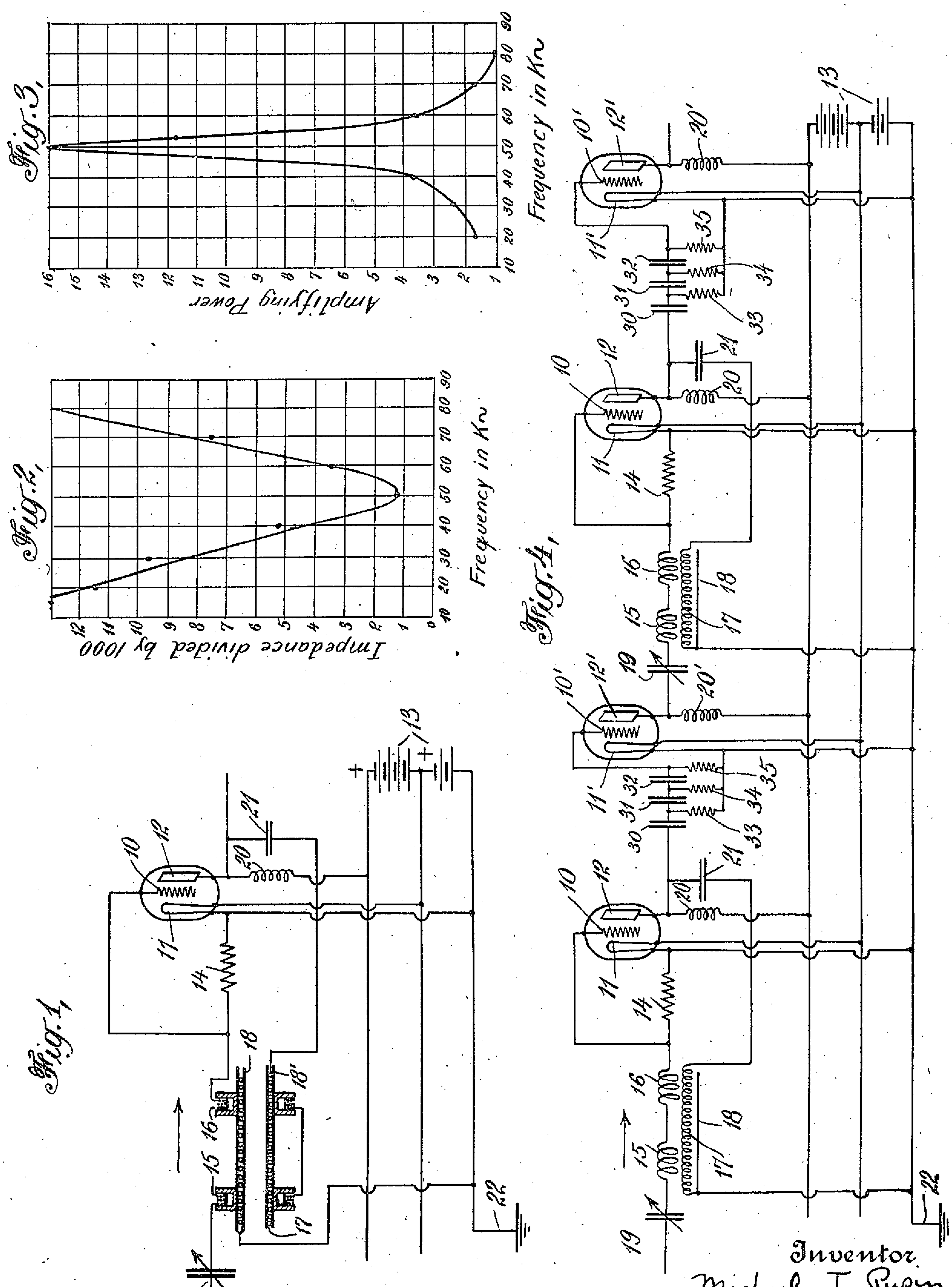
Apr. 24, 1923. 1,452,933

M. I. PUPIN

SELECTIVE AMPLIFYING APPARATUS

Original Filed Oct. 10, 1918 3 Sheets-Sheet 1



Inventor
Michael I. Pupin
By his Attorneys
Pennie, Davis, Marvin & Edmonds

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SELECTIVE AMPLIFYING APPARATUS

Original Filed Oct. 10, 1918 3 Sheets-Sheet 2

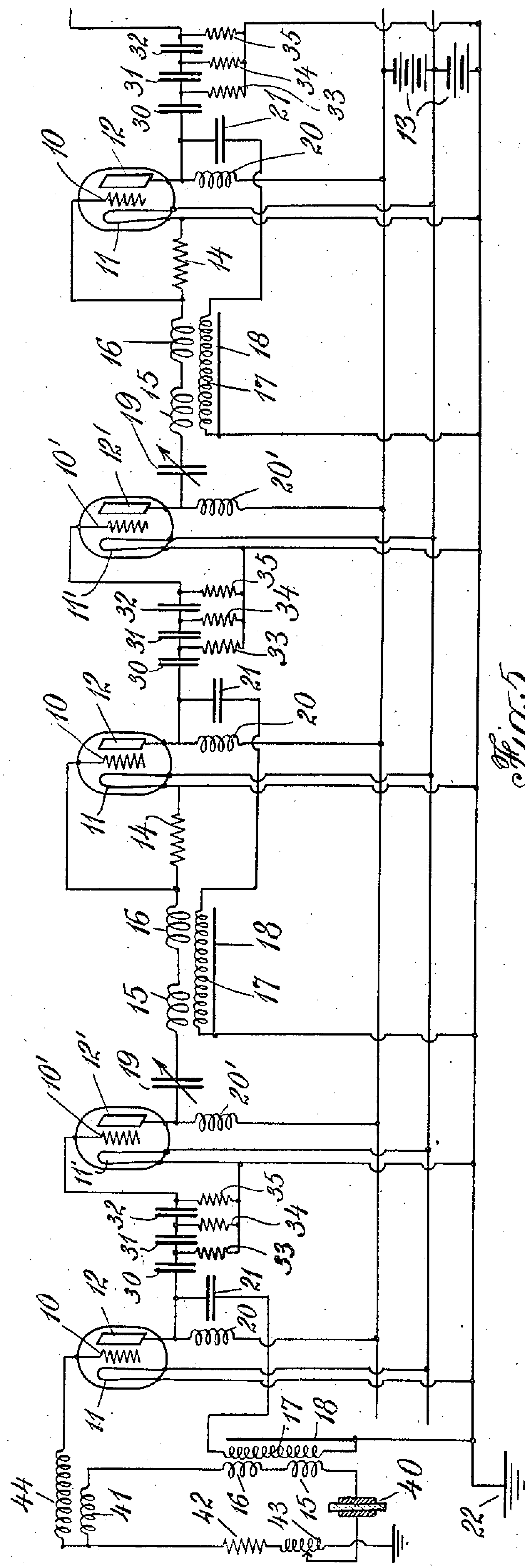

Fig. 6.

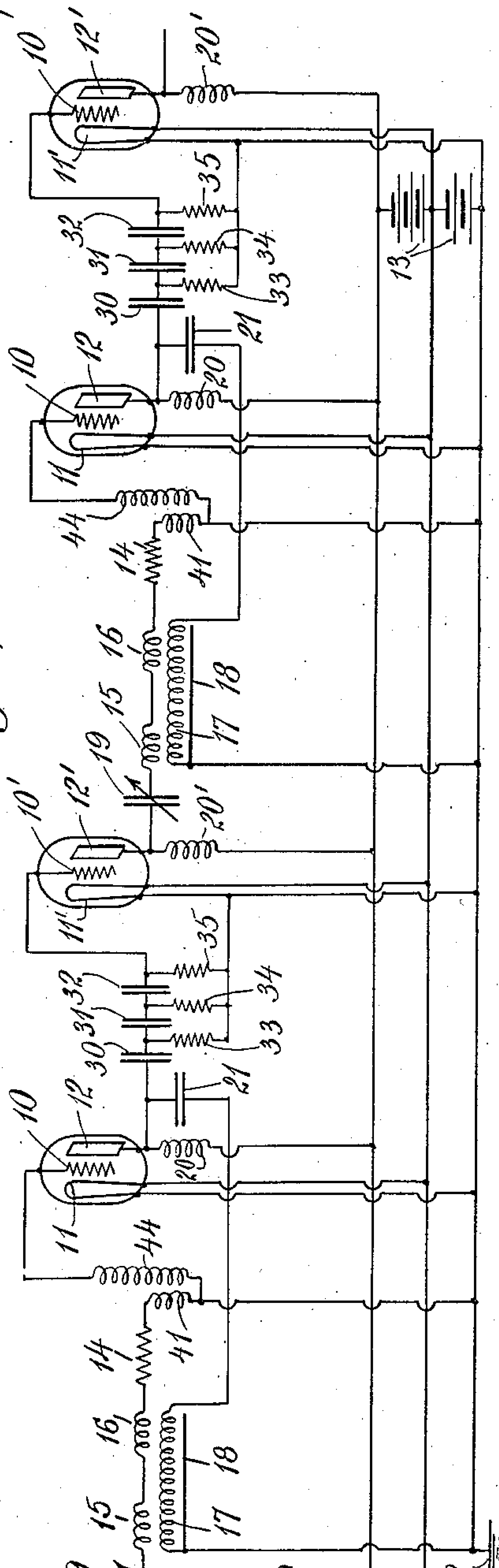

Fig. 5.

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Original Filed Oct. 10, 1918 3 Sheets-Sheet 3

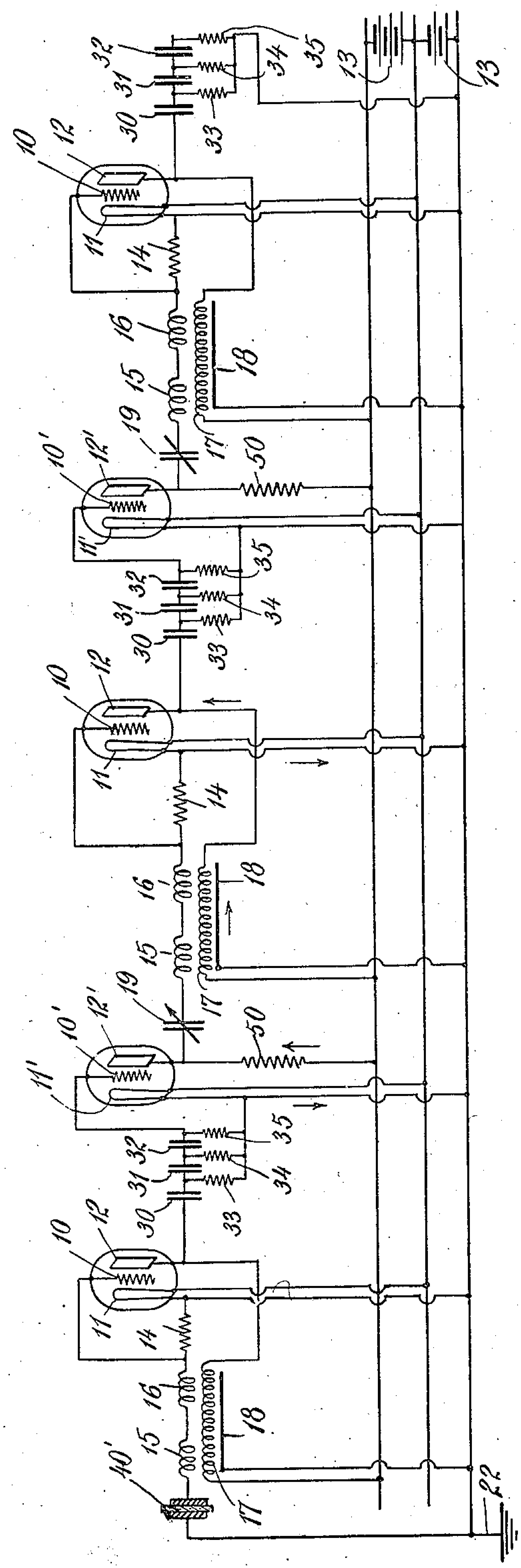

Fig. 7.

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Patented Apr. 24, 1923. 1,452,933

UNITED STATES PATENT OFFICE.

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SELECTIVE AMPLIFYING APPARATUS.

Application filed October 10, 1918, Serial No. 257,571. Renewed September 14, 1922. Serial No. 588,287.

To all whom it may concern:

Be it known that I, Michael I. Pupin, a citizen of the United States, residing at Norfolk, in the county of Litchfield, and State of Connecticut, have invented certain new and useful Improvements in Selective Amplifying Apparatus; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

This invention relates to selective amplifying apparatus for electric energy waves, and has for its general object the provision of an improved apparatus of this character. A more particular object of the invention is the provision of a selective multi-step vacuum tube amplifier. Other objects of the invention will be brought out in the course of the following description.

In the art of wireless telegraphy and telephony of today, selectivity with respect to the frequency of the signalling harmonic electromotive forces is obtained by balancing inductance reactions against capacity reactions, and a high degree of selectivity is obtained by the employment of conductors of relatively low resistance reactions, and large time constants. Selectivity obtained in this manner produces a system of electrical conductors in which the natural oscillations are undamped, so that disturbing electrical pulses following each other at rapid intervals maintain in such a system of electrical conductors a more or less continuous train of oscillations of the same periods as those for which the conductors are selective. The disturbances arising from these oscillations are just as objectionable as the disturbances that would be produced by the pulses directly. Hence, this kind of selectivity is no protection against disturbances due to pulse excitation. While the present invention makes use of the balancing of inductance reactions by capacity reactions, it does not depend upon this balancing for the high degree of selectivity and instead of employing electrical conductors of relatively small resistance reactions and large time constants, the dissipative reactions are made as large as practicable, and the time constants are as small as practicable, so that the natural oscillations, when they exist at all, are very highly damped, so highly indeed, that they are incapable of producing, by interference beats, the well known heterodyne low frequency, and for this reason, as will be shown presently, the selectivity described here will protect from disturbing interferences due to pulse excitation just as well as it does with respect to steady harmonic electromotive forces.

The selective amplifying apparatus of the present invention is made selective with respect to the impressed (signalling) frequency by the action of a device for balancing in phase and amplitude alternating or pulsating electromotive force waves. A suitable device for this purpose is described in my copending application Serial No. 257,570, filed October 10, 1918, and I shall throughout this specification, as in the copending case, designate the device as a wave balance.

In its broad aspect, the invention involves the provision of a circuit of high dissipative impedance and an amplifying device excited by an electrical reaction of the circuit, together with means for impressing on the circuit a negative resistance reaction whereby power is conveyed to the circuit from a source independent thereof and the exciting electrical reaction is increased. The negative resistance reaction is, in accordance with the invention, obtained from a negative resistance compensator of such a character that the desired selective action of the apparatus is due to the electrical reactions thereof. The wave balance of my aforementioned application is admirably adapted for use as such a negative resistance compensator. In the preferred form of the invention, the wave balance is electrically associated with a vacuum tube amplifier and a high resistance conductor, the resistance load, so arranged that the exciting electromotive force for the grid of the amplifier is dependent upon the voltage drop or resistance reaction of the resistance load, and this reaction is augmented by arranging the wave conductor so that at the signalling frequency the E. M. F. induced in its secondaries acts, in part, as a negative resistance reaction. I prefer to employ a multi-step apparatus containing several single steps and in which each step has a moderate selectivity which is then transformed in geometrical progression into high selectivity by the cooperation of the several steps acting in cascade. In such an apparatus, each step includes a circuit of high dissipative impedance and an amplifying device excited by an electrical reaction of the circuit together with a negative resistance compensator which by conveying power to the circuit from a source independent thereof increases the exciting electrical reaction. Such a form of the invention is of particular advantage in super-audible or high frequency sound signalling systems utilizing compressional waves propagated through suitable media. This type of signalling system will be referred to hereinafter as supersonic signalling, and in this connection another aim of the invention is the provision of an improved signalling system by supersonics.

In the accompanying drawings, which form a part of this specification, Fig. 1 represents, diagrammatically, a single step vacuum tube amplifier embodying the principles of the present invention; Figs. 2 and 3 are explanatory curves which will be explained in detail hereinafter; Fig. 4 represents, diagrammatically, a multi-step vacuum tube amplifier embodying the invention; Figs. 5 and 7 diagrammatically represent modified arrangements embodying the principles of the invention; and Fig. 6 represents, diagrammatically, a supersonic signalling system embodying the invention.

Referring to Fig. 1 of the drawings, there is diagrammatically represented a low impedance vacuum tube having a grid 10, a heating filament 11, and a plate 12. A local source of direct current energy, such, for example, as the battery 13, serves to supply the relatively low voltage, say about seven volts, for maintaining a filament current of about 1.75 amperes, and the relatively high voltage, say about 110 volts, for the wing or electron current between the filament 11 and the plate 12.

A conductor 14 of high resistance, say about 16,000 ohms, made up of high resistance material and given a form possessing as small capacity as possible, is included in series relation with the source of electromotive force to be amplified, and is connected to the grounded terminal of the filament 11. Included in series relation with the high resistance conductor 14 are the two secondary coils 15 and 16 of a wave balance of the form described in my aforementioned application. This wave balance comprises inner and outer laminated layers of tin foil 18 and 18′ between which is positioned the coiled wave conductor 17, separated by suitable dielectric layers from each tin foil layer. The wave conductor has substantially uniformly distributed inductance and capacity and possesses sufficiently high resistance and capacity to make it a true wave conductor and to render it practically aperiodic. The secondary coils 15 and 16 are inductively associated with the wave conductor 17 and are relatively movable with respect to each other and to the wave conductor. The foregoing elements of the wave balance are diagrammatically indicated in Fig. 1 of the drawings, while in the other figures of the drawings the wave conductor and tin foil layers are symbolically represented by reference numerals 17 and 18, respectively.

A condenser 19 of suitable and variable capacity is included in series with the secondary coils 15 and 16. I have found that the secondary coils 15 and 16 may advantageously have about five hundred turns of No. 39 copper wire wound in six layers which are separated by several thicknesses of paraffined paper in order to reduce their mutual capacity. The distance between these layers and the outer tinfoil layer should be as large as practicable, so as to diminish the capacity to ground of the layers.

The plate 12 is connected to the positive terminal of the battery 13 through a suitable inductance coil 20 having an inductance of about .04 henries at 50,000 P. P. S., its winding and magnetic circuit being so constructed as to avoid capacity as much as practicable. One terminal of the wave conductor 17 is connected to plate 12 through a blocking condenser 21 designed to prevent the direct current voltage of plate 12 from establishing a direct current through the wave conductor. The other terminal of the wave conductor 17 is grounded through the common ground connection 22.

The characteristic elements of the arrangement just described are:

First.—The secondary coils or circuits 15 and 16 of the wave balance are placed at approximately half a wave length from each other for the frequency of the impressed (signalling) electromotive force, that is, the frequency which is to be transmitted over them in the direction indicated by the arrow, and they are connected in the reverse order. That is to say, if a direct current is sent through them and develops in coil 15 a plus pole on the left and a minus pole on the right, then this current will develop in the coil 16 a minus pole on the left and a plus pole on the right. Hence, an alternating current of the signalling frequency flowing through the wave conductor 17 will develop in coils 15 and 16 electromotive forces in the same direction, since these two coils are positioned approximately one-half a wave length apart. For lower frequencies, for which the wave length is longer, the electromotive forces developed in the two secondary coils will be opposing each other. This "inverse series connection" of the two secondary coils of the wave balance is an important feature of this invention, since the greatest selectivity is obtained when the secondary coils are so connected.

Second.—The inductive relation of the secondary coils 15 and 16 to the wave conductor 17 is such that at the frequency to be transmitted, one component (vectorially) of the electromotive force induced in the secondary coils acts as a negative resistance reaction of suitable magnitude, which denotes that power is transferred to the circuit including the secondary coils and the high resistance conductor 14 from the direct current battery 13 which maintains the electron current. The meaning and character of this negative resistance reaction is explained and discussed in my co-pending application Serial No. 51,150, filed September 17, 1915, and in a co-pending application of Edwin H. Armstrong and myself, Serial No. 51,151, filed September 17, 1915. To produce this negative resistance reaction of suitable amount, the terminals of the secondary coils 15 and 16 are properly connected into the circuit and the relative positions of the coils properly adjusted. In this operation, one must be guided by a Wheatstone bridge. The negative resistance reaction acts against the positive resistance reaction of conductor 14 which has a high resistance, and in this manner the effective resistance of the conductor is diminished. To this diminution is due, in part, the selectivity of the conductor just mentioned.

Third.—When at the signalling frequency, one component of the electromotive force induced in the secondary coils 15 and 16 acts as a negative resistance reaction of suitable magnitude, then the other component of this induced electromotive force will appear, generally, as a capacity reaction which will reduce the inductance reaction of the secondary coils. The remainder of the inductance reaction is reduced further by the capacity of the variable condenser 19 or, if that remainder is a capacity reaction, then an inductance reaction is introduced into the circuit by substituting in place of the variable condenser 19 a suitable variable inductance. It is desirable, but not absolutely necessary, that for the signalling frequency the only effective reaction in the circuit 19—15—16—14—22 be the resistance reaction, and for this reason the circuit may be said to be tuned for this frequency, but it will be shown presently that this tuning is different from ordinary tuning inasmuch as it not only avoids small damping, but, on the contrary, makes it as large as practicable, the aim being to produce selectivity and employ tuning without resonance.

The grid 10 of the vacuum tube amplifier is excited by the resistance reaction due to the high resistance conductor 14. Hence, the larger current which is established by a given alternating electromotive force between the source of this electromotive force and ground, the larger will be the resistance reaction of the conductor 14, and the larger will be the excitation of the grid 10, and hence the larger will be the amplifying power of the vacuum tube; that is to say, the larger will be the ratio between the alternating potential at the plate 12 and the fundamental alternating potential impressed on the condenser 19. But the current in the circuit 19—15—16—14—22 corresponding to a given alternating potential impressed on the condenser 19 depends on the impedance, only, of this circuit. Hence every operation employed here to lower this impedance will increase the amplifying power of the arrangement represented in Fig. 1.

In Fig. 2 of the drawings, there is shown a curve in which the abscissæ represent the frequency in kilo-cycles of the alternating electromotive force impressed upon the circuit 19—15—16—14—22 and the ordinates multiplied by 10^3 represent the corresponding impedance of the same circuit. This curve was plotted from the following table in which the first column, designated *f*, gives the frequency in kilo-cycles of the impressed voltage. While the columns, designated R, X_L, X_C, I, give the corresponding resistances, inductance reactances, capacity reactances and impedances, respectively, of the circuit. The data given in this table were obtained experimentally by a high frequency Wheatstone bridge.

f	R	X_L	X_C	I
15	12500	0	4300	13130
20	10120	0	4570	11550
30	8100	0	5500	9620
40	4000	0	3310	5200
50	1300	0	0	1300
60	−210	3537	0	3540
70	580	7426	0	7500
80	2480	12780	0	13020

From the curve of Fig. 2, it will be observed that the circuit 19—15—16—14—22 behaves similarly to a tuned circuit of large selectivity, although it has a high effective resistance and a small time constant. In the case specifically described herein, the natural resistance of the conductor 14 is very large, 16,000 ohms, and it is diminished at the critical frequency by the combined action of the vacuum tube and the wave balance to 1300 ohms, the effective inductance being quite small at this frequency, approximately 10^{-2} henry, so that the time constant is small, making the natural oscillations of the conductor highly damped. Owing to the "inverse series connection" of the two secondary coils 15 and 16 of the wave balance and the phase shifting of the electromotive forces induced in these coils, the effective resistance in the circuit 19—15—16—14—22 increases rapidly, and also the capacity reaction increases, but not so rapidly, when the frequency of the impressed electromotive force diminishes. When the frequency increases, the effective resistance increases also, but not so rapidly as the effective inductance. This is shown clearly in the curve of Fig. 2. The result is a circuit with a highly damped natural oscillation, possessing, nevertheless, a high degree of selectivity. A simple consideration will show that this result is impossible by tuning, in the usual way, an ordinary circuit having a small time constant.

In Fig. 3 of the drawings, there is shown a curve the abscissæ of which represent the frequency in kilo-cycles (K) of the impressed electromotive force and the ordinates represent the amplifying power of the single step amplifier for these frequencies. The data from which this curve was drawn were obtained experimentally by the wave balance method described in my copending application Serial Number 257,570, aforementioned. As is to be expected, the curve of Fig. 3 is of the same character as that of Fig. 2. It will be observed that frequencies considerably above or below the critical frequency are not only not amplified by the action of the vacuum tube, but that they are actually weakened.

A multi-step amplifier having for several of its steps single step amplifiers like the one described in connection with Fig. 1 can have its selectivity increased to any desirable limit by increasing the number of these selective steps, although each step may have a very moderate selectivity. Such a multistep amplifier acts like an aperiodic pilot conductor. An aperiodic pilot conductor is characterized by the fact that it is not capable of sustaining local oscillations, that is, the unit sections of which it is composed are not capable of sustaining local oscillations because they have no natural period of oscillation. The high selectivity obtained in this way is another characteristic feature of this invention. It holds good not only for harmonic electromotive forces, but also, as is well known, for pulses in the sense that a selective and highly damped multistep amplifier, as hereinafter described, will eliminate all the harmonic components of the pulse, the frequencies of which differ appreciably from the critical frequency of the multi-step amplifier, and, on account of the high damping, will not be set into violent vibrations by impulse excitation. This multi-step amplifier will now be briefly described.

Referring to Fig. 4 of the drawings, the first step of the selective multi-step amplifier therein diagrammatically represented is the same as shown in Fig. 1, and corresponding elements of the two figures are represented by the same reference numerals. The second step comprises a vacuum tube having a filament 11′, a grip 10′ and a plate 12′, with its associated inductance 20′, corresponding to the inductance 20 in the first step. This second step is connected to the first step by a three-step pilot conductor, consisting of three equal condensers 30, 31, 32, connected in series and three shunting resistances 33, 34, 35. This pilot conductor and its action are fully described in my copending application Serial Number 215,293, filed February 4, 1918, and need not be further considered herein. The third step is identical with the first step and the fourth step is identical with the second step. It will thus be seen that the several steps of the multi-step apparatus are connected in series or cascade. As indicated in Fig. 4, the two steps, rendered selective by the action of the wave balance, are separated by a step which does not employ the wave balance. This is done for the purpose of diminishing the coupling between steps having a wave balance, a procedure which is not absolutely necessary, but often desirable when great stability in the operation of the selective multi-step amplifier is aimed at.

The inductance or impedance coil 20′ should have as high resistance as practicable, which is adjusted by selecting steel plates for the iron core which have the proper thickness. This high resistance is desirable for the purpose of preventing the formation of undamped oscillatory circuits including the coil 20′ and the secondary coils 15 and 16 and their capacity to ground.

Fig. 5 of the drawings diagrammatically represents an arrangement of apparatus in which a wave balance and vacuum tube amplifier are employed, in accordance with the principles of the present invention, in combination with a step-up transformer. The specific details of this arrangement and its particular advantages are described in an application filed concurrently herewith, Serial Number 257,572. In the arrangement of Fig. 5, the grid 10 of the vacuum tube is excited by the secondary voltage of the step-up transformer 41—44. The primary winding 41 of the transformer is included in the circuit of high dissipative impedance including the high resistance 14, the secondary coils 15 and 16 and the adjustable condenser 19. One terminal of the primary and secondary windings 41 and 44, respectively, of the transformer are connected together and to the ground connection 22. The other elements of the wave balance and vacuum tube are connected as in Fig. 4. A pilot conductor, comprising condensers 30, 31 and 32 and resistances 33, 34 and 35, and a vacuum tube 10′—11′—12′, serve to couple together, as in the arrangement of Fig. 4, alternate steps including the wave balance, so that the several steps of the multistep apparatus are thus connected in series or cascade.

It will be noted in the arrangement of Fig. 5, that the grid of the first vacuum tube is excited by the voltage of the transformer's secondary winding 44 instead of by the resistance reaction of the conductor 14. Otherwise, the function and operation of the high resistance conductor 14 is the same as in the arrangements hereinbefore described. The circuit in which the primary winding 41 is included has a high dissipative impedance, but, due to the action of the wave balance, the effective impedance at the critical frequency, that is, the frequency of the impressed (signalling) electromotive force, is greatly reduced. As in the preceding arrangements, so in the arrangement of Fig. 5, the grid 10 of the vacuum tube is excited by an electrical reaction of a circuit of high dissipative impedance, and the wave balance, acting as a negative resistance compensator, conveys power to this circuit from a source independent thereof, for example the vacuum tube battery, and thereby increases the exciting electrical reaction.

In Fig. 6 of the drawings, there is diagrammatically represented a system of receiving apparatus for supersonic signalling in which a selective multi-step vacuum tube amplifier embodying the principles of the present invention is employed in the reception of the signals by supersonics. In this figure, a quartz oscillator 40, comprising a quartz crystal having metallic electrodes or conducting plates operatively arranged on the surface of the crystal, or similar receiving device, employed in supersonic signalling, has its conducting plates connected in series with the primary winding 41 of a transformer and the secondary coils 15 and 16 of a wave balance. A high resistance 42 and an adjustable inductance 43 are also shown in the figure as included in this series circuit. The resistance 42 corresponds to the resistance 14 and constitutes the load resistance hereinbefore described. The inductance 43 is included for the purpose of reducing the capacity reaction of the oscillator 40. The secondary winding 44 of the transformer is connected to the grid 10 of the vacuum tube amplifier, just as in the arrangement of Fig. 5. From the foregoing descriptions, it will be evident that the vacuum tube and wave balance are connected so as to suitably reduce the effective primary resistance of the transformer, as described and explained in my aforementioned application Serial Number 257,572. The first vacuum tube 10′—11′—12′, with its associated pilot conductor, serves to couple the transformer step or unit to the selective multi-step amplifier of the type described in connection with Fig. 4. The right-hand terminal of the arrangement represented in Fig. 5. is connected to a suitable heterodyne receiver. The structure represented in Fig. 5 will amplify over a thousand times the electromotive force produced between the plates of the quartz oscillator by the action of supersonic sound waves of 50,000 P. P. S., but will not perceptibly transmit any electromotive force generated in the quartz oscillator by ordinary sound waves due to noises generated by the motion of ships or sea waves, nor will it transmit internal disturbance due to the ordinary irregular actions of the vacuum tubes.

It should be observed that the vacuum tubes employed here are low impedence tubes, so-called power-tubes, which are not usually employed in the construction of amplifiers. on account of their low amplification power. In this invention, however, they are given a large load to carry, the resistance load mentioned above, and under these conditions the power-tubes have a chance to do work and thus produce a high degree of amplification. It should also be observed that high-impedance tubes are not efficient in amplifying very high frequencies for reasons which are well understood and need not be discussed here. The system described here is, I believe, the first efficient system for amplifying very high frequencies.

There are obviously other arrangements of circuits by which energy can be transferred selectively from a local source to the exciting circuit for the purpose of increasing the electrical reaction which excites the amplifying or controlling device without modifying seriously the aperiodic character of the exciting circuit, but all these arrangements are equivalent modifications of the one described herein which I now consider to be the best arrangement for carrying out in practice the fundamental principles of this invention.

Fig. 7 of the drawings diagrammatically represents a system of receiving apparatus for supersonic signalling embodying the principles of the present invention in a slightly modified form than hereinbefore considered. In this system, the supersonic oscillator receiver 40′ is connected in series with the secondary coils 15 and 16 of the wave balance. The reactance 20 and condenser 21 of the former arrangements are, however, omitted in the simplified arrangement of Fig. 7, and the wave conductor 17 is connected between the plate 12 of the vacuum tube and the positive or ungrounded terminal of the battery 13. The tin foil layers 18 and 18′ are not electrically connected to the wave conductor, as in the preceding arrangements, but are connected together and to the common ground connection 22. The reactances 20′ are, moreover, replaced by resistances 50 of about 12,000 ohms. Otherwise, the multistep amplifying apparatus of Fig. 7 is the same as hereinbefore described, and corresponding elements are designated by the same reference characters. The arrangement of Fig. 7 is of particular advantage in cases where it is possible to use low voltage. It will be noted that the wave conductor 17 is included in the electron circuit of the vacuum tube 10—11—12, and, accordingly, the wave balance 17—18, acting as a negative resistance compensator, serves to overcome the resistance 50 by negative resistance reaction.

The selectivity obtained in accordance with the principles of the present invention, while it resembles ordinary tuning secured by suitable combinations of inductance and capacity, is entirely different in certain important respects, notably among which are the high effective resistance and small time constant of the circuit. An inspection of the data from which the curve of Fig. 2 was drawn, will show that while the high impedance at the higher frequencies is largely due to inductive reactance, as in ordinary tuning, at the lower frequencies the high impedance is largely due to resistance rather than capacity reactance, as in ordinary tuning. This result is brought about by the high effective resistance or dissipative impedance of the circuit, which is a characteristic feature of the present invention. However, at the critical or signalling frequency, this high effective resistance is substantially overcome by the negative resistance reaction. By providing this high effective resistance, all oscillatory circuits, in which the occurrence of disturbing oscillations affects the selectivity, are rendered substantially aperiodic, without, however, impairing the selectivity for the critical or signalling frequency, because at this frequency the negative resistance compensator serves to substantially wipe out or overcome the high effective resistance.

The wave balance with its secondary coils or circuits in inverse series connection has particular advantages as a negative resistance compensator in combination with a circuit of high dissipative impedance. As a result of the inverse series connection, the selectivity is increased, because neglecting the possible presence of odd harmonics which would not appreciably affect the system, at only the critical or signalling frequency do the induced electromotive forces of these secondary coils act in conjunction. At all other frequencies the electromotive forces induced in the two secondary coils are more or less in opposition. Furthermore, as a result of the phase shifting of the electromotive forces induced in the secondary circuits at frequencies other than the critical or signalling frequency, the inductance itself of the secondary coils is substantially a minimum at the critical frequency, and actually increases as the frequency increases, thereby further increasing the selectivity. For these reasons, I prefer to employ a wave balance in which the secondary coils are arranged in inverse series connection, but it will be understood by those skilled in the art, in view of the foregoing explanations, that the broad principle underlying the present invention does not necessarily involve this particular connection of the secondary coils, or even, in fact, the use of distinct secondary coils or circuits, since the wave balance may be in the form of an autotransformer without departing from the spirit of the invention. In fact, the wave balance may be considered broadly as a wave conductor arranged to transfer by induction electric wave energy from a suitable source to the circuit of high dissipative impedance. And, finally, it is to be understood that the negative resistance reaction need not be obtained from a wave balance, since the invention contemplates broadly the use of any type of negative resistance compensator for conveying electric wave energy to a circuit of high dissipative impedance, in a system in which all oscillatory circuits are substantially aperiodic.

What I claim is:

1. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit containing a high resistance conductor, a control device excited by an electrical reaction of said circuit, a source of electric energy, and a negative resistance compensator controlled by said device and which by conveying power to said circuit from said source increases said exciting electrical reaction.

2. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit containing a high resistance conductor, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, and a negative resistance compensator controlled by said tube and which by conveying power from said source increases said exciting electrical reaction thereof.

3. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit containing a high resistance conductor, a source of electric energy, a vacuum tube exited by an electrical reaction of said circuit, and a negative resistance compensator for impressing upon said circuit a negative resistance reaction whose energy is derived from said source and of a frequency determined by the pulsating electromotive force of said tube.

4. A multi-step selective amplifying apparatus comprising several units connected

in cascade, each of said units including a high resistance conductor, a vacuum tube excited by the resistance reaction of said conductor, a source of electric energy, and a negative resistance compensator arranged to transfer from said source to the circuit of said conductor electric wave energy under the control of the pulsating electromotive force of said tube.

5. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit of high dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, and a wave balance having secondary circuits in inverse series connection and arranged to be energized by the pulsating electromotive force of said tube for the purpose of impressing upon said circuit a negative resistance reaction of the frequency of the electromotive force to be amplified.

6. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit of high dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, and a wave balance arranged to transfer by induction from said source to said circuit electric wave energy under the control of the pulsating electromotive force of said tube.

7. A multi-step selective amplifying apparatus comprising several units connected in cascade, each of said units including a circuit containing a high resistance conductor, a control device excited by an electrical reaction of said circuit, a source of electric energy, a wave conductor arranged to be energized by a pulsating electromotive force whose energy is derived from said source and whose frequency is determined by said device, and means inductively associated with said wave conductor and arranged to impress upon said circuit a negative resistance reaction designed to diminish the losses due to the high resistance of said circuit.

8. A multi-step selective amplifying apparatus comprising several units, each of said units including a circuit of high dissipative impedance, a control device excited by an electrical reaction of said circuit, a source of electric energy, a negative resistance compensator controlled by said device and which by conveying power from said source to said circuit increases said exciting electrical reaction, and a pilot conductor for connecting said units in cascade.

9. A multi-step selective amplifying apparatus comprising several units, each of said units including a circuit of high dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, a negative resistance compensator arranged to transfer from said source to said circuit electric wave energy under the control of the pulsating electromotive force of said tube, and a pilot conductor having a vacuum tube associated therewith for connecting said units in cascade.

10. A multi-step selective amplifying apparatus comprising several units connected in cascade, alternate units of said apparatus including a circuit of high dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, a negative resistance compensator controlled by said tube and which by conveying power from said source to said circuit increases said exciting electrical reaction, the other units of said apparatus including a pilot conductor having capacity and resistance, and a vacuum tube associated with said pilot conductor.

11. A multi-step selective amplifying apparatus comprising several units, each of said units including,—(1) a resistance load,—(2) a vacuum tube excited by the resistance reaction of said load,—(3) a source of electric energy,—and (4) a wave balance having secondary coils in inverse series connection and arranged to transfer from said source to the circuit of said load electric wave energy under the control of the pulsating electromotive force of said tube for the purpose of increasing the selectivity of the circuit of said load and for thereby increasing the resistance reaction of the load, and a pilot conductor and vacuum tube associated therewith for connecting said units in cascade.

12. A selective amplifying apparatus comprising a circuit of high dissipative impedance, a control device excited by an electrical reaction of said circuit, and means controlled by said device for impressing on said circuit a negative resistance reaction sufficiently large to compensate to any desirable limit the losses due to the high dissipative impedance of said circuit, all oscillatory circuits of said apparatus in which the occurrence of disturbing oscillations affects the selectivity of the apparatus being substantially aperiodic.

13. A selective amplifying apparatus comprising a circuit of high dissipative impedance, a control device excited by an electrical reaction of said circuit, a source of electric energy, and a negative resistance compensator controlled by said device for transferring electric wave energy from said source to said circuit, all oscillatory circuits of said apparatus in which the occurrence of disturbing oscillations affects the selectivity of the apparatus being substantially aperiodic.

14. A selective amplifying apparatus comprising a circuit of high dissipative im-

pedance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, and a negative resistance compensator arranged to transfer from said source to said circuit electric wave energy under the control of the pulsating electromotive force of said tube, all oscillatory circuits of said apparatus in which the occurrence of disturbing oscillations affects the selectivity of the apparatus being substantially aperiodic.

15. A selective amplifying apparatus comprising a circuit of large resistance, a control device excited by an electrical reaction of said circuit, a source of electric energy, a wave conductor arranged to be energized by a pulsating electromotive force whose energy is derived from said source and whose frequency is determined by said device, and secondary coils inductively associated with said wave conductor and arranged to impress upon said circuit a negative resistance reaction designed to diminish the losses due to the high resistance of said circuit.

16. A selective amplifying apparatus comprising a circuit of high resistance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, a wave conductor arranged to be energized by a pulsating electromotive force whose energy is derived from said source and of a frequency determined by the pulsating electromotive force of said tube, and means inductively associated with said wave conductor and arranged to impress upon said circuit a negative resistance reaction designed to diminsh the losses due to the high resistance of said circuit.

17. A selective amplifying apparatus comprising a circuit of large dissipative impedance, a control device excited by an electrical reaction of said circuit, a source of electric energy, and a wave balance arranged to transfer by induction and under the control of said device electric wave energy from said source to said circuit.

18. A selective amplifying apparatus comprising a circuit of large dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, a source of electric energy, and a wave balance arranged to transfer by induction and under the control of the pulsating electromotive force of said tube electric wave energy from said source to said circuit.

19. In an apparatus of the character described, an electric circuit, a source of electric energy, and a wave balance having a wave conductor and secondary coils in inverse series connection for impressing on said circuit a negative resistance reaction whose energy is derived from said source.

20. In an apparatus of the character described, a source of alternating electromotive force, an electric circuit connected to said source, an independent source of electric energy, and a wave balance having a wave conductor energized by a pulsating electromotive force whose frequency is determined by the frequency of said alternating electromotive force and whose energy is derived from said independent source and having secondary coils in inverse series connection for impressing on said circuit a negative resistance reaction.

21. In an apparatus of the character described, a source of alternating electromotive force, an electric circuit connected to said source and having large dissipative impedance, an independent source of electric energy, and means for rendering the impedance of said circuit selective with respect to the frequency of said alternating source and including a wave balance having a wave conductor energized by a pulsating electromotive force whose frequency is determined by the frequency of said alternating source and whose energy is derived from said independent source.

22. In an apparatus of the character described, a source of alternating electromotive force, an electric circuit connected to said source and having large dissipative impedance, a vacuum tube excited by an electrical reaction of said circuit, and means for rendering the impedance of said circuit selective with respect to the frequency of said alternating source and for increasing said exciting electrical reaction, said means including a wave balance having a wave conductor controlled by the pulsating electromotive force of said tube and arranged to transfer by induction electric wave energy from said source to said circuit.

23. In an apparatus of the character described, a circuit having large dissipative impedance, a source of electric energy, and a wave balance having a wave conductor energized by a pulsating electromotive force of a predetermined frequency and having secondary coils in inverse series connection associated with said circuit and which by conveying power thereto from said source renders the circuit selective with respect to alternating electromotive forces of said predetermined frequency.

24. A selective amplifying apparatus, comprising a source of electromotive force to be amplified, a high resistance conductor connected in series relation with said source, a vacuum tube amplifier excited by the resistance reaction of said conductor, and means electrically associated with said conductor for impressing on the circuit thereof a negative resistance reaction designed to increase the resistance reaction of said conductor and hence the excitation of said amplifier.

25. A selective amplifying apparatus

comprising a source of electromotive force to be amplified, a high resistance conductor connected in series relation with said source, a vacuum tube amplifier having its grid excited by the voltage drop of said conductor, a local source of electric energy for said amplifier, and means electrically connected to said conductor for impressing on the circuit thereof an electromotive force of the same frequency as the electromotive force to be amplified and whose energy is derived from said local source.

26. A selective amplifying apparatus, comprising a wave balance having a wave conductor and two secondary coils inductively associated therewith and spaced apart substantially one-half wave length with respect to the frequency of the electromotive force to be amplified, a high resistance conductor connected in series relation with said coils, a device for amplifying alternating electromotive forces arranged to be excited by the resistance reaction of said high resistance conductor, a local source of electric energy, and means for impressing on said wave conductor an electromotive force of the same frequency as the electromotive force to be amplified and whose energy is derived from said local source.

27. A selective amplifying apparatus, comprising a source of electromotive force to be amplified, a high resistance conductor connected in series relation with said source, a vacuum tube having a grid excited by the resistance reaction of said conductor, a wave balance having a wave conductor and two secondary circuits inductively associated therewith and included in series relation in the circuit of said high resistance conductor, said secondary circuits being so arranged and connected that the electromotive forces induced therein of the frequency of the electromotive force to be amplified are of the same time phase and act in conjunction, a source of electric energy, and means for impressing on said wave conductor an electromotive force of the same frequency as the electromotive force to be amplified and whose energy is derived from said source.

In testimony whereof I affix my signature.

MICHAEL IDVORSKY PUPIN.