FILTERING CIRCUITS

Application filed April 17, 1930. Serial No. 445,060.

This invention relates to selective transmission networks and more particularly to networks adapted for use in superheterodyne receivers.

In radio receiving sets of the superheterodyne type, as is well known, the incoming radio wave is modulated with a locally generated wave to produce a beat wave, usually of somewhat lower frequency, which is better adapted for amplification than is the incoming wave. The frequency of the wave to be amplified will be referred to herein as the intermediate frequency. One or more amplifying stages, tuned to the intermediate frequency, are usually provided.

A difficulty in the operation of superheterodyne receivers arises due to the fact that at any given setting of the tuning adjustments such receivers are inherently sensitive to incoming waves of more than one frequency. There are generally two waves which may be present in the receiver, either of which, beating with the local wave, will produce the intermediate frequency for which the amplifying stages are tuned. Interference results when signals are received simultaneously over these two waves. Such interference is particularly prevalent in the ordinary broadcasting range in which the operating frequencies of the broadcasting stations are spaced at equal frequency intervals of about 10,000 c. p. s. The intermediate frequency of the receiver is usually fixed, and the result is that the interfering frequency is separated from the desired signal by a fixed frequency interval. This latter fact is of importance in connection with the designing of expedients for removing the difficulty occasioned by the intereference, as will be pointed out more particularly hereinafter.

Changing the beat frequency of the local oscillator will alleviate a given case of interference. The change, however, will generally not serve to reduce the number of possible interferences but merely to bring in a different combination of interfering signals, generally of the same magnitude as the particular interference which has been avoided.

Sharper tuning may be resorted to as a means of reducing the strength of the interfering signals. However, if the tuning is sufficiently sharp for this purpose it is found to be too sharp to admit the full band of frequencies required for faithful reproduction of signals, especially in the case of the transmission of speech and music.

The principal objects of the present invention are first; the suppression of the undesired beat frequency and second the provision of band selectivity for the desired signals.

Another object of the present invention is to permit the selection of a band of frequencies the width of which remains substantially constant as the tuning is varied.

Another object is to provide for ready adjustment of a selected band throughout a wide range of frequencies.

A further object is to provide for substantially uniform efficiency of transmission throughout the received band.

It is well known that a network comprising a series of coupled tuned circuits will have the transmission characteristics of a band filter when provided with properly proportioned damping means in the terminal meshes. If the transmission band is relatively narrow the resistance inherent in the tuning coils may provide sufficient damping to produce a band characteristic in the absence of properly proportioned terminal impedances. It is found, however, that the band width varies with the tuning adjustment of such a system. In order to maintain a constant band width over an extended tuning range it is necessary to vary the coupling in such a manner as to offset the tendency toward variation of the band width.

A selective transmission circuit which has been proposed in a copending application of H. T. Budenbom, Serial No. 374,742, filed June 29, 1929, consists of a pair of tuned input and output circuits coupled together by an inductively connected link circuit containing a suppression member or wave trap. The link circuit is designed to provide a suitable amount of coupling at each frequency so that a substantially uniform band width is secured over a wide range of tuning adjustments, and at the same time to suppress the transmission of waves separated from the selected band by a fixed interval.

In the present invention there are employed tuned input and output circuits and a tuned coupling circuit which latter also serves as a wave trap. The three tuned circuits are directly connected either in series or in parallel, thus obviating the necessity of employing an inductively coupled link circuit. The adjustable tuning elements of the circuits are mechanically connected together and may be operated by means of a single control. When the tuning elements are thus varied, the width of the transmission band is maintained substantially constant and transmission is suppressed at a frequency separated from the band by a fixed frequency interval. The tuning coils employed contain sufficient inherent resistance to provide the degree of damping necessary for maintaining substantially uniform transmission throughout the band.

The invention may be best understood from the following description with reference to the drawing, in which Fig. 1 shows one circuit embodying the invention, Fig. 1—A shows a modification of a portion of the circuit of Fig. 1, Fig. 2 is a simplified diagram showing the electrical equivalent of a portion of the circuit of Fig. 1, Fig. 3 shows a second form of circuit embodying the invention, and Fig. 4 is a simplified diagram showing the electrical equivalent of a portion of the circuit of Fig. 2.

Referring to Fig. 1, a transmission network N_1 embodying the invention is disclosed with suitable connections for coupling an antenna AN to a space discharge device or vacuum tube V_1. The network N_1 comprises two similar branches L_1C_1 and $L_1'C_1'$ respectively, and a dissimilar branch L_2C_2. The three branches are connected in parallel relation between the junction points A and A'. The elements L_1, L_1' and L_2 are substantially pure inductances and the elements C_1, C_1' and C_2 are capacitances, also substantially pure. The inductance L_1 is illustrated as forming the secondary winding of a transformer T which loosely couples the antenna AN to the network N_1. The antenna is connected through the primary winding of transformer T to ground GND. The particular method employed for coupling an antenna or other supply circuit to the network N_1 is not essential to the utilization of this invention and may be varied as desired.

The terminals B and B' of network N_1 are illustrated as being connected to the input terminals of a vacuum tube V_1. An oscillator O is also shown connected to the input circuit of V_1 for supplying a beat frequency to the tube.

The oscillator O has a tuning adjustment whereby the beat frequency can be regulated.

The capacitances C_1, C_1' and C_2 are all of the adjustable type and their variable parts are mechanically coupled to each other and to the tuning element of the oscillator in such manner that all may be adjusted simultaneously by turning a single handle or knob. This adjustment serves to control the beat frequency, the tuning or location of the limits of the transmission band in the frequency scale and the frequency at which the coupling between the antenna and the tube is suppressed.

For the purposes of this specification, a resonant frequency of a network having input and output terminals is defined as any frequency at which a maximum or indefinitely large voltage is developed across the output terminals when electrical energy of the same frequency is supplied to the input terminals. Similarly, an anti-resonant frequency is defined as any frequency at which a minimum voltage is developed across the output terminals or at which no voltage at all will be developed.

The network N_1 has two resonant frequencies and one anti-resonant frequency, as defined above. The resonant frequencies determine approximately the edges of a band of free transmission. The anti-resonant frequency is the frequency at which the coupling between the meshes of the network is suppressed.

The equations which determine the resonant and anti-resonant frequencies of network N_1 in terms of the values of the inductances and capacitances will now be derived.

Fig. 2 is a simplified circuit diagram which approximately represents the network N_1 and the effect of the reactions between the network and the antenna AN and vacuum tube V_1 respectively. Z_1 represents the impedance of either circuit branch L_1C_1 or L_1' C_1'. Z_2 is the impedance of the branch L_2C_2. The electromotive force e represents the induced voltage which is impressed upon the network N_1 by an applied wave incident upon antenna AN and effective through transformer T. X_c is the reactance of the condenser C_1'. The voltage V effective across the reactance X_c is substantially that applied to the tube V_1 by the network N_1. The voltage effective across the parallel branches Z_1 and Z_2 is denoted by V'.

The electromotive force e, in accordance with the well known laws of electric circuits, divides between the series branch Z_1 and the parallel combination of Z_1 and Z_2 in the proportion which the impedances of the respective portions bear to the total impedance of the circuit. The impedance of the parallel combination of Z_1 and Z_2 is $Z_1Z_2/(Z_1+Z_2)$. The total impedance over which e is distributed is $Z_1+Z_1Z_2/(Z_1+Z_2)$. The ratio of these two impedances is the proportional part of e which is equal to V'. This relation may be expressed by the following equation.

$$(1)\quad V' = \frac{Z_1Z_2/(Z_1+Z_2)}{Z_1+Z_1Z_2/(Z_1+Z_2)}e$$

The equation may be simplified by dividing both the numerator and the denominator by Z_1 and multiplying both by (Z_1+Z_2). The result of this operation is

$$(2)\quad V' = \frac{Z_2}{Z_1+2Z_2}e$$

The voltage V' is divided between the inductance and the capacitance in proportion to the respective impedances of those elements. The ratio of the reactance X_c to the total impedance Z_1 represents the proportional part of V' which is equal to V. This relation may be expressed by the equation

$$(3)\quad V = \frac{X_c}{Z_1}V'$$

By substituting in Eq. (3) the value of V' given by Eq. (2) the voltage V derived from the network may be expressed in terms of the impressed electromotive force e. The result is as follows:

$$(4)\quad V = \frac{X_cZ_2}{Z_1(Z_1+2Z_2)}e$$

The circuit of Fig. 2 is resonant when the voltage V is infinitely large whatever the value of e may be. By inspection of Eq. (4) it is found that resonance occurs when either Z_1 or the combination (Z_1+2Z_2) is equal to zero. The equations which determine the resonant frequency are

$$(5)\quad Z_1=0,$$

$$(6)\quad Z_1+2Z_2=0.$$

Expressed in words, the resonant frequency defined by Eq. (5) is the frequency of resonance of the branch Z_1 and that defined by Eq. (6) is the frequency at which the branch Z_1 resonates with twice Z_2.

The circuit of Fig. 2 is anti-resonant when the voltage V is zero whatever the value of e may be. This occurs when Z_2 is equal to zero, as will be evident from further inspection of Eq. (4). The equation for determining anti-resonance is

$$(7)\quad Z_2=0$$

Anti-resonance obviously occurs when the branch containing the impedance Z_2 becomes a short circuit due to its own resonance.

A closely approximate formula for determining the band width of the network N_1 will now be derived. For convenience the following abbreviations will be used

$$(8)\quad \omega_1 = \frac{1}{\sqrt{L_1C_1}},$$

$$(9)\quad \omega_0 = \frac{1}{\sqrt{L_2C_2}}.$$

The quantities ω_1 and ω_0 are the resonant frequencies of the impedances Z_1 and Z_2 respectively, both expressed in electrical radians per second. Frequencies so expressed will be referred to as angular frequencies to distinguish them from the more usual frequencies expressed in cycles per second. The angular frequency ω_1 constitutes one limit of the transmission band. The other limiting frequency will be designated ω_2 and the band width may then be expressed as $\omega_2-\omega_1$. The value of ω_2 is determined by resonance of Z_1 with $2Z_2$ as indicated by Eq. (6). In terms of the values of the reactance elements.

$$(10)\quad \omega_2 = \frac{1}{\sqrt{L_1C_1}}\cdot\frac{\sqrt{1+2\frac{C_1}{C_2}}}{\sqrt{1+2\frac{L_2}{L_1}}}$$

Because the coupling between the two meshes of network N_1 will ordinarily be small, C_1 will be small in comparison with C_2 and L_2 will be small in comparison with L_1. It is well known that if a quantity x is a small fraction the following approximation will be found to hold:

$$(11)\quad \sqrt{1+x}=1+\tfrac{1}{2}x$$

By applying this approximation to Eq. (10) the following result is obtained:

$$(12)\quad \omega_2 = \frac{1}{\sqrt{L_1C_1}}\cdot\frac{1+\frac{C_1}{C_2}}{1+\frac{L_2}{L_1}}$$

The value of the band width readily follows

$$(13)\quad \omega_2-\omega_1=\omega_1\frac{L_2}{L_2+L_1}\left(\frac{\omega_0^2}{\omega_1^2}-1\right),\text{ or}$$

$$(14)\quad \omega_2-\omega_1=\frac{L_2}{L_1+L_2}(\omega_0-\omega_1)\left(1+\frac{\omega_0}{\omega_1}\right)$$

Eq. (14), shows that if the inductances are not varied and if the interval $(\omega_0-\omega_1)$ is maintained constant the band width remains nearly constant, diminishing slightly as the frequency ω_1 increases. If the interval $(\omega_0-\omega_1)$ is not very great the diminution of the band width with increasing frequency is very small.

The limiting frequency ω_1 is varied by adjusting the variable condensers C_1 and C_1' simultaneously, keeping the two always equal in value. The suppression frequency ω_0 is varied by adjusting the value of C_2. The condensers C_1, C_1' and C_2 are mechanically coupled and the blades are given such shapes that the frequencies ω_0 and ω_1 are at all times separated by a predetermined and fixed frequency interval. A simple method of maintaining the fixed frequency interval is to use condensers of the so called "straight line frequency" type and to have the condenser C_2 mechanically displaced from the others. The beat frequency oscillator, also mechanically coupled is simultaneously adjusted, usually to a frequency which is separated from ω_1 by another predetermined and fixed interval. The beat frequency and the suppression frequency are commonly spaced at equal frequency intervals from the center of the transmission band.

Fig. 1—A shows a modification of the branch L_2C_2 of Fig. 1. As noted above, in order that the coupling between the meshes of network N_1 shall be small C_2 will be several times as large as C_1. In case the required value of C_2 is inconveniently large, a transformer T_4 may be employed to couple a smaller condenser C_2' with an inductance L_2'. The inductance L_2' may be equal to L_2 if desired. C_2', however may be several times as small as C_2 and the effect of the transformer will be to magnify the capacity of C_2' in proportion to the ratio of the turns in the respective windings of the transformer T_4.

Fig. 3 discloses an arrangement alternative to that of Fig. 1. The network N_2 is illustrated as being employed to couple the output circuit of a vacuum tube V_2 with the input circuit of another tube V_3. N_2 consists of three anti-resonant circuits connected in series relation and is the converse of N_1 of Fig. 1, which consists of three resonant circuits connected in parallel. A beat frequency oscillator O is coupled by means of a transformer T_3 to the grid electrode of V_3, and is provided with a tuning adjustment.

The network N_2 is adjusted by means of variable inductances, L_1, L_1' and L_2 which are mechanically coupled to each other and to the tuning element of the oscillator O. The network has two resonant frequencies which determine the respective limits of its transmission band and an anti-resonant frequency at which the coupling between the input and output terminals of the network is suppressed.

The equations which determine the resonant and anti-resonant frequencies of network N_2 will now be derived.

Fig. 4 is a simplified circuit diagram which approximately represents the network N_2 and the effect of the reactions between the network and the tubes V_2 and V_3 respectively. The tube V_2 acts substantially as a source of alternating current of constant amplitude because the internal impedance of the tube is generally large in comparison with the impedance of network N_2. This constant current is represented by I_0 in Fig. 4. The voltage V across impedance Z_1 is applied to the input circuit of tube V_3. The current I_0 is divided between the two parallel paths of the circuit of Fig. 4 in proportion to the admittances of the respective paths. The current in the output path will be designated I_2, and is determined by the following equation:

$$(15)\quad I_2=\frac{Z_1}{2Z_1+Z_2}I_0$$

The voltage V is determined by the following equation:

$$(16)\quad V=Z_1I_2=\frac{Z_1^2}{2Z_1+Z_2}I_0$$

Eq. (16) shows that there is a maximum value of V when Z_1 is infinite and another when $2Z_1+Z_2$ is equal to zero. These conditions determine the limiting frequencies of the transmission band and may be expressed as follows:

$$(17)\quad Z_1=\infty$$

$$(18)\quad 2Z_1+Z_2=0$$

Eq. (16) shows further that there is a minimum or zero value of V when Z_2 is infinite. This condition determines the frequency at which the coupling between the input and output terminals of the network is suppressed and may be expressed as follows:

$$(19)\quad Z_2=\infty$$

By a process of mathematical deduction similar to that applied to the circuit of Fig. 2 it can be shown that the band width for the circuit of Fig. 4 is approximately determined by the following equation:

$$(20)\quad \omega_2-\omega_1=\frac{C_2}{C_1+C_2}(\omega_0-\omega_1)\left(1+\frac{\omega_0}{\omega_1}\right)$$

The band width is nearly constant when L_1, L_1' and L_2 are varied, provided C_1 and C_2 are constant (or maintained in a fixed ratio) and the interval between ω_0 and ω_1 is kept constant. For greatest constancy of the band width, ω_0 and ω_1 should also be fairly close together.

The limiting frequency ω_1 is varied by adjusting the variable inductances L_1 and L_1' simultaneously, keeping the two always equal in value. The suppression frequency ω_0 is varied by adjusting the value of L_2. The variable inductances are mechanically coupled in such manner that the frequencies ω_0 and ω_1 are at all times separated by a predetermined and fixed frequency interval. The beat frequency oscillator also mechanically coupled, is simultaneously adjusted, usually to a frequency which is separated from ω_1 by another predetermined and fixed interval.

What is claimed is:

1. A selective network comprising input and output tuned circuits and a tuned coupling circuit connected in parallel with said input and output circuits, the tuning elements of said circuits being mechanically connected whereby said input and output circuits are maintained in syntony and transmission therebetween is suppressed at a frequency different by a substantially constant amount from the frequency of tuning of said syntonous circuits.

2. A selective network comprising series resonant input and output circuits and a series resonant coupling circuit connected in

parallel with said input and output circuits, the tuning elements of said circuits being mechanically connected whereby said input and output circuits are maintained in syntony and transmission between said circuits is suppressed at a frequency differing by a substantially constant amount from the frequency of tuning of the said syntonous circuits.

3. A selective circuit comprising tuned input and output branches and a tuned coupling branch each branch consisting of a fixed inductance and a variable condenser connected in series, said branches being connected in parallel and said variable condensers being mechanically connected whereby said input and output branches are maintained in syntony and transmission therebetween is suppressed by said coupling branch at a frequency different by a substantially constant amount from the frequency of tuning of said syntonous circuits.

4. A selective circuit comprising input and output tuned circuits and a tuned coupling circuit connected in parallel with said input and output circuits, the tuning elements of said circuits being mechanically connected whereby said input and output circuits are maintained in syntony and said coupling circuit is maintained in resonance at a frequency differing from the frequency of said syntony by a substantially constant amount.

5. A selective circuit comprising input and output tuned circuits, a tuned coupling circuit connected in parallel with said input and output circuits, a source of alternating currents, said source being adjustable as to frequency, means mechanically connecting the tuning elements of said circuits and of said source, whereby said input and output circuits are maintained in syntony while said coupling circuit and said source are respectively maintained in adjustment at frequencies differing from the frequency of said syntony by substantially constant amounts.

6. A selective network comprising input and output tuned circuits and a tuned coupling circuit of relatively small coupling effect connected in parallel with said input and output circuits to adapt said network to transmit a band of frequencies, the tuning elements of said circuits being mechanically connected whereby said input and output circuits are maintained in syntony, transmission therebetween is suppressed at a frequency different by a substantial amount from the frequency of tuning of said syntonous circuits, and the transmission band is maintained of substantially constant width over a range of tuning adjustments.

7. A selective network comprising input and output tuned circuits the tuning elements of which are mechanically connected for the maintenance of syntony and a tuned coupling circuit connected in parallel with said input and output circuits, said coupling circuit being adapted to maintain a substantially constant width band transmission characteristic throughout the tuning range and including a variable element mechanically coupled to the tuning elements of the syntonous circuits whereby transmission between said input and output circuits is suppressed at a frequency differing by a substantially constant amount from the frequency of tuning of said input and output circuits.

8. A selective circuit comprising a pair of syntonous tuned circuits having their tuning elements mechanically connected for the maintenance of syntony, a tuned coupling circuit connected in parallel with said syntonous circuits, said coupling circuit being adapted to maintain a substantially constant width band transmission characteristic throughout the tuning range and including a variable element mechanically coupled to the tuning elements of the syntonous circuits whereby transmission between said circuits is suppressed at a frequency differing by a substantially constant amount from the frequency of tuning of said syntonous circuits.

In witness whereof, I hereunto subscribe my name this 14th day of April, 1930.

GEORGE H. STEVENSON.