May 9, 1933.

H. A. WHEELER

1,907,916

COUPLING SYSTEM

Filed Aug. 19, 1930

2 Sheets-Sheet 1

Fig. 1,

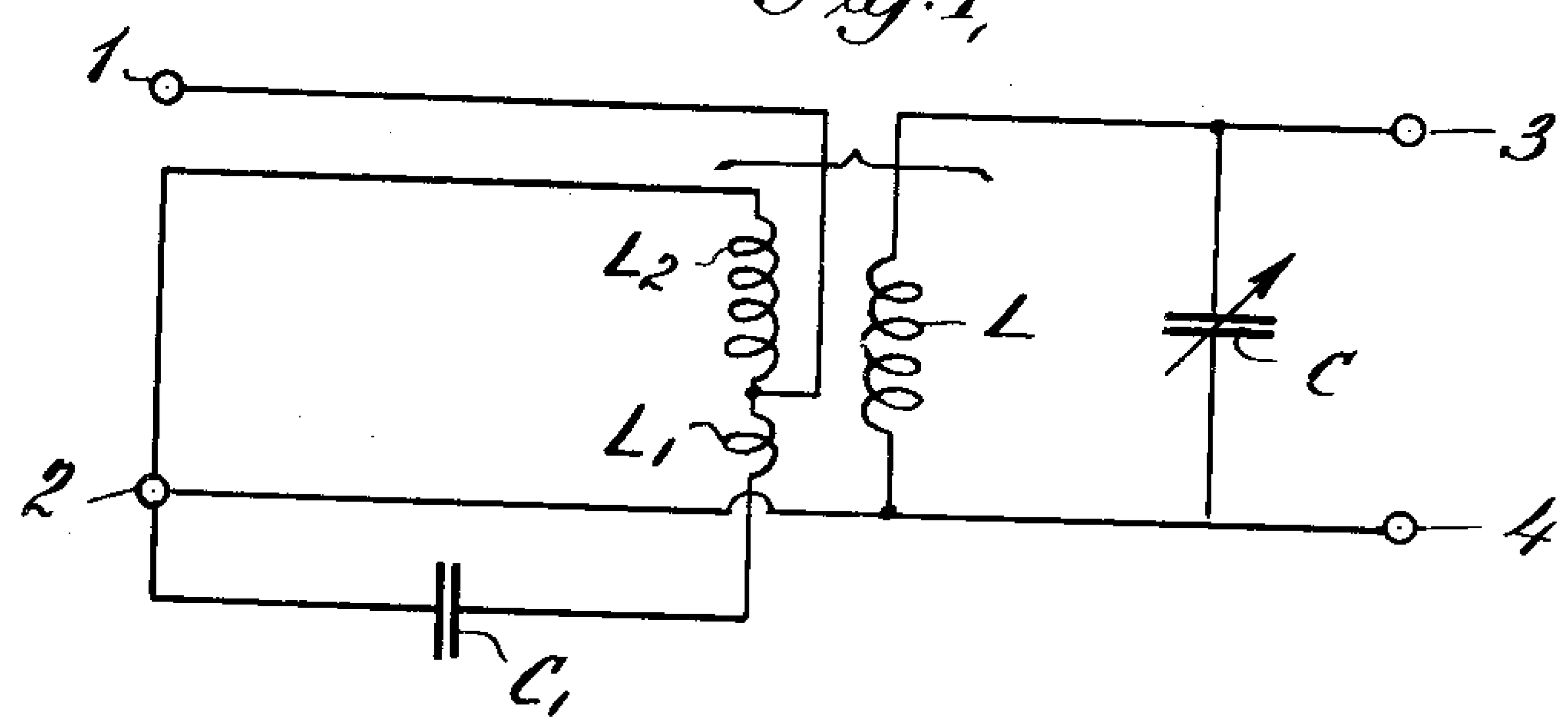



Fig. 2,

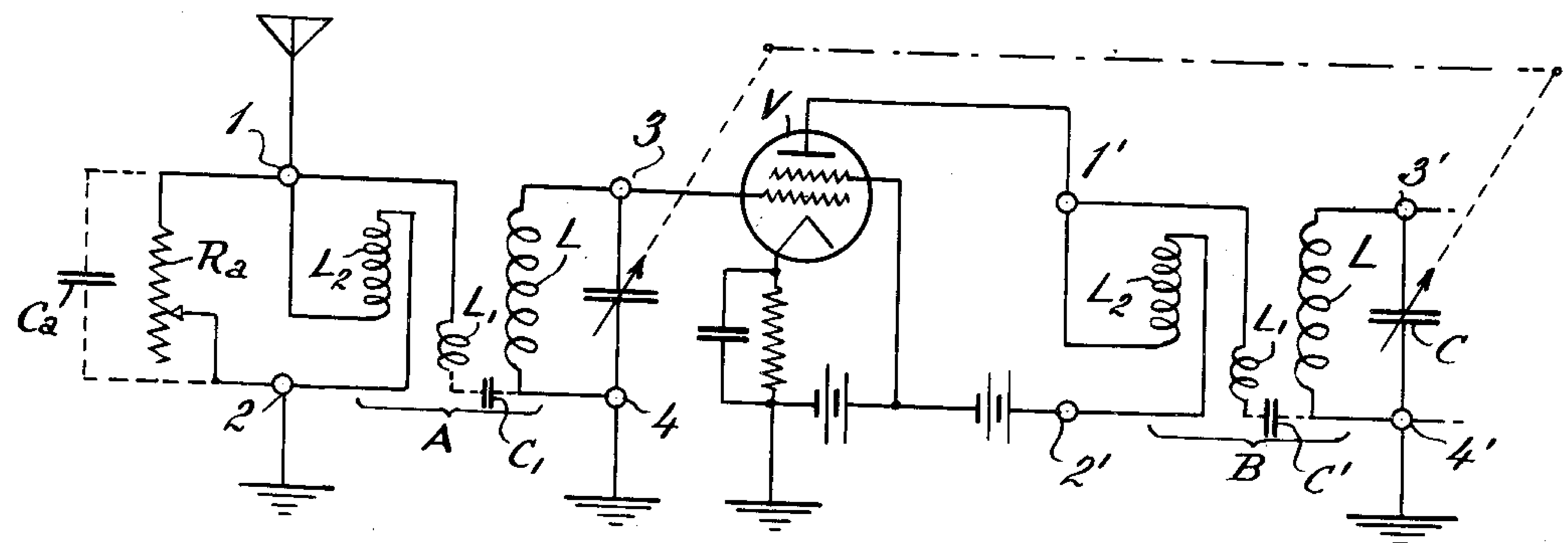
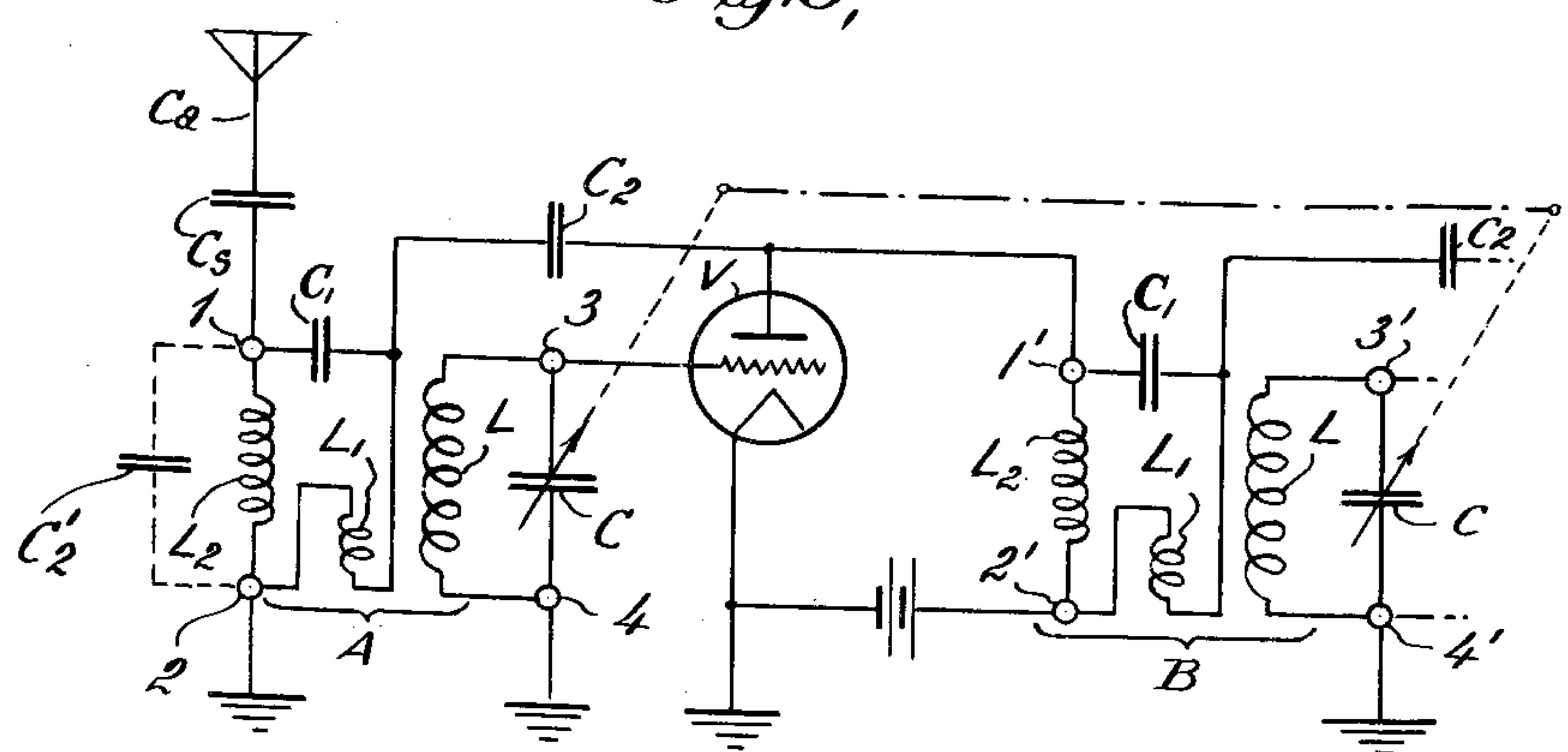



Fig. 3,

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May 9, 1933. H. A. WHEELER 1,907,916

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Fig. 4,

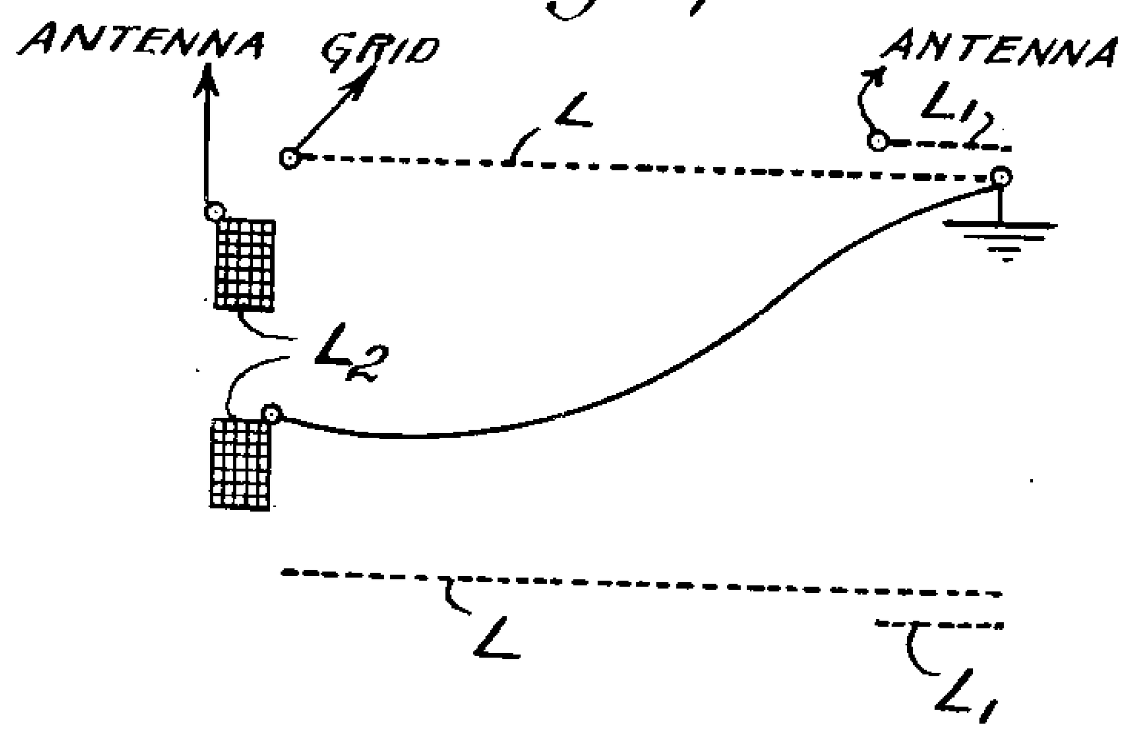



Fig. 4a,

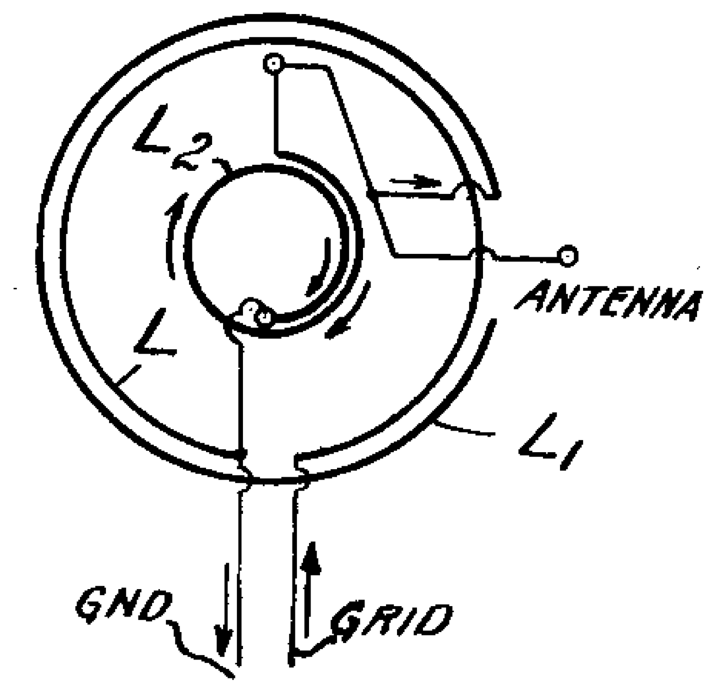



Fig. 5,

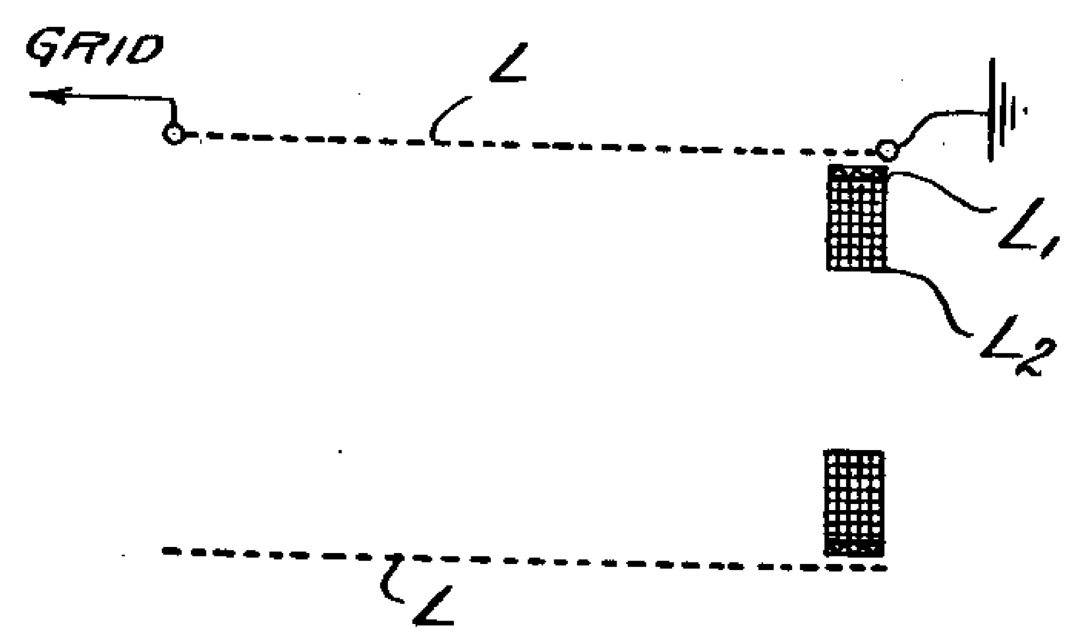
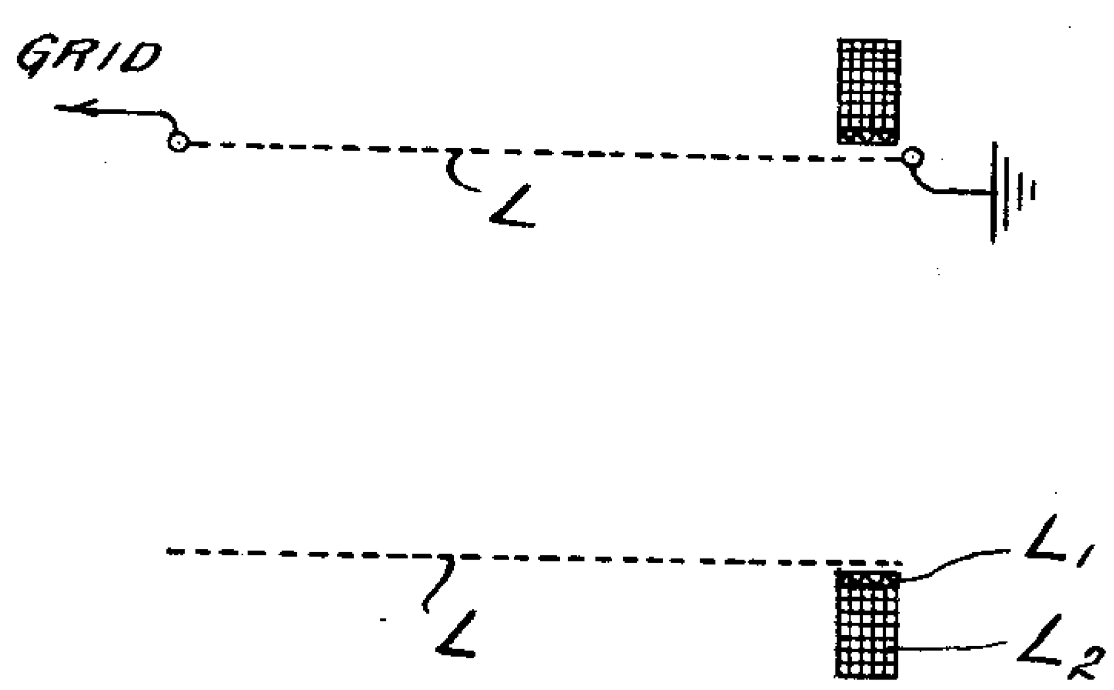



Fig. 6,

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Patented May 9, 1933

1,907,916

# UNITED STATES PATENT OFFICE

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## COUPLING SYSTEM

Application filed August 19, 1930. Serial No. 476,394.

This invention relates to high-frequency electric coupling networks tunable over a range in frequency, and is adapted more especially for interconnecting successive elements of a high-frequency thermionic amplifier or radio system.

The coupling networks of the present invention are characterized in that the voltage amplification produced thereby is caused to vary automatically as the resonant frequency is changed by tuning in a manner which is under the control of the designer; the design in general being preferably such as to produce a substantially constant resultant amplification, i. e. uniform sensitivity throughout the tunable frequency range.

The invention also provides a preferred transformer structure which, because of its unique construction, may be used advantageously as a part of the coupling systems herein described.

With the elementary type of high-frequency coupling circuit, of which a two-winding transformer having a tunable secondary is a typical example, the variation of amplification with frequency is not under the control of the designer; but inevitably increases with frequency throughout the tunable range in a manner well understood, with consequent detrimental effects upon the amplification, selectivity and stability of the system.

In the type of coupling circuit just referred to, there exists between the primary and tunable secondary circuits a degree of coupling which is substantially constant throughout the tunable frequency range, a condition which is partially responsible for the mentioned increase of amplification with frequency. The present invention avoids the disadvantages resulting from the prior systems, including constant coupling, by proper inclusion of certain reactance elements so related that the effective coupling between the input circuit and the output circuit automatically decreases with increase of frequency, whereby the normal increase in amplification with frequency may be partially or wholly offset. Coupling circuits broadly operative in accordance with the principles disclosed herein, but differing from the present invention as regards both circuit connections and the specific modes of operation thereof, are described in U. S. Patent No. 1,763,380, issued June 10, 1930 to C. E. Trube, and in his copending applications Serial No. 101,906, filed April 14, 1926, and Serial No. 120,045, filed July 2, 1926.

As was indicated above, the voltage ratio or coupling in a high-frequency coupling system affects the degree of amplification and the selectivity, and when used as an inter-tube coupling system affects the stability as well. At each frequency there is a particular ratio of output voltage to input voltage that results in the best compromise design. This ratio varies considerably with frequency, being relatively high at the higher frequencies. The present invention provides means for securing substantially the most desirable ratio at all frequencies without having any adjustable element except the tuning adjustment. The circuits are so arranged that the tuning characteristics will be electrically similar in all corresponding circuits, so that, if desired, uni-control operation may be secured. The coupling systems of this invention are also so arranged that when used in connection with thermionic tubes which are likely to produce undesired oscillations, the grid-plate capacity coupling thereof may readily be neutralized by the mere addition to the coupling system of an appropriate neutralizing capacity, as will be explained hereinafter.

Referring to the drawings,

Fig. 1 illustrates a fundamental coupling system in accordance with this invention which may be employed, for example, to couple an antenna system to a thermionic tube or to couple two thermionic tubes in cascade;

Fig. 2. is a circuit arrangement showing the coupling system of Fig. 1 in a specific application to a tuned radio-frequency amplifier;

Fig. 3 illustrates the circuit connections of a radio-frequency amplifier somewhat similar to that of Fig. 2, but in which the coupling systems are slightly modified;

Fig. 4 shows the physical relations of coils in a transformer structure suitable for use in the coupling system of Fig. 2;

Fig. 4a is a partial end view of the transformer structure of Fig. 4, and illustrates the direction of winding the transformer coils;

Fig. 5 represents another coil structure useful in a system such as illustrated in Fig. 1; and

Fig. 6 illustrates an alternative transformer structure also applicable to the coupling system of Fig. 1.

Referring first to Fig. 1, the coupling system there illustrated comprises input terminals 1, 2, and output terminals 3, 4. Generally speaking, the input terminals would normally be connected either between antenna and ground of a receiving system or between the plate and cathode terminals of a thermionic tube. The output terminals 3, 4 would usually be connected to the input electrodes of a thermionic tube. Preferably, coil $L_1$ would have much fewer turns than coil L, so that there is a step-up voltage ratio between them. The input path through the coupling system is from the high-potential terminal 1 to the low-potential terminal 2, and includes two branches, the inductance $L_2$ comprising one branch and the inductance $L_1$ and capacity $C_1$ in series comprising the other branch. Hence, the input current divides between the two branches, but in a proportion which varies with the frequency. Inductance $L_2$, taken with any capacities in the primary circuit, is resonant at a frequency lower, but not greatly lower, than the tuning range. Therefore the branch through $L_1$, $C_1$ has a relatively lower reactance at the higher frequencies, and carries a greater proportion of the current at the higher frequencies. The opposite is true of the branch through $L_2$, which carries a greater proportion of the current at the lower frequencies. These two components of the input current are substantially 180° out of phase because the first branch is dominantly capacitive and the second branch is dominantly inductive. Therefore coils $L_1$ and $L_2$ are connected with opposite electromagnetic polarities in order to secure additive coupling relationship.

The coupling between the primary and secondary circuits at the higher frequencies depends almost entirely upon the small primary coil $L_1$, and at the lower frequencies almost entirely upon the large primary coil $L_2$. The coefficient of coupling between $L_1$ and L should be as close as practical considerations permit, and must be close enough to make the leakage inductance of coil $L_1$ so small as to be unimportant. However, the actual coefficient of coupling between $L_1$ and L may vary somewhat with different designs of transformer structure. The larger primary coil $L_2$ ordinarily would have a higher inductance than that of the secondary coil L, and be resonant with the total capacity in the primary circuit, including the capacity $C_1$, at a frequency slightly lower than the lowest frequency of the tuning range of the secondary circuit. The coefficient of coupling between $L_2$ and L must be substantially less than unity, ordinarily the value being intermediate between 5 and 50%. Coefficients of coupling about 10 to 20% are more commonly used. The coefficient of coupling between the primary coils $L_1$ and $L_2$ should be as small as the structural arrangement of the transformer will permit; but a substantial degree of coupling between these two coils is allowable without destroying the essential performance of the coupling circuit.

The coupling system of Fig. 1 is intended to be tuned by variable condenser C connected across the terminals of secondary coil L, which are also the output terminals 3, 4 of the coupling system. The combination of coil L and condenser C comprises the main resonant circuit of the coupling system. With proper design of the circuit elements, the voltage ratio between the input and output terminals may, in accordance with this invention, be made to vary automatically as desired, as the tuning is varied by the single adjustable element C. Thus by employing several similar coupling systems, one in each stage of a thermionic amplifier, the tuning condensers may be connected together mechanically for uni-control operation, in accordance with common practice.

From the foregoing it will be clear that by proper design and relation of the elements the electrical characteristics of the coupling system of this invention may be made to vary considerably with change of frequency. For example, the added coupling due to coil $L_2$ may be proportioned either to cause the input-to-output voltage ratio to increase with increase of frequency, to decrease with increase of frequency, or to remain substantially constant, all depending upon the requirements of each individual case. The specific arrangement of the impedance elements in the circuit of Fig. 1 is especially advantageous for reasons which will be discussed in more detail in connection with Fig. 2.

The circuit arrangement of Fig. 2 utilizes the type of coupling system shown in Fig. 1, both as antenna and inter-tube coupling systems. Specifically, the system of the present arrangement is an improved form of Fig. 1 in that the capacity $C_1$ is here formed by winding coil $L_1$ in such manner that there is present an inherent capacity between $L_1$ and the bottom of the secondary coil L. (A practical structure by which this circuit arrangement may be effected is illustrated in Figs. 4 and 4a.) Here the input terminals of the coupling system are the antenna and ground, respectively, and between these terminals the large primary coil $L_2$ is connected, as in Fig. 1. Between these same terminals, also, a variable resistance $R_a$ is preferably connected.

If this rheostat is of about 10,000 ohms, the effect of the shunt resistance will be to prevent sharp resonance in the primary circuit which would otherwise detrimentally affect the selectively and the resonant frequency of the secondary circuit, providing a small antenna is used, making the resonant frequency of the primary circuit close to the lowest frequency of the tuning range. Furthermore, it is convenient to make resistance $R_a$ variable so that it may serve as a volume or amplification control, which is here especially advantageous because the variation of the resistance for that purpose does not alter to any substantial degree the selectively or the resonant frequency of the secondary circuit.

In this system the antenna circuit is designed to meet the requirements of uni-control tuning, wherefor antennas of various sizes can be employed without materially altering the resonant frequency of the secondary circuit of the antenna coupling transformer. To this end a compromise design based upon two considerations must be followed. First, a reduction of the coupling not only greatly reduces the effect of the antenna capacity $C_a$ upon the resonant frequency of the secondary circuit, but also reduces the step-up ratio between the secondary voltage of the transformer and the signal voltage of the antenna. It is desirable to maintain this ratio as high as possible because the signal voltage on the secondary circuit, which is applied to the grid of the first tube V, must be sufficiently great to override the electrical noises arising in the receiver from two causes. The first cause, which is usually the more important, is the thermal agitation of the electrons in the first tuned circuit of the receiver. The second cause is the discontinuity of the electron stream in the first radio-frequency amplifier tube V. It will be apparent that noises resulting from these phenomena will be heard as disagreeable background noises unless the signal voltage transferred from the antenna circuit is sufficiently great in magnitude. Secondly, the maximum amount of detuning which is permissible in the antenna transformer is about 1% of the resonant frequency. This invention includes as a part thereof a transformer coil structure wherein an appropriate compromise between these two objectives has been achieved. The detuning effect in the secondary circuit is less than 1% of the resonant frequency for antenna capacities varying from a minimum value of 50 $\mu\mu$f up to any large value including a direct short-circuit between antenna and ground terminals. This detuning effect is constant over the frequency range, being held at the largest permissible value in order to secure the greatest possible coupling and step-up ratio. The step-up ratio of this coil structure varies from about 7 at 550 kc. to 15 or 20 at 1500 kc.

The antenna coupling system of Fig. 2 couples the antenna to the first radio-frequency amplifying thermionic tube V, which is here represented to be of the 4-electrode or screen grid type. The output circuit of this tube is connected to the input circuit of a second coupling system similar to that used for coupling the antenna; and in turn this coupling system would ordinarily be connected at the terminals 3′, 4′ to the input terminals of a second radio-frequency amplifying tube similar to V. Present day practice would require, probably, a third similar coupling system and thermionic tube followed by a fourth such coupling system connected to a thermionic detector tube. The detector would be followed by an audio-frequency amplifier and a translating device such as a loud speaker. The four coupling systems just referred to include four tuning condensers, two of which are illustrated in Fig. 2 and identified by reference character C. These several tuning condensers may conveniently be adjusted simultaneously by a single control, as represented by the dotted line connecting the arrows of the tuning condensers C. The structure of transformer B will, in general, be similar to that represented by reference character A, but the design of transformer B will have to be modified to take account of the difference in the capacity and resistance of the output circuit of the thermionic tube V as compared with the capacity and resistance of the antenna circuit in the case of transformer A.

Fig. 3 is a circuit arrangement essentially similar to that of Fig. 2, but differs specifically therefrom in two respects, one being that the coupling system itself is slightly different from that of Figs. 1 and 2, and the other being that 3-electrode tubes are employed in place of the 4-electrode tubes of Fig. 2. This coupling system is that of Fig. 5 of U. S. Patent No. 1,763,380, above-mentioned, here combined in novel manner with capacity neutralization and other desirable features. Without further explanation it may be assumed that the system of Fig. 3 may be continued after terminals 3′, 4′ in exactly the same manner as was above described in connection with the arrangement of Fig. 2.

The slight rearrangement of the coupling circuit of Fig. 3 makes convenient the use of the small primary coil $L_1$ also as a neutralizing coil; and thus this specific arrangement is particularly adapted for use with a 3-electrode thermionic tube, which, without such stabilizing means, would normally produce undesired oscillations. In this circuit arrangement the grid-plate capacity coupling is neutralized by means of the neutralizing condenser $C_2$ connected in series with the neutralizing coil $L_1$ between the plate of the tube and the cathode system or ground. Coil $L_1$ being closely coupled to secondary coil L, with proper polarity, the neutralization will be effective over the entire operating frequency range when neutralizing capacity $C_2$ has once been adjusted to the correct value, as is set forth, for example, in U. S. Patent No. 1,489,228, issued April 1, 1924 to L. A. Hazeltine.

In this figure, as in Fig. 2, the second amplifying tube is not shown, but the second neutralizing condenser $C_2$ is shown, and would, of course, be connected to the plate of the second tube, just as illustrated in connection with the circuit of the first tube. The manner in which the neutralizing circuit is here combined with the coupling circuit is somewhat similar to certain arrangements described in U. S. Letters Patent 1,829,058, issued to J. H. Pressley, October 27, 1931, and in my U. S. Letters Patent 1,868,155, issued July 19, 1932, although the specific arrangements are different.

In order to insure like tuning in the circuits of the coupling transformers of Fig. 3, especially when uni-control operation is employed, it is desirable that the capacity across the input terminals of each transformer be of the same value. In the system of Fig. 3, the neutralizing capacity $C_2$ is, because of the small inductance of coil $L_1$, effectively in parallel with the inherent plate-filament capacity of the thermionic tube, and determines to a large degree the input capacity across the terminals of $L_2$. In order to make the input capacity of the antenna coupling system equal to that of the succeeding stages, a condenser $C_s$ is shown connected in series with the antenna capacity $C_a$, so that the effective capacity $C_2'$ between the antenna and ground terminals is approximately equal to the capacity effectively across the input terminals of the other transformers. This feature is more fully discussed in my patent above referred to.

The structure of the transformers applicable to the system of Fig. 3 may in practice vary within rather wide limits, according to the requirements of any particular receiver. For example, structures such as described in my mentioned patent and in the patent to J. H. Pressley above referred to may well be employed. Such a transformer may be designed so that the coupling capacity $C_1$ is inherent between portions of the transformer windings themselves, although in this specific circuit arrangement such design is not so convenient as in the arrangement of Fig. 2.

Figs. 4 and 4*a* illustrate the essential features of a preferred coil structure suitable for use as the antenna coupling transformer A of Fig. 2, of which the essential construction data is given below. Although this design has proven exceptionally satisfactory for the purpose intended, it may be varied, of course, to suit different requirements while retaining the essential improvements introduced by this invention.

Secondary coil (L), inductance—258$\mu$H 144 turns #28 enameled wire spaced 64 turns per inch.

Large primary coil ($L_2$), inductance—618$\mu$H 240 turns #36 double silk covered wire random-wound.

Small primary coil ($L_1$) 20 turns #30 enameled wire spaced 64 turns per inch.

Mutual inductance between L and $L_2$—27$\mu$H.

Coefficient of coupling between L and $L_2$—7%.

Capacity $C_1$ between L and $L_1$—90$\mu\mu$f.

These windings may be supported by a cylindrical insulating form about 3¾ inches long and 1¼ inches in diameter.

The secondary winding L may be wound upon this form in a single layer beginning about ½ inch from the lefthand end of the cylindrical form. The small primary coil $L_1$ would then be wound beginning at the extreme righthand end of the secondary coil L and covering that coil in a single layer for such distance as the 20 turns may require, a sheet of 10-mil celluloid having been interposed. The large primary coil $L_2$ may be supported on an insulating spool or bobbin, being random-wound in a slot in the spool about $\frac{3}{16}$ inch wide and about ⅜ inch deep. The bobbin should be located within the cylindrical form near the lefthand end approximately beneath the end of secondary coil L which is to be connected to the grid of the following tube.

Fig. 4*a* shows a partial end view of the windings upon the coil structure of Fig 4, and illustrates the directions in which the three coils of the transformer are wound. It is to be noted that the small primary coil $L_1$ is connected at one end to the antenna and is left open at the other end. This coil thus acts also as the plate of a condenser of which a few turns at the end of coil L act as the other plate.

The structure just described relates particularly to an antenna coupling transformer which will provide a high voltage amplification at the higher frequencies. Consequently, the subsequent interstage transformers, of which transformer B of Fig. 2 is one, may appropriately be designed to have a higher amplification at the lower frequencies, thereby maintaining a substantially uniform sensitivity for the amplifier as a whole. The structural design of these interstage transformers may in general be similar to that of Fig. 4; and electrically the design should follow the rules that the large primary $L_2$, taken together with the capacity effectively in parallel therewith, be resonant at a frequency slightly below the lowest frequency of the operating range of the tuned system, and that the coefficient of coupling between $L_1$ and L and between $L_2$ and L fall within the limits prescribed above.

The coil structure illustrated in Figs. 4 and 4*a* has, as already described, the advantage of providing, by virtue of its own construction, the capacity $C_1$ of the coupling system illustrated in Fig. 2. The alternative structures shown in Figs. 5 and 6 have for their purpose a further simplification, and may be used with the circuit of Fig. 1 or Fig. 3. In both of these cases the two primary coils are wound continuously on a bobbin, or as a self-supporting "Universal" coil, a tap being provided for the intermediate connection between coils $L_1$ and $L_2$. If the circuit of Fig. 1 is used with these coil structures, it is possible in some cases to eliminate the condenser $C_1$, as in Fig. 2, by employing the natural capacity between coils $L_1$ and L. In these two structures the electromagnetic coupling between L and $L_1$ should be quite close, whereas the coupling between L and $L_2$ need be only moderate. The only important difference between the structural arrangements of Figs. 5 and 6 is that in Fig. 5 the coils $L_1$ and $L_2$ are mounted inside of the cylindrical single layer coil L, whereas in the structure of Fig. 6 they are outside of the coil L, but in both cases coils $L_1$ and $L_2$ bear the same electrical relations to coil L.

I claim:

1. A tunable high-frequency coupling system for coupling an antenna to a high-frequency thermionic amplifying tube, said system including an input path comprising two parallel branches connected between antenna and ground, a first of said branches comprising only a large inductance, the second of said branches comprising a much smaller inductance connected at one end to said antenna and at the other end in series with an effective capacity to ground, whereby said capacity is effectively in parallel with said large inductance, and a resonant circuit comprising an inductance coil and a variable condenser effectively in parallel between the input terminals of said amplifying tube, said variable condenser being adjustable to tune said coupling system over a frequency range, the inductance coil of said resonant circuit being electromagnetically coupled to each of the inductances of said input path and being in close proximity to said smaller inductance whereby there exists a substantial capacity therebetween which constitutes said effective capacity to ground, said large inductance together with the total capacity effectively in parallel therewith being resonant at a frequency somewhat below the lowest frequency of said range.

2. A high-frequency coupling system adapted to couple two successive tubes of a tuned thermionic amplifier, an input path through said coupling system comprising two parallel branches connected between the plate electrode of the first of said tubes and the cathode system, a first of said branches comprising only a large inductance, the second of said branches comprising a much smaller inductance connected at one end to said plate electrode and at the other end through an effective capacity to said cathode system, whereby said capacity is effectively in parallel with said large inductance, and a resonant circuit comprising an inductance coil and a variable condenser effectively in parallel between the input electrodes of the second of said tubes, said condenser being adjustable to tune said coupling system over a frequency range, the inductance coil of said resonant circuit being electromagnetically coupled to each inductance of said input path and being located in close proximity with said smaller inductance whereby there exists a substantial inter-winding capacity therebetween which constitutes said effective capacity, said large inductance together with the total capacity in parallel therewith (including the plate-cathode capacity of the first of said tubes and said capacity in series with said smaller inductance) being resonant at a frequency somewhat lower than the lowest frequency of said frequency range.

3. A tuned high-frequency coupling system having an input terminal, an output terminal and a common terminal, an input path comprising two parallel branches connected between said input and said common terminals, the first of said branches comprising only a large inductance, the second of said branches comprising a much smaller inductance having one end connected effectively through a series capacity to said input terminal, and having the other end connected to said common terminal, whereby said capacity is effectively in parallel with said large inductance, and a resonant circuit comprising an inductance coil and a variable condenser effectively in parallel between said output and said common terminals, said output and said common terminals being connected respectively to the grid and cathode of a thermionic amplifying tube, said variable condenser being adjustable to tune said coupling system over a frequency range, said resonant circuit being electromagnetically coupled to each of said inductances of said input path, the larger of the inductances of said input path together with the total capacity effectively in parallel therewith being resonant at a frequency somewhat below the lowest frequency of said range, and a neutralizing capacity connected from the plate electrode of said amplifying tube to the junction point of said smaller inductance and said series capacity, whereby capacity coupling between said plate and grid electrodes may be neutralized.

4. A high-frequency coupling system adapted for use in coupling an antenna and ground system with the input of a thermionic tube having a cathode and a grid electrode, said transformer comprising in combination

a first single-layer cylindrical winding tunable by a variable condenser over a desired frequency range, one end of said cylindrical winding being connected to the grid of said tube and the other end being connected to the cathode thereof, a second and shorter cylindrical winding having much fewer turns than said first winding coaxially located opposite the cathode end thereof and insulated therefrom, the end of said second winding opposite the cathode end of said first winding being unconnected and the other end thereof being connected to said antenna, whereby there is established a capacity effectively between the cathode system and said second winding, and a third winding of compact form connected between said antenna and ground comprising many more turns than said first and second windings and positioned close to said first winding, the coefficient of coupling between said first and third windings being less than the coefficient of coupling between said first and second windings, whereby there is secured a desired variation of coupling with frequency of tuning.

5. A high-frequency coupling system adapted for use in a coupling network associated with the grid electrode and cathode of a thermionic tube, said network having two input terminals only one of which is connected to said cathode, said network comprising a single-layer distributed cylindrdical winding connected in parallel with a variable condenser between the grid and cathode of said tube, whereby said coupling network may be tuned over a desired frequency range, and a compact multi-layer annular winding having more turns than said cylindrical winding comprising two coil portions one of which contains many more turns than the other, the small coil portion of said multi-layer winding being placed closer to the cathode end of said cylindrical winding than the large portion thereof, the junction point between said two coil portions being connected to the remaining one of said input terminals, the remaining end of the small coil portion being effectively connected through a capacity to the cathode system, and the remaining end of the large coil portion being connected to said input terminal connected to said cathode system.

6. A tunable high frequency coupling system having an input terminal, an output terminal and a common terminal, an input path comprising two parallel branches connected from said input terminal to said common terminal, a first of said branches comprising a relatively large primary inductance, the second of said branches comprising a much smaller primary inductance, said inductances being joined together and their junction being connected to said input terminal, and a resonant circuit comprising elements including a secondary coil and a capacity effectively in parallel between said output and common terminals, one of said elements being adjustable to tune said coupling system throughout a range in frequency, said resonant circuit being electromagnetically coupled to both of said inductances, said smaller primary inductance being located in close proximity to said secondary inductance whereby there exists a substantial inter-winding capacity between said smaller primary inductance and said secondary inductance which inter-winding capacity is effectively in series between said smaller primary inductance and said common terminal, said coupling capacity serving to tune said larger primary inductance to a frequency below said frequency range.

7. A tunable high frequency coupling system having an input terminal, an output terminal and a common terminal, an input path comprising two parallel branches between said input and said common terminals, a first of said branches comprising only a large inductance, the second of said branches comprising a much smaller primary inductance, said inductances being joined together and the junction being connected to said input terminal, and a resonant circuit comprising an inductance and a variable condenser in parallel between said output and common terminals, said condenser being adjustable to tune said coupling system over a frequency range, the inductance of said resonant circuit being electromagnetically coupled to both of said primary inductances, said smaller primary inductance being located in close proximity to said secondary inductance whereby there exists a substantial inter-winding capacity which is effectively in series between said smaller primary winding and said common terminal which inter-winding capacity serves to tune said larger primary inductance to a frequency slightly below said frequency range.

In testimony whereof I affix my signature.

HAROLD A. WHEELER.