April 19, 1932. J. K. JOHNSON 1,855,055

HIGH FREQUENCY TRANSFORMER

Original Filed Feb. 13, 1931 2 Sheets-Sheet 1

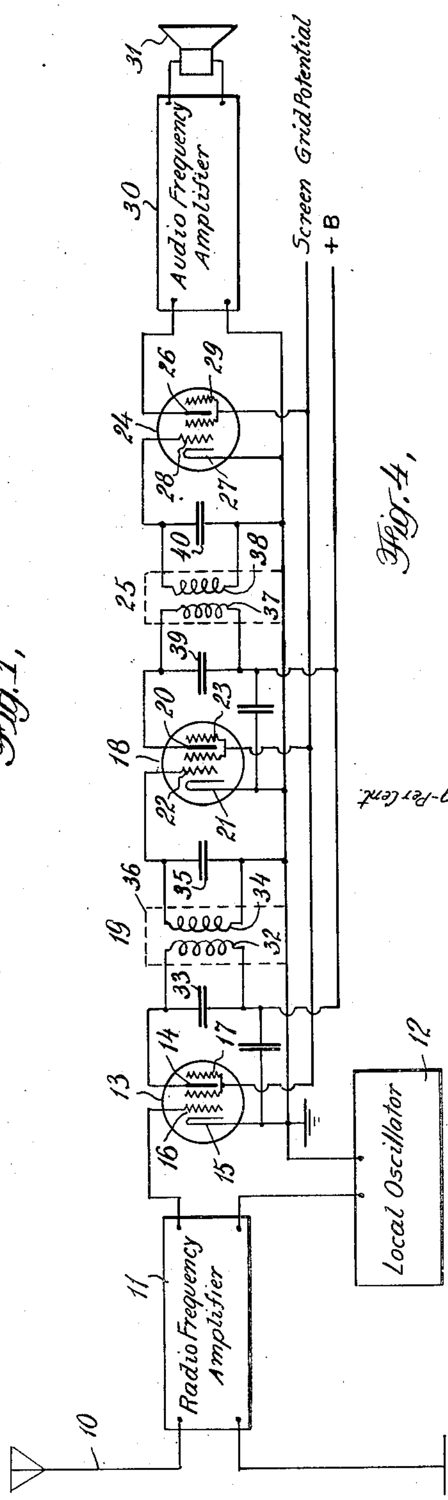

Fig. 1.

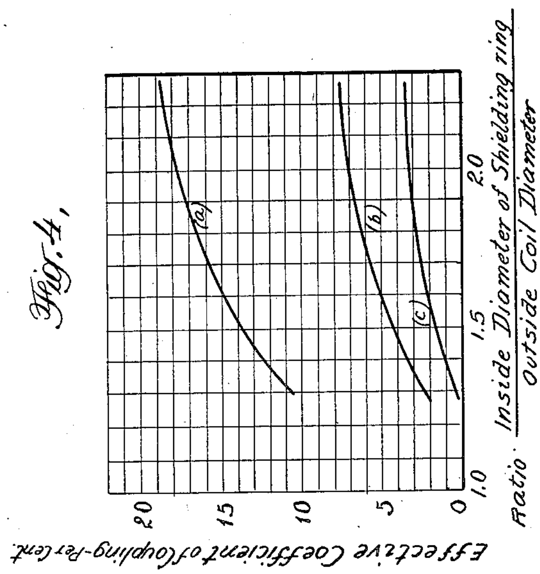

Fig. 4.

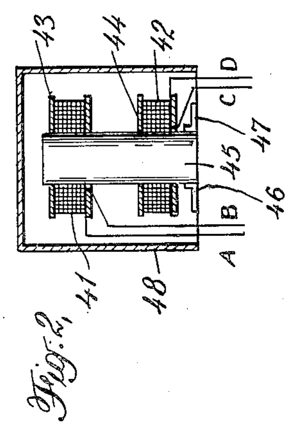

Fig. 2.

INVENTOR
J. Kelly Johnson
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

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Fig. 5

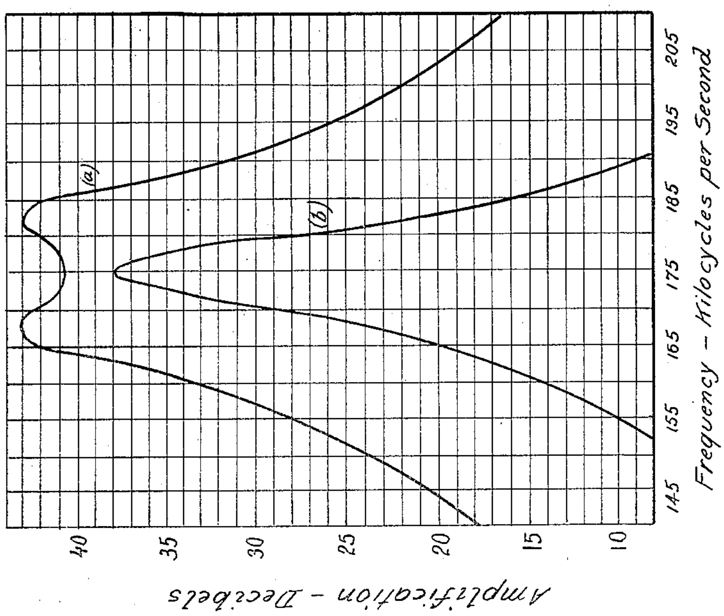
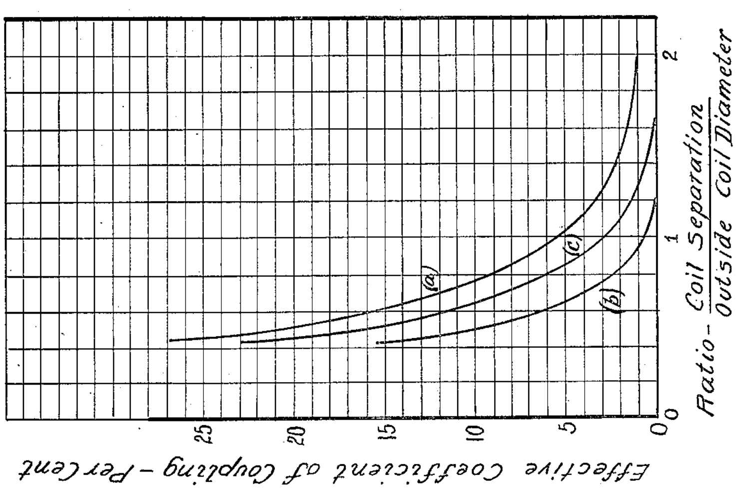


Fig. 3



INVENTOR
J. Kelly Johnson
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Patented Apr. 19, 1932 1,855,055

UNITED STATES PATENT OFFICE

JOHN KELLY JOHNSON, OF HARTSDALE, NEW YORK, ASSIGNOR TO HAZELTINE CORPORATION, A CORPORATION OF DELAWARE

HIGH FREQUENCY TRANSFORMER

Original application filed February 13, 1931, Serial No. 515,560. Divided and this application filed February 28, 1931. Serial No. 518,996.

This invention relates to carrier-frequency coupling systems and more particularly to systems adapted to couple vacuum tubes in an amplifier of high or medium-high frequencies.

The coupling systems of the present invention are suitable for use in radio-frequency amplifiers and are particularly well adapted for use in amplifiers of medium-high frequencies, such as the intermediate-frequency amplifier of a superheterodyne type of radio receiver.

This application is a division of my copending original application, Serial No. 515,560, filed Feb. 13, 1931.

The principal object of this invention is to adjust the degree of coupling between two circuits of a carrier-frequency coupling system to the proper value to provide a high degree of amplification, uniform transmission and good selectivity.

Another object is to provide a coupling system which shall be compact, inexpensive and easily adjustable.

The coupling systems contemplated in this invention comprise an input circuit which is connected to a pair of input terminals and an output circuit which is connected to a pair of output terminals. The input and output circuits each include an inductance tuned by a capacity; these inductance elements are coils which are spaced in close relation to each other so that there exists a substantial degree of magnetic coupling therebetween. The coupling system will generally be connected between the output of one tube of a high-frequency amplifier and the input of a succeeding tube. There may be two or more of these coupling systems coupled in tandem.

An important feature of the invention is the provision of an electrical conducting shielding arrangement surrounding, or partially surrounding, both coils. This shielding arrangement has the effect of reducing the degree of coupling between the inductances of the input and output circuits to a lower value than would exist in the absence of the shield. The amount by which the effective coupling between the coils is reduced by virtue of the shield, depends upon the form and separation of the coils and upon the spacing of the shield from the coils.

In high-frequency transformers heretofore employed which comprise primary and secondary windings each of which is tuned to the same frequency by fixed or adjustable capacities, it has been found necessary, where relatively loose coupling between circuits is required, to physically space the coils a considerable distance apart, or in the alternative, to provide an auxiliary element between the windings to reduce the electromagnetic coupling. If this relatively great spacing between the coils is not provided, or if there is present no auxiliary means for reducing the coupling, there results the well-known effect of double resonance which makes it impossible to tune the system to a single frequency. The reaction of one circuit upon the other produces the two resonant peaks of which differs from the frequency to which each coil is individually tuned. When the electromagnetic coupling between the two circuits is decreased, the frequency difference between these resonant peaks decreases, so as optimum coupling is approached, the double resonant peaks merge into the single resonance.

It has been found possible to vary the effective coefficient of electromagnetic coupling and hence the mutual inductance between the coils within wide limits by varying the relative sizes of the shielding ring and of the coils and the spacing between coils. By arranging the shielding ring close to the coils it is possible to locate the coils in close proximity to each other while at the same time maintaining absolute control over the effective coefficient of coupling and the mutual inductance between coils, and hence the reaction of one circuit upon the other. Practically, it is possible to so arrange the elements of the coil structure that it is small, compact and inexpensive to manufacture.

Of the drawings:

Fig. 1 illustrates a radio receiver of the superheterodyne type in which the intermediate-frequency amplifier employs coupling systems of the type of this invention;

Fig. 2 illustrates the construction of the inductances and the arrangement of the shielding of the coupling systems;

Fig. 3 shows graphically how the ratio of the coil separation to the coil diameter affects the effective coefficient of coupling between the coils;

Fig. 4 shows graphically the change in effective electromagnetic coupling as a function of the ratio of the coil diameter to the diameter of the shielding ring;

Fig. 5 shows transmission characteristics of the coupling system with and without the shield.

Fig. 1 illustrates a conventional type of superheterodyne radio receiver embodying the invention. The receiver comprises an antenna circuit 10 connected to a radio-frequency amplifier shown in generalized form as the rectangular 11. The output of the radio-frequency amplifier is associated with a local oscillator indicated in generalized form by the rectangle 12. The local oscillator and the radio-frequency amplifier are connected in the input of a vacuum tube modulator 13, the purpose of the modulator being to modulate the amplified signals from the amplifier with the oscillations from the local oscillator. The construction of a local oscillator and of an amplifier for this purpose and the manner of their connection in the input circuit of the modulator are well understood in the art, and require no further discussion here.

The modulator tube 13 is of the four-electrode type comprising an anode 14, a cathode 15, a control grid 16 and a screen grid 17. The modulator 13 operates in the well understood manner upon the signal voltage and the local oscillator voltage to produce a signal in its output having a carrier frequency which is the difference between the frequency of the radio signal and the frequency of the local oscillator. Since this difference in frequency is lower than the frequencies of the radio signaling range, it is called an intermediate frequency.

The output of the modulator is coupled to the input of an intermediate-frequency amplifier 18 through a coupling system 19. The amplifier 18 is also of the four-electrode type and includes an anode 20, a cathode 21, a control grid 22 and a screen grid 23. The output of the intermediate-frequency amplifier is coupled to a detector tube 24 through a coupling system 25. The detector tube, which is also of the four-electrode type, includes an anode 26, a cathode 27, a control grid 28 and a screen grid 29. The output of the detector feeds into an audio-frequency amplifier represented by the rectangle 30. The output of the audio amplifier operates a loudspeaker 31.

There are illustrated no sources of operating potentials for the various electrodes of the vacuum tubes of the receiver. The manner of applying these energizing potentials is well understood in the art and since it constitutes no part of the present invention, these sources are not illustrated.

The feature of this invention resides in the coupling systems 19 and 25 associated with the intermediate-frequency amplifier. The coupling system 19 comprises two circuits, the first of which is connected in the output of modulator 13 and the second of which is connected in the input of amplifier 18. The first circuit includes an inductance 32 shunted by a fixed capacity 33, connected in the anode circuit of modulator 13. The second circuit includes an inductance 34 shunted by a fixed capacity 35, connected in the input circuit of amplifier 18. The inductances 32 and 34 are so arranged that there exists a substantial degree of magnetic coupling between them. The elements of the coupling system are so selected that each of the coupled circuits is tuned to the frequency to be transmitted by the amplifier. There is provided a metallic shield 36 which encloses the inductances 32 and 34; the shield is physically situated with respect to the inductances, in accordance with this invention, in a manner which will be later explained in greater detail.

The coupling system 25 in the output of the intermediate-frequency amplifier 18 is similar in its circuit arrangement to coupling system 19; it includes inductively related inductances 37 and 38 situated respectively in the output circuit of the amplifier 18 and in the input circuit of the detector 24. The inductance 37 is shunted by a fixed condenser 39, and inductance 38 is shunted by fixed condenser 40.

Fig. 2 illustrates in cross-section the construction and assembly of the inductively related inductances and the associated shielding ring, of coupling systems 19 and 25. The arrangement comprises coils 41 and 42 random wound, or layer wound, respectively on bobbins 43 and 44. The bobbins are fastened over a core 45 which is adapted to be fastened to a base, or chassis, by brackets 46 and 47. Coil 41 is the anode circuit coil and coil 42 is the grid circuit coil. The coil terminals marked A, B, C and D, represent respectively the connections to the anode, the B-battery, the cathode and the grid of the associated tubes. Surrounding the bobbins containing the coils is a cylindrically-shaped shielding ring 48 closed at the upper end and adapted to be fastened to the base at the other end. The shielding ring is preferably heavy copper or aluminum or other metal having low specific electrical resistance. Any joints used in completing the ring should be of very low resistance, so that the total electrical resistance of the entire ring is very low. The shielding ring is located in close proximity to the coils so that there exists a substantial coupling between the ring and the coils.

Signal current flowing through one of the coils produces a magnetic field which interlinks with the turns of the second coil and with the shield. Currents are thereby induced in the second coil and in the shield. The current induced in the shield, in turn, produces a magnetic field which is approximately opposite in phase to the field of the first coil. As a result, the degree of coupling between the two coils is reduced to a lower value than would exist in the absence of the shield.

Due to the close spacing between the shielding device and the coils and because of the low resistance of the shielding device, the coefficient of coupling between the coils and the shield will usually be greater than that between the two coils. It has been found possible, in fact, to reduce the effective magnetic coupling between coils practically to zero.

The dimensions of the coils will, of course, be dependent upon the intermediate frequency which the amplifier is required to transmit. The following table gives a suitable design for a coupling system for transmitting a carrier frequency of 175 kilocycles per second, and the associated sidebands, this frequency having been found highly satisfactory for the intermediate frequency of a superheterodyne receiver:

Diameter of core—½″.

Each winding—900 turns, #38 B. & S. gauge, double silk covered copper wire.

Width of each coil—¼″.

Distance between coils—$\frac{7}{16}$″.

Outside diameter of each coil—$\frac{15}{16}$″.

Inside diameter of shielding ring—1⅜″.

Length of shielding ring—1⅜″.

The above dimensions will provide a coil structure having an inductance of about 8.8 millihenries in each coil; the effective coefficient of coupling between each coil will be about four per cent. In order to cause each of the coils to be resonant at a frequency of 175 kilocycles, the fixed capacity shunting each coil should be about 100 micro-micro-farads.

Fig. 3 illustrates a family of curves which indicate the relationship of the effective coefficient of coupling between coils to the ratio of the separation between coils to the outside diameter of the coils. In this figure curve "*a*" illustrates the variation of the effective coefficient of coupling between coils in the absence of any shielding ring. Curve "*b*" illustrates the variation in the coefficient of coupling when the coils are placed within a shielding ring which is so proportioned that the inside diameter of the ring is one and one-third times the outside coil diameter. Curve "*c*" indicates the variation in the effective coefficient of coupling when the inside diameter of the shielding ring is two times the outside coil diameter. A casual inspection of the curves of Fig. 3 shows that the effective coupling between the coils becomes smaller when the distance between coils becomes greater relative to the outside coil diameter.

Fig. 4 illustrates another family of curves which may be derived from the curves of Fig. 3 and which show the effect of the diameter of the shielding ring upon the effective electromagnetic coupling between the coils. In this figure the effective coefficient of coupling is plotted against the ratio of the inside diameter of the shielding ring to the outside coil diameter. Curve "*a*" shows the variation of the effective coefficient of coupling between the coils when the distance between the coil centers is one-half the outside coil diameter. Curve "*b*" illustrates the variation in the effective coefficient of coupling when the distance between the coil centers is three quarters of the outside coil diameter. Curve "*c*" indicates the variation when the distance between coil centers is equal to the outside coil diameter.

The curves of Figs. 3 and 4 are experimental curves obtained from the coil structures having the design constants given in the above table.

Experiments with coil and shielding ring structures of various sizes and shapes have indicated that the most important variables are the ratio of the inside diameter of the shielding ring to the outside coil diameter, and the ratio of the coil separation to the outside coil diameter.

The most favorable ratios of the inside shielding ring diameter to the outside coil diameter lie between one and two. The spacing required between coils is subject to variation, dependent upon the desired coefficient of coupling and hence the mutual inductance required, the power factor of the coils, the form factor of the coils, and the diameter of the shielding ring. When the coil structure is proportioned in accordance with the above table, favorable results are obtained when the spacing between the centers of the coils does not exceed the mean diameter of either coil. Where the radius of the core itself is equal to or greater than the depth of winding of the coil, the spacing between centers of the respective coils may be reduced to a distance which is of the same order of magnitude as one-half of the mean diameter of the coil. It should be understood that the above mentioned preferred proportions should not be construed to be limitations upon the invention, but are given to indicate how favorable results may be obtained.

Fig. 5 illustrates amplification characteristics of a coupling system such as 19 and 25 of Fig. 1. Curve "*a*" of Fig. 5 illustrates the amplification characteristic when the shielding ring is removed; the coupling coefficient in this case is about 15%. This is the condition of over-optimum coupling which gives rise to the double resonance effect. Curve "b" illustrates the resonance characteristic of the same coupling system when the shielding ring is in place. The effective coupling coefficient between coils is reduced by the ring to about 4%. This is slightly below optimum and produces the single resonance effect.

By the term "optimum" coupling is meant that degree of coupling between the input and output circuits of a coupling system which will provide the maximum amplification. It is well known that when the coupling between a pair of syntonously tuned circuits of a coupling system is optimum, or less than optimum, the system is characterized by a single resonance. When the coupling becomes greater than optimum, the resonances spread, giving rise to the double-resonance effect. The distance in the frequency scale between the two resonances is greater, the greater the degree of coupling; so it is possible to obtain any desired spacing by adjusting the coupling by means of the shield.

In some amplifiers the design requires moderately over-optimum coupling to be employed so that the double-resonance effect is obtained to a slight degree, whereby there results a broadening of the transmission band of frequencies; other design conditions require that there be a single resonance. It is within the contemplation of this invention to provide either type of resonance characteristic. It is clear that whether a double resonance effect or a single resonance effect is to be obtained, the required coefficient of coupling is quite critical. This critical value can be readily obtained in accordance with this invention, by suitably proportioning the dimensions of the shielding ring in relation to the coil dimensions.

Although there is illustrated in Fig. 1 only one double tuned coupling system between each successive tube, there are instances where it is desirable to provide more than one such double tuned system between stages. A plurality of double tuned systems may be coupled either inductively or capacitively in tandem between successive vacuum tubes.

Although the coupling systems have been described as being particularly well suited for use in the intermediate frequency amplifiers of superheterodyne receivers, the invention should not be construed to be limited to such receivers. The coupling systems of this invention are equally applicable to radio-frequency amplifiers and to any other high-frequency system.

What is claimed is:

1. A high-frequency coupling system comprising two coils and a shielding device, said coils being electromagnetically coupled to each other and having their centers separated by a distance which is between one-half and two times their outside diameters, said shielding device surrounding said coils, the diameter of said shielding device being of the same order of magnitude as the separation between the coils whereby the coupling between said coils and said device is substantially greater than the coupling between said coils.

2. A high-frequency transformer comprising a primary coil, a secondary coil and a shielding ring, said coils being multi-layer wound, the distance between the centers of said coils being no greater than the outside diameter of said coils, and said shielding ring surrounding said coils, the ratio of the inside diameter of said shielding ring to the outside diameter of said coils being no greater than two.

3. A high-frequency transformer comprising a primary coil, a secondary coil and a shielding device surrounding said coils, said shielding device having an electrically conducting surface situated no further from said coils than half the coil diameter, said coils being spaced apart by a distance no less than the approximate radial depth of said windings, whereby the coefficient of coupling between said coils and said ring is greater than the coefficient of coupling between said coils.

4. A high-frequency transformer comprising a primary coil, a secondary coil and a shielding ring, the coefficient of coupling between said coils being about 15 per cent in the absence of said shielding ring, and said shielding ring closely surrounding said coils by a distance sufficient to reduce the effective coefficient of coupling between said coils to about 4 per cent.

5. A high-frequency transformer comprising a pair of coils, each of said coils being wound in layers, said coils being co-axially situated and separated from each other by a distance between their centers not exceeding the outside diameter of said coils, and a shielding ring circumferentially surrounding said coils, the inside diameter of said ring being less than twice the outside diameter of said coils.

6. A shielded high-frequency transformer comprising a pair of coils and a shield, said coils being layer-wound and having a radial depth of winding which is of the same order of magnitude as the width of said coils, said coils being fitted on a core and spaced apart by a distance which is less than the outside diameter of said coils, said shield being placed closely around said coils so that the coefficient of coupling between one of said coils and said shield is greater than the coefficient of coupling between said coils would be in the absence of said shield.

7. A shielded high-frequency transformer according to claim 6 in which said coils are

wound with approximately the same number of turns.

8. A carrier frequency transformer adapted to transmit a carrier wave and side bands corresponding to voice waves comprising a pair of coils placed in such close inductive relation to each other that when said coils are acting alone, transmission of signals through them is characterized by a pair of resonance peaks, a low resistance shielding means surrounding said coils and having a diameter less than twice that of said coils whereby said resonant peaks become more closely spaced and are separated by a frequency difference no greater than the frequency range of said side bands.

In testimony whereof I affix my signature.

J. KELLY JOHNSON.

DISCLAIMER

1,855,055.—*John Kelly Johnson*, Hartsdale, N. Y. HIGH FREQUENCY TRANSFORMER. Patent dated April 19, 1932. Disclaimer filed March 26, 1937, by the assignee, *Hazeltine Corporation*.

Hereby enters this disclaimer to claims 1 and 8 of said patent.

[*Official Gazette April 20, 1937.*]