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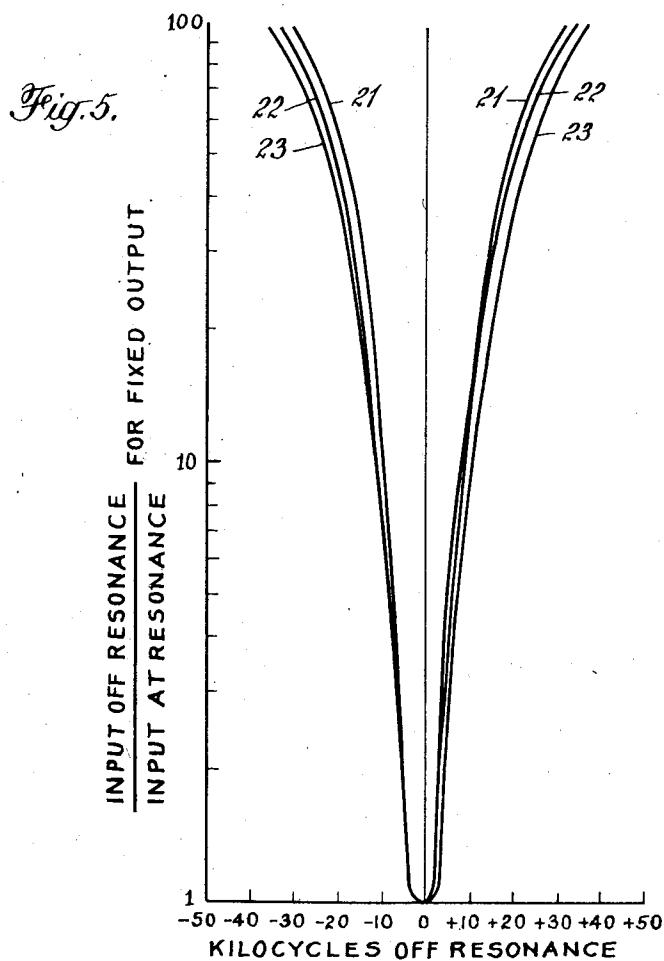
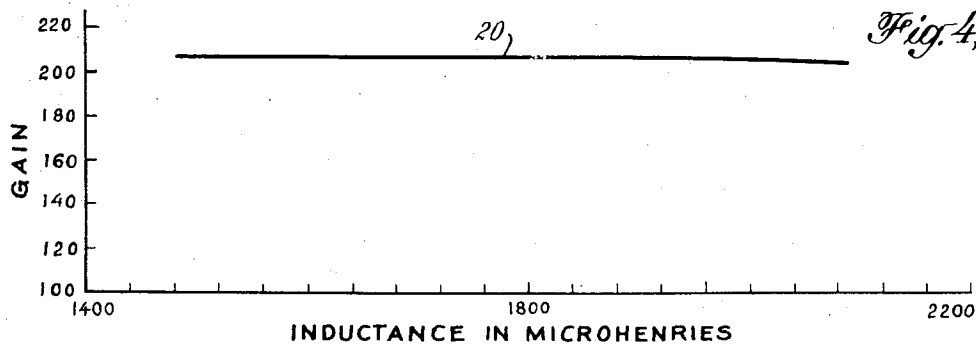
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PERMEABILITY-TUNED INTERMEDIATE-FREQUENCY TRANSFORMER

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2 Sheets-Sheet 2



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PERMEABILITY-TUNED INTERMEDIATE-FREQUENCY TRANSFORMER

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6 Claims. (Cl. 178-44)

This invention relates to improvements in high-frequency resonant systems, such, for example, as those which are generally employed between the output terminals of a first vacuum tube and the input terminals of a second vacuum tube, and which are intended for operation at a particular frequency, for example, in the intermediate-frequency amplifiers of radio receivers of the superheterodyne type.

Resonant systems of the above-mentioned type are of two principal forms, one employing a single resonant circuit and the other employing two coupled resonant circuits, each circuit having an inductor and a capacitor, one or both of which elements is adjustable to align the circuits at a particular frequency or to permit varying the resonant frequency of each circuit over a limited range. The present invention is particularly addressed to the form employing two resonant circuits.

Fixed air-core inductors shunted by adjustable tuning capacitors have been in common use in coupled resonant-circuit devices, the two inductors being so arranged with respect to each other as to provide, at some chosen frequency, a desired degree of inductive coupling between the two resonant circuits. The usual type of adjustable "trimmer" capacitor, however, is appreciably affected by changes in temperature, and such capacitors also change in capacitance value with time, thus making it difficult if not impossible to maintain the desired performance characteristics in capacitively tuned fixed-inductance coupled resonant-circuit devices of the types now commonly employed.

The difficulty just described may be eliminated by employing fixed capacitors and accomplishing tuning by the use of variable inductors, preferably of the type employing movable ferromagnetic cores for inductance adjustment. In such a device, the resonant circuits may be tuned by inductance variation to secure alignment at a desired frequency and, once established, this alignment is substantially permanent. Several forms of coupled resonant-circuit devices adjustable by movable ferromagnetic cores have already been proposed, and in some of these the arrangement is such as to maintain the overall selectivity nearly the same for all positions of the adjustable cores.

Under certain circumstances, and in certain types of radio broadcast receivers and other similar apparatus, however, it may be highly desirable to maintain the gain, rather than the selectivity, of such a coupling device substantially

constant as the cores are adjusted to secure resonance at the desired frequency. As will be clear from what is to follow, this is a different and a considerably more difficult problem than maintaining constant selectivity, and its solution demands a radically different choice and arrangement of the components. The present invention presents the solution of this problem and describes illustrative embodiments which in actual practice have been found to achieve the desired result in a highly satisfactory manner.

It is to be noted that since the conditions which must be fulfilled to secure constant gain are mathematically different from those required for constant selectivity, any practical device which achieves substantial constancy of one will of necessity have some variation of the other. Thus devices according to the present invention, including the illustrative embodiments herein described, will have some variation in their selectivity as the cores are adjusted, but, as will be explained, this variation is small, particularly at critical coupling.

In accordance with the invention, the result is secured by a construction such that each circuit has constant gain, and the coupling between the circuits automatically varies as the cores are moved so as to maintain the over-all gain substantially constant.

It is an object of the invention, therefore, to provide a high-frequency coupling device in which substantially uniform gain is secured, regardless of inductance adjustment, without resort to expensive or complicated mechanical arrangements.

It is also an object of this invention to provide a high-frequency coupling device in which the coupling between the resonant circuits is automatically regulated to compensate for the effect of adjustments of the individual resonant-circuit inductance values on the over-all gain characteristic.

In the design of devices in accordance with the invention, it is necessary to first determine the frequency at which they are to be operated. A particular device will, in general, be adjustable to secure resonance at a particular frequency. When the device is installed in the receiver and is adjusted to operate at the particular frequency for which it was designed, the inductance is varied to compensate for deviations in the capacitances in the circuits with which the device is associated, in such a way as to bring the product of the total effective capacitance and the total effective inductance to the correct value for the

particular frequency. Thus, if the capacitance value in a particular case is high, the inductance value is adjusted to be correspondingly lower, and vice versa.

- 5 The condition to be fulfilled if each of the circuits is to have constant gain is that the ratio of its inductance to the product of its resistance and its capacitance, or L/RC , shall remain constant for any setting of the adjustments necessary to secure resonance at the intended frequency.

10 The method by which the over-all gain of a device in accordance with my present invention is kept substantially constant consists first in arranging each of the circuits so that its individual dynamic resistance or L/RC ratio will remain constant, and second in arranging the coupling between the two circuits so that it will automatically vary in accordance with a required relation to provide substantially constant over-all gain, regardless of adjustments in either of the circuits.

20 Since the capacitances in each circuit are fixed, the inductors are so constructed that, at the chosen frequency and regardless of any adjustment of inductance, they maintain substantially constant the ratio of inductance to the product of resistance and capacitance, L/RC , for the individual circuits. Each circuit then has constant gain throughout its range of adjustability. The device is preferably so designed that the capacitive coupling between the circuits is negligible, and the arrangement is such that the inductive coupling coefficient k_1 changes automatically by the correct amount for any change in the inductance values, L_1 or L_2 , of either of the inductors, these quantities being related in the well-known equation

$$k_1 = \frac{Z_m}{\sqrt{Z_1 Z_2}} \quad (1)$$

25 In accordance with my invention, the inductance adjustment in each of the circuits is secured by movement of a ferromagnetic core relative to the inductance coil in that circuit, these coils with their cores being so positioned that movement of either core to adjust the inductance in that circuit automatically and simultaneously produces an appropriate change in the coupling between the circuits, so that the over-all gain of the device for any and all positions of either of the cores within the range of their adjustability remains substantially unchanged.

30 It may be shown that if the L/RC ratio in each of the circuits remains constant, constant over-all gain is realized under the condition of critical coupling between the circuits when the coupling coefficient is inversely proportional to the circuit capacitances or directly proportional to the circuit inductances. Pairs of coupled circuits of the type here under consideration, however, are usually operated at a degree of coupling somewhat greater than the critical value, in order to secure a desired width of band of the frequencies passed. Mathematical analysis of both the over-coupled and the undercoupled conditions shows that the coupling coefficient may be expressed in terms of the individual circuit inductance values as follows:

$$k = \frac{L_1(h \pm \sqrt{h^2 - 4G^2 L_1^2})}{2Gh\sqrt{L_1 L_2}} \quad (2)$$

70 where G is the over-all gain, at the center of the response curve, which is to be constant; and h is a constant which depends upon the inductance

and capacitance of each circuit and the frequency, and is defined by

$$h = \frac{\omega L_1 L_2}{\sqrt{R_1 R_2}} \quad (3)$$

Equation (2) therefore gives the required variation of k for variations in the circuit inductances, L_1 and L_2 .

To maintain constant L/RC in each of the circuits, the size of the magnetic particles in the core and the method of insulation and degree of compression must be chosen with respect to the type of magnetic material employed. Core materials suitable for use in embodiments of my invention and methods of constructing such cores are described in United States Patents Nos. 1,940,228, 1,932,689 and 1,982,690 to Polydoroff. In general, if a core is to maintain the L/RC ratio in a circuit constant, it must increase the resistance in the circuit considerably more rapidly than it increases the inductance as it is inserted into the coil. Since, in any practical case, the core must be designed with respect to the coil with which it is to be used, it is not possible to give specific directions for its construction, but the illustrative example to be described in connection with the drawings will be an adequate guide to the man skilled in the art.

The invention will now be described by reference to a preferred embodiment shown in the accompanying drawings, in which:

Fig. 1 is an elevation, partly in section, of one form of coupling device useful in carrying out my invention;

Fig. 2 is a view of the coupling device of Fig. 1, taken on the line 2-2 of Fig. 1;

Fig. 3 is a schematic circuit diagram showing a coupling device such as the one illustrated in Figs. 1 and 2 connected between two vacuum tubes; and

Figs. 4 and 5 show graphically how the gain and selectivity, respectively, of a device in accordance with the invention vary as the inductance is changed in each of the resonant circuits.

Referring to Figs. 1 and 2 of the drawings, there is shown a coupling device consisting of base plate 1 supporting spaced and internally threaded plugs 2 and 3 of metal or other suitable material. Tubes 4 and 5 of insulating material are respectively mounted on plugs 2 and 3, with their axes in parallel relation. Tube 4 supports an inductance coil 6, which is preferably wound in two sections or "pies", and within the tube is disposed core 7 with a free sliding fit. Core 7 is made of compressed comminuted ferromagnetic material, and is attached to screw 8 by an insulating connector 9. Coil 6 and core 7 comprise adjustable inductor 6-7. Screw 8 engages the threads in plug 2, so that core 7 may be moved axially with respect to coil 6 by turning screw 8. Tube 5 contains a similar core 10, similarly attached to a screw 11 engaging plug 3, for co-operation with inductance coil 12 wound on the outside of tube 5. Core 10 and coil 12 comprise adjustable inductor 10-12. The outer ends of screws 8 and 11 are slotted to receive a screw driver.

Base plate 1 also supports terminal lugs 13 to which are soldered fixed capacitors 14 and 15, which are connected respectively in shunt with coils 6 and 12. A metal shield can 16 surrounds base plate 1 and the parts carried thereby, base plate 1 being supported adjacent one side wall of shield can 16 by nuts 17 engaging the exter-

nally threaded portions of plugs 2 and 3 which extend through the shield can.

In one successful embodiment of the invention intended to be used at 456 kilocycles, tubes 4 and 5 have an inside diameter of $\frac{1}{4}$ inch and a length of $1\frac{1}{4}$ inches. Coils 6 and 12 each consist of two pies $\frac{3}{32}$ inch wide and $\frac{3}{4}$ inch apart. Each pie consists of 190 turns of 30/48 single-silk covered enamelled Litz wire. The inductance of each coil is 1267 microhenries in air. The Q of each coil in air is 157, and is 150 when shield can 16 is in place. When cores 7 and 10 are fully inserted in coils 6 and 12, respectively, the inductance of each coil is increased to 2294 microhenries, so that the cores have an effective permeability of approximately 1.8 when used with the above-described two-pie coils. Coils 6 and 12 are mounted $1\frac{1}{4}$ inches between centers, and are equally spaced from base plate 1.

Referring to Fig. 3 of the drawings, vacuum tubes 18 and 19 are coupled by a coupling device contained within shield 16. The output circuit of vacuum tube 18 includes an input resonant circuit comprising inductor 10-12 and shunt capacitor 15. Similarly, an output resonant circuit comprising inductor 6-7 and shunt capacitor 14 is connected in the input circuit of vacuum tube 19. By adjustment of cores 10 and 7 relatively to coils 12 and 6, respectively, the effective inductances of the input and output resonant circuits may be varied. Input inductor 10-12 is inductively coupled to output inductor 6-7, the degree of coupling depending upon the spacing between tubes 4 and 5 and upon the positions of cores 7 and 10 relative to coils 6 and 12, respectively.

In operation, the insertion of cores 7 and 10 into coils 6 and 12 respectively simultaneously increases the inductance of coils 6 and 12 while maintaining the L/RC ratio of each resonant circuit substantially constant, and varies the inductive coupling between inductors 6-7 and 10-12 substantially in accordance with Equation (2) given above, and the over-all gain of the coupling device is maintained substantially constant. The above-mentioned inductance adjustment is made, not to vary the frequency at which the device is to operate, but to compensate for small variations in the tube and circuit capacitances and thus secure resonance at the desired frequency.

Referring to Fig. 4 of the drawings, curve 20 shows the gain of a device in accordance with the invention when it is associated with an amplifying vacuum tube in the manner shown in Fig. 3. The gain variation is about one per cent for a wide range of inductance variation.

In Fig. 5 of the drawings, the selectivity of a 456-kilocycle device in accordance with the invention is graphically presented. Curves 21, 22 and 23 show the selectivity for inductance values of 1505 microhenries, 1690 microhenries and 2100 microhenries, respectively. At a ratio of output off resonance to output at resonance of 10, the variation of band width is only two kilocycles, and the maximum band width is 22 kilocycles.

If the inductors are made in accordance with the disclosure of United States Patent No. 1,982,690 to Polydoroff, the magnetic core may be utilized to increase the L/R and hence the Q of the coil.

As will be seen from Figs. 1 and 2 of the drawings, the full range of adjustability of the cores does not completely remove them from the coils.

Thus for any condition of adjustment, the cores are partly inserted and the initial insertion of the core may be made to produce a substantial increase in the Q of the inductor. This initial Q, although somewhat decreased when the core is further inserted for adjustment of the inductance value, nevertheless remains higher than the Q of the air-core coil alone at the frequency at which the device is designed to operate.

Thus the use of properly designed inductors employing ferromagnetic cores provides not only substantially constant gain throughout the range of adjustability, but also an improved degree of selectivity over that previously realized in coupling devices intended for the same purpose.

The scope of the invention is not limited to the embodiments shown in the drawings and described herein, but includes as well such further modified forms as will occur to those skilled in the art to embody the principles hereinabove disclosed.

Having thus described my invention, what I claim is:

1. A selective high-frequency coupling device including in combination input and output resonant circuits each having an inductor and a fixed capacitor and intended for operation at a given frequency, means for adjusting the inductance of each of said circuits to compensate for changes in the capacitance thereof due to conditions of use to thereby maintain resonance at said frequency, said circuits being so coupled as to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

2. A selective high-frequency coupling device including in combination input and output resonant circuits each having an inductor and a fixed capacitor and intended for operation at a given frequency, means for adjusting the inductance of each of said circuits to compensate for changes in the capacitance thereof due to conditions of use to thereby maintain resonance at said frequency, said means varying the effective resistance of said inductors in such a way as to maintain the ratio of inductance to the product of resistance and capacitance for each of said circuits substantially constant, and said circuits being so coupled as to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

3. A selective high-frequency coupling device including in combination input and output resonant circuits each having an inductor and a fixed capacitor and intended for operation at a given frequency, movable ferromagnetic cores for adjusting the inductance of each of said circuits to compensate for changes in the capacitance thereof due to conditions of use to thereby maintain resonance at said frequency, said cores varying the resistance of said inductors in such a way as to maintain the ratio of inductance to the product of resistance and capacitance for each of said circuits substantially constant, and said circuits being so coupled as to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

4. A selective high-frequency coupling device including in combination a pair of coupled resonant circuits each having an inductor and a fixed capacitor and intended for operation at a given frequency, movable ferromagnetic cores for adjusting the inductance of each of said circuits to compensate for changes in the capaci-

tance thereof due to conditions of use to thereby maintain resonance at said frequency, the coupling between said circuits being varied by said cores in such a way as to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

5. A selective high-frequency coupling device including in combination a pair of coupled resonant circuits each having an inductor and a fixed capacitor and intended for operation at a given frequency, movable ferromagnetic cores for adjusting the inductance of each of said circuits to compensate for changes in the capacitance thereof due to conditions of use to thereby maintain resonance at said frequency, said cores varying the effective resistance of each inductor in such a way as to maintain the ratio of inductance to the product of resistance and capacitance for each of said circuits substantially constant and

simultaneously varying the coupling between said circuits in such a way as to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

6. A selective high-frequency coupling device including in combination input and output resonant circuits each having an inductor and a fixed capacitor, and inductance-adjusting means associated with each of said inductors for tuning the corresponding circuit to resonance at a given frequency, said circuits being coupled, said inductance-adjusting means and said coupling cooperating to maintain the ratio of inductance to the product of resistance and capacitance for each of said circuits substantially constant and to maintain the over-all gain of said coupling device substantially constant regardless of said inductance adjustment.

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Certificate of Correction

Patent No. 2,158,255.

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It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, lines 38-39, for the equation

$$"k_1 = \frac{Z_m}{\sqrt{Z_1 Z_2}} \quad \text{read} \quad k_1 = \frac{L_m}{\sqrt{L_1 L_2}};$$

page 3, first column, line 64, for the word "output" both occurrences, read *input*; and second column, line 72, claim 4, for "fixer" read *fixed*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 4th day of July, A. D. 1939.

[SEAL]

Henry Van Arsedale

Acting Commissioner of Patents.