Feb. 8, 1944. H. R. SUMMERHAYES, JR 2,341,346

HIGH FREQUENCY COUPLING CIRCUITS

Filed Feb. 20, 1942

Fig. 1.

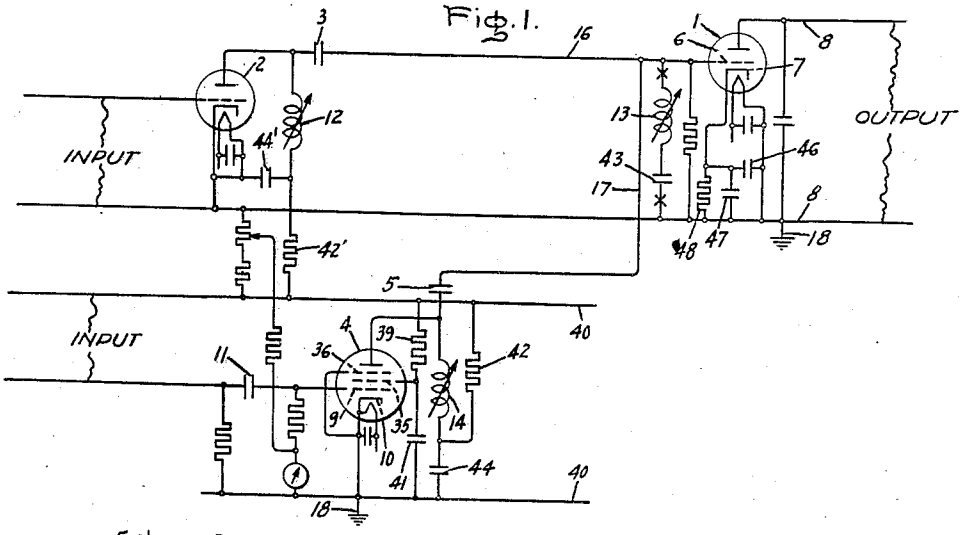


Fig. 2.

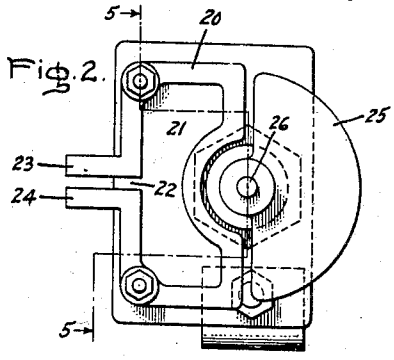


Fig. 5.

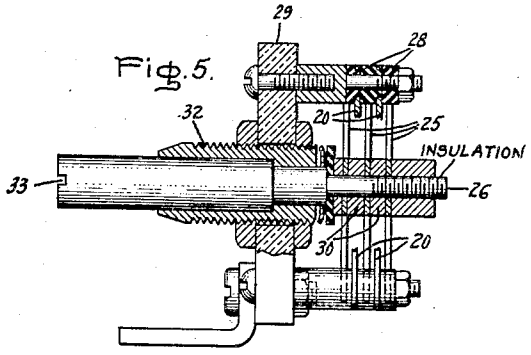


Fig. 3.

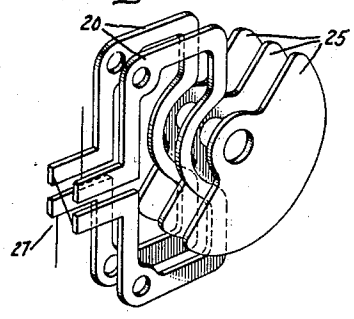
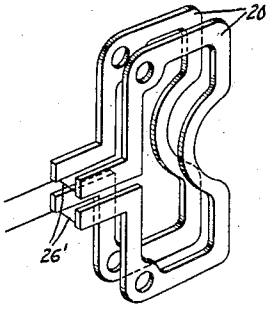


Fig. 4.



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HIGH FREQUENCY COUPLING CIRCUIT

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Application February 20, 1942, Serial No. 431,767

6 Claims. (Cl. 250—20)

My invention relates to high frequency coupling circuits employed between electron discharge devices and particularly to such circuits operating at frequencies at or approaching the range of frequencies where distributed reactance effects of the necessarily employed connections are so great as to dictate circuit structure designed to utilize such distributed reactance effects. Such circuit structure may comprise for example, conductors of desired length spaced to operate as standing wave lines and having connections thereto at points to afford the desired impedance effects.

Such structure is ordinarily expensive to build, is bulky, imposes undesired space requirements, and in general, is to be avoided in cases where circuit structure having concentrated reactance constants can be employed. This is especially true if the frequency at which the system operates is to be variable to any substantial extent.

An object of my invention is to provide an economical interstage circuit for use between electron discharge devices to afford coupling at such frequencies and in which concentrated variable reactance is employed to vary the tuning of the circuit over a wide range including frequencies where distributed constants are controlling in the design of the circuit.

More particularly, my invention relates to such coupling employed in a converter to couple the output of each of two amplifiers to the input of a frequency converter, the amplifiers operating at frequencies variable over a wide range and being different by only a very small percentage of either frequency.

An object of my invention is to provide an economical coupling network for such application which is tunable over a wide range by variation of concentrated inductance devices only and in which the upper limit of the range of frequencies is well within the range where circuit structure commonly employed is that of the distributed reactance type.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the drawing in which Fig. 1 represents the circuit structure of my invention; Figs. 2, 3, and 4 represent an inductance device for employment therein, and Fig. 5 represents in greater detail the mechanical structure of such an inductance device.

Referring to Fig. 1 of the drawing, I have illustrated therein at 1, an electron discharge device which operates as a frequency converter. Oscillations of a desired frequency are supplied thereto from a discharge device 2 through a coupling condenser 3 and oscillations of a different desired frequency are supplied thereto from a second discharge device 4 through a coupling condenser 5. These oscillations both appear between the input electrode 6 and cathode 7 of the discharge device 1 and combine to produce oscillations in the output circuit of discharge device 1 having a frequency equal to the difference between the two applied frequencies. These difference, or beat, frequency oscillations may be supplied over conductors 8 to any suitable load circuit.

I contemplate my invention for use more particularly in connection with frequency monitors for broadcast stations which operate by frequency modulation of the transmitted carrier wave. The carrier wave, the frequency of which is to be monitored, is supplied between the grid 9 and cathode 10 of the discharge device 4 through a coupling condenser 11. These frequencies may extend, for example, from 260 megacycles to 350 megacycles dependent upon the broadcasting station the frequency of which is to be monitored. Such oscillations are amplified by the discharge device 4 and combined between the grid 6 and cathode 7 of discharge device 1 with other oscillations of known frequency which are supplied through the discharge device 2. These other oscillations may have a frequency varying, for example, from 254.6 megacycles to 344.6 megacycles, or, in other words, over a range 5.4 megacycles lower than the range of frequencies supplied through discharge device 4. Thus a frequency of 5.4 megacycles is produced upon the output circuit 8 for any two applied frequencies.

The frequency of 350 megacycles is well within the range where careful consideration must be given to the distributed reactance effects and the circuit structure employed may well be that of the distributed reactance type, that is, circuit structure employing parallel spaced conductors operating as standing wave lines, etc., and provided with slidable bridge members, for example, for variation thereof. It is undesirable to employ structure of such character in a frequency monitor contemplated for the applications in which I contemplate my invention to find its

greatest utility, not only because of the expense of the apparatus and its cumbersomeness but also because the frequency must be variable over such a broad range as to render coupling circuits of that type difficult to build. I have found, however, that by the employment of the system presently to be described, such structure may be avoided and that the circuit may be tuned for operation at any frequency in the desired range solely by variation of concentrated inductance devices.

The inductance devices employed in accordance with my invention are indicated conventionally at 12, 13, and 14 in Fig. 1. The inductance device 12 is connected between the anode and cathode of the discharge device 2. The inductance device 13 is connected between the control electrode 6 and the cathode 7 of discharge device 1 and the inductance device 14 is connected between the anode and cathode of discharge device 4. So connected, the upper terminals of the inductance devices 12, 13, 14 are all connected together through the conductors 16 and 17 and the lower terminals of inductances 12, 13, and 14 are connected together through respective condensers 44', 43 and 44 and to ground as indicated at 18.

The condensers 44', 43 and 44 in series with the respective inductance devices 12, 13, and 14 are bypass condensers having substantially zero reactance at the frequencies employed. These condensers are of very small physical dimensions thereby avoiding any undesired reactance effects encountered by reason of the lengths of leads, etc. The discharge devices 2 and 4, in the physical embodiment of the equipment, are spaced as close as practicable to the discharge device 1 but in such practical spacing of the discharge devices, the length of each of the conductors 16 and 17 may be, for example, 2 inches or more. At a frequency of 350 megacycles the length of the connections between discharge devices 2 and 1 and between discharge devices 4 and 1 comprise a substantial part of a quarter of a wave length and hence these connections afford a very substantial impedance to the transmission of these high frequency oscillations. I have found, however, that very satisfactory transmission of oscillations of desired frequency from the discharge devices 2 and 4 to the converter 1 is had by employment of the inductance 12, 13, and 14 of the type later to be described in the manner explained.

While I am not entirely satisfied as to the exact manner of the operation of the apparatus I believe that the inductance 12, when adjusted for operation, resonates with the interelectrode capacity between the output electrodes of discharge device 2, that the inductance 13, when properly adjusted, resonates with the interelectrode capacity between the input electrodes of the discharge device 1 and that the inductance device 14 resonates with the interelectrode capacity between the output electrodes of discharge device 4, all of these resonances occurring at some frequency between the two applied frequencies. Since these inductances so resonate, they produce high impedances between these different pairs of electrodes at that frequency. The two applied frequencies differ by such a small percentage, less than two per cent, that this high impedance exists for both of the applied frequencies. That is the Q of the circuit or the ratio of inductive reactance to resistance, is not so great but that these frequencies may both fall near the top of the resonance curve. This impedance between the different electrodes of the different pairs of electrodes is so high that the impedance of the interconnecting conductors comprising conductors 16, 17 and the cathode return conductors is small in comparison therewith.

It may be, however, that these inductances 12, 13, and 14 all operate in parallel as a single inductance to resonate with the sum of the capacities existing across the circuit, and that the shunt combination of the three inductances reduces the total inductance across the circuit to a sufficiently low value to produce the required resonance at the highest frequencies in the range. Since the different inductances are spaced apart sufficiently to avoid substantial mutual coupling therebetween such reduction in inductance is readily possible. Such consideration might suggest that the three inductances be all connected together across a single pair of points on the circuit. However, three such inductances spaced closely together would have sufficient mutual to prevent reduction to the required low value at the high frequencies. This is true even though the different inductances be positioned in planes mutually at right angles to each other. It might also suggest a single inductance device with more stator plates connected in parallel and more rotor plates. However, the addition of more stator and rotor plates is not likely to afford the required reduction in inductance because of the mutual between the different stator plates. Accordingly, I believe that my invention operates according to the theory first above explained, particularly at the upper end of the range.

Whatever may be the theory of the operation of the circuit, however, I have found that very satisfactory transmission takes place with the equipment arranged as thus explained and that such efficient transmission may be had at any frequency in the range of from 260 to 350 megacycles by variation only of the concentrated inductance devices 12, 13, and 14.

These inductance devices 12, 13, and 14 are of the type described and claimed in copending application S. N. 363,016 of Lewis H. Van Billiard, filed October 26, 1940, entitled Tuning system, and which is assigned to the same assignee as my present application.

Fig. 2 represents a plan view of one of these inductance devices. It comprises a plate 20, which may be an ordinary sheet metal punching as is ordinarily used in the stator section of a variable condenser. This plate 20 has a large aperture 21 punched therein, leaving a portion of the plate formed about the periphery of the aperture, this periphery being broken at 22. The two terminals of the inductance are taken from points adjacent this break 22 in the periphery, such points being indicated at 23 and 24. These points, or terminals, may be connected through the bypass condensers as shown in Fig. 1, with connecting leads as short as possible, to the respective electrodes of the discharge device to which the inductance is to be connected.

In order that the inductance be variable, a pair of rotor plates 25 are provided, mounted upon a shaft 26 about which it is rotatable. These plates may each be in the form of a half of a disk rotatable from the position shown in Fig. 2 to a position in proximity to the plate 20, one on either side of that plate, whereby they practically cover the aperture 21 in the plate 20 and

since they are conducting members they reduce the inductance between terminals 23 and 24 substantially to zero. As the members 25 are rotated from such position to the position shown the inductance between terminals 23 and 24 changes from substantially zero value to one of very substantial value at the frequencies employed.

Fig. 3 represents, in a perspective view, such an inductance device in which two stator members 20 are arranged in parallel space relation and connected in series as indicated at 27. This device also comprises three of the rotor members 25 positioned for rotation into interleaved relationship with the stator plates 20. Thus it will be seen that the inductance of this device varies substantially from zero to values which may be approximately twice as great, or even more than that obtained with but a single stator plate.

Fig. 4 represents the arrangement in which two stator plates 20 are connected as indicated at 26' for parallel operation to reduce the inductance obtainable. It will, of course, be understood that in such an inductance device more stator plates may be utilized and that the stator plates may be connected in parallel relation, series relation, or series-parallel relation, as may be required.

Fig. 5 is a sectional view with parts in elevation taken on the line 5—5 of Fig. 2. The stator plates 20 are shown broken away but positioned in parallel relation, in interleaved relation with the rotor plates 25. The stator plates are mounted in insulating material 28, bolted in any suitable way to the form member 29. The rotor plates are likewise mounted together in parallel space relation between the bushings 30 which may be either conducting or nonconducting but which are mounted upon a nonconducting shaft 26 arranged in a bearing member 32, for rotation, as by means of a screwdriver applied to a notch 33 in the end of the shaft. Of course, any suitable handle or knob may be provided as desired.

The structure of the inductance devices employed is very important in the operation of the circuit described and in addition affords the advantage that they are economical to build. These inductance devices may comprise the frame structure of any ordinary standard variable condenser. The stator plates of such a condenser may be removed and suitable punchings, as indicated, substituted therefor. The shaft may also be removed and replaced by the nonconducting shaft indicated in Fig. 5.

The stator plates being of sheet metal and of sufficient strength to be rigid and self-supporting, may have holes punched therein to permit mounting in close parallel space relation so that the rotor plates may move freely therebetween without contact therewith, and also with a minimum of space between the different plates. These stator plates may also be shaped so that the terminals 23 and 24 thereof may be spaced as close together as possible to reduce the length of the path between the terminals to as little as possible. In this way, a minimum of inductance is obtainable when the rotor plates are in full interleaved relation with the stator plates.

With such a structure, inductances of concentrated, readily variable form and of sufficiently low value to operate at the highest frequencies in the ranges mentioned and over the ranges mentioned are readily obtainable. I have found in the operation of the system that in the upper portion of the range extending, for example, from 300 to 350 megacycles, all three of the inductances, 12, 13, and 14 are necessarily in the circuit. In the range from 260 to 300 megacycles, however, I find it necessary to remove one of these inductances, preferably the inductance 13. This may be effected by breaking the circuit at the points near adjacent terminals of this inductance which are marked X on Fig. 1 of the drawing.

Preferably in the equipment thus described, the discharge device 4 is one employing a screen grid 35 and a suppressor grid 36, the screen grid being connected through a resistance 39 to a source of operating potential which may be connected between conductors 40. The suppressor grid is connected to the cathode of the discharge device. Of course, the screen grid is grounded at the frequencies in question through a condenser 41. Voltage is also supplied to the anode of discharge device 4 through a suitable isolation filter comprising resistance 42 and condenser 44. Similar circuits are of course employed in connection with the other discharge devices, that in connection with discharge device 2 being indicated at 42' and 44'.

The cathode of discharge device 1 is grounded through a condenser 46 at the frequencies of currents supplied to the input of the discharge device, this condenser being one of small capacity arranged as close as is practicable to the cathode of the discharge device. It is also grounded for currents of the 5.4 megacycle frequency through a larger condenser 47 which is connected across a cathode bias resistance 48.

While I have shown a particular embodiment of my invention, it will of course be understood that I do not wish to be limited thereto since various modifications both in the circuit elements and in the instrumentalities employed may be made and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. In combination, a pair of amplifiers operating at frequencies differing from each other by a small percentage and varying over a wide range, each of said amplifiers having a pair of output electrodes, a discharge device having a pair of input electrodes, all of said pairs of electrodes being connected in parallel, the frequencies at which said amplifiers operate being so high that the length of the connections from said pairs of output electrodes to the input electrodes of said discharge device is a substantial part of a quarter of a wave length of the waves at which the respective amplifiers operate, and a pair of inductances, each inductance being connected between said electrodes of a respective one of said amplifiers and spaced close thereto so that said length of said connections extends from said inductance to said discharge device, said inductance being variable to resonate with the interelectrode capacity between the respective electrodes at any frequency in a wide range.

2. In combination, a pair of electron discharge amplifiers, each of said amplifiers having an anode and a cathode, an electron discharge device operating as a frequency converter having a cathode, a control electrode, and an output circuit, all of said cathodes being connected together and each of said anodes being connected to said control electrode through a respective conductor having a length equal to a substantial portion of a quarter of a wave length of the wave at which the respective amplifier operates, said amplifiers operating at short wave lengths varying over a

wide range, the frequency at which one amplifier operates being different from that of the other by a small percentage thereby producing a low frequency in said output circuit of said converter, and a pair of inductance devices, each inductance device being connected between said anode and cathode of one of said amplifiers and proportioned to resonate with the capacity between the respective electrodes and positioned an unsubstantial part of a wave length from said respective electrodes.

3. In combination, a pair of electron discharge amplifiers, each of said amplifiers having an anode and a cathode, an electron discharge device operating as a frequency converter comprising a cathode, a control electrode, and an output circuit, said anodes being connected to said control electrode through respective conductors having a length equal to a substantial portion of a quarter of a wave length of the wave at which the respective amplifier operates, said amplifiers operating at short wave lengths varying over a wide range, the frequency at which one amplifier operates being different from that of the other by a small percentage, thereby producing a low frequency in said output circuit of said converter, a plurality of inductance devices, each inductance device being connected between said electrodes of a respective one of said amplifiers and converter, and proportioned to resonate with the interelectrode capacity between the respective electrodes, said inductances being spaced adjacent said respective electrodes.

4. In combination, a pair of electron discharge devices operating at high frequency, one of said devices having a pair of input electrodes and the other of said devices having a pair of output electrodes, said pairs of electrodes being connected in parallel whereby oscillations from said output electrodes are supplied to said input electrodes, said devices being mounted as close together as practicable but the frequency of said oscillations being so great that the short interconnections between said pairs of electrodes have a length equal to a substantial part of a quarter of a wave length of said oscillations, a pair of inductances, each inductance being connected between a respective pair of said electrodes and resonating with the capacity therebetween, and being spaced apart by said substantial part of a quarter of a wave length.

5. In combination, a high frequency electron discharge amplifier having a pair of output electrodes, a second electron discharge device having a pair of input electrodes, capacitive coupling between said pairs of electrodes through connections having a length such that substantial inherent impedance produced by reason of distributed reactance exists in said connections at the frequency at which said amplifier operates, a pair of inductance devices, each inductance device comprising a conductor shaped about the periphery of an enclosure, said periphery being broken at one point, the points of said conductor adjacent said break being connected to opposite electrodes of a respective one of said pairs, and a conducting member parallel with said plane of said conductor and movable into proximity thereto to reduce the inductance of said conductor, said inductance being substantially zero on one extreme of movement of said member and of substantial value at the other extreme of movement of said member, said inductance of each of said inductance devices being variable to resonate with the capacity between the respective electrodes to which it is connected at any frequency in a wide range.

6. In combination, a pair of electron discharge devices operating at high frequency, each of said devices having a pair of output electrodes, a third electron discharge device having a pair of input electrodes, a plurality of conducting plates, each conducting plate being shaped to form an enclosure and having inductance between two closely spaced points thereof, said points of each plate being connected to opposite electrodes of a respective one of said pairs, said plates being spaced apart sufficiently to have little mutual inductance, connections between said different pairs of electrodes, and a plurality of movable plates, each movable plate being spaced in parallel relation with a respective one of said first plates and movable to close spaced relation thereto whereby the inductance of said plates may be reduced to resonate with the capacity between the respective electrodes at a frequency so high that the length of the conductors comprising said connections is a substantial part of a quarter of the operating wave length, and efficient transfer of energy from said pair of discharge devices to said third discharge device is produced.

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