C. W. RICE.

METHOD OF AND APPARATUS FOR AMPLIFICATION OF SMALL CURRENTS.

APPLICATION FILED JULY 31, 1917.

1,401,644.

Patented Dec. 27, 1921.

2 SHEETS—SHEET 1.

Fig. 1.

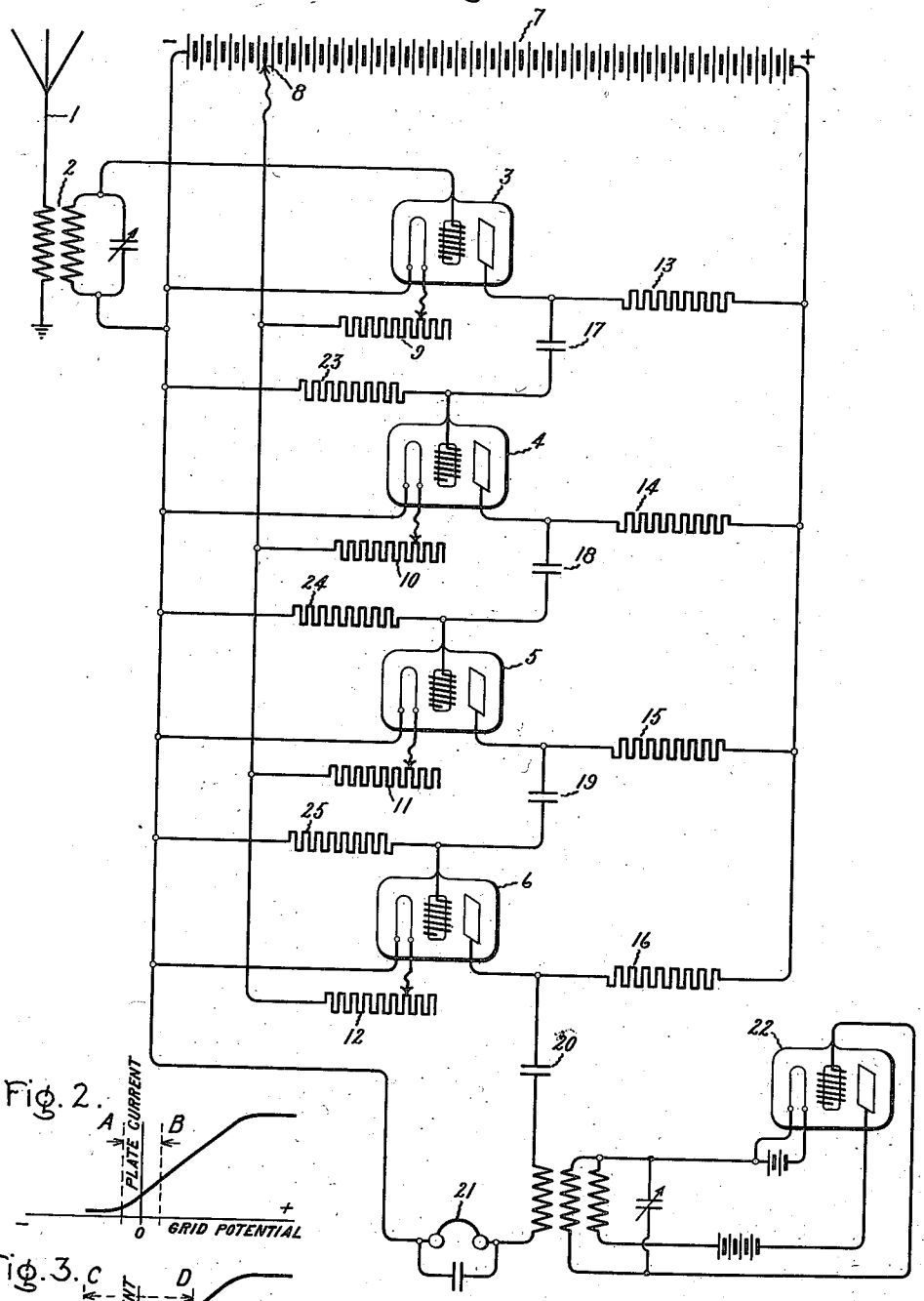
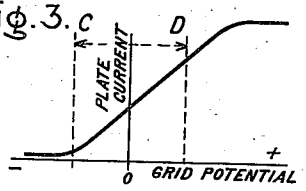


Fig. 2.

Fig. 3.



Inventor:
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by
His Attorney.

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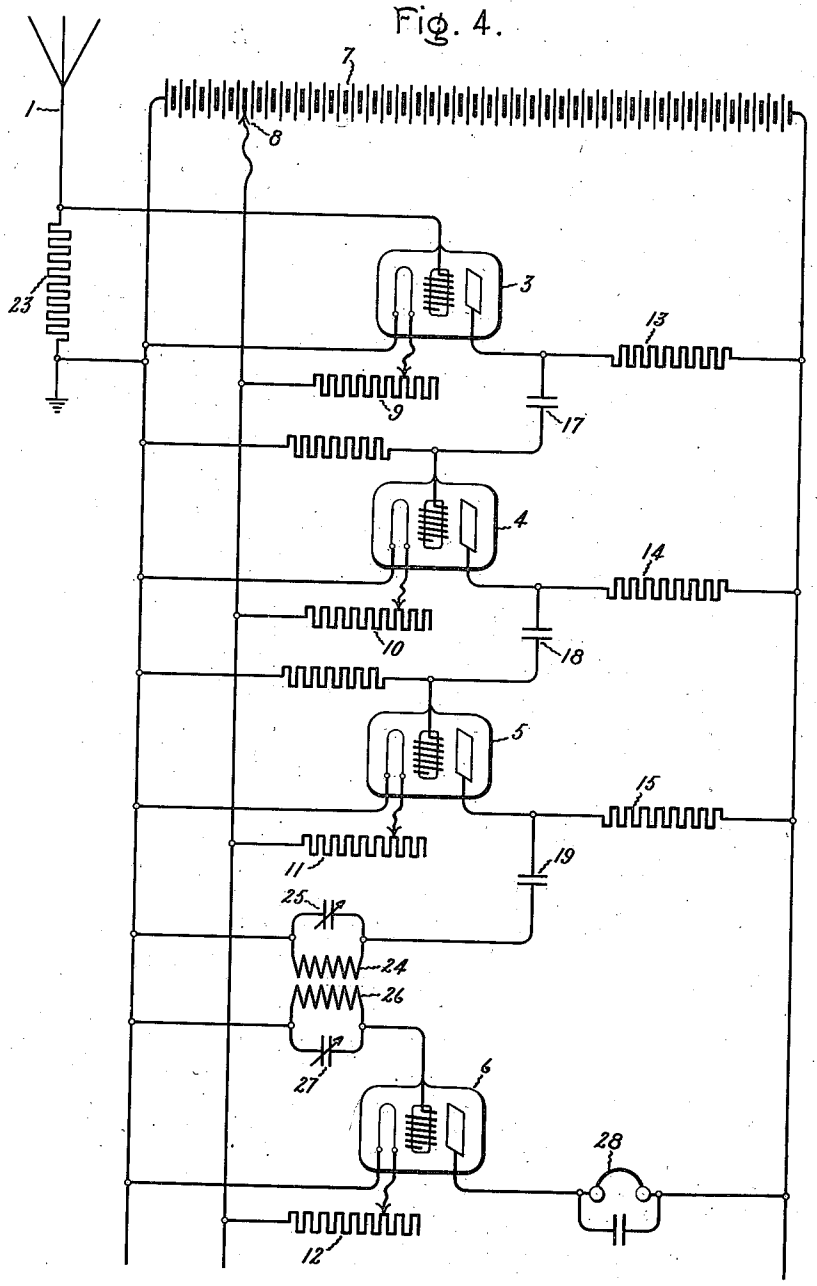
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2 SHEETS—SHEET 2.

Fig. 4.



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UNITED STATES PATENT OFFICE.

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METHOD OF AND APPARATUS FOR AMPLIFICATION OF SMALL CURRENTS.

1,401,644. Specification of Letters Patent. Patented Dec. 27, 1921.

Application filed July 31, 1917. Serial No. 183,785.

To all whom it may concern:

Be it known that I, CHESTER W. RICE, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Apparatus for Amplification of Small Currents, of which the following is a specification.

My present invention relates to the amplification of electric currents of small intensity and particularly currents such as are produced in an antenna by received radio signals.

One of the objects of my invention is to provide an efficient system for amplifying small currents whereby a high degree of amplification may be secured.

A further object of my invention is to provide a system for receiving radio signals in which the effect upon the receiving apparatus of static or strays may be largely overcome.

In carrying my invention into effect I employ a plurality of electron discharge relays or amplifiers preferably of the high vacuum or pliotron type and connect these relays in cascade. The plate circuits of all of these amplifiers are supplied with current from a common source and a high resistance is inserted in each plate circuit. The electric current which is to be amplified is applied to the grid circuit of the first amplifier of the series and current in the plate circuit of that amplifier is varied in accordance with the well known operation of amplifiers of the type mentioned. As a result there will be a variation in the potential difference between the cathode and anode of the amplifier and this variable potential is applied to the grid circuit of the second amplifier. The variable potential between cathode and anode of the second amplifier is in turn applied to the grid circuit of the third amplifier and so on throughout the series. The plate circuit of the last amplifier includes a telephone receiver or other device for detecting the received signals.

In order to overcome the effect of strays upon the receiving apparatus I adjust the operating characteristic of one of the amplifiers of the series in such a way that the amplified current produced by stray impulses in one direction cannot exceed that produced by the signaling impulses. I also adjust the next amplifier of the series in such a way that the amplified current produced by stray impulses in the opposite direction cannot exceed that produced by the signaling impulses. As a result stray impulses have no greater effect upon the receiving apparatus than the signaling impulses and hence do not prevent the continuous reception of signals.

The features of my invention which I consider novel are pointed out with particularity in the appended claims. The invention itself however both as to its organization and method of operation together with further objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 is a diagrammatic representation of the circuit connections which may be employed; Figs. 2 and 3 are curves showing the relations which may exist between grid potential and plate current in different amplifiers of the series and Fig. 4 shows a modification of the system illustrated in Fig. 1 in which an aperiodic antenna is used for receiving.

As indicated in Fig. 1 the antenna 1 is connected by means of the usual inductive coupling 2 to the grid circuit of the amplifier 3. The plate circuit of this amplifier as well as the plate circuits of amplifiers 4, 5 and 6 is supplied with current from the battery 7. By means of a tap from this battery at 8 the filamentary cathodes of the amplifiers are supplied with heating current at the proper voltage, variable resistances 9, 10, 11 and 12 in series with the different cathodes allowing for the adjustment of the temperature of each cathode independently of the others. In the plate circuits of amplifiers 3, 4, 5 and 6 I insert high resistances 13, 14, 15 and 16. When current is received in the antenna the potential of the grid of amplifier 3 is varied and the current through the amplifier varies accordingly. As a result the potential of the anode of the amplifier varies with respect to the cathode and this variable potential is applied to the grid of amplifier 4 by means of the condenser 17. The resulting variable potential of the anode of amplifier 4 is applied to the grid of amplifier 5 by means of condenser 18 and the variable potential of the anode of amplifier 5 is applied to the grid of amplifier 6 by means of the condenser 19. While I have indicated only

four amplifiers thus connected in series as many amplifiers as desired or as may be necessary to secure the desired degree of amplification may be thus connected. In the present case the variable potential of the anode of amplifier 6 is applied by means of the condenser 20 to the telephone receiver 21 in order to render the received signals audible. In case the signals to be received are transmitted by means of continuous waves, local oscillations for receiving by the heterodyne method may be produced by the electron discharge generator 22 connected as shown so as to impress local oscillations upon the circuit which includes the telephone 21.

In order that the grids of the amplifiers may normally be maintained at the same potential as the cathodes high resistance connections 23, 24 and 25 may be employed between the cathodes and grids of amplifiers 4, 5 and 6 as indicated. If by reason of the operating characteristic of the particular amplifiers employed, it is desired to maintain their grids normally at different potentials from that of the cathodes, batteries of the desired strength and polarity may be inserted in these connections between grid and cathode.

When the current received by the antenna 1 makes the grid of amplifier 3 more positive the current through the amplifier will increase and the anode of the amplifier will become less positive. As a result there will be a decrease in the current through amplifier 4 and the anode of this amplifier will become more positive. This will produce an increase in the current through amplifier 5 and make its anode less positive, thereby causing a decrease in the current through amplifier 6. Thus a positive impulse applied to the grid of amplifier 3 produces a greatly amplified negative impulse of the same shape across amplifier 3 which is transmitted to the grid of amplifier 4 where it produces an amplified positive impulse of the same shape across amplifier 4. This positive impulse applied to the grid of amplifier 5 produces an amplified negative impulse of the same shape across amplifier 5 and this negative impulse applied to the grid of amplifier 6 produces an amplified positive impulse across amplifier 6 and at the terminals of the receiver 21.

I have found that a one hundred fold amplification in each amplifier may readily be obtained with the system which I have described, that is, from the first three amplifiers connected in series a one million fold amplification may be secured. The amplifiers 3, 4 and 5 should preferably be high resistance tubes, that is tubes in which the anode and cathode are at some distance from each other and a fine grid is placed close to the filament. With such tubes the resistances 13, 14 and 15 may be of the order of one million ohms as the currents required for operation are very small. The last amplifier 6 should preferably be a low resistance low amplification or high current tube as considerable current is required for the operation of the receiving apparatus. In other words this amplifier should have its cathode and anode close together with a relatively coarse grid between them. The resistance 16 may be of a few thousand ohms.

In practice it will be found desirable to make the condensers connecting the first amplifiers of the series of small capacity so that they will permit the passage of the high frequency components of the current but will offer a high impedance to the audio frequency components. The last condensers of the series should have a higher capacity so that they will allow the audio frequency components of the current produced to pass through without offering a high impedance to their flow. Under these conditions this system has the important property of acting as detector and amplifier simultaneously; that is, there will be a gradual transition from pure radio to practically pure audio between the first and last amplifiers.

In Figs. 2 and 3 I have shown two typical operating characteristics of amplifiers of the type which I employ. From these characteristics it will be seen that when the grid potential becomes sufficiently negative the current in the plate circuit becomes practically zero, that is any further change in the grid potential in the negative direction produces no change in the current in the plate circuit. On the other hand when the grid potential reaches a certain positive value any further change in that direction produces no change in the current. These critical grid potentials beyond which no change in plate current occurs depend upon the structure of the tube and upon the heating current in the cathode. By taking advantage of this feature in the operation of the amplifier I am able to overcome the overpowering effect upon the signals of static or "strays" in the following manner. Assume that Fig. 2 represents the characteristic of amplifier 5 and that the received signals have been amplified to such an extent that they cause the grid potential to vary between the values represented by the lines A and B. The entire range of change in grid potential produced by signaling impulses will then be effective in varying the plate current. If now a "stray" is received upon the antenna of greater intensity than the signal a negative grid potential produced thereby of greater value than that of the signal will have no effect upon the plate current of amplifier 5 although a greater positive impulse will increase the current beyond the value which corresponds to potential B. A greater current through

amplifier 5 however means a more negative potential upon the grid of amplifier 6. Assume now that Fig. 3 represents the operating characteristic of amplifier 6 and that the signals which are received and amplified by amplifier 5 cause the grid potential to vary between the values represented by the lines C and B. The stray impulse which was amplified by amplifier 5 is now in the negative direction and hence has no more effect upon the current in amplifier 6 than the signals. Thus it will be apparent that by operating the amplifiers in this way current produced by stray impulses will be limited so that it will be of no greater value than the current produced by the signals and hence these stray impulses will not interfere with the reception of the desired signals.

While in the case illustrated the amplifiers are shown as working on the lower part of their current curves and with grid potential normally zero with respect to the cathode it will be apparent that they may equally well be adjusted to work upon the upper part of their current curves by proper adjustment of the relation between the grid potential-plate current characteristic and the normal grid potential. It will also be apparent that irrespective of the position of the current curve with respect to the vertical line representing zero grid potential the amplifier may be adjusted by varying the normal grid potential so that a change of the signaling current in one direction will reduce the plate current to its minimum possible value or increase it to its maximum value. The position of the current curves with respect to the line representing normal grid potential may also be varied by varying the current through the cathode, the latter being the most convenient method. In practice I find it convenient to adjust the system at first so that the amplifiers will operate at a region near the central point of the ascending portion of the current curve, and then pick up the station from which messages are to be received. Under these conditions the stray and other extraneous noises may be so loud as to make the reception of the signals difficult or even impossible. The position of the current curves may then be shifted either by variation of the normal grid potential or of the filament current. The magnitude of the foreign sounds will then be observed to decrease whereas the signal may not be appreciably affected. A point may finally be reached where all foreign noises are reduced in amplitude to a value corresponding to that of the signals and the signals will then be easily readable.

In the system illustrated in Fig. 4 I have indicated a connection which will be found especially suitable for the elimination of strays. In this case the antenna 1 is rendered aperiodic by inserting therein a resistance 23 having a value equal to the square root of $\frac{L}{C}$ where L and C represent the inductance and capacity respectively of the antenna. In this way a reflection of any impulses received on the antenna is prevented and all impulses received thereby are amplified. In order to select from the amplified impulses those corresponding to the signals which it is desired to receive the connection between amplifier 5 and amplifier 6 is tuned by means of the inductance 24 and capacity 25 to the frequency of the signals to be received. The grid circuit of amplifier 6 is tuned in a similar manner by means of inductance 26 and condenser 27 and the connection between the amplifiers is completed by coupling inductances 24 and 26. The receiver 28 in this case is shown as inserted directly in the plate circuit of amplifier 6 although it will be understood, of course, that this plate circuit may also be tuned, if desired, and the receiver may be connected thereto as indicated in Fig. 1.

While I have described my invention with particular reference to the reception of radio signals and have shown but two circuit connections by means of which this may be accomplished, I do not wish to be limited to the use of the particular circuit connections, shown and described as it will be apparent that my system may be utilized to advantage for the amplification of small currents from any source whatever, and that many modifications in the connections used may be made without departing from the scope of my invention as set forth in the appended claims.

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

1. The method of amplifying a variable electric current which consists in applying the current to be amplified to the grid circuit of an electron discharge amplifier having its operating characteristic adjusted in such a way that the amplified current variations therethrough produced by changes of the original current in one direction cannot exceed a predetermined desired value and applying the amplified current variations to the grid circuit of a second electron discharge relay having its operating characteristic adjusted in such a way that the amplified current variations therethrough produced by changes in the original current in the opposite direction cannot exceed a predetermined desired value.

2. The method of amplifying a variable electric current which consists in applying the current to be amplified to the grid circuit of an electron discharge amplifier, limiting to a predetermined desired value the amplified current variations through said amplifier produced by changes in the original current in one direction, applying the

amplified current variations produced in the first amplifier to the grid circuit of a second electron discharge amplifier and limiting to a predetermined desired value the amplified current variations therethrough produced by changes in the original current in the opposite direction.

3. The method of amplifying a variable electric current which consists in applying the current to be amplified to the grid circuit of an electron discharge amplifier having its operating characteristic adjusted in such a way that the amplified current variations therethrough produced by changes of the original current in one direction cannot exceed a predetermined desired value, and applying the amplified current variations to the grid circuit of a second electron discharge amplifier in such a way that an increase of current in the first amplifier produces a corresponding decrease in current in the second amplifier, the second amplifier having its operating characteristic so adjusted that the amplified current variations therethrough produced by changes of the original current in the opposite direction cannot exceed a predetermined desired value.

4. The method of amplifying a variable electric current which consists in applying the current to be amplified to the grid circuit of an electron discharge amplifier, limiting to a predetermined desired value, the amplified current variations through said amplifier produced by changes in the original current in one direction, applying the amplified current variations to the grid circuit of a second electron discharge amplifier in such a way that a change of current in one direction in the first amplifier produces a change of current in the opposite direction in the second amplifier and limiting to a predetermined desired value the amplified current variations through said second amplifier produced by changes in the original current in the opposite direction.

5. The method of eliminating the effect of strays upon a radio receiving system which consists in applying the received impulses to the grid circuit of an electron discharge amplifier having its operating characteristic so adjusted that the current changes therethrough produced by stray impulses in one direction cannot exceed those produced by the signals which it is desired to receive, and applying the amplified impulses to the grid circuit of a second electron discharge amplifier having its operating characteristic so adjusted that the current changes therethrough produced by stray impulses in the opposite direction cannot exceed those produced by the signals which it is desired to receive.

6. The method of eliminating the effect of strays upon a radio receiving system which consists in applying the received impulses to the grid circuit of an electron discharge amplifier, limiting the amplified current variations therethrough produced by stray impulses in one direction to a value substantially the same as that of the amplified current variations produced by the signals which are to be received, applying the amplified current variations produced in the first amplifier to the grid circuit of a second electron discharge amplifier, and limiting the amplified current variations therethrough produced by stray impulses in the opposite direction to a value substantially the same as that of the current variations produced by the signals which are to be received.

7. The method of eliminating the effect of strays upon a radio receiving system which consists in producing successive amplifications of received impulses by means of a plurality of electron discharge amplifiers connected in series, limiting the amplified current variations through one of the series of amplifiers produced by stray impulses in one direction to a value substantially the same as that of the amplified current variations produced by the signals which are to be received and limiting the amplified current variations through a succeeding amplifier of the series produced by stray impulses in the opposite direction to a value substantially the same as that of the amplified current variations produced by the signals which are to be received.

8. Means for amplifying a variable electric current comprising a plurality of electron discharge amplifiers having plate and grid circuits, means for supplying currents to be amplified to the grid circuit of one of said amplifiers, said amplifier being so adjusted that current variations in the plate circuit thereof produced by changes in the original current in one direction will be limited to a predetermined desired value, and means for supplying the current variations in the plate circuit of the first amplifier to the grid circuit of a second amplifier, the second amplifier being so adjusted that current variations in the plate circuit thereof produced by changes in the original current in the opposite direction will be limited to a predetermined desired value.

9. A radio receiving system comprising a plurality of electron discharge amplifiers having plate and grid circuits, means for supplying received impulses to the grid circuit of one of said amplifiers, said amplifier being so adjusted that current variations produced in the plate circuit thereof by stray impulses in one direction only will be limited to a value substantially the same as that of the current variations produced by the signals to be received, means for supplying the current variations produced in the plate circuit of the first amplifier to the

grid circuit of a second amplifier, said second amplifier being so adjusted that current variations produced in the plate circuit thereof by stray impulses in the opposite direction only will be limited to a value substantially the same as that of the current variations produced by the signals which are to be received.

10. The method of receiving and detecting radio signals in a system comprising a plurality of electron discharge amplifiers connected in cascade, which consists in producing successive amplifications of received impulses, and progressively increasing the audio frequency component of the amplified impulses with respect to the radio frequency component.

11. The combination in a radio receiving system of a plurality of electron discharge amplifiers connected in cascade relation, each of which has a cathode, an anode and a grid, and plate and grid circuits, means for impressing received impulses upon the grid circuit of the first of said amplifiers, and a detector operatively related to the plate circuit of the last amplifier of the series, the circuit connections being so arranged that the impedance between successive amplifiers offered to the audio frequency component of the received impulses progressively decreases from the first to the last of the series of amplifiers.

12. The combination in a system for amplifying electric currents of a plurality of electron discharge amplifiers, each of which has a cathode, an anode and a grid, and plate and grid circuits, means for impressing the current to be amplified upon the grid circuit of one of said amplifiers, high ohmic resistances in the plate circuits of said amplifiers and connections from each of the anodes of said amplifiers except the last of the series to the grid of the next succeeding amplifier of the series, each of said connections including a condenser, the capacities of said condensers gradually increasing in value from the first to the last of the series.

In witness whereof, I have hereunto set my hand this 30th day of July, 1917.

CHESTER W. RICE.