Jan. 24, 1933. H. A. WHEELER 1,895,091

ELECTRIC COUPLING CIRCUIT

Filed Aug. 19, 1930

Fig. 1,

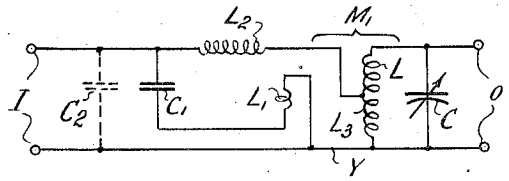


Fig. 2,

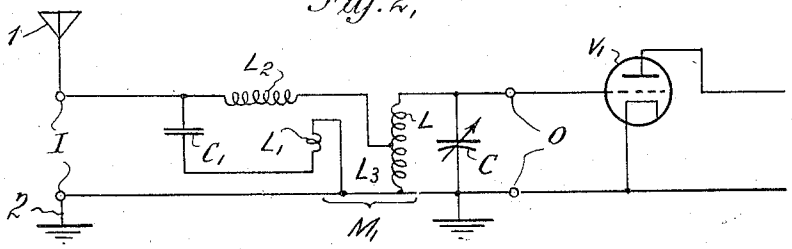


Fig. 3,

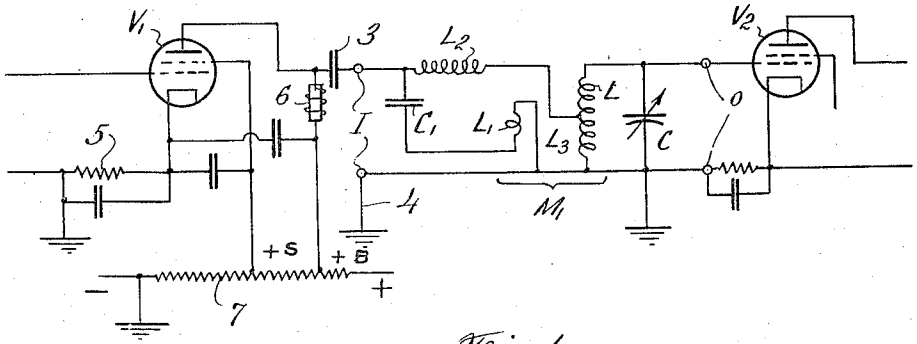
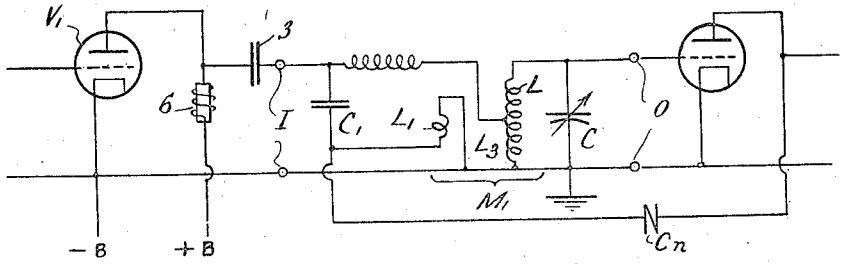


Fig. 4,



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UNITED STATES PATENT OFFICE

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ELECTRIC COUPLING CIRCUIT

Application filed August 19, 1930. Serial No. 476,393.

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

The coupling circuits of the present invention are characterized in that the voltage amplification produced thereby is caused to vary automatically with the frequency of 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.

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

In the elementary type of coupling circuit referred to there exists between the primary and tunable secondary circuits a degree of coupling which is substantially constant throughout the tunable range, a condition which is partially responsible for the mentioned increase in amplification with frequency. The present invention avoids the resulting disadvantages by proper inclusion of suitable reactance elements adapted to provide an effective coupling between the input and tunable output circuits which automatically decreases with increase in the tuned frequency and thereby may be proportioned to offset wholly or in part the factors operative to produce an increase in amplification with frequency.

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 set forth in Patent No. 1,763,380 issued to C. E. Trube, and in his copending applications Serial Nos. 101,906, filed April 14, 1926 and 120,045 filed July 2, 1926.

The coupling circuits of the present invention embody the following essential elements, namely: a tunable secondary circuit including a fixed inductive winding and variable capacity bridged between output terminals, and a primary circuit including in closed series connection in the order named, a tapped portion of the secondary winding, a first primary coil uncoupled magnetically to said secondary winding, a fixed capacity and a second primary winding of relatively few turns compared to the said first primary winding, the second primary winding being magnetically coupled to the secondary winding in such manner as to transfer energy from the primary to the secondary circuit in additive relation to that of the tapped portion of the secondary. Input terminals are so connected to the closed primary circuit as to provide therebetween a pair of parallel paths, one path containing the first primary winding and the tapped portion of the secondary winding while the other path contains the fixed capacity and the second primary winding.

An additional capacity may or may not be connected between the input terminals, or in the operation of the circuit, capacity may exist between these terminals due to the type of input circuit connected thereto. Irrespective of the particular arrangement used, the resultant capacity associated with the inductance of the primary circuit, including the fixed capacity of the closed series connection as well as any capacity existing between the input terminals, should be such as to render the primary circuit resonant at a frequency lower, but not greatly lower than the lowest frequency within the tunable range.

The objects attained by such design (1) provide an effective coupling between the primary and secondary circuits which automatically falls off as the resonance frequency of tuning is increased, but at a rate proportioned to produce a desired variation in amplification with frequency, and (2) control the variations of the input impedance of the coupling circuit throughout the tunable range in such

manner as to insure improved stability, selectivity and amplification in the operation of the circuit.

The manner in which the results of the present invention are achieved will be more clearly understood upon detailed consideration of the circuit connections set forth in the drawing of which:

Fig. 1 shows in diagrammatic form the elementary coupling circuit of this invention;

Fig. 2 show the coupling circuit of Fig. 1 as utilized for interconnecting an antenna circuit and the input to a thermionic tube;

Fig. 3 is a diagrammatic representation of the circuit as employed for interconnecting a pair of screen-grid thermionic tubes in cascade relation; while

Fig. 4 shows an interstage connection employing triode tubes wherein the coupling circuit is arranged in conjunction with a suitable capacity to provide neutralization of the interelectrode tube capacities.

Like elements are similarly designated in the several figures.

Referring to the drawing the coupling circuit includes a resonant secondary circuit consisting of a fixed inductive winding L and a variable tuning condenser C bridged between the output terminals O. The primary circuit associated with input terminals I includes inclosed series connection in the order named; a portion L_3 of secondary winding L, a fixed inductive winding L_2, magnetically uncoupled from winding L, a fixed capacity C_1, and a second primary winding L_1 of relatively few turns compared to L_2, magnetically coupled to winding L as indicated.

The input terminals I are connected between the elements C_1 and L_2 and between L_1 and L_3 respectively, in order to provide the parallel paths therebetween one of which contains windings L_2 and L_3 while the other path contains elements C_1 and L_1.

The capacity C_2 shown dotted, is intended to represent the entire capacity connected between the input terminals while the circuit is in operation, and in conjunction with capacity C_1 together with any additional capacities associated with the primary circuit inductance which includes elements L_1, L_2 and L_3, should be such as to tune the primary circuit to a frequency lower, but not greatly lower, than the lowest frequency within the tunable range as determined by adjustment of condenser C. It is not essential to the operation of the circuit that a capacity C_2 exist between input terminals I. In the event that the capacity C_2 is zero, however, it is required that the capacity C_1 be of such magnitude as to render the primary circuit resonant at the low frequency specified above.

The elements of the primary circuit as thus proportioned assure that the path between the input terminals I containing the elements C_1 and L_1 will be capacitively reactive throughout the tunable range and hence of decreasing impedance for increases in tuned frequency; whereas the path containing elements L_2 and L_3 being inductively reactive, will increase in impedance with the frequency of tuning. Thus the windings L_1 and L_3 produce effects in the tuned circuit LC which vary in opposite sense with the tuning adjustment.

The circuit including the winding L_1 has its greatest effect at the higher tuned frequencies due to approach to series resonance between condenser C_1 and the relatively small effective inductance of winding L_1. The circuit including the winding L_3 is most effective at the lower tuned frequencies due to approach to parallel resonance at the mentioned frequency below the tuning range of the primary circuit as a whole, i. e., windings L_2 and L_3 and the total capacity effectively in shunt thereto.

By properly proportioning these effects which vary oppositely with frequency, and combining them in additive relation in the tuned secondary circuit, a resulting effective coupling is obtained between primary and tuned secondary circuits which may be caused automatically to decrease with increase in tuned frequency, in a manner which is under control of the designer, and which with sufficient accuracy is expressed by the following equation:

$$(1)\quad m = m_3 + m_4/(f^2/f_2^2 - 1)$$

where f is the frequency of tuning, f_2 the resonant frequency of the primary circuit and

$$(2)\quad m_3 = -M_1C_1/(C_1+C_2)$$

$$(3)\quad m_4 = -[M_3 + M_1C_1/(C_1+C_2)]$$

M_1 and M_3 being the mutual inductance between windings L_1 and L and between L_3 and L respectively, while the values of C_1 and C_2 are as indicated in the drawing.

The additive effects of windings L_1 and L_3 upon the tuned secondary circuit LC are obtained by connecting windings L_1 and L in opposite open circuit polarity to the lower input terminal I. This reversal of connection is required to offset the substantial phase opposition of the primary circuit currents flowing in the paths C_1—L_1 and L_2—L_3, respectively, resulting from the predominant capacitive reactance of the former and the inductive reactance of the latter throughout the tunable frequency range.

In Fig. 2 the input terminals I of the coupling circuit are connected to an antenna 1 and a ground 2 respectively, while the output terminals O are connected to grid and cathode respectively of a thermionic tube V_1. The capacity C_2 of Fig. 1 in Fig. 2 comprises the effective antenna-to-ground capacity of the antenna 1 which in conjunction with capacity C_1 renders the primary circuit reso-

nant at a frequency below the tunable range.

In Fig. 3 wherein the coupling circuit interconnects a pair of screen grid tubes V_1 and V_2 in cascade relation, the upper input terminal I is connected to the anode of tube V_1 through a blocking condenser 3 while the lower input terminal I is joined to the cathode of tube V_1 through the ground 4 and the space current grid bias circuit 5 comprising resistance shunted by a high frequency bypass condenser.

Space current for tube V_1 is supplied through a choke coil 6 connected directly from the anode thereof to the +B tap of resistance 7 forming part of a direct current supply circuit. The blocking condenser 3 is interposed between the upper input terminal and the choke coil 6 to prevent grounding the anode potential through the coupling circuit.

The output terminals O of the coupling are connected respectively to the grid and through the bias circuit to the cathode of tube V_2. The capacity C_2 of Fig. 1 comprises in Fig. 3 the anode-to-ground capacity of tube V_1, the capacity 3 in series therewith being sufficiently large that in general its effect may be neglected in comparison. The inductance of the primary circuit in conjunction with the associated capacities is of course resonant at a frequency slightly below the tunable range.

The coupling circuit of Fig. 4 interconnects a pair of triode tubes in cascade relation, each tube including anode, cathode and grid electrodes only. In order to neutralize the grid-to-anode capacity of tube V_2, a condenser C_N is connected from the anode thereof to a point between the fixed capacity C_1 and the primary winding L_1. The neutralization is accomplished in the manner disclosed in Patent No. 1,450,080 to L. A. Hazeltine the magnetic coupling between windings L_1 and L being close.

In Fig. 4 the total anode-to-ground capacity of tube V_1 corresponds to the capacity C_2 of Fig. 1. If tube V_1 also has a neutralizing condenser like C_N connected to its anode, then this also is effectively in parallel with the input terminals. It will be noted that in all of the Figures, 2 to 4 inclusive, the rotor element of the variable condenser C is grounded, a very desirable feature since it prevents certain interstage couplings.

I claim:

1. An electrical coupling system comprising a tunable secondary circuit including a fixed secondary winding and variable capacity bridged between output terminals, a primary circuit including in closed series connection, in the order recited, a portion of said secondary winding, a fixed inductance, a fixed capacity and a primary winding magnetically coupled to said secondary and of small inductance relative to said fixed inductance, a pair of input terminals connected to said primary circuit for providing shunt paths therebetween, one path including said fixed inductance and said secondary winding portion, and the other including said fixed capacity and primary winding, the inductance of said primary circuit in conjunction with associated capacity being resonant at a frequency below the tunable range for controlling the variation in coupling between said primary and secondary circuits throughout a tunable frequency range.

2. A high frequency electrical coupling circuit for interconnecting successive elements of a radio receiving system comprising in combination a tunable secondary circuit comprising fixed secondary inductance and variable capacity bridged between output terminals, a primary circuit including in closed series connection in the order recited a portion of said secondary inductance, a fixed inductance, a fixed capacity and a primary winding magnetically coupled to said secondary inductance and of small inductance relative to said primary inductance, and a pair of input terminals so connected to said primary circuit as to provide shunt paths therebetween, one path including said fixed primary inductance and said secondary portion, and the other path including said fixed capacity and primary winding, the inductance of said primary circuit in conjunction with the associated capacities, including any capacity effectively bridged between said input terminals, in the operation of said circuit being resonant at a frequency slightly below the tunable range for controlling the variation in coupling between said primary and secondary circuits throughout said frequency range.

3. In combination a high frequency electrical coupling circuit including a tunable secondary circuit comprising a fixed secondary winding and variable capacity bridged between a pair of output terminals, a primary circuit comprising in closed series connection in the order recited a portion of said secondary winding, a fixed inductance, a fixed capacity and a primary winding of small inductance relative to said fixed inductance and magnetically coupled to said secondary winding, a pair of input terminals connected between said fixed inductance and capacity and between said primary and said portion of said secondary windings respectively, and an input circuit connected to said input terminals, the inductance of said primary circuit, in conjunction with said fixed capacity and any capacity effectively bridging said input terminals due to said input circuit, being resonant at a frequency slightly below the tunable range for controlling the variation in coupling between said primary and secondary circuits throughout said frequency range.

4. In combination a high frequency amplifier comprising an electrical coupling circuit connecting a pair of thermionic tubes in cascade relation each tube having anode, cathode and control grid, said coupling circuit including a tunable secondary circuit comprising a fixed secondary winding and variable capacity bridged between grid and cathode of the second tube, and a primary circuit comprising in closed series connection a portion of said secondary winding, a fixed inductance, a fixed capacity and a primary winding of small inductance relative to said fixed inductance and magnetically coupled to said secondary, a connection from the anode of said first tube to a point between said fixed inductance and capacity and from the cathode thereof to a point between said primary winding and said portion of said secondary winding, the inductance of said primary circuit in conjunction with said fixed capacity and the anode-to-ground capacity of said first tube being resonant at a frequency slightly below the tunable range whereby in the operation of said amplifier uniformly high degrees of amplification are obtained throughout said frequency range.

5. In combination a high frequency electrical coupling system connected between an antenna circuit and a thermionic tube having anode, cathode and control grid, said coupling circuit comprising a fixed secondary winding and variable capacity bridged between said grid and cathode, and a primary circuit comprising in closed series connection, a portion of said secondary winding, a fixed inductance, a fixed capacity and a primary winding magnetically coupled to said secondary, said antenna circuit being joined to input terminals connected between said fixed inductance and capacity and between said primary winding and said portion of said secondary winding respectively, the inductance of said primary circuit in conjunction with said fixed capacity and the capacity of said antenna circuit effectively between said input terminals being resonant at a frequency slightly below the tunable range whereby in the operation of said system uniformly high degrees of amplification are obtained throughout said frequency range.

6. A high frequency electrical coupling circuit for interconnecting successive elements of a multi-stage thermionic radio receiver or amplifier comprising a tunable secondary circuit including a fixed secondary winding and variable capacity bridged between a pair of output terminals, and a primary circuit comprising a portion of said secondary winding and a fixed primary inductance serially connected between a pair of input terminals, together with a fixed capacity and a primary winding of small inductance relative to said primary inductance, also serially connected between said input terminals, the inductance of said primary circuit in conjunction with all associated capacities in the operation of said circuit being resonant at a frequency below the tunable range, said primary winding being coupled magnetically to said secondary winding and connected with opposite open circuit polarity relative to that of said secondary winding.

7. In combination a pair of thermionic tubes each including anode, cathode and control grid, and a high frequency coupling circuit connecting said tubes in cascade relation, said circuit including a fixed secondary winding and variable capacity in parallel joined at one side to the grid of the second tube and at the opposite side to said cathodes in common, a tap from an intermediate point of said secondary winding through fixed inductance to the anode of the first tube, a primary winding of small inductance relative to said fixed inductance and magnetically coupled to said secondary, said primary winding being connected from said cathode of said first tube through a fixed capacity to the anode thereof, and a condenser proportioned to neutralize the grid-to-anode capacity of said second tube connected from the anode thereof to a point between said fixed capacity and said primary winding, said primary winding having opposite polarity relative to that of said secondary winding.

8. In combination a high frequency electrical circuit coupling a pair of thermionic tubes in cascade relation, each tube including anode, cathode and grid, said circuit comprising a tunable secondary circuit including a fixed inductive winding shunted by variable capacity bridged from the grid of said second tube to said cathodes in common, a tap from an intermediate point of said secondary winding thru a fixed inductance to the anode of said first tube, a primary winding of small magnitude relative to said fixed inductance connected at one terminal to said cathodes and at its opposite terminal through a fixed capacity to the anode of said first tube, and to the anode of said second tube through a capacity proportioned to neutralize the anode-to-grid capacity thereof, said primary winding being so coupled magnetically to said secondary as to accomplish said neutralization, and said fixed inductance of said coupling circuit in conjunction with the associated capacities including the anode-to-ground capacity of said first tube, being resonant at a frequency slightly below the tunable range whereby in the operation of said circuit uniformly high degrees of amplification are obtained throughout said range.

In testimony whereof I affix my signature.

HAROLD A. WHEELER.