

March 15, 1938.

W. A. SCHAPER

2,111,373

PERMEABILITY TUNED DEVICE

Filed March 7, 1935

2 Sheets-Sheet 1

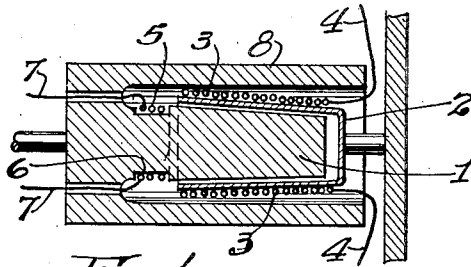


Fig. 1

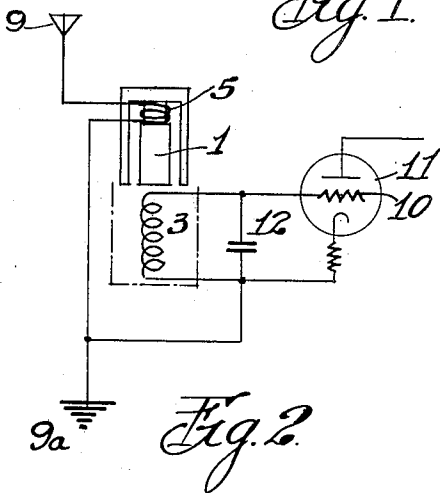


Fig. 2

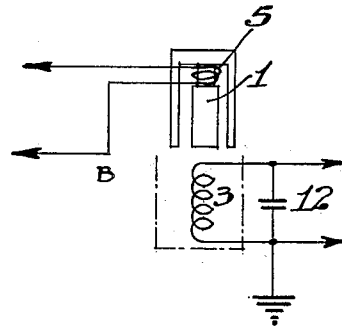


Fig. 4

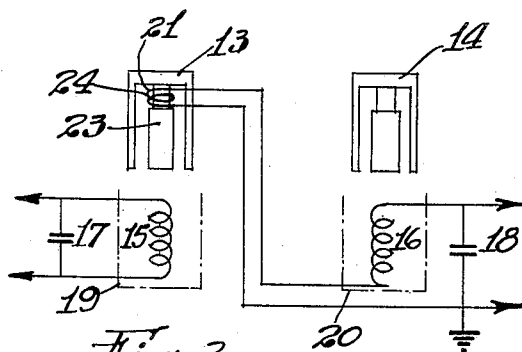


Fig. 3

INVENTOR,
WILLIAM A. SCHAPER,

BY
Thomas C. Leonard,

ATTORNEY.

March 15, 1938.

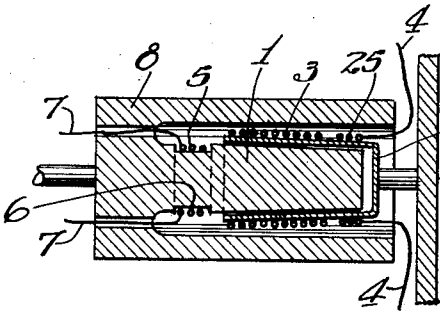
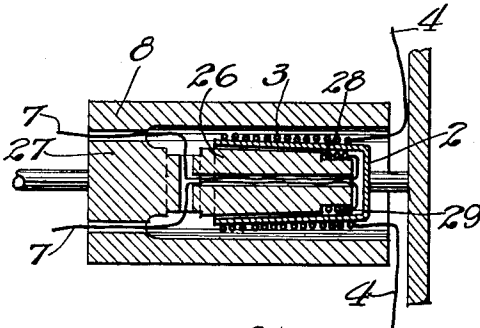
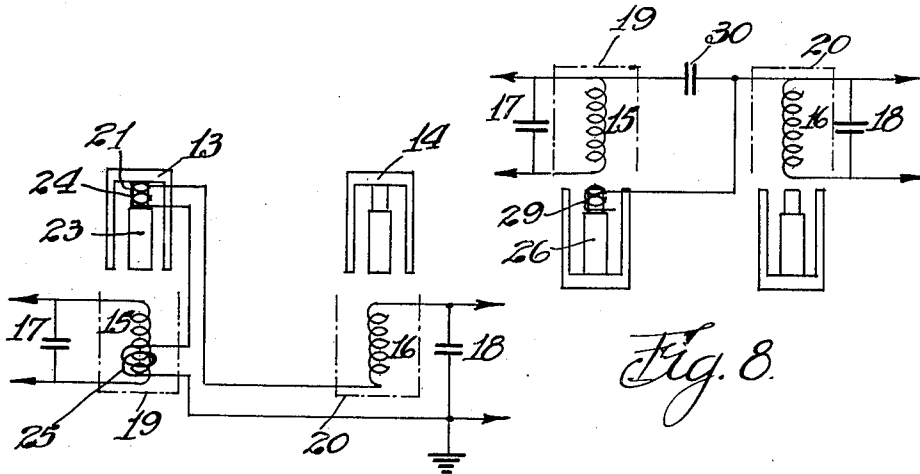
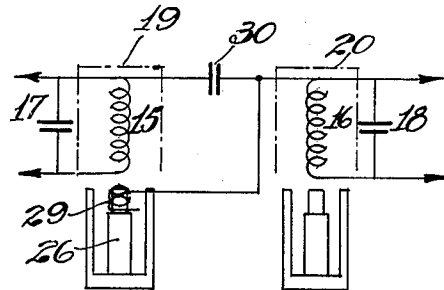
W. A. SCHAPER

2,111,373

PERMEABILITY TUNED DEVICE

Filed March 7, 1935

2 Sheets-Sheet 2



INVENTOR,
WILLIAM A. SCHAPER,

BY
Thos. G. Stevens
 ATTORNEY.

UNITED STATES PATENT OFFICE

2,111,373

PERMEABILITY-TUNED DEVICE

William A. Schaper, Chicago, Ill., assignor to
Johnson Laboratories, Inc., Chicago, Ill., a cor-
poration of Illinois

Application March 7, 1935, Serial No. 9,880

13 Claims. (Cl. 250—20)

This invention relates to high-frequency signalling systems, and more especially to improvements in receivers for radio- and carrier-frequency waves. Specifically, the invention discloses improved coupling systems for high-frequency receivers.

It is an object of my invention to provide a coupling system having substantially uniform performance over a wide band of frequencies, the two characteristics which determine the performance being gain or amplification and selectivity. Another object is to provide a coupling system which automatically adjusts the value of its coupling in accordance with the frequency to which it is tuned. Another object of my invention is to so vary the coupling in a high-frequency system including amplifiers that the gain of the system is maintained substantially constant over a band of frequencies. Another object is to so vary the coupling with respect to the inductance and high-frequency resistance of the coil used, that the selectivity of the system is maintained constant over a band of frequencies. These and other objects will be apparent from what is to follow.

It has long been known that the current in a receiving antenna varies directly with the frequency. This is stated mathematically in "Principles of Radio Communication" (second edition) by John H. Morecroft, page 859, as follows:

$$I_r = \frac{188II_t}{\lambda dR} \text{ or } \frac{62.74II_t f}{10^7 dR}$$

where:

- I_r = effective receiving antenna current, in amperes
- I_t = effective transmitting antenna current, in amperes
- l_r = actual height of receiving antenna, in centimeters
- l_t = actual height of transmitting antenna, in centimeters
- f = frequency, in kilocycles
- λ = wavelength, in centimeters
- d = distance between antennas, in centimeters
- R = effective resistance of receiving antenna, in ohms.

The direct proportionality between antenna current and frequency means that the current increases threefold as the frequency varies from 500 to 1500 kilocycles, for instance, which is approximately the frequency band covered by the present broadcast stations. This change in antenna current causes a similar variation in

the voltage developed in the antenna winding of the first coupling device in a conventional radio receiver, and therefore in the induced secondary voltage, which likewise affects the gain and selectivity of the antenna stage.

It has also long been well known that due to the conditions which exist in a thermionic amplifier, there is also a tendency for the amplification to increase markedly as the frequency increases. Mathematically, the situation in such an amplifier will depend upon the circuit arrangement used, but in general it may be stated that the impedance of the output circuit is usually lower than the output impedance of the thermionic tube, but increases as the frequency increases, thus producing a closer match and greater amplification. Thus, the characteristics of both the antenna circuit and the thermionic amplifiers are such as to produce very much greater response to the higher frequency signals.

It has also long been well known that the selectivity of a resonant circuit, or several resonant circuits in cascade, varies inversely with the frequency of the signal to be selected. It is desirable that the selectivity should remain constant so that the width of the admitted band of frequencies will be the same for all frequencies within the tuning range of the device. Several different solutions of this problem have been proposed, but each of them presents difficulties, either because of additional complication of the circuit, or because although constant selectivity is achieved the gain possible with the system is materially decreased, or, lastly, because it becomes very difficult to accurately produce the corrective component in quantities.

Various attempts have been made to solve these problems. Miller, for instance, to overcome the difficulty in the antenna circuit, employs high-inductance primary windings which resonate the antenna circuit at a frequency somewhat lower than the lowest frequency to which the system may be tuned. Other investigators have employed capacitive coupling arranged to increasingly oppose the inductive coupling as the frequency increases. This latter expedient has been applied to both antenna and interstage circuits, and many other arrangements have been proposed, some of which represent considerable additional complication and cost. The results at best represent a compromise which only approaches the desired uniform performance over a wide band of frequencies, but in no case have the results been entirely satisfactory, especially for use in high-grade receivers designed to give

practically uniform selectivity and gain over at least one wide band of frequencies.

In the system of the present invention, the coupling between two circuits is automatically varied as the tunable circuits are tuned over the frequency band. In this manner, the proper degree of coupling is maintained regardless of the frequency of operation. This result is accomplished by mounting a coupling winding on a magnetic core which is movable relatively to the inductance coil in one of the circuits, the movement of the core also partially or completely accomplishing the tuning of that circuit to the desired frequency.

The present invention will be better understood by reference to the accompanying drawings showing two embodiments thereof, in which:

Figure 1 is an elevation, partly in section, of an antenna coupling device adapted to be used in accordance with the present invention;

Figure 2 is a wiring diagram showing one system employing the device of Figure 1;

Figure 3 is a wiring diagram showing a second method of connecting the device of Figure 1;

Figure 4 is a wiring diagram showing a third method of connecting the device of Figure 1;

Figure 5 is a modification of the device of Figure 1, in which an additional winding is incorporated;

Figure 6 is a wiring diagram showing a system employing the modified device of Figure 5;

Figure 7 is a second modification of the device of Figure 1, in which the winding on the core is differently arranged; and

Figure 8 is a wiring diagram showing a system employing the device of Figure 7.

Referring to Figure 1, cylindrical or tapering core member 1 is arranged to enter coil form 2, of insulating material, on which is wound secondary winding 3. Leads 4 provide connections to coil 3. Primary winding 5 is wound in slot 6 in core member 1, and leads 7 provide electrical connections to coil 5. To increase the amount of inductance variation due to movement of the core member 1, a cylindrical magnetic member 8 may be employed, wedged on or otherwise suitably secured to an enlarged portion of core member 1. Core member 1 and member 8 are preferably made by compressing individually insulated magnetic particles of very small size. The size of the particles which will be most advantageous for use in any particular design will depend largely upon the frequencies which the system is designed to cover. In general, the higher the frequencies, the smaller the particles will be. The insulation of the individual particles must be sufficiently complete to produce a very high electrical resistivity in the compressed members, which will then have very low electrical losses.

Referring to Figure 2, primary winding 5 is connected between antenna 9 and ground 9a. Secondary winding 3 is connected between grid 10 of vacuum tube 11 and ground 9a. Secondary winding 3 is shunted by condenser 12, which may be fixed, adjustable, or variable, according to the particular design of the system. In one design, for instance, the position of the core member 1 and the capacity of the tuning condenser 12 may be simultaneously varied by a single control. Another design employs an adjustable condenser 12 for initial low-frequency alignment, tuning being accomplished by movement of the core member 1. These variations are immaterial to the scope of the present invention.

In operation, the resonant frequency of the system increases as the core is withdrawn from the secondary winding, since the removal of the high-permeability core from the coil decreases its inductance. At the same time, withdrawal of the core increases the spacing and hence decreases the inductive and capacitive coupling between the primary and secondary windings, thus substantially compensating for the increase in current and the decrease in selectivity which would occur were the coupling to remain fixed at its low-frequency value.

Figure 3 shows the device of Figure 1 employed as an interstage coupling system. It will be seen that there are two core members 13, 14 and two coils 15, 16, although in this case the coils are not transformer secondaries as was the case of coil 3 in Figure 2. The cores 13, 14 will normally be arranged to be actuated in unison from a single control knob or handle, although they may in some cases be independently actuated. Condenser 17 is shunted across coil 15, to form a resonant circuit 15, 17, which is tuned over a band of frequencies by core 13.

Similarly, condenser 18 is shunted across coil 16 and forms a second resonant circuit 16, 18, which is tuned by core 14. The two circuits, 15, 17 and 16, 18, are tuned by the cores 13, 14 over the same band of frequencies. A shield 19 surrounds coil 15 and a shield 20 surrounds coil 16, so that there is no direct inductive or capacitive coupling between the two coils.

Wound in an annular depression 21 in the central plug 23 of core 13, there is a winding 24 having a relatively small number of turns. This winding is connected in series with coil 16 and is included in the tuned circuit 16, 18. As the cores 13, 14 are moved into and out of the coils 15, 16, the winding 24 also moves into and out of the coil 15, thereby producing a varying degree of coupling between the circuit 15, 17 and the circuit 16, 18. Depending upon the characteristics of the thermionic tubes between which the system of Figure 3 is used, and depending upon the frequency band to be covered, the winding 24 can be designed to give a desired variation of coupling as the system is tuned. It will be noted that the winding 24 is placed at the inside end of the core plug 23, in a position remote from the coil 15.

The device of Figure 1 may also be used as an interstage coupling device. This arrangement is shown in Figure 4, which is identical with Figure 2 except that the terminals of the winding 5 are shown as being available for connection to the output terminals of a thermionic tube instead of being connected to an antenna and ground, and vacuum tube 11 is not shown.

Figure 5 illustrates a device similar to that of Figure 1, except that there is included an additional winding 25, also having a relatively small number of turns, and wound directly adjacent the coil 3.

One method of employing the device of Figure 5 is shown in Figure 6, which is similar in all respects to Figure 3 except that it shows the additional winding 25 connected in series with the coil 16 and the winding 24. Since the winding 25 remains stationary on the coil 15, there will be a certain minimum coupling between the circuits 15, 17, and 16, 18. Since the winding 24 upon the plug 23 of core 13 moves with the core as the circuits are tuned, there will be an additional varying coupling between circuits 15, 17 and 16, 18. By properly proportioning the wind-

ings 24, 25 with respect to the thermionic tubes used and the frequency band to be covered, a more advantageous relation between the frequency to which the circuits are tuned and the coupling between them, than is possible with the arrangement of Figure 3, can be secured.

Figure 7 shows a second modification of the device of Figure 1. In this case, the core plug 26 of the core 27 has an annular depression 28 at its outer end. In this depression there is a winding 29. The device of Figure 7 is otherwise in all respects similar to the device of Figure 1.

Figure 8 shows one method of utilizing the device of Figure 7. Electrically this arrangement is similar to that of Figures 3 and 6, except that varying capacitive rather than varying inductive coupling is employed. To accomplish this, a fixed coupling condenser 30 is connected between the high-potential terminals of coils 15 and 16, and provides an unvarying coupling capacitance between circuits 15, 17 and 16, 18. Additionally, the winding 29 on the core plug 26 is connected to the high-potential terminal of the coil 16, the other end of the winding 29 being left unconnected. There is no electrical connection to the core 26. As the core 26 is moved into and out of the coil 15, the winding 29 has a varying degree of capacitive coupling to the coil 15, and therefore provides a varying capacitive coupling between circuit 15, 17 and circuit 16, 18.

By properly proportioning the condenser 30 and the winding 29 with respect to the tubes used and the frequencies to be covered, a desired variation of the capacitive coupling between circuits 15, 17 and 16, 18 can be secured.

It is to be noted that whereas in Figure 3 one end of the winding 24 is shown connected to ground, in Figure 8 the winding 29 is connected to the high-potential side of coil 16, the other end being left open. In Figure 3 the capacitive coupling change will be minimized, whereas in Figure 8 it will be a maximum. The winding 29, which is used only as one electrode of a variable capacitance device, may be replaced by a conductive sleeve or cylinder, but this would tend to increase the losses and therefore the high-frequency resistance of the coil 15. If, however, the winding 29 is of wire similar to that used for the coils 15, 16, the losses are not materially increased.

It is not possible, in this specification, to give specific values for the inductances of the coils, the capacitances of the condensers, and the number of turns of the coupling windings, since these will depend entirely upon the thermionic tubes employed and the frequency range to be covered. Those skilled in the art, however, will have no difficulty in appropriately choosing these values to suit the conditions of particular designs. It is to be understood, therefore, that the physical embodiments of my invention shown in Figures 1, 5 and 7, and the delineations of the diagrams of Figures 2, 3, 4, 6 and 8, are not to be taken as in any way indicative of the physical dimensions or proportions of any of the parts.

Referring again to Figures 3, 6 and 8, it will be noted that I have shown the coupling windings 24, 25 and 29 in each case as being associated with the second or right-hand resonant circuit, which would normally be connected to the input terminals of a second thermionic amplifier, the first or left-hand resonant circuit being in that case connected to the output terminals of a first thermionic amplifier. While this will usually be the preferred arrangement, it is to be

understood that the opposite arrangement, in which the coupling windings 24, 25 and 29 are associated with the first or left-hand resonant circuit, is equally within the scope of my invention. Additionally, it is to be understood that the thermionic tubes with which the arrangements of any of these figures are used need not necessarily be utilized as amplifiers, but may have other functions. Lastly, it is to be noted that a plurality of resonant circuits consisting, for example, of coils 16, condensers 18, cores 14, stationary coupling windings 25 and moving coupling windings 24, may be arranged in cascade, without the intervention of any thermionic devices whatever, without departing from the scope of my invention.

Referring now to the systems shown in any of the figures, it remains to point out in what manner advantage may be taken of the variable coupling to secure constant selectivity. This may best be explained with respect to Figure 6, although it is to be understood that the same teaching is applicable to any of the other figures. Referring then to Figure 6, it will be assumed, for the moment, that no method of coupling the circuit 15, 17 to the circuit 16, 18 has as yet been provided. The core 13 is present however and will tune the circuit 15, 17 from a maximum frequency, when the core is all the way out as shown, to a minimum frequency, when the core is fully inserted into the coil.

The coil 15 will be designed to have a certain ratio of inductance to high-frequency resistance at the maximum frequency, and this ratio will determine the selectivity of the circuit 15, 17 at that frequency, the core being removed and having no effect. The shield 19, however, which is necessary to exclude outside influences and to prevent direct coupling from the coil 15 to the coil 16, will have an effect. The losses in the shield will increase the effective high-frequency resistance of the coil and thus decrease the inductance-to-resistance ratio of the coil, and the selectivity of the circuit at the maximum frequency. The same applies to the coil 16 and its shield 20.

Still assuming that as yet no means for coupling the circuit 15, 17 to the circuit 16, 18 has been provided, it is to be noted that as the core 13 is advanced into the coil 15, and as the core 14 is simultaneously advanced into the coil 16, three different effects occur. The cores gradually increase the effective inductances of the coils and thus tune the circuits to lower and lower frequencies. The cores also gradually increase the losses in the circuits, thus tending to maintain the inductance-to-resistance ratio constant. And, finally, the cores gradually eliminate the effects of the shields 19, 20, so that when the cores are all the way in, the inductance-decreasing and loss-increasing influence of the shield is no longer present.

It has been shown by Polydoroff that, neglecting the effect of the shields 19, 20, the losses introduced by the cores 13, 14 can be so proportioned that the circuits 15, 17 and 16, 18 may be made to have the same inductance-to-resistance ratio, and therefore the same selectivity, at the maximum and minimum frequencies. However, without additional precautions, the selectivity of the system will not be as good at frequencies intermediate the two extreme frequencies as it is at those frequencies.

This deficiency is due to the fact that the initial portions of the cores 13, 14, as they first

enter the coils 15, 16, increase the losses too rapidly to maintain the inductance-to-resistance ratio constant. It has been shown by Polydoroff that this defect can be overcome by varying the magnetic density in the cores, and that when the density is properly proportioned with respect to the motion of the core, the inductance-to-resistance ratio may be maintained substantially constant, the circuits then having constant selectivity. This method, however, demands a careful technique and high precision in the production of the cores.

Polydoroff has also shown that by using particles of sufficiently small size and adequately insulating them, the losses in a homogeneous core may be made considerably less than the value necessary to maintain constant inductance-to-resistance ratio and constant selectivity. With cores of this type, the selectivity of the system increases as it is tuned to the lower frequencies. If the cores have losses sufficiently low, the inductance-to-resistance ratio, and consequently the selectivity of the system, is as good at all frequencies as it is at the maximum frequency, that is, there is no decrease in selectivity, even when the cores first enter the coils.

Let it be assumed that the cores 13, 14 in Figure 6 are of this last mentioned type, so that as they are advanced into the coils 15, 16 the selectivity of the system tends to increase. By properly designing the coupling windings 24, 25, the coupling may be made to increase, as the cores are advanced into the coils, at a rate just sufficient to compensate for the tendency toward increasing selectivity, and in this manner the selectivity of the system as a whole may be maintained substantially constant. The relative number of turns in the windings 24 and 25, in any particular case, will depend upon the cores employed, upon the other advantages which are to be taken of the variable coupling, and upon the degree to which it is desired to maintain the selectivity constant.

Having thus described my invention, what I claim is:

1. In a radio receiver, a vacuum-tube amplifier having input terminals, an inductance coil and a condenser connected in parallel between said input terminals and forming a selective resonant circuit, a homogeneous compressed comminuted magnetic core movable into and out of said coil for varying the inductance of said coil to tune said circuit over a range of frequencies, and a low-loss winding mounted upon and movable as a unit with said core for variably coupling said circuit to a source of oscillations, said winding being so proportioned as to maintain the selectivity of said circuit substantially constant throughout said range of frequencies.

2. In a high-frequency system, a selective resonant circuit comprising a condenser and an inductance device, said device including an inductance coil connected across said condenser and a homogeneous compressed comminuted magnetic core movable into and out of said inductance coil to tune said circuit over a range of frequencies, and a low-loss winding mounted upon and movable as a unit with said core, said low-loss winding being so proportioned that the effective inductance of said inductance coil and the coupling between said low-loss winding and said inductance coil are simultaneously varied in such manner as to maintain the selectivity of said circuit substantially constant throughout said range of frequencies.

3. A radio-frequency coupling device including

a resonant circuit comprising a condenser and an inductance coil, a homogeneous compressed comminuted magnetic core, a low-loss winding mounted upon and movable as a unit with said core, and means for moving said core and said winding into and out of said inductance coil to vary the effective inductance of said inductance coil and to vary the coupling between said winding and said inductance coil, said core and said winding being such that said circuit may be tuned by the motion of said core over a range of frequencies and being such that said device will have substantially constant performance throughout said range.

4. A device for coupling an antenna to the first amplifying vacuum tube in a radio receiver, including an inductance coil and a condenser forming a resonant circuit operatively connected to the input terminals of said amplifier, a homogeneous compressed comminuted magnetic core movable into and out of said coil for varying the effective inductance thereof to tune said circuit over a range of frequencies, and a low-loss winding mounted upon and movable as a unit with said core connected between said antenna and ground, said winding being so proportioned that the coupling between said antenna and said amplifier is automatically varied as said resonant circuit is tuned over said range in such manner as to maintain the performance of said device substantially constant.

5. A transformer having a secondary winding, a condenser connected across said secondary winding to form a resonant circuit, a homogeneous compressed comminuted magnetic core movable into and out of said secondary winding for varying the effective inductance thereof to tune said circuit over a range of frequencies, and a low-loss winding mounted upon and movable as a unit with said core for variably coupling said secondary winding to a source of oscillations, said low-loss winding being so proportioned that the performance of said transformer is substantially constant throughout said frequency range.

6. A transformer having primary and secondary windings, a condenser connected across said secondary winding to form a resonant circuit, a homogeneous compressed comminuted magnetic core movable into and out of said secondary winding, said primary winding being wound upon said core, and means for moving said core and said primary winding relatively to said secondary winding to vary the effective inductance of said secondary winding to tune said circuit over a range of frequencies and to simultaneously vary the coupling between said secondary winding and said primary winding, said primary winding being so proportioned that the performance of said transformer remains substantially constant throughout said tuning range.

7. A radio-frequency coupling system including at least two resonant circuits each having an inductance coil and a condenser, a homogeneous compressed comminuted magnetic core movable into and out of one of said coils for varying the effective inductance thereof, and means including a low-loss winding mounted upon and movable as a unit with said core for automatically and simultaneously varying the coupling between said two resonant circuits.

8. In a high-frequency system, an input circuit including a coil, a selective resonant circuit including a coil and a condenser, a homogeneous compressed comminuted magnetic core movable into and out of one of said coils to tune one of

5 said circuits over a range of frequencies, and a winding mounted upon and movable as a unit with said core for variably coupling said circuits, said winding being so proportioned that at least one characteristic of the over-all performance of said circuits is maintained substantially constant throughout said range of frequencies.

10 9. In a high-frequency system, a condenser and an inductance coil connected in parallel to form a resonant circuit, a homogeneous compressed comminuted magnetic core, a low-loss winding mounted upon said magnetic core, and means for moving said magnetic core and said low-loss winding into and out of said inductance coil for varying the effective inductance of said inductance coil to tune said resonant circuit over a range of frequencies and for simultaneously varying the coupling between said resonant circuit and said low-loss winding, said low-loss winding being so proportioned that the performance of said system remains substantially constant throughout said frequency range.

15 10. A radio receiver including plural variable inductance devices each having an inductance coil shunted by a condenser to form a resonant circuit and a homogeneous compressed comminuted magnetic core movable into and out of said inductance coil, and a low-loss winding mounted upon and movable as a unit with the core in one of said variable inductance devices and connected in series with the inductance coil in another of said inductance devices, said low-loss winding being so proportioned that the coupling between said two variable inductance devices is automatically varied as said resonant circuits are tuned over a range of frequencies in such manner as to maintain the performance of said circuits substantially constant throughout said frequency range.

20 11. A high-frequency system including plural variable inductance devices each having an inductance coil shunted by a condenser to form a

resonant circuit, a homogeneous compressed comminuted magnetic core movable into and out of each of said inductance coils, a first winding upon the inductance coil in a first variable inductance device and a low-loss winding mounted upon and movable as a unit with the core in said first variable inductance device, said two windings being in series with the inductance coil in a second variable inductance device and being so proportioned that the coupling between said two variable inductance devices is automatically varied by motion of said core as said circuits are tuned over a range of frequencies in such manner as to maintain the performance of said circuits substantially constant throughout said range.

15 12. A radio-frequency coupling system including at least two resonant circuits each having an inductance coil, a condenser and a homogeneous compressed comminuted magnetic core movable into and out of said inductance coil, and a low-loss winding mounted upon and movable as a unit with the core associated with one of said resonant circuits, said winding being connected in series with the inductance coil in another of said circuits.

20 13. In a high-frequency system, a first vacuum tube having an output electrode and a second vacuum tube having an input electrode, a resonant circuit connected to said output electrode, a resonant circuit connected to said input electrode, each of said resonant circuits including an inductance coil, a condenser and a homogeneous compressed comminuted magnetic core movable into and out of said coil to tune said resonant circuit over a band of frequencies, and a low-loss winding mounted upon and movable as a unit with the core associated with one of said circuits, said low-loss winding being connected in series with the inductance coil in the other of said circuits.

40 WILLIAM A. SCHAPER.