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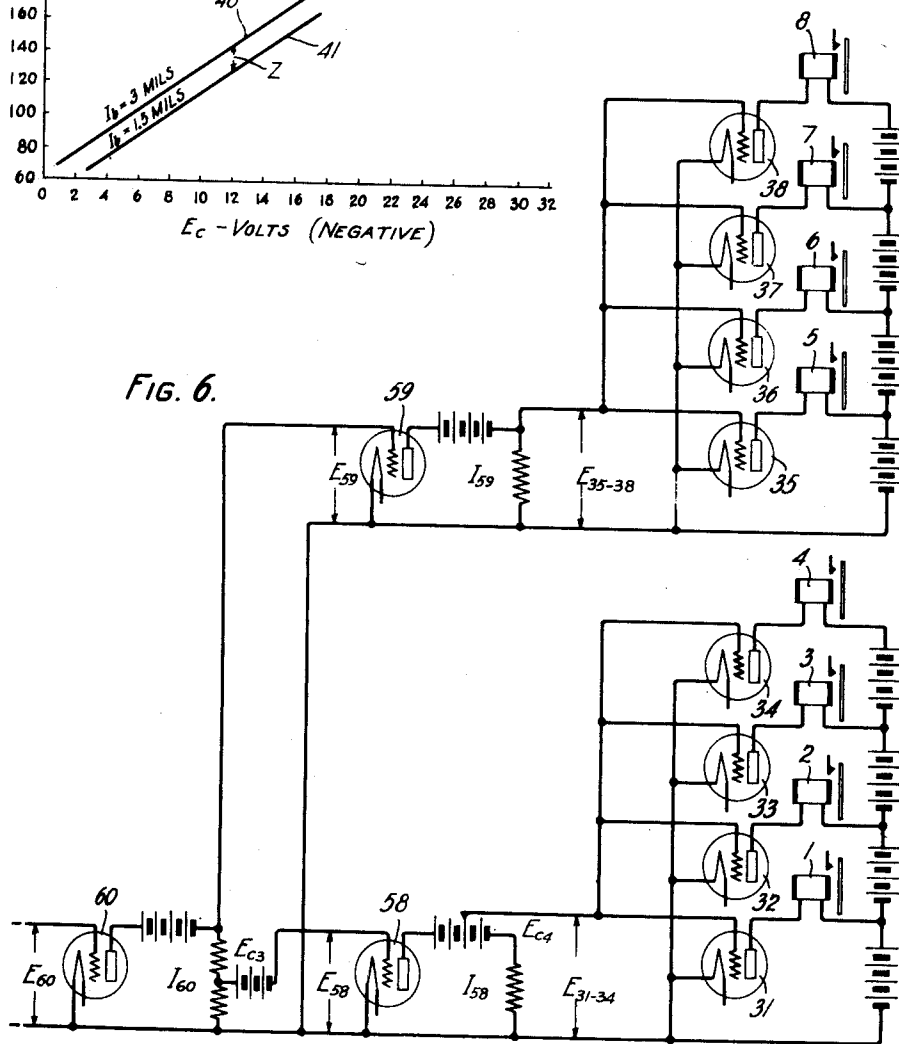
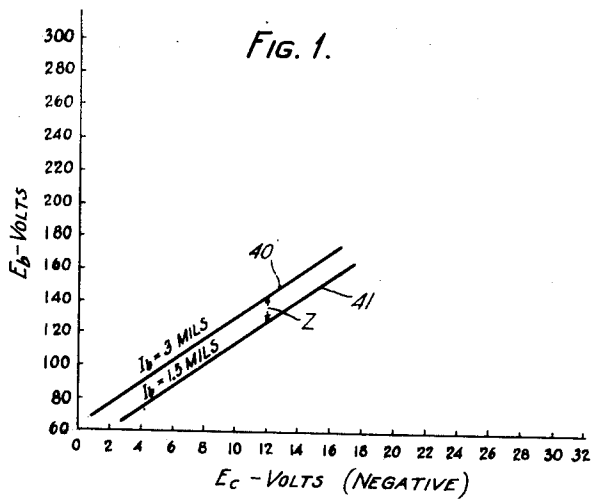
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1,823,739

SYSTEM OPERATING ON A MARGINAL CURRENT BASIS

Filed March 31, 1928

4 Sheets-Sheet 1



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SYSTEM OPERATING ON A MARGINAL CURRENT BASIS

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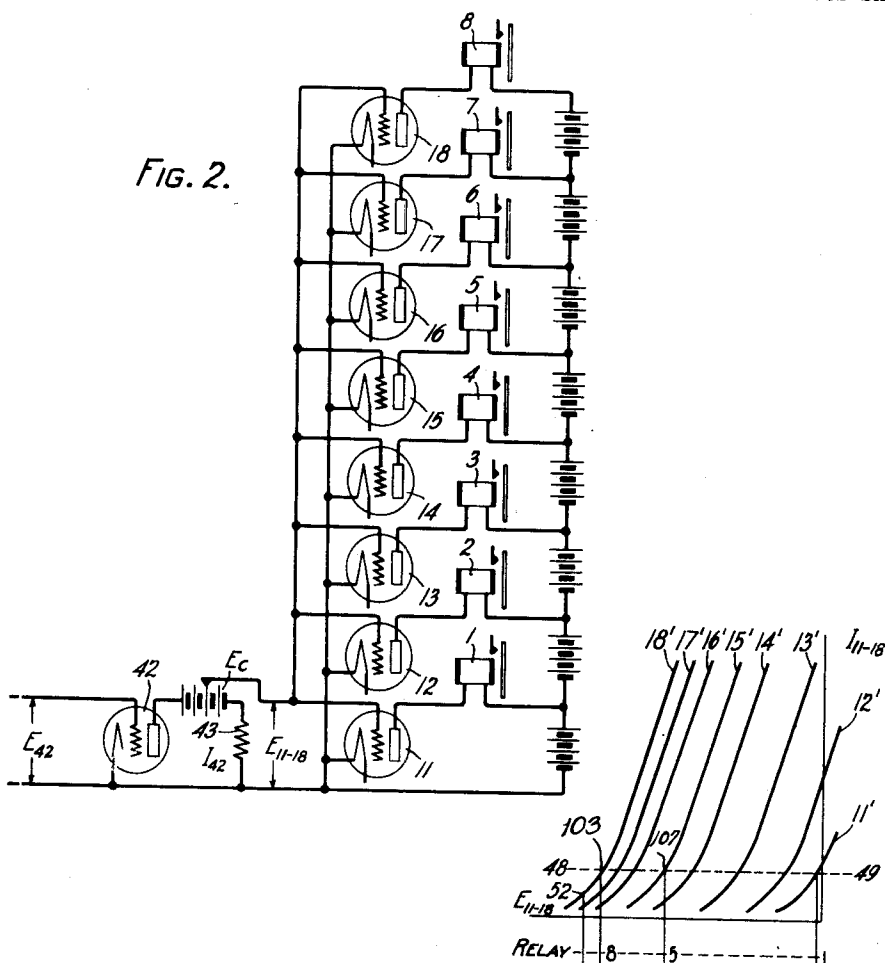
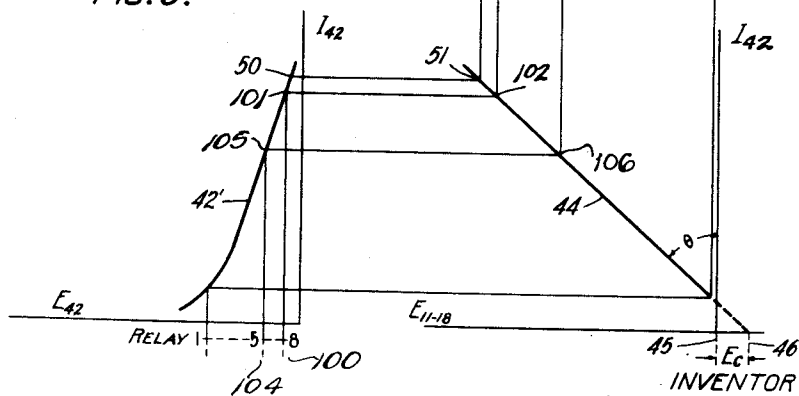


FIG. 3.



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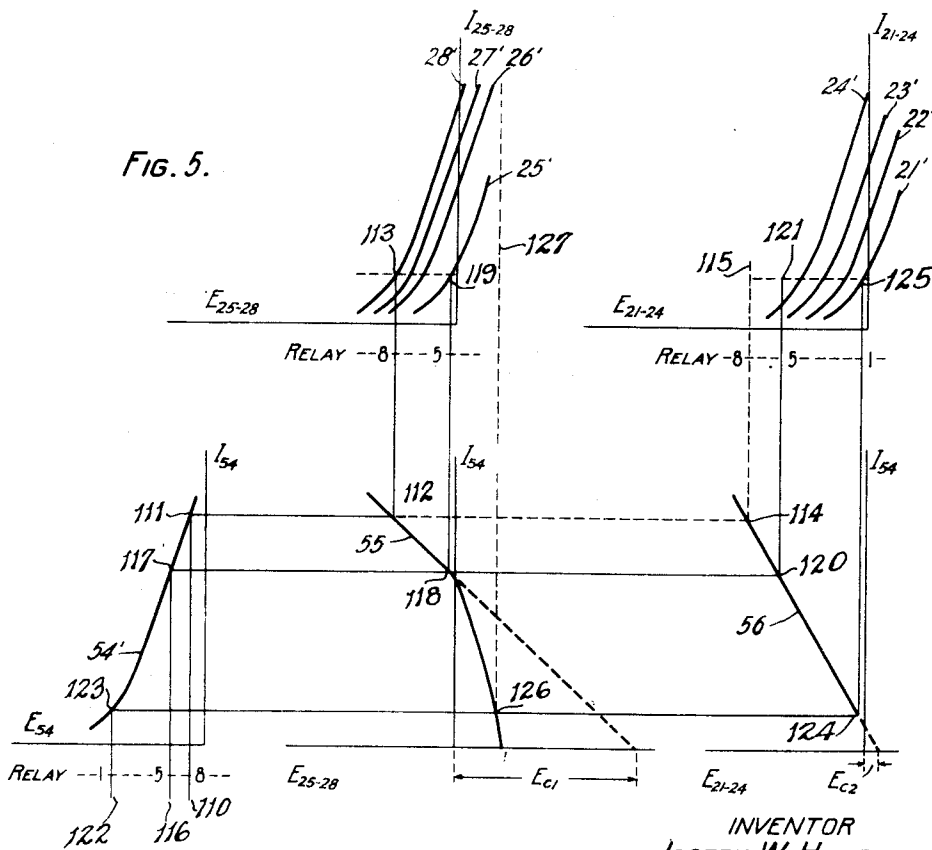
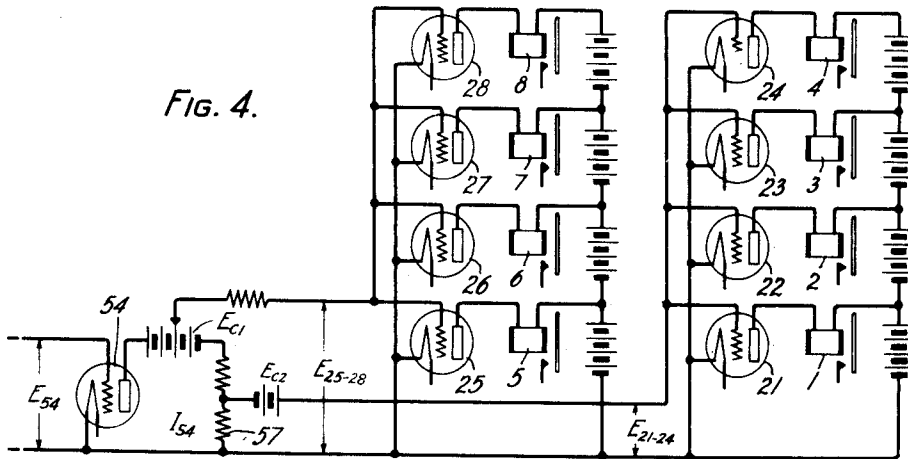
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SYSTEM OPERATING ON A MARGINAL CURRENT BASIS

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4 Sheets-Sheet 3



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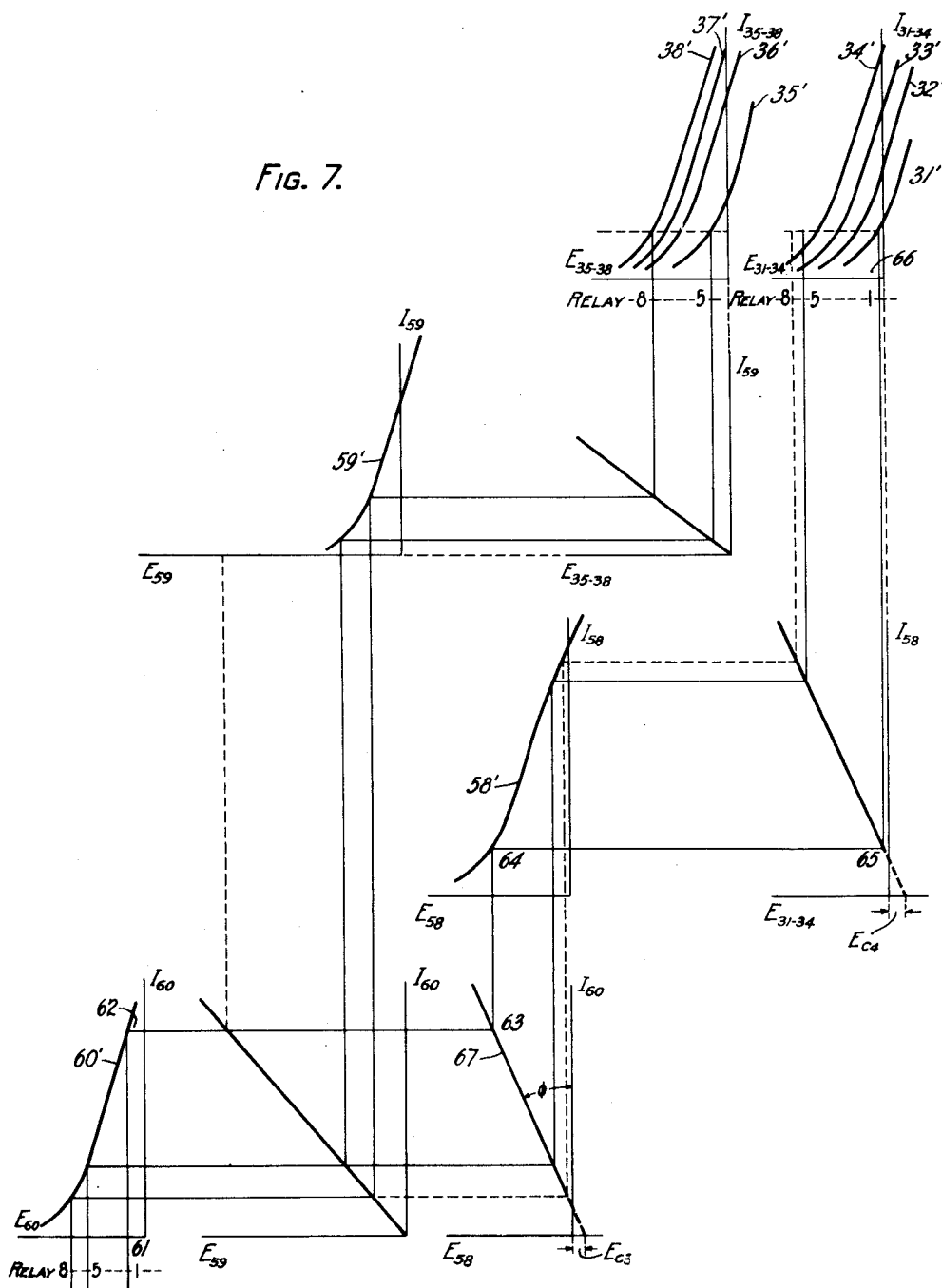
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4 Sheets-Sheet 4

FIG. 7.



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SYSTEM OPERATING ON A MARGINAL CURRENT BASIS

Application filed March 31, 1928. Serial No. 286,191.

This invention, in its broad aspect, relates to a method of and a means for combining the properties of a plurality of electron discharge devices, or their equivalents, arranged in what might be termed a "pyramidal relation" to secure a desired resultant property. It involves controlling the order and extent of operation of discharge devices which may be, for example, thermionic vacuum tube devices.

The invention in a more specific aspect relates to a system for receiving and for definitely and sharply discriminating between current impulses or waves varying in amplitude. The invention is not limited to any specific use but may advantageously find application in any system transmitting a number of indications by different magnitudes of current or voltage. One example of such a system would be a picture transmission system in which different color or tone values in the picture are represented by different current or voltage values on a line. The invention provides accurate and sharp discrimination between the successive voltage or current values. The plurality of response elements may be employed in any suitable manner to register the indications at the receiving point. The invention is applicable also to other than a receiving circuit.

Arrangements have heretofore been employed for obtaining a definite or sharp discrimination between signals in the form of current impulses or waves varying in amplitude by connecting in parallel a plurality of electron discharge devices, or their equivalents, suitably biased. The limitation of a system utilizing parallel connections becomes apparent when the number of increments of current or voltage values to be distinguished is large, for if a definite percentage of the voltage or current values which one tube responds to is maintained over that which the tube responding to the next lower or higher increment, the grid bias and plate voltage values become excessive and when more than a few increments are to be distinguished between, the capacity of some of the tubes is exceeded.

It is an object of this invention to overcome

the limitations of such a system by the arrangement of electron discharge devices or their equivalents in groups such that the current and voltage values within each group may be chosen separately and independently of other groups. This may be accomplished by arranging the groups of discharge devices in branch circuits leading, preferably, from individual tubes, this arrangement being referred to herein as "pyramidal connection".

The simplest form of pyramidal connection would be two groups of electron discharge devices, or their equivalents, the devices in each group connected in parallel and marginally biased by means of different plate potentials and the groups of electron discharge devices controlled by a single preceding amplifier or other means to provide a different grid bias for the tubes in each group. By grouping the electron discharge devices in pyramidal connection a system can be built up which will respond to very small increments of current or voltage to secure almost any desired result and no tube will be required to carry an excessive plate current or to have a large positive grid bias.

While in the description which follows the invention has been illustrated as applied to a signal discriminating or control device, it is capable of use for other purposes as well.

The features of the invention will best be understood by reference to the accompanying drawings which show diagrammatically systems of arranging the devices in pyramidal relation and diagrams of the characteristics of the electron discharge devices which it is preferred to employ.

Fig. 1 represents the relation between plate voltage and negative grid potential for which a particular type of vacuum tube with which applicant has worked will give a space current of a certain value.

Fig. 2 represents a group of eight marginally biased rectifier tubes connected in parallel to the output of a direct current amplifier tube.

Fig. 3 represents the characteristics of the rectifier tubes and amplifier tube shown in Fig. 2.

55

60

65

70

75

80

85

90

95

100

Fig. 4 represents two groups of four marginally biased rectifier tubes in accordance with the invention, each group connected to the same amplifier tube but having different grid potentials and interstage connecting resistances of different values.

Fig. 5 represents the characteristics of the rectifier tubes and amplifier tube shown in Fig. 4.

Fig. 6 represents two groups of four marginally biased rectifier tubes in accordance with the invention, each group connected to an independent amplifier and the two amplifiers connected to a single preceding amplifier.

Fig. 7 represents one typical set of characteristics such as the rectifier and amplifier ensemble shown in Fig. 6, may be made to exhibit, although it will be understood from the description to follow that characteristics widely different from these and for many varieties of conditions may readily be obtained.

Referring to Fig. 1 the straight line 40 represents the observed values of grid bias E_g and plate potential E_b which will produce a constant space current in a particular vacuum tube. The straight line 41 represents the values of grid bias and plate potential for the same tube, which will produce a space current of one-half that represented by line 40. Since lines 40 and 41 are parallel the plate voltage difference required to double or halve the current will be the same for any particular value of grid bias and is represented by Z .

Referring to Fig. 2, eight marginally biased vacuum tubes 11 to 18 are shown connected in parallel and having the same grid bias E_{11-18} . Vacuum tube 42 represents a direct current amplifier having in its output circuit the interstage resistance 43. The filament circuits of the tubes 11 to 18 inclusive, are connected to the filament of vacuum tube 42 and one terminal of the interstage resistance 43. The other terminal of the interstage resistance 43 is connected to the negative terminal of the plate battery for vacuum tube 42. The grids of the vacuum tubes 11 to 18 inclusive, are connected together and to a suitable point of the plate battery for the vacuum tube 42. The grid bias E_{11-18} is therefore obtained by combining the voltage drop in the interstage resistance 43 and the voltage E_c , which is part of the plate voltage of vacuum tube 42. As shown in this figure the plate potential for vacuum tube 12 is larger than that for vacuum tube 11, that for vacuum 13 is larger than for vacuum tube 12 and that for each succeeding tube in the chain is larger than in the case of the next preceding tube. In the plate circuit of each of these tubes is a relay winding. The relays 1 to 8 illustrated have the same operating characteristics, that is, they will

all operate on the same current value. It is desirable for the proper marginal operation of the circuits that when the current for any particular relay reaches its operating value the current through the next relay in the train should not exceed one-half this operating value. It is also desirable that when the current through the last relay reaches its operating value the grid potential should still be negative. It is apparent, therefore, that the plate voltage to be used on vacuum tube 11 (to which Fig. 1 curves are applicable) should be at least the voltage indicated on line 40 at or above the point where line 40 crosses the zero grid potential line. As shown in Fig. 1 this is approximately 65 volts for the tubes employed. The plate voltage to be used on vacuum tube 12 should be at least as large as that used on tube 11, plus the voltage difference Z shown on Fig. 1.

Fig. 3, curves 11' to 18', show the relation between the space currents I_{11-18} through rectifier tubes 11 to 18 respectively and the grid voltage E_{11-18} applied to these tubes. The straight line 44, shows the relation between the current I_{42} flowing through the interstage resistance 43 of the preceding direct current amplifier 42 and the voltage E_{11-18} applied to the grids of the rectifier tubes 11 to 18. The intercept (45-46) of characteristic 44 on the horizontal axis corresponds to the steady polarizing potential E_c in the grid circuit of the rectifiers 11 to 18 when no space current flows through the interstage resistance 43 and the angle θ which characteristic 44 makes with the vertical axis is a measure of the resistance through which the space current I_{42} flows. The characteristic curve 42' shows the relation between the space current I_{42} in resistance 43 and the potential E_{42} on the grid of the amplifier tube 42. The horizontal dotted line 48-49 represents the current value at which the relays 1 to 8 operate. As shown on this diagram by projecting downwardly from the intersection of line 48-49 with each characteristic 11' to 18', when the current in any particular relay reaches the operating value, the current in the next relay of the train does not exceed one-half the operating value. The significance of the diagrams, Fig. 3, is that when the grid voltage E_{42} on the tube 42 is very slightly negative the space current I_{42} is near its maximum value, as shown by curve 42'. The horizontal projection of point 50 on curve 42' to the characteristic line 44 at 51 and the vertical projection to curve 18' at point 52 shows that the grid voltage E_{11-18} at the common point of the rectifier tubes 11 to 18 is sufficiently negative to prevent any of them from passing the required operating space current. As the grid potential of the amplifier tube 42 becomes more negative thereby reducing the space current through the interstage resistance 43 which in turn reduces the

negative potential E_{11-18} on the grids of the rectifier tubes 11 to 18, the relays 8 to 1 are operated in turn at certain values of grid bias E_{42} on tube 42. The reason for this may be better understood by considering the current and voltage values in the circuit for a given value of E_{42} . When the grid biasing potential E_{42} of the tube 42 has a negative value corresponding to that shown where the line 104—105 crosses the E_{42} axis, the current I_{42} flowing through the resistance 43 has a value corresponding to the point at which the line 105—106 crosses the I_{42} axis. The voltage drop across the resistance 43, which tends to negatively bias the grids of tubes 11 to 18 inclusive with respect to their filaments, combines with the voltage E_c , which tends to positively bias the grids of tubes 11 to 18, and the resultant biasing potential E_{11-18} has the negative value shown where the line 106—107 crosses the E_{11-18} axis. This value of E_{11-18} produces space currents in the tubes 11 to 18 inclusive of the values as indicated where the line 106—107, or the extension thereof crosses the characteristic curves 11' to 18' of the tubes 11 to 18 inclusive.

These current values I_{11-18} for the tubes 15 to 18 inclusive are large enough to operate the relays 5 to 8 inclusive, (as shown by the dotted line 48—49) but not large enough to operate the relays 1 to 4 inclusive. A biasing potential value E_{42} corresponding to the point where the line 100—101 crosses the E_{42} axis will cause the operation of relay 8 only. This is shown by the lines 100—101, 101—102 and 102—103. The number of relays 1 to 8 which are operated at any given value of grid bias E_{42} can be determined by extending lines through that value parallel to the line 100—101 to the curve 42', parallel to line 101—102 from the curve 42' to line 44 and parallel to line 102—103 from the line 44 through the characteristic curve 11' to 18'. The value of grid bias E_{42} which a particular relay will operate on is determined by extending a line from the point of intersection of the characteristic (curves 11' to 18') of the tube associated with that relay and line 48—49 parallel to line 52—51 to line 44 and then parallel to line 51—50 to curve 42'.

The circuit arrangement shown in Fig. 2 is perhaps the simplest method of operating marginally biased vacuum tubes. It has, however, certain limitations. One of these is that as the grid voltage E_{42} decreases, the space current through the rectifier tubes having the higher plate voltages becomes excessive, which is undesirable both from the standpoint of the tube and the relay.

Another limitation is that very high plate voltages are required if more than a very few relays are to be marginally operated. One possible means of limiting the plate voltage would be to allow the grids on some

of the tubes to go positive and to include a series resistance in the grid circuits of these tubes to prevent them from getting too high a positive grid potential. This is objectionable, however, due to the large space currents which will result. If, however, tubes having tungsten or similar filaments which would saturate soon after the operating current is reached were employed the space currents could be considerably reduced.

Still another method would be to include in series with the relay and plate circuit of the tube, a resistance or lamp, the resistance value of which would increase rapidly with current after the operating point of the relay has been passed.

The preferred method of operating marginally biased vacuum tubes is in accordance with this invention, as follows: If the eight tubes and their associated relays are divided into two groups of four each and provision made for obtaining grid bias properly chosen and of different values for the tubes in each group the plate voltages required for the proper operation of the circuit can be considerably reduced. Fig. 4 shows such a method employing an amplifier tube 54 connected to the voltage source and having the interstage resistance values and grid bias for the two groups properly chosen and of different values. The grid filament circuit of the vacuum tube 54 is connected to a source of varying voltage E_{54} . The positive terminal of a plate battery is connected to the plate of vacuum tube 54. The negative terminal of this battery is connected to a tapped resistance 57 the other end of which resistance is connected to the filament of vacuum tube 54. The plate circuits of vacuum tubes 21 to 28 inclusive, include relays 1 to 8 respectively. The plate potential of vacuum tube 22 is larger than that of vacuum tube 21. That of vacuum tube 23 is larger than 22 and that of vacuum tube 24 larger than that of 23. The plate potentials of the vacuum tubes 25 to 28 inclusive, are substantially the same as those of vacuum tubes 21 to 24 respectively. The grids of vacuum tubes 25 to 28 inclusive are connected together and through a resistance to a suitable point of the plate battery of vacuum tube 54. The filaments of vacuum tubes 25 to 28 inclusive are connected together and to the connection of the filament of vacuum tube 54 and the one terminal of the resistance 57. The filaments of vacuum tubes 21 to 24 inclusive, are connected together and to the point of connection of the filament of vacuum tube 54 and resistance 57. The grids of vacuum tubes 21 to 24 inclusive, are connected together and to the positive terminal of a battery E_{c2} , the negative terminal of which is connected to the tap on the resistance 57.

The locations of the characteristics 25' to 28' (Fig. 5) for the tubes 25 to 28 are deter-

mined as before by the requirement that the grids shall not be positive when the last relay is operated. The grid voltages E_{25-28} corresponding to these plate potentials at which the relays 5 to 8 operate are determined as explained in connection with Fig. 2.

The adjustment of the interstage connections is determined jointly by the values of grid voltages E_{25-28} and E_{21-24} at which the relay operation takes place and by the current I_{54} through the interstage connections. Starting, therefore, with the vertical projections of characteristic 54' of tube 54 (Fig. 5) which are determined by the arbitrarily assigned voltage increments of E_{54} we obtain the horizontal projections through values of I_{54} to characteristic 55 and vertical projections to the values of E_{25-28} at which relays 5 to 8 are to operate.

The plate voltages for tubes 21 to 24 must, of course, be so chosen that when relay 5 is operated the current through relay 4, as shown on curve 24', is not greater than one-half the operating value of the relay. The intersections on line 56 of the horizontal projections through the values of I_{54} with the vertical projections through the operating values of E_{21-24} will give the points which determine the slope of line 56, the characteristics 21' to 24' of tubes 21 to 24 and also the values for the coupling resistance 57 and the biasing potential. When the grid biasing potential E_{54} of the tube 54 has a negative value corresponding to that shown where the line 110—111 crosses the E_{54} axis the current I_{54} flowing through the resistance 57 has a value corresponding to the point where the line 111—112 crosses the I_{54} axis. The voltage drop across the resistance 57, which tends to negatively bias the grids of the tubes 25 to 28 inclusive, combines with the voltage E_{c1} , which tends to positively bias the grids of tubes 25 to 28, and the resultant biasing potential E_{25-28} has the negative value shown where the line 112—113 crosses the E_{25-28} axis. This value of E_{25-28} produces space currents in the tubes 25 to 28 of the values indicated where the line 112—113 crosses the curves 25' to 28' respectively. The current value I_{28} is large enough to operate relay 8 but the current values I_{25} to I_{27} inclusive are not large enough to operate relays 5 to 7 inclusive. At this value of E_{54} the current I_{54} through the resistance 57 produces a voltage across that portion of the resistance 57 which is connected from the filament of tube 54 to the negative terminal of E_{c2} which tends to negatively bias the grids of the tubes 21 to 24 inclusive. This voltage combines with the voltage E_{c2} , which tends to positively bias the grids of the tubes 21 to 24 inclusive, and the resultant biasing potential E_{21-24} has the negative value shown where the line 114—115 crosses the E_{21-24} axis. This value of E_{21-24} produces space currents in

the tubes 21 to 24 inclusive which are of too small a value to cause the operation of the associated relays 1 to 4 inclusive. When the voltage E_{54} is of the value shown where the line 116—117 crosses the E_{54} axis, the relays 5 to 8 inclusive are operated, as shown by the lines 116—117, 117—118, and 118—119, but the relays 1 to 4 inclusive are not operated, as shown by the lines 116—117, 117—120 and 120—121. When the voltage E_{54} is of the value shown where the line 122—123 crosses the E_{54} axis, the relays 1 to 8 inclusive are operated as shown by the lines 122—123, 123—124, 124—125 and 126—127.

In Fig. 6 relays 1 to 4 are connected to the output of vacuum tubes 31 to 34, and these vacuum tubes are connected to the output of amplifier tube 58. Also, relays 5 to 8 are connected to the output of vacuum tubes 35 to 38, and these vacuum tubes are connected to the output of amplifier tube 59. Amplifier tubes 58 and 59 are in turn connected to the output of a single preceding amplifier tube 60. The connections of the relays 1 to 4 inclusive and the vacuum tubes 31 to 34 inclusive and their associated plate potentials to the output circuit of vacuum tube 58 are the same as the connections of the relays 1 to 4 inclusive and vacuum tubes 11 to 14 inclusive and their associated plate potentials to the vacuum tube 42, Fig. 2, which have been described above in detail. The connections of the relays 5 to 8 inclusive and vacuum tubes 35 to 38 inclusive and their associated plate potentials to the vacuum tube 59 are the same as for the relays 1 to 4 and vacuum tubes 31 to 34 and their associated plate potentials, except that the grids of tubes 35 to 38 inclusive are connected to the negative terminal of the plate battery of tube 59 instead of to a point intermediate the positive and negative terminals thereof. The vacuum tube 60 has a plate battery and tapped resistance connected in its output circuit in the same manner as the corresponding elements in the output circuit of vacuum tube 54, Fig. 4. The grid of vacuum tube 59 is connected to the negative terminal of the plate battery of vacuum tube 60. The grid of vacuum tube 58 is connected to the positive terminal of battery E_{c3} and the negative terminal of E_{c3} is connected to a tap on the resistance in the output circuit of tube 60.

Fig. 7 shows the characteristic curves of the tubes employed in Fig. 6 and the characteristics from which the biasing potentials and interstage resistance values may be determined as in the case of the arrangements shown in Figs. 2 and 4.

A system such as shown in Figs. 6 and 7 has marked advantages over these represented by Figs. 2 and 4. The plate potentials required for the operation of eight marginally biased relays is considerably less than that for an arrangement such as shown in Fig. 2.

For the condition at which relay 1 is to operate as shown on Fig. 7, lines 61—62, 62—63, 63—64, 64—65, and 65—66, no grids are positive and no tube carries an excessive plate current. The characteristic curve 60' of tube 60 shows that as the grid voltage of tube 60 changes from the value at which relay 8 operates to the value at which relay 5 operates, the current in the plate circuit of amplifier tube 60 increases, thereby increasing the negative potentials on the grids of amplifier tubes 58 and 59 as shown on characteristic curves 58' and 59' of tubes 58 and 59. The curvatures of the two characteristics 58' and 59' are of considerable importance, being utilized to secure some of the conditions desired. Inasmuch as a small portion of the drop across the plate circuit of amplifier tube 60 is used for the input to amplifier tube 58, as indicated by the relatively small angle ϕ between the characteristic 67 and the vertical axis, there is very little change in the space current I_{ss} of amplifier tube 58 and consequently very little change in the voltage on the grids of rectifier tubes 31 to 34. As the negative grid potential of tube 60 decreases beyond the value at which relay 5 operates, the space current I_{ss} in amplifier tube 59 becomes zero and remains at this value for all further decreases in the negative grid potential of tube 60 because the interstage connection between tube 59 and rectifier tubes 35 to 38 contains no polarizing potential, and, therefore, the grid voltage on rectifiers 35 to 38 inclusive becomes and remains zero for all values of E_{60} which are less negative than that at which relay 5 will operate. The result accomplished by this adjustment is, therefore, to utilize the curvature of the amplifier tube 59 to prevent excessive positive potentials from appearing on the grids of rectifier tubes 35 to 38 whenever the grid potential E_{60} of amplifier tube 60 is such as to operate relays 1 to 4, inclusive. When the grid voltage E_{60} of the tube 60 has the value shown where the line 61—62 crosses the E_{60} axis of the E_{60} — I_{60} characteristic, the current value I_{60} through the resistance in the output circuit of tube 60 has the value shown where the line 62—63 crosses the I_{60} axis. This value of I_{60} produces a voltage drop across that portion of the resistance in the output circuit of the tube 60 between the filament of tube 58 and the negative terminal of battery E_{c3} which combines with the voltage E_{c3} to produce a negative grid bias E_{58} for the tube 58 having the value shown where the line 63—64 crosses the E_{58} axis. (This is obtained from the E_{58} — I_{60} characteristic by extending the line 63—64 to the E_{58} axis.) This grid bias E_{58} produces a space current I_{58} in the output circuit of the tube 58 and having the value shown where the line 64—65 crosses the I_{58} axis of the E_{58} — I_{58} characteristic. The space current I_{58} produces a volt-

age drop in the resistance in the output circuit of tube 58 which combines with the voltage E_{c4} to produce the biasing voltage E_{31-34} having the value shown where the line 65—66 crosses the E_{31-34} axis. (This is obtained from the E_{31-34} — I_{58} characteristic by extending the line 65—66 to the E_{31-34} axis.) The grid biasing potentials E_{31-34} cause space currents to flow in the tubes 31 to 34 inclusive, having values shown by the E_{31-34} — I_{31-34} characteristics and the values are those where the line 65—66 intersects the curves 31' to 34' respectively. As this value is equal to or greater than that required to operate the relays 1 to 4 inclusive (as shown on the E_{31-34} — I_{31-34} characteristic by the dotted line parallel to the E_{31-34} axis) the relays 1 to 4 inclusive will operate.

The relays 5 to 8 will also be operated, as can be determined from the E_{60} — I_{60} , E_{59} — I_{60} , E_{59} — I_{59} , E_{35-38} — I_{59} and E_{35-38} — I_{35-38} characteristics in a similar manner to that outlined above for the relays 1 to 4 inclusive. The value of E_{60} at the point where the line 61—62 crosses the E_{60} axis produces a current I_{60} of the value where the line 62—63 crosses the I_{60} axis of the E_{60} — I_{60} characteristic. This value of I_{60} produces a voltage E_{59} having the value shown where the dotted line from the E_{60} — I_{60} characteristic to the E_{59} axis of the E_{59} — I_{60} characteristic crosses the E_{59} axis. As shown on the E_{59} — I_{59} characteristic this is far too negative to permit any space current I_{59} from flowing in the tube 59. The biasing potential E_{35-38} is therefore zero and the current value I_{35-38} flowing in the plate circuits of the tubes 35 to 38 inclusive through the associated relays 5 to 8 inclusive is determined from the E_{35-38} — I_{35-38} characteristics. The currents will be greater than the value shown by the dotted line and the relays 5 to 8 inclusive will be operated.

In a similar manner it can be determined what relays will be operated for the other values of E_{60} .

It would be feasible with a system similar to that shown in Fig. 6 to operate sixteen relays instead of eight by connecting to amplifier 60 two additional groups similar to relays 1 to 4, tubes 31 to 34 and amplifier 58. Also, thirty-two such relays could be operated by grouping the relays and their rectifier tubes as before, connecting each group to a marginally biased amplifier, connecting the eight marginally biased amplifiers in groups of four each, connecting each group of marginally biased amplifiers to a single preceding amplifier and connecting these two last mentioned amplifiers to a single preceding amplifier. By this method of pyramiding the marginally biased amplifier tubes any desired number of relays can be employed to distinguish between very small increments of current or voltage input.

The selectively operated relays disclosed are merely typical current responsive devices and may obviously be replaced by other types of current responsive devices. Also, in place of the vacuum tubes other discharge devices with similar potential-input, current-output type of characteristic as the vacuum tube described could be used. While the various arrangements as disclosed are for discriminating between increments of direct current or voltage, it is obvious that they could be readily adapted for discriminating between other currents or voltages.

The invention is also capable of other modifications and adaptations not specifically referred to, but included within the scope of the appended claims.

What is claimed is:

1. A system for discriminating between impressed voltages on a marginal basis comprising space discharge devices divided into groups, sources of voltage individual to the groups and common to the devices within each group applied to the terminals of all of the individual devices, each device within the same group having a response element connected to its output and having a different normal operating voltage applied to its terminals such that the response characteristics of the respective combinations of discharge device and response element to impressed voltages of successive levels of the same polarity are marginally selective from group to group and individually within each group, and means to impress voltages at successively different levels on all of said devices in common to operate said response elements selectively.

2. In combination with a control circuit, a plurality of groups of three-element space discharge devices connected in common to said control circuit, said groups having respectively different response characteristics for different voltage levels of the same polarity in said control circuit, a plurality of response elements connected to be operated by said devices respectively, the devices within each group having respectively different normal anode voltages whereby the response elements within each group are operated in succession for voltage values increasing in a given direction in the control circuit, the anode voltage range in one group overlapping the anode voltage range in another group.

3. In combination with a control circuit, a plurality of banks of three-element space discharge devices, said banks of devices being connected in common to said control circuit, the devices within each bank having successively larger normal anode voltages, the range of anode voltages in one bank being of the same order of magnitude as those in another bank and each bank having a successively larger normal negative grid bias

such that for ascending values of voltage impressed on said discharge devices from said control circuit the space currents in the several discharge devices reach a given value successively in the devices of each group and successively from group to group.

4. In combination, an electric discharge device connected to a control circuit, a plurality of banks of electric discharge devices connected to the output circuit of said first mentioned electric discharge device through interstage resistances of different values, sources of anode voltage connected to said discharge devices, the anode voltages for one bank being, at least in part, of the same order of magnitude as the anode voltages for another bank, said discharge devices having individual response elements connected to their outputs, the respective combinations of discharge device and response elements having graduated response characteristics for voltages of different value in said control circuit, such that with voltage changes increasing in given direction in the control circuit, the devices cause the operation of the individual response elements in predetermined sequence within each bank of devices and from one bank to another.

5. In combination, means to put on a line currents of different magnitudes and at the receiving end a plurality of vacuum tubes to which the currents from the line are applied, said vacuum tubes arranged in pyramidal relation and consisting of a plurality of stages, said vacuum tubes in each stage having relatively displaced characteristics of similar shape, said vacuum tubes to which the currents from the line are applied arranged to amplify the received currents and discriminate between relatively large current increments, said vacuum tubes in each succeeding stage arranged to amplify and discriminate between relatively smaller current increments, and operating means associated with the output circuit of said tubes in the last stage.

6. The combination with a source of variable voltage of a voltage discriminating system which comprises means for amplifying and discriminating between relatively large voltage increments, a plurality of means for amplifying and discriminating between relatively small voltage increments, said last mentioned means in electrical connection with the output of said first mentioned means, and a plurality of operating means in electrical connection with the output of each of said last mentioned means.

7. In combination, a line over which currents of different magnitudes are transmitted, an amplifier connected to said line, groups of thermionic discharge devices connected to said amplifier, each of said groups connected to an interstage resistance of a different value and having a different grid bias, said thermi-

onic discharge devices in each group marginally biased with respect to the others of said group by means of different plate potentials, and operating means connected in the output of each of said thermionic discharge devices.

8. In combination with a control circuit, a plurality of three electrode discharge tubes, one of said tubes comprising the first stage connected to said control circuit, other of said tubes comprising the second stage connected in parallel and in tandem with first mentioned tube through interstage resistances and marginally biased to have similar characteristics relatively displaced whereby a rise in the grid potential of said first mentioned tube produces a fall in the grid potential of said last mentioned tubes comprising the second stages, said fall in the grid potential of each of said last mentioned tubes producing a rise in the grid potential of others of said tubes comprising the third stages connected in parallel and each of said third stage groups connected in tandem with one of said tubes comprising the second stage through interstage resistances and marginally biased so that the tubes in each group comprising the third stages have similar characteristics relatively displaced whereby each different value of grid potential of said first mentioned tube comprising the first stage produces a different value of plate current in each tube in the last mentioned groups comprising the third stages from that of every other tube in the same group or other groups of said third stages.

9. A voltage amplifying and discriminating system which comprises a first stage consisting of an electron valve in connection with the voltage source, a second stage consisting of two marginally biased electron valves in parallel connection with the output circuit of said valve comprising the first stage by means of interstate resistances, a third stage consisting of two groups each having four marginally biased electron valves, the input circuits of the valves in each of said groups in parallel connection to the output circuit of one of the two said mentioned valves comprising the second stage through an interstage resistance, and means to be controlled in the output circuits of each of said eight valves comprising the third stage, said interstage resistances and said marginal biasing so designed and proportioned that when the space currents through all the valves in one of said groups comprising the third stage have reached a certain predetermined value the space current of the valve of the second stage connected to said valves in said last mentioned group in the third stage becomes zero, thereby causing the grid potentials on the valves in said last mentioned group of the third stage to remain at zero when the voltage input of the system is such that the

valves in the other of said groups of the third stage pass the desired space current.

10. In combination with a control circuit, a three element space discharge device comprising the first stage connected to said control circuit, two three element space discharge devices comprising the second stage connected in parallel to the output of said discharge device comprising the first stage by means of interstage resistances two banks of three-element space discharge devices, each of said banks of devices being connected to the output of one of said discharge devices comprising the second stage by means of interstage resistances, the devices within each bank having successively larger anode voltages, the range of anode voltages in one bank being of the same order of magnitude as those in the other bank, the first bank and said discharge device of the second stage connected thereto having zero grid bias, the second bank and said discharge device of the second stage having a negative grid bias, said negative grid biasing and said interstage resistances so proportioned and designed that for voltage values increasing in a positive direction in said control circuit the space currents in the several discharge devices comprising the two said banks reach a given value successively in the devices of each bank and successively from the first bank to the second bank and such that after all the devices of the first bank have reached said given value and before any device in said second bank has reached that value the space current of the device in the second stage which is connected to said first bank and the biasing potential on said first bank becomes zero and remains zero for all further increase in the voltage value in said control circuit.

11. The combination with a source of variable voltage of a voltage discriminating system which comprises means for amplifying and discriminating between relatively large voltage increments; said means comprising electron discharge devices, a plurality of means for amplifying and discriminating between relatively small voltage increments, said last mentioned means comprising electron discharge devices in electrical connection with the output of said first mentioned means, and a plurality of operating means in electrical connection with the output of each of said last mentioned means.

12. In combination, means to put on a line currents of different magnitudes and at the receiving end a plurality of three electrode vacuum tubes to which the currents from the line are applied, said vacuum tubes being arranged in groups, the tubes in each group being in parallel connection and marginally biased by means of different plate potentials, the range of plate potentials in at least one of said groups being of the same order of magnitude as that in another group, means

between said line and the input circuit of at least one group of said vacuum tubes for producing a different grid bias for the different groups and the same grid bias for the tubes in each of said groups, and operating means
5 in the output circuits of each of said tubes.

13. A voltage discriminating system which comprises a group of marginally biased electron discharge valves in parallel connection
10 with a variable voltage source, the input circuit of each of said valves connected to an inter-stage resistance of a different value, other marginally biased electron valves having their input circuits in parallel connection
15 with the output circuit of each of said first mentioned valves and means to be controlled connected in the output circuits of each of the said second mentioned valves.

In witness whereof, I hereunto subscribe
20 my name this 29th day of March, 1928.

JOSEPH W. HORTON.

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