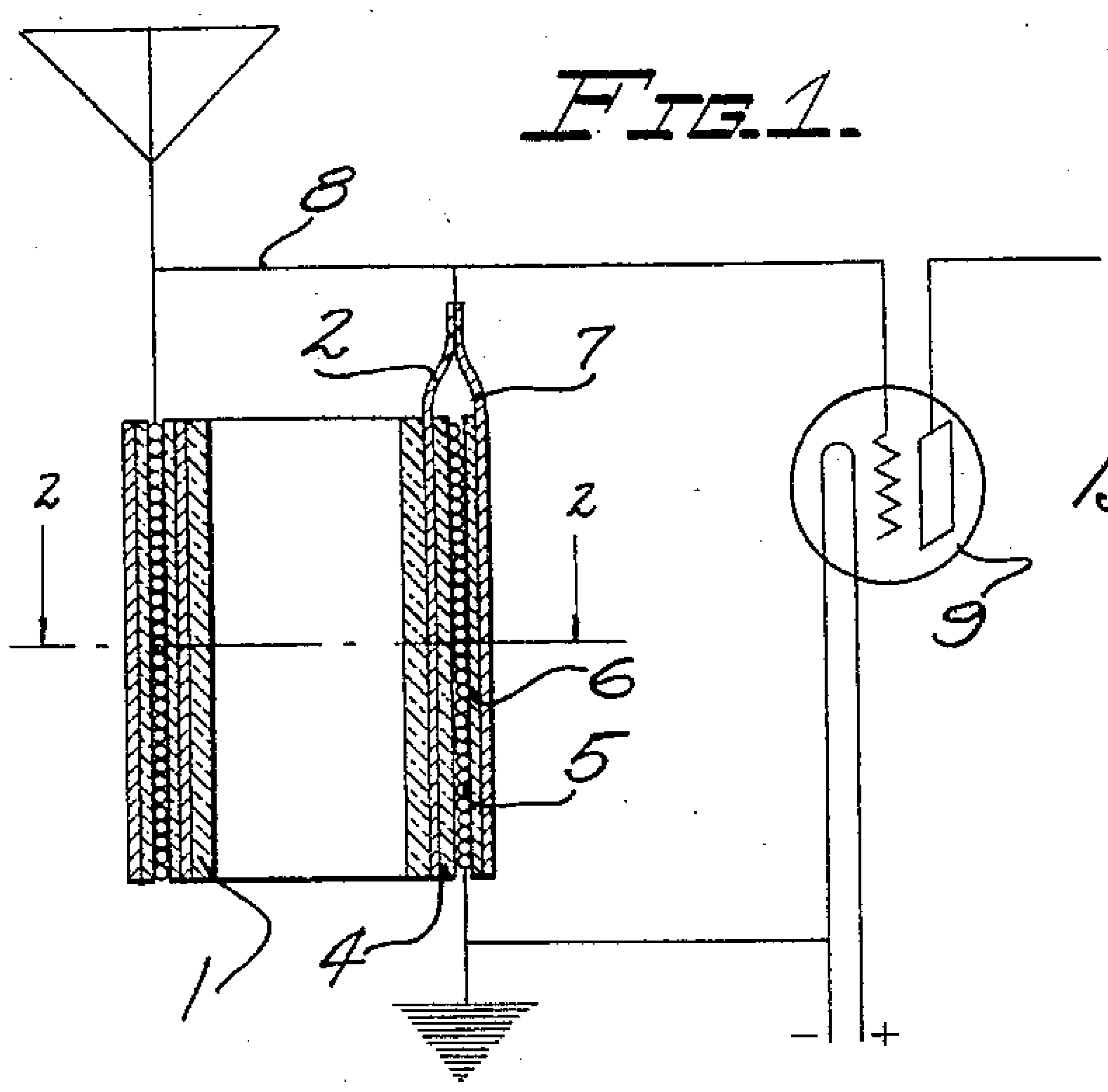
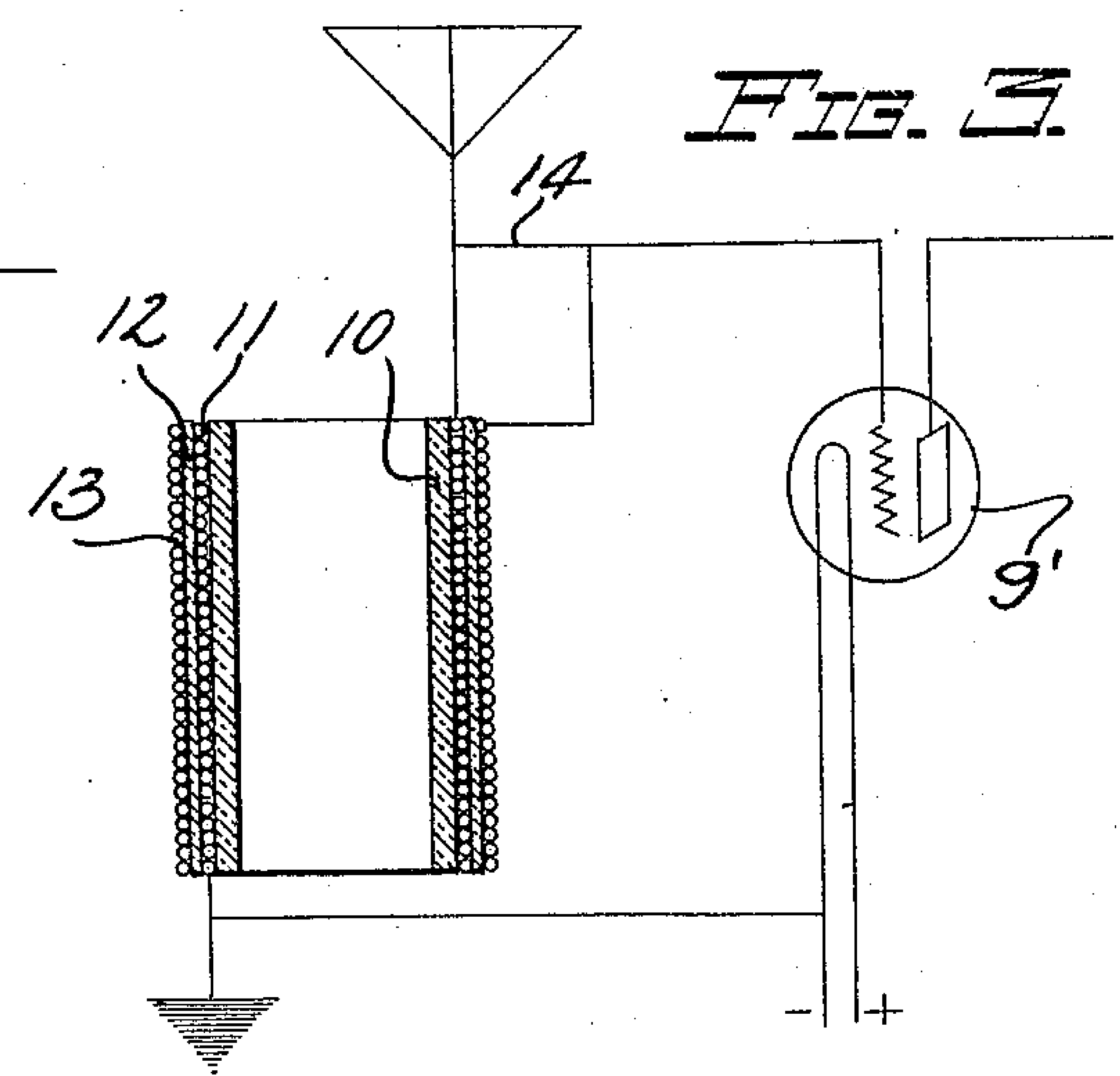
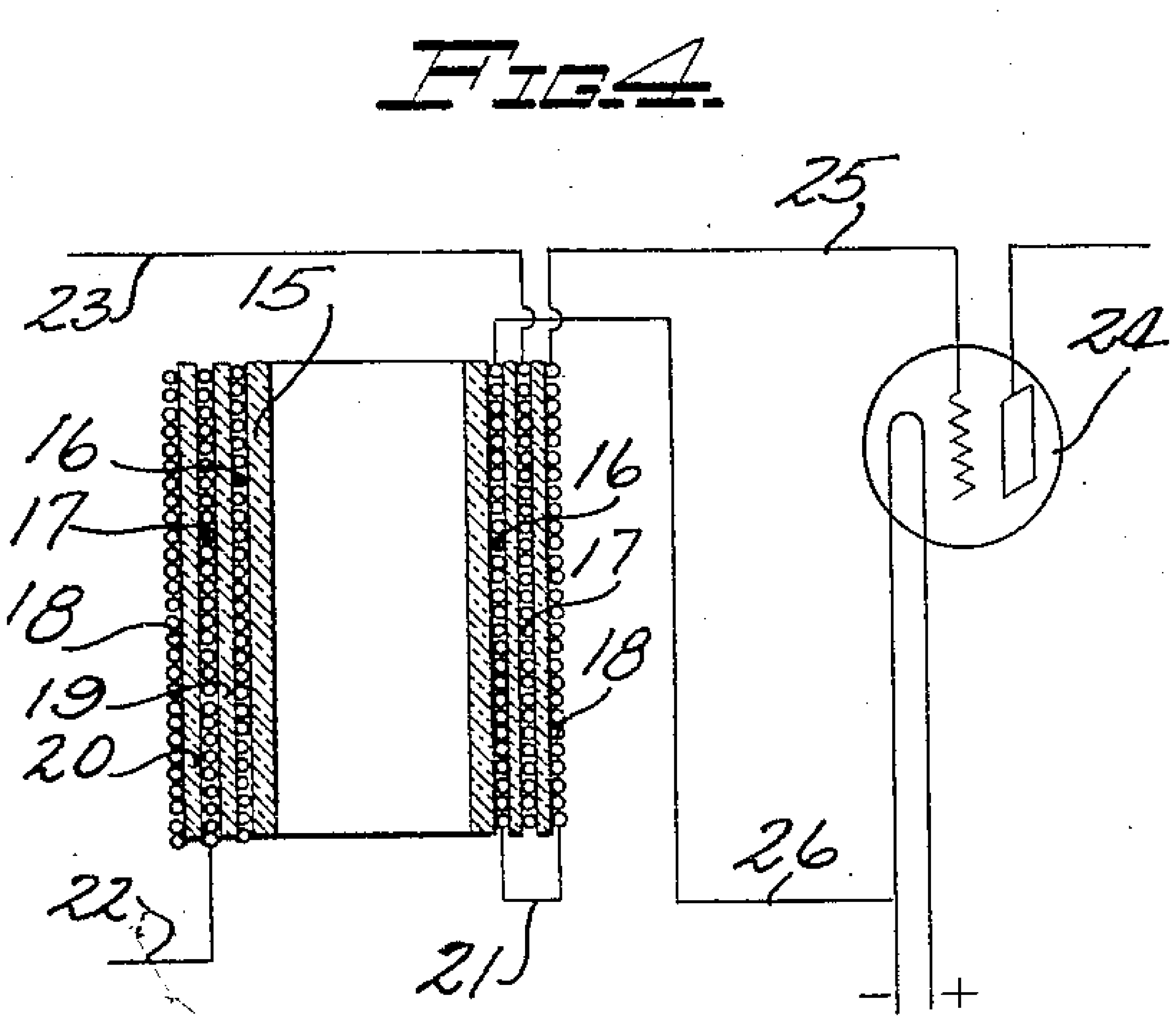
Feb. 14, 1933. E. R. STOEKLE 1,897,082

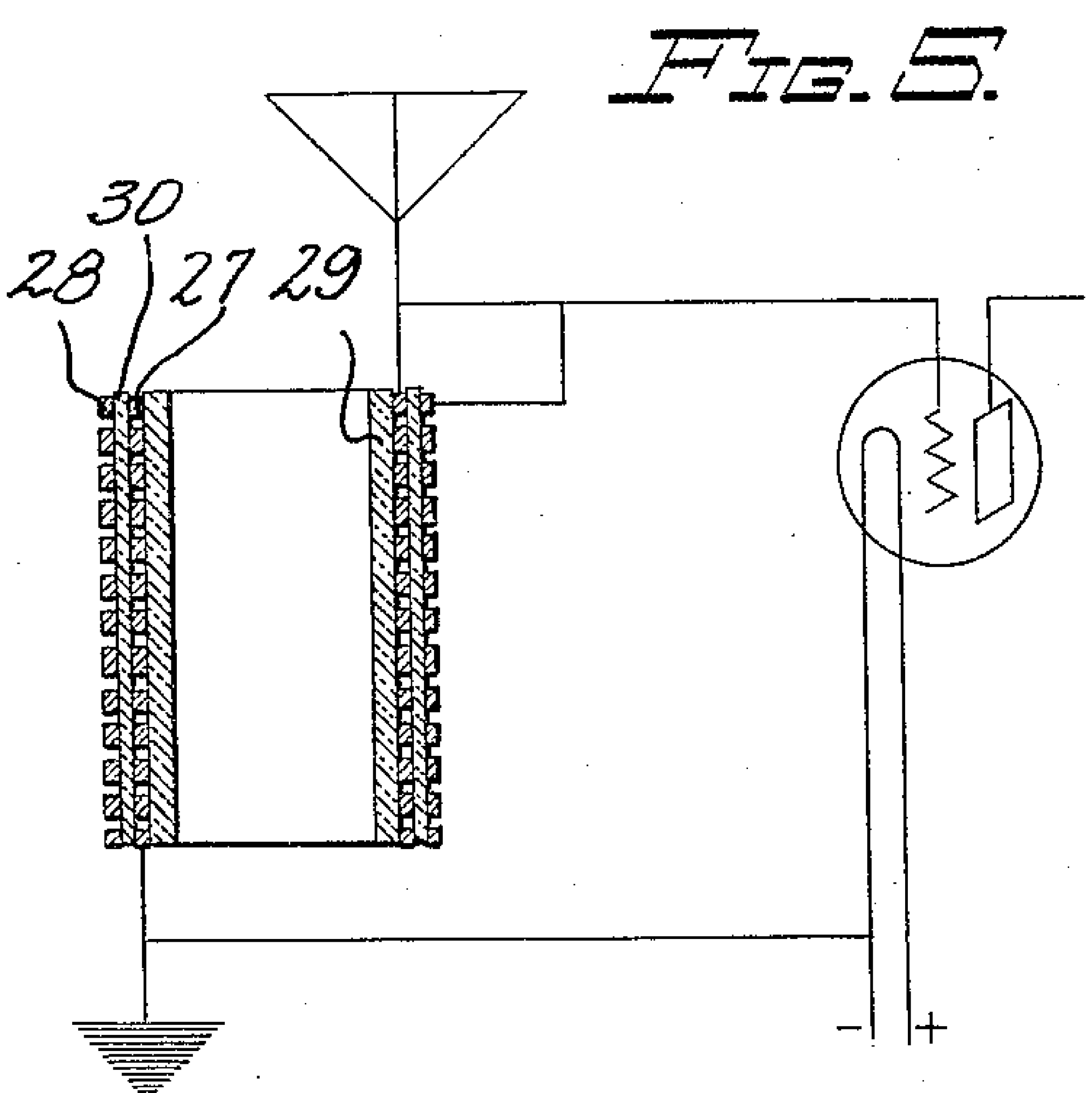
BROAD BAND FREQUENCY RESPONSIVE MEANS

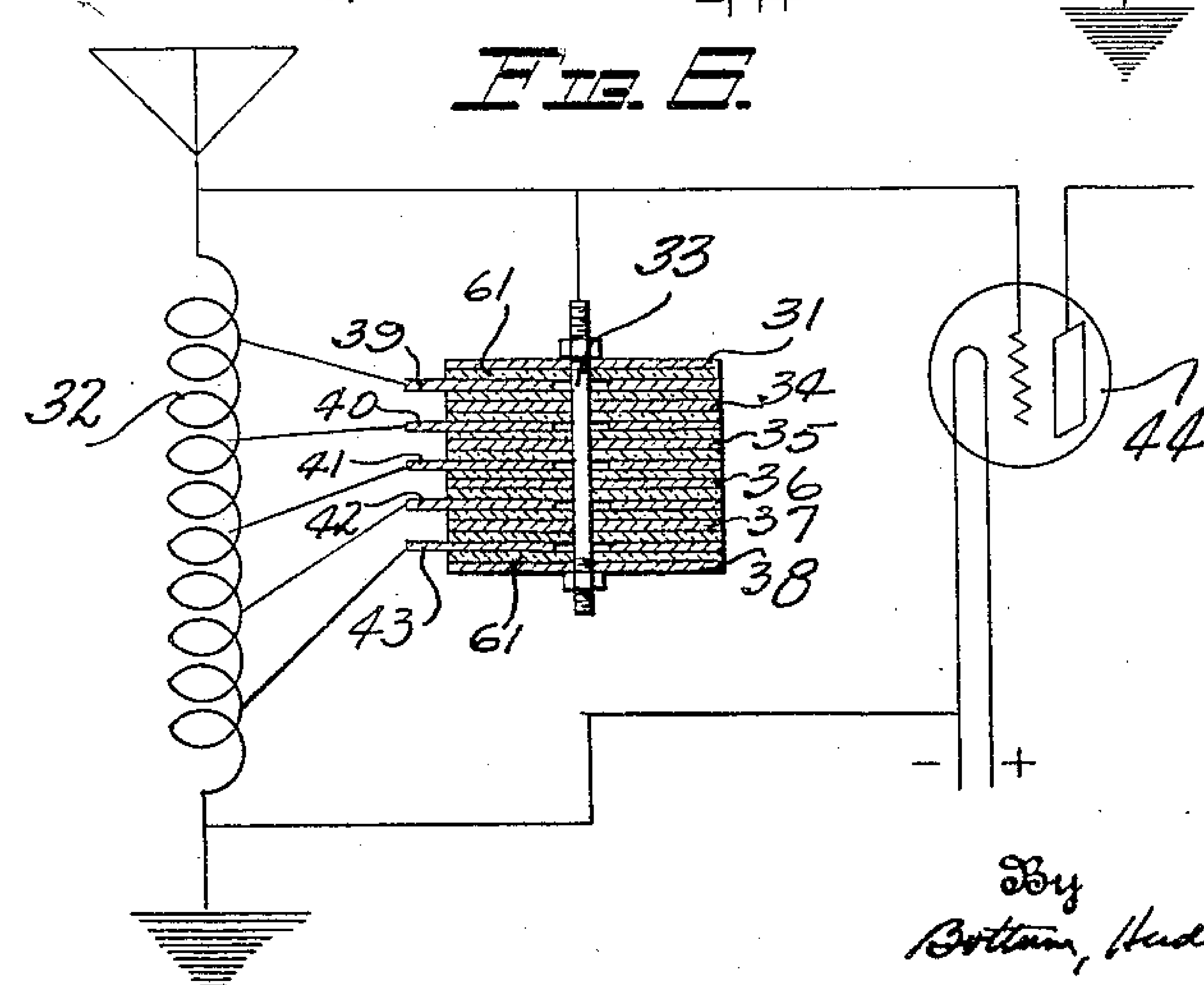
Filed Aug. 19, 1929 2 Sheets-Sheet 1

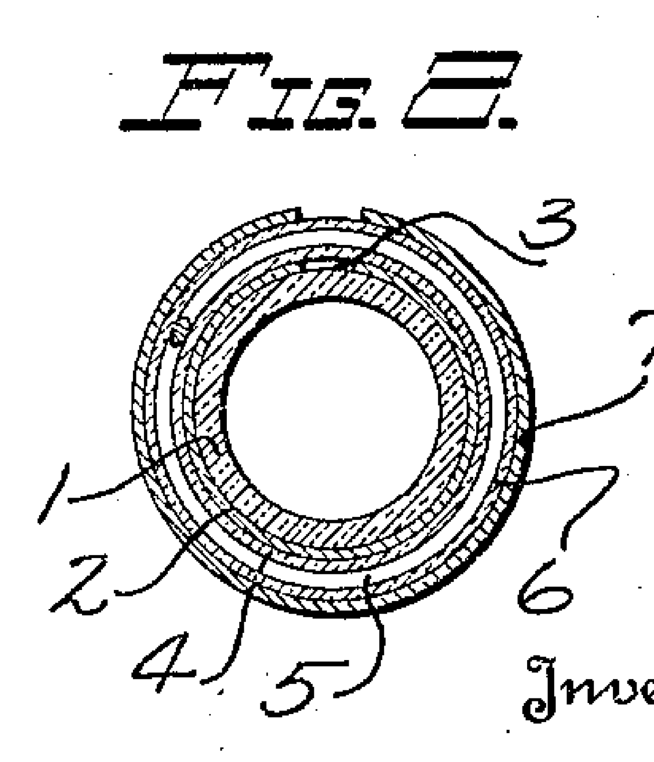












Inventor

Erwin R. Stoekle

By Bottum, Hudnall, Lecher, McNamara and Michael

Attorney

Feb. 14, 1933. E. R. STOEKLE 1,897,082

BROAD BAND FREQUENCY RESPONSIVE MEANS

Filed Aug. 19, 1929 2 Sheets-Sheet 2

FIG. 7.

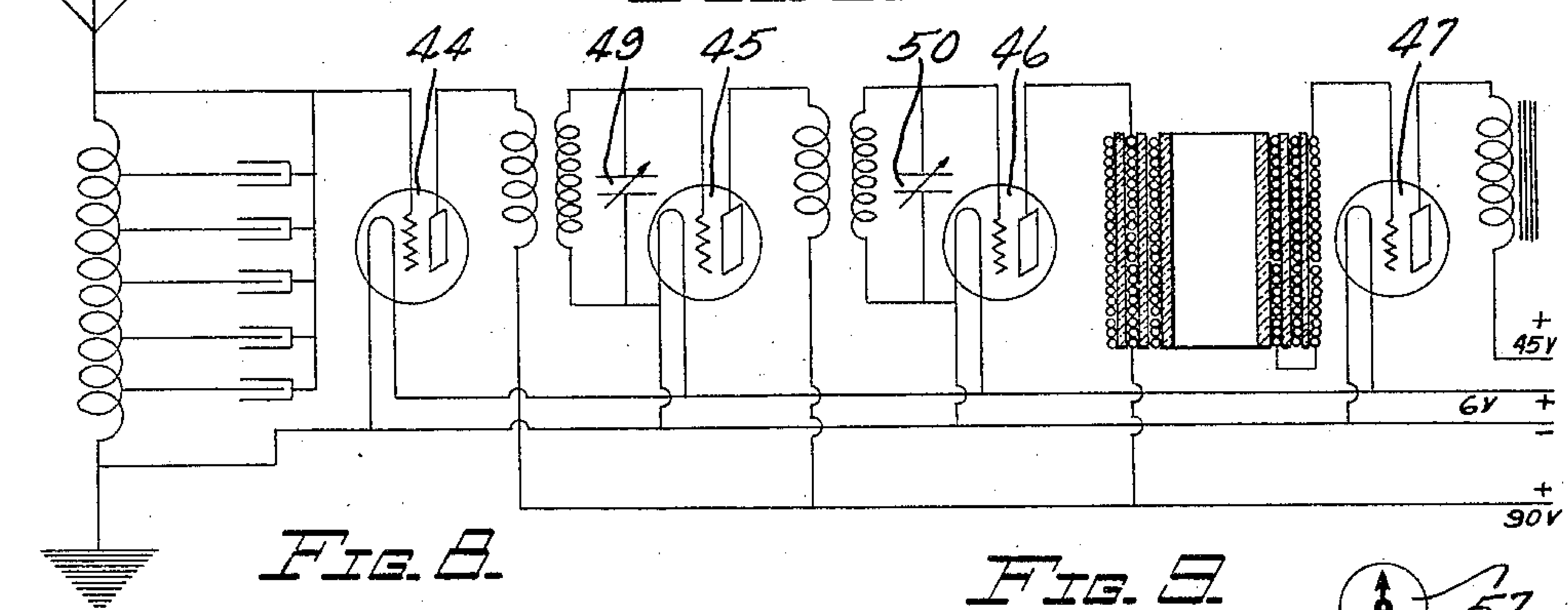


FIG. 8.

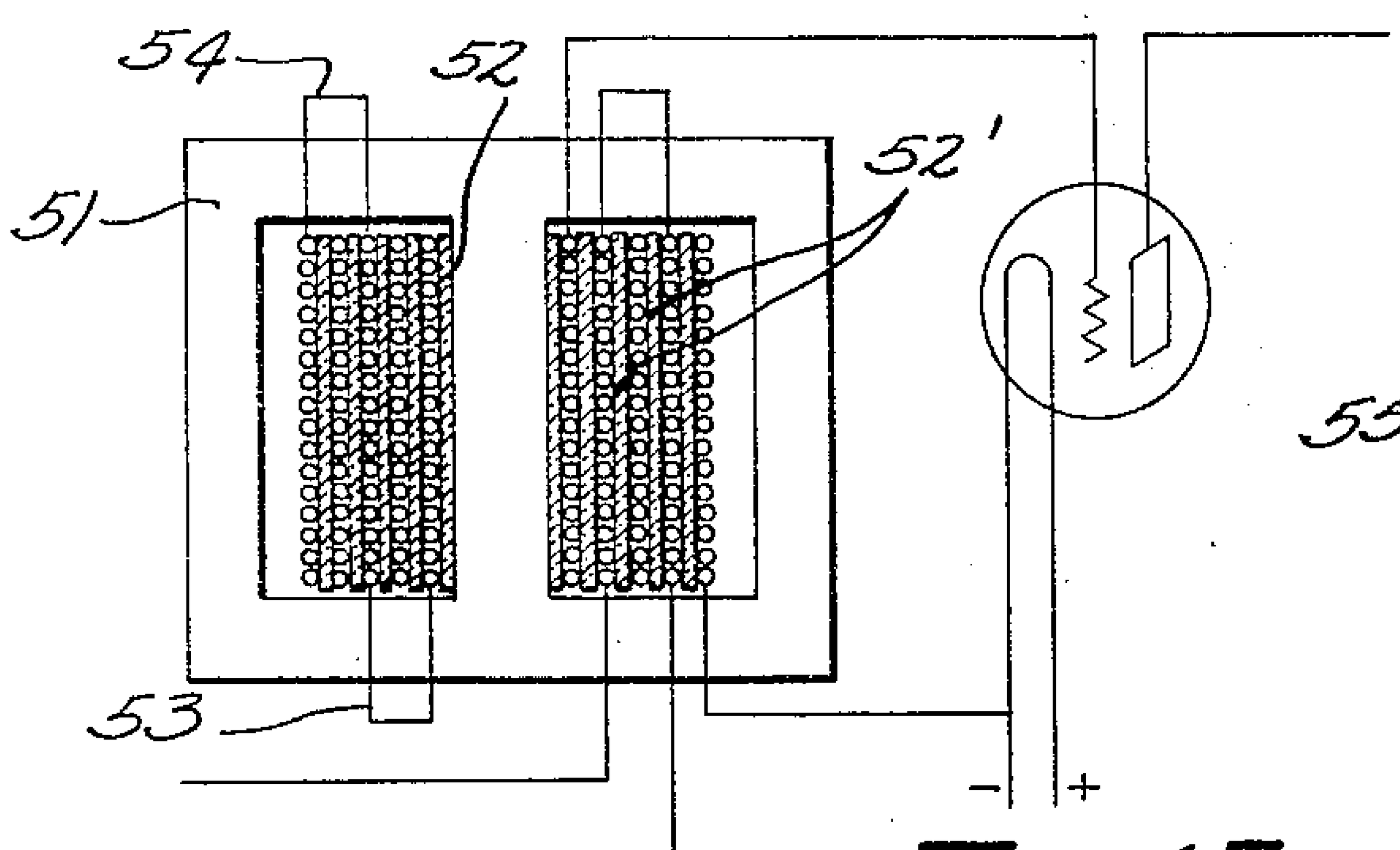


FIG. 9.

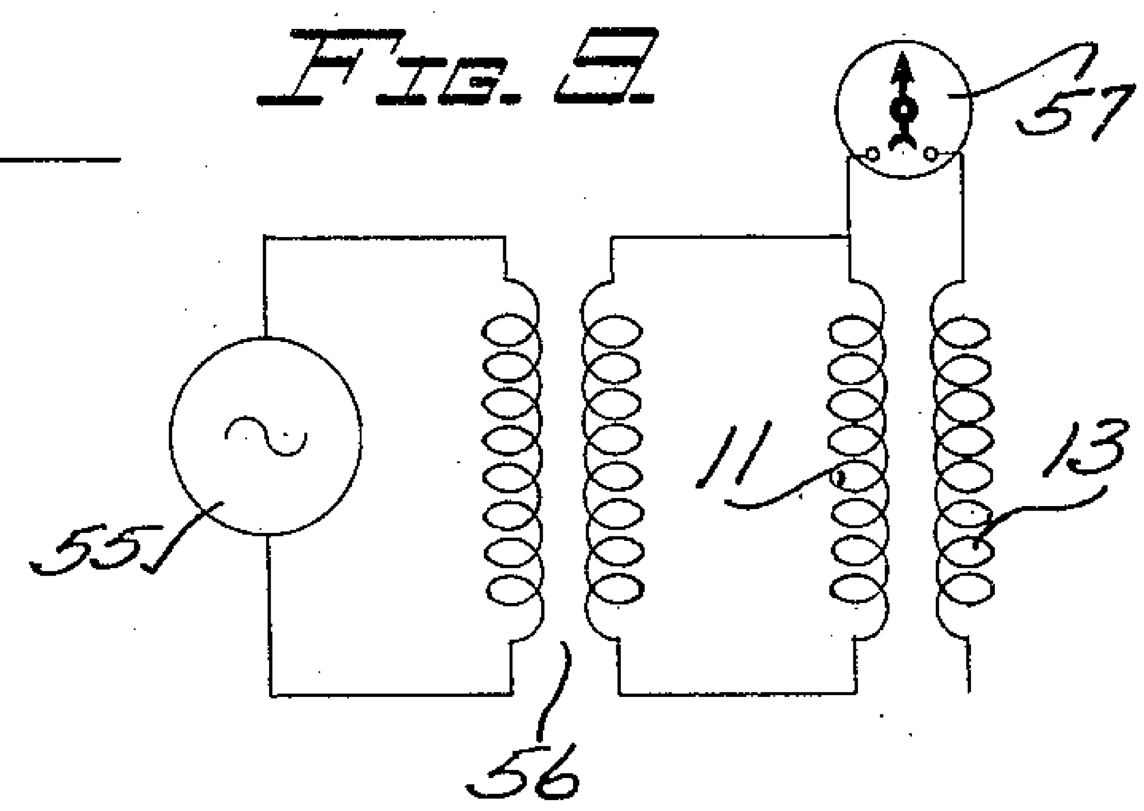
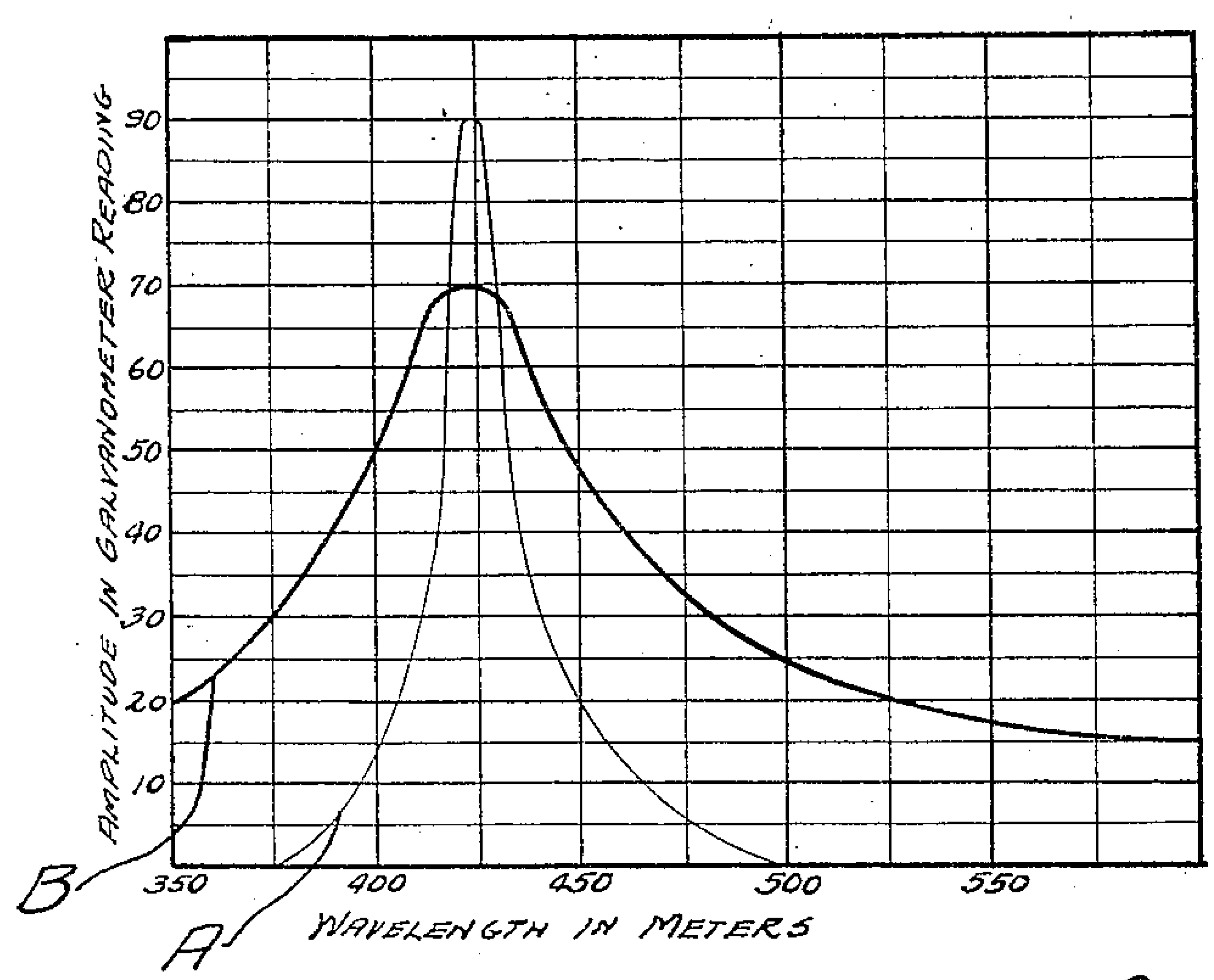


FIG. 10.



Inventor

Erwin R. Stoekle

By Bottum, Hudnall, Lecher, McNamara and Michael

Attorney

Patented Feb. 14, 1933

1,897,082

UNITED STATES PATENT OFFICE

ERWIN R. STOEKLE, OF MILWAUKEE, WISCONSIN, ASSIGNOR TO CENTRAL RADIO LABORATORIES, OF MILWAUKEE, WISCONSIN, A CORPORATION OF WISCONSIN

BROAD BAND FREQUENCY RESPONSIVE MEANS

Application filed August 19, 1929. Serial No. 386,760.

This invention relates to electrical circuits and more particularly to means broadly tuned to a band of frequencies adapted for use in radio circuits and amplifying systems.

Heretofore, in the art several known radio receiving systems have employed one or more sharply tuneable circuits which provide the necessary selectivity in combination with series of so-called untuned cascade vacuum tube amplifiers connected to the tuneable circuit or circuits to provide the necessary amplification. Other known forms of radio receiving systems employ a so-called untuned antenna coil and subsequent stages of cascade amplifiers having tuned input circuits. These so-called untuned amplifiers are really tuned to a definite frequency, the electrical impedance factors of the circuit being fixed; and the so-called untuned antenna coils are really coils tuned with the antenna inductance and capacity to resonance with a certain frequency or band of frequencies.

It is therefore common to find radio receiving sets operating efficiently near one frequency or over a narrow band of frequencies but less efficiently over other portions of the broadcast range. Heretofore in the art it has been customary to broaden the frequency response of such units, the impedance characteristic of which are not manually variable, by introducing into the circuit resistance or damping factors in the form of iron cores. While the use of such means results in the desired broadening of the response, it also produces the undesirable effect of reducing the amplitude of the incoming waves.

An object of the present invention is to broaden the response of such amplifiers or antenna coils as those mentioned above so that they may be efficiently operated over a wide band of frequencies while the losses which reduce the amplitude of the electrical waves passing therethrough are maintained low.

Another object is to provide a novel combination of a coupling unit and vacuum tube which will be more efficient over a broad band of frequencies than those heretofore devised.

In carrying out these and other objects a circuit is so constituted as to have self inductance and distributed capacity combined and related in such a novel manner as to make a circuit substantially resonant to a wide band of frequencies. In one embodiment of such a circuit an induction coil is incorporated therein. A condenser plate and dielectric material are so associated with the coil as to provide cvapacity between the coil and the plate, the coil thus acting as one plate of the condenser. The plate is connected to one end of the coil so that the result is somewhat the same as though a condenser were placed in parallel with a portion of the coil and in series with another portion. Such a coil unit will be broadly tuned for the reasons explained hereinafter and may be advantageously employed as a coupling between the stages of an amplifier, in the antenna circuit of a radio system having tuned stages of amplification or in other circuits or systems where a broadly responsive coupling is desired.

Other objects and advantages reside in certain novel features of the construction, arrangement and combination of parts which will be hereinafter more fully described and particularly pointed out in the appended claims, reference being had to the accompanying drawings forming a part of this specification, and in which:

Figure 1 is a cross-sectional view of a radio frequency coil embodying one form of the present invention with a diagrammatic showing of an associated vacuum tube circuit;

Figure 2 is a cross-sectional view of the coil of Figure 1, the view being taken on the line 2—2 of Figure 1;

Figure 3 is a cross-sectional view of another and preferred form of radio frequency coil with a diagram showing the associated vacuum tube circuit;

Figure 4 is a cross-sectional view of another form of radio frequency coil and a diagrammatic showing of an associated amplifier circuit the coil being adapted for use primarily as a coupling between the stages of a radio frequency amplifier;

Figure 5 is a cross-sectional view of a further modified form of radio frequency coil and a diagram of the associated circuit;

Figure 6 is a diagrammatic showing of an antenna circuit with a cross-sectional view of a multi tap condenser connected therein;

Figure 7 is a diagrammatic view of a radio receiving system having the coil units of Figures 4 and 6 embodied therein;

Figure 8 is a diagrammatic showing of a multi layer coil and associated amplifier tube, the coil being adapted to broadly tune the input circuit of an audio frequency amplifier;

Figure 9 is a diagrammatic view showing test apparatus connected to the coil of Figure 3 so as to measure the electrical properties thereof, and

Figure 10 is a chart illustrating the principles of the present invention, one of the curve thereon being plotted from readings taken on testing apparatus like that of Figure 9.

Referring to Figures 1 and 2 of the drawings which illustrate the invention in its simplest form, reference numeral 1 indicates a suitable cylindrical insulating core or base for supporting a coil and condenser plates. The condenser plates, shown as two in number, are made of conducting material such as tin foil and are positioned on opposite sides of a single layer coil 5. In building this unit, a conducting layer or plate 2 is mounted directly upon the insulating core 1, the plate being formed into cylinder to conform with the shape of the core and being split longitudinally as shown at 3, Figure 2, to prevent the circulation of eddy currents therein. Around the cylindrical layer 2, an insulating coating 4 is provided. This coating serves as a binder for the layer 2, and as a core for the spiral winding of the coil 5. The coil 5 is then wound and is covered with a second insulating coating 6 which supports a second and outer cylindrical conducting layer 7, which is shaped like the inner layer 2 and correspondingly split as shown at 3′ of Fig. 2 to prevent the circulation of eddy currents therein. The conducting layers 2 and 7 are then connected together and to the upper end of the coil 5 by means of a conductor such as that shown at 8. As shown in this Figure the conductor 8 is also connected to the antenna and to the grid of the vacuum tube 9 while the lower end of the coil 5 is connected to the ground and to the filament of the vacuum tube, thus placing the combined coil and condenser unit in the antenna-ground circuit in parallel with the vacuum tube.

It will be noted that the lower end of the conducting cylinders 2 and 7 are not electrically connected to anything. These cylinders serve as one plate of a condenser, however, the other plate of the condenser being the coil 5 or a portion thereof. The insulating coatings 4 and 6 serve as the dielectric of this condenser. Since the antenna circuit thus has both inductance (the coil 5) and capacity (the coil 5 and plates 2 and 7) therein it will be evident that it is tuned for resonance with a certain frequency or band of frequencies and that when an electromotive force of a resonant frequency is impressed thereon, the tuning of the coil is such as to render the vacuum tube operative in the usual manner.

The present construction differs from an ordinary circuit having inductance and capacity, however, and is such as to render the antenna circuit responsive to a broad band of frequencies. The theoretical operation of the system of Figure 1 in accomplishing this result will now be explained.

In an ordinary circuit, as for example one having an inductance coil and a condenser in parallel the inductance and capacity are usually regarded as fixed values so that theoretically at least there is only one frequency to which the circuit is tuned for resonance. The conditions for resonance may be expressed by the well known formulæ

$$f=\frac{1}{2\pi\sqrt{LC}}$$

in which f is the frequency of the impressed electromotive force. L is the inductance of the circuit and C the capacity. In the system of Figure 1, however, because of the peculiar manner in which the condenser plates 2 and 7 are associated with the coil 5 and the manner in which the coil and plates are connected to the antenna and ground, both the inductance L and capacity C of the circuit vary inversely with a changing frequency and the conditions for resonance exist over a wide band of frequencies.

Assuming an electromotive force of resonant frequency is impressed between the antenna and ground of Figure 1, current will flow through two parallel paths, one being an inductive path through the coil 5 per se and the other being an inductive and a capacitive path through a portion of the coil 5 and the plates 2 and 7. In the second path mentioned, a portion of the coil acts like one plate of an ordinary condenser.

If the frequency of the impressed electromotive force is increased the inductive reactance X_L of the coil will increase and the capacitive reactance X_C between the plates 2 and 7 and the coil 5 will decrease in accordance with the well known laws expressed by the formulæ

$$X_L=2\pi fL \text{ and } X_C=\frac{1}{2\pi fC}$$

in which f L and C represent the frequency, inductance and capacity respectively of the circuit. The current naturally follows the path of the least impedance so that as the inductive reactance increases and the capacitive reactance decreases, due to an increase in frequency, more current will flow through the second path mentioned above (that is, the path which contains the capacitive reactance) and less through the first mentioned path. An increase in frequency will lessen the effective number of turns in the coil or the current does not penetrate the coil as far as it did under natural resonant frequency. This results in a decrease in the inductance of the coil. The effective area of the coil (that is, the area capable of sustaining a charge of opposite polarity to that on the plates 2 and 7) is also reduced so that a decrease in capacity between the coil 5 and the plates 2 and 7 also results since the difference in potential between the coil and the plates 2 and 7 is distributed over a smaller area of the coil. Thus an increase in frequency causes a decrease in both inductance and capacity so that the conditions for resonance as expressed by the formulæ still hold so that a broadening of the response of the circuit is effected, whereas an ordinary circuit in which the inductance and capacity are not mutually affected by each other to any considerable extent is detuned upon an increase in frequency.

Similarly if the frequency of the impressed electromotive force is decreased, the inductive reactance decreases and the capacitive reactance increases, resulting in an increase in both the inductance and capacity so that the conditions for resonance still hold. It will thus be seen that the condenser and the coil mutually modify the action of each other so that the action of one is controlled not only by conditions in the circuit but also by conditions in the other. In other words, with increased or high frequencies of the broadcast range, the entire coil does not have opportunity to function as an inductance nor does the entire condenser have opportunity to function as a capacity because the current is shunted through a small part of the condenser after it has penetrated only a few turns of the coil. As a consequence, with an increase in frequency a decrease in the effective or functioning inductance and capacity of the circuit results. Conversely when the frequency decreases, more turns of the coil will be penetrated due to the decrease in the inductive reactance and a greater portion of the condenser will function or be effective. It is to be noted that this broadening in tuning of the coil unit is not accompanied by an increase in resistance or by the introduction of other losses.

Referring now to Figure 3 which shows a preferred form of construction a cylindrical insulating tube or core 10 is provided for supporting a pair of insulated coils. The coil 11 is first wound upon the core and is then coated with an insulating layer 12 upon which the second coil 13 is wound as shown. The direction of winding of the coils 11 and 13 is important and is such that if the coils were connected in parallel by connecting the upper ends to the antenna and the lower ends to the ground, the magnetic fluxes generated by the passage of current therethrough will be in opposition. In actual practice the coils are not connected in parallel, however, the lower end of the coil 13 being free and not electrically connected to anything. The upper ends of the coils 11 and 13 are connected to each other by a conductor 14 which also connects the upper ends to the antenna and to the grid of a vacuum tube 9′ while the lower end of the coil 11 is connected to the filament of the vacuum tube and to the ground so as to place the coil unit in parallel with the input circuit of the tube.

In this structure it will be seen that the second winding 13 takes the place of the condenser plates 2 and 7 of the embodiment of Figure 1 being separated from the coil 11 by the dielectric 12. The coil 13 acts to give an additional inductance to the circuit, however, in addition to acting as the plate of a condenser. The operation of this unit is the same as that of Figure 1 except for this additional inductance of the coil 13. Due to the fact that the inductive reactance of the turns of both coils 11 and 13 increases with increasing frequency whereas the capacitive reactance between them decreases with increasing frequency, a progressively lesser number of turns will be effective in the input circuit of the vacuum tube as the frequency increases. This will result in a decrease of both the inductance and capacity effective in the input circuit as in the embodiment of Figure 1 and for the same theoretical reasons except that the coil 13, being wound in opposition to the coil 11 further broadens the tuning. Assuming the frequency increases above natural resonance, the impedance through the circuit of the coil 13 will decrease, since this circuit contains capacitive reactance. More current will thus flow in coil 13 and the opposition to the field built up by current in the coil 11 will be increased. The effective inductance of coil 11 is thus decreased by the combined action of the inductance of the coil 13 and the capacity between the coil 13 and coil 11. Therefore, the tuning of the input circuit of the vacuum tube will tend to adjust itself to the incoming frequency and an increased efficiency of the coupling will result over a broad band of frequency.

Figure 4 shows a radio frequency transformer embodying the principles of the invention. An insulating tube 15 is provided upon which three windings 16, 17 and 18 are wound, the windings being separated by insulating coatings 19 and 20 similar to that of the construction of Figures 1 and 3. In order to broadly tune this transformer, large capacity between the primary and secondary is provided. This result is effected by using the winding 17 as the primary and the windings 16 and 18 as the secondary. The windings 16 and 18 may be connected in series or in parallel so long as the fields created by the passage of current therethrough have the same polarity. In the construction shown, these windings are connected in series by a connector 21. The primary winding 17 may be connected to a source of alternating current, such as the output of an amplifier, by the conductors 22 and 23. The secondary windings 16 and 18 may be connected to the grid and filament of a vacuum tube 24 by means of the conductors 25 and 26. When the windings are so connected, there is large capacity between and distributed along the turns of the primary and secondary, because the secondary is on both sides of the primary coil. The large capacity shunts off a portion of the current and as an increase in frequency of the impressed voltage causes a decrease in the penetration or effective turns in the primary as well as a decrease in the effective capacity between the primary and secondary, the inductance and capacity in the input circuit of the vacuum tube will automatically tend to adjust the circuit to resonance with the frequency of the impressed voltage over a relatively wide band.

An alternating electromotive force impressed across an intermediate winding 17 will penetrate a progressively greater number of turns as the frequency decreases which will result in more current being induced in the windings 16 and 18 by the current in the intermediate winding 17 and will also cause greater electrical capacity between the coils 16 and 18 and the coil 17 thus the input circuit will tend to adjust itself to resonance with the impressed electromotive force over a relatively wide band of frequencies.

Figure 5 shows a form of broadly tuned coil like that of Figure 3 in all respects except that the two coils 27 and 28 are composed of a material in the form of flattened wire or ribbon in order to increase the distributed capacity between them. In this figure the coil 27 is wound directly upon the tube 29 and is then covered with an insulating coating 30 upon which the outer coil 28 is wound. The connection and operation of this coil is the same as that of Figure 3.

Figure 6 shows a further modification in which the broad tuning is accomplished by means of a multi-tap condenser unit which is connected to a coil, such as that diagrammatically shown at 32 at suitable points along its length. The condenser unit may consist of a metallic stud or bolt 33 upon which metallic plates or disks 31, 34, 35, 36, 37 and 38 are mounted, these plates being electrically connected to each other and to the stud. Alternating with and insulated from the above plates are conducting plates 39, 40, 41, 42 and 43. These alternating sets of plates are separated by a suitable dielectric such as mica sheets 61. Each of the plates 39, 40, 41, 42 and 43 is connected to a section of the coil 32 whereas the plates 34, 35, 36, 37 and 38 are connected through the stud 33 to the grid of the vacuum tube 44, the antenna and the upper end of the coil 32, as shown. The small section condensers, as those formed by adjacent plates of the condenser unit, thus form a series of parallel circuits with the sections of the coil 32 in a manner shown in Figure 6 and shown diagrammatically in the input circuit of the first vacuum tube 44 of Figure 7. Such a vacuum tube input circuit will therefore respond to a broad band of frequencies determined by the natural frequencies of the several sectional parallel circuits and the combination thereof.

Figure 7 shows a portion of a radio receiving system up to and including the detector tube. The vacuum tubes 44, 45 and 46 are radio frequency amplifiers and the vacuum tube 47 is the detector. The input circuit of the tube 44 is broadly tuned by means of the sectional condenser unit of the type shown in Figure 6 as mentioned above. The input circuits of tubes 45 and 46 are of the usual form being sharply tunable by means of variable condensers 49 and 50 in order to attain selectivity. The input circuit of the detector 47 is broadly tuned by means of a radio frequency transformer of the type shown in Figure 4. In view of the fact that the efficiency of the conventional tuned input circuits of tubes 45 and 46 is greatest at the shorter wave length (approximately 350 meters) of the broadest range, it is desirable to make the broadly tuned input circuits of tubes 44 and 47 with the resonance peak near the maximum wave lengths of the broadcast range (approximately 450 meters). This will give the flattest response of the entire amplifier over the broadcast range of frequencies.

Figure 8 illustrates a form of broadly tuned transformer adapted for audio frequency amplification. The object of this arrangement is to transmit with maximum frequency all of the audio frequencies from a detector or the like through audio frequency amplifiers to a sound reproducer or speaker.

The same principles of inductance and distributed capacity are applicable in this circuit as in the previously described radio frequency circuits except that the values of inductance and capacity must be much greater. In order to accomplish this a coil wound and constructed similar to that of Figure 4 may be used, except that more layers of windings separated by dielectric sheets are needed and the inductance of the unit must be increased by some means such as a laminated iron core 51. In illustrating this transformer, five layers of windings are shown, the first layer of windings being insulated from the iron core by means of an insulating tube 52 and being connected at its lower end to the lower end of the third winding by a conductor 53, the upper end of the third winding being connected to the upper end of the fifth winding by the conductor 54. The second and fourth layers of windings are insulated from the first, third and fifth windings by dielectric sheets 52′ and are connected in series so as to constitute the primary of the transformer while the first, third and fifth windings constitute the secondary thereof. Just as described for radio frequency currents in connection with the device of Figure 4, the alternation of the primary and secondary windings causes a large capacity between these elements which is effective to broadly tune the transformer, the inductance and capacity between the layers of the coils varying with the impressed frequency in such a manner as to make the input circuit of the vacuum tube respond to a broad band of audio frequencies. This tends to equally amplify all the frequencies impressed thereon and the tone quality of the amplified audio signal is increased.

Referring now to Figure 9, the coil of Figure 3 is shown connected to a variable frequency source 55 through a transformer 56. A galvanometer 57 is connected across the upper ends of the coils 11 and 13 so as to be responsive to the inductive and capacity coupling between these two coils.

In determining the coupling between these coils, the variable frequency source 55 so connected may be operated to impress an electromotive force upon the coil 11 over a wave length range from approximately 350 to 600 meters.

The results obtained by the manipulation of a test system like that of Figure 9 upon a coil actually constructed in the form shown in Figure 3 are plotted on the chart of Figure 10, in which the curved line B illustrates the response of the coil as indicated by the galvanometer over the frequency range shown. The sharply peaked resonance curve A of Figure 10 shows the response of a coil having an inductance valve equal to that of the coil 11 and having an air condenser connected in parallel therewith when subjected to the same varying wave lengths. It is apparent from the inspection of this chart that a very much broader band of wave lengths is embraced by the curve B than by the curve A thus illustrating the results desired in this invention.

While only a few of the embodiments of the invention have been shown and described herein, it is obvious that by making suitable changes in the inductance and capacity valves of the coils shown in Figures 1, 3, 5 and 6 they also may be adapted to audio frequency as well as the form shown in Figure 4 and that many other changes may be made in the structure and in the method of connecting the coils to the apparatus with which they are used without departing from the spirit of the invention or the scope of the annexed claims.

What I claim is:

1. In combination with an electrical system, means for impressing energy thereon including two parallel electrical paths, one inductive and containing an induction coil and the other capacitive and including said induction coil and a condenser plate co-extensive with and closely adjacent said coil, there being a di-electric between the coil and the condenser plate whereby as the frequency increases the current will flow more and more through the capacitive path and less through the inductive path and as the frequency decreases the current will flow more and more through the inductive path and less through the capacitive path.

2. In combination with an electrical system, means for impressing energy thereon including an electrical circuit, an induction coil having its terminals connected across the circuit, a second coil disposed in capacitive relation to the first coil, said second coil having one end only connected to said circuit, there being a dielectric between said coils so that the two coils constitute the plates of a condenser as well as the inductance in the circuit and whereby the inductive and capacitive reactance of the coils automatically vary the extent of the coils effective as inductance and capacity in the circuit inversely with changes in frequency so as to maintain the circuit resonant to a broad band of frequencies.

3. A vacuum tube amplifier of radio frequency signals comprising a series of vacuum tubes, the output circuit of one tube being coupled to the input circuit of the next succeeding tube in the series by means of closely adjacent, coaxial coils placed one within the other and separated by a dielectric to provide a capacitative as well as an inductive coupling between the coils, one of said coils being conductively connected at one point only to the circuit with which it is associated whereby the effective inductance and capacity of said circuit will vary with the frequency in such a manner as to transfer a wave of large amplitude to said input circuit over a broad band of frequencies.

4. In combination, a vacuum tube, an input circuit for the tube including an antenna having an induction coil connected across said circuit, a multitap condenser unit having a set of plates connected to the coil at spaced points therealong, a second set of plates connected to one side of said circuit and a dielectric between adjacent plates of the sets.

5. In combination, a vacuum tube, an input circuit for the tube including an antenna, an induction coil connected to the antenna and to the ground, a second coil arranged concentrically with respect to and in capacitive rela-

tion to the first coil and connected to one side only of the circuit, there being a dielectric between said coils, thereafter whereby to provide a distributed capacity coupling between said coils.

6. Means for broadly tuning an alternating current circuit to render the same substantially resonant to a broad band of frequencies including a plurality of juxtaposed inductance coils arranged concentrically one within the other, both terminals of one of said coils being connected across the circuit and the other of said coils having a free end and an end connected to one end of the coil connected across the circuit.

7. An electrical circuit having an induction coil incorporated therein, a condenser plate connected to one side of the circuit and disposed closely adjacent the coil, said condenser plate being co-extensive with said coil there being a dielectric between the coil and the condenser plate so that the coil constitutes the other plate of the condenser as well as the inductance in the circuit and whereby the inductive and capacitive reactance of the coil and the plate automatically vary the extent of the coil and the plate effective as inductance and capacity in the circuit inversely with changes in frequency so as to maintain the circuit resonant to a broad band of frequencies.

8. An electrical circuit having an induction coil incorporated therein, means coacting with the coil to provide a condenser, one plate of which is subject to the electrical conditions obtaining in the coil, the other plate of which is connected to a part of the circuit whereby the inductive and capacitive reactances of the coil and condenser vary the number of turns of the coil and the area of the condenser effective as inductance and capacity in the circuit inversely with changes in the frequency.

9. An electrical circuit having inductive means incorporated therein, means connected to a part of the circuit and coacting with the inductive means to supply distributed capacity in electrical relation to and co-extensive with the inductive means whereby the inductive and capacitive reactances are varied with changes in the frequency impressed on the circuit and control the extent of the inductive and distributed capacitive means effective in the circuit to thus automatically maintaining the circuit in resonance with the frequency impressed thereon.

In witness whereof, I hereof affix my signature.

ERWIN R. STOEKLE.