

Aug. 13, 1946.

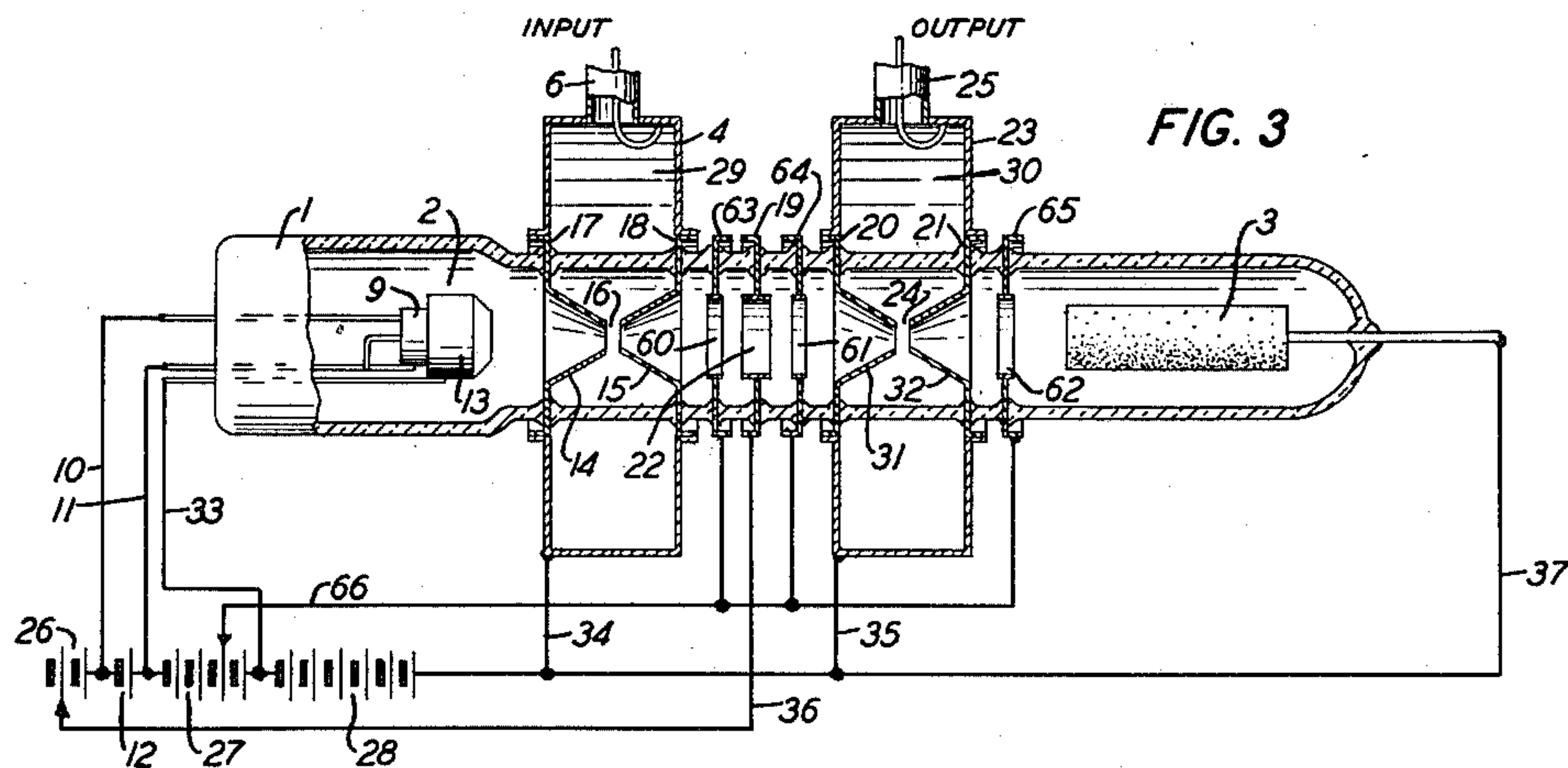
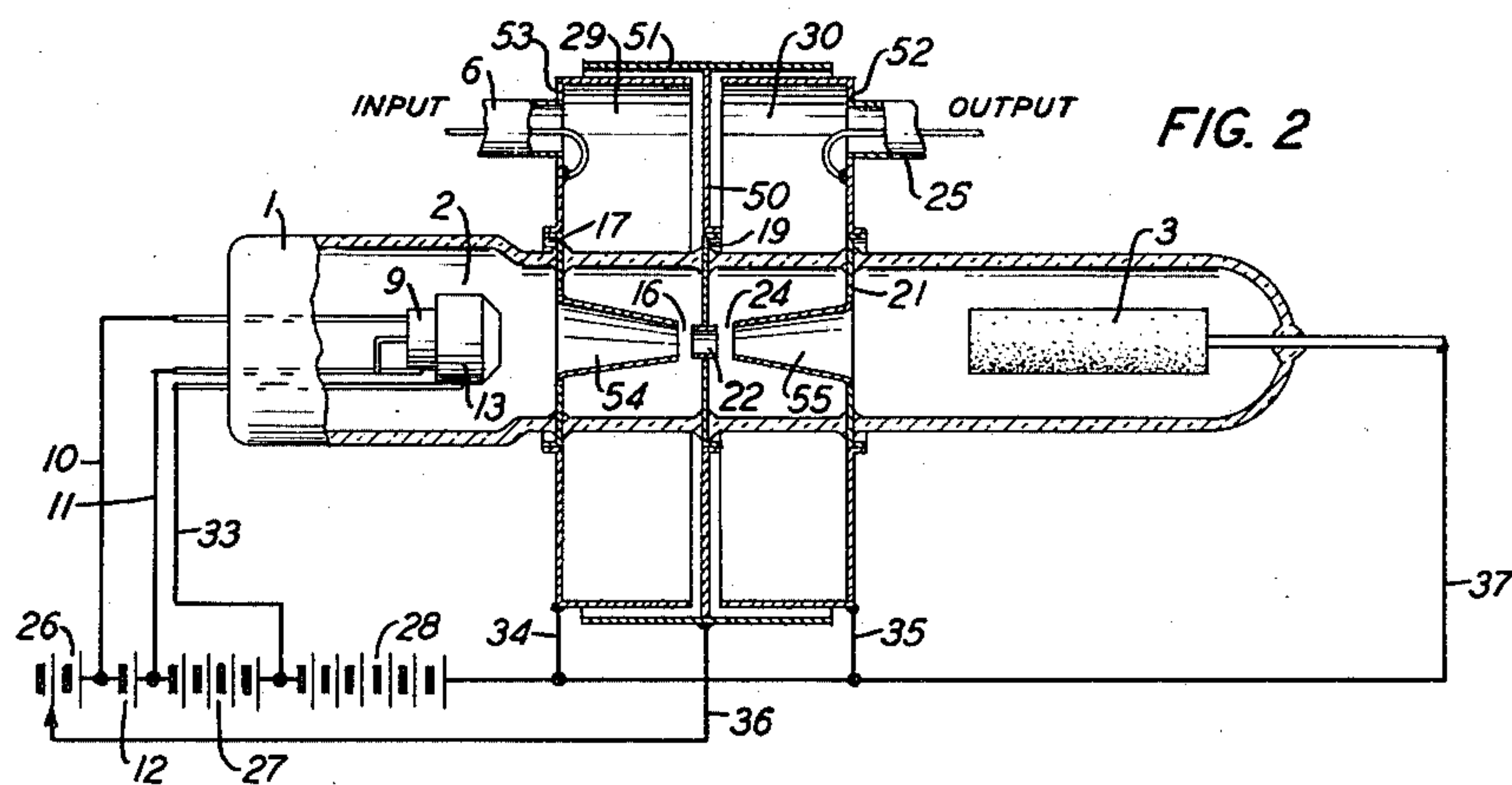
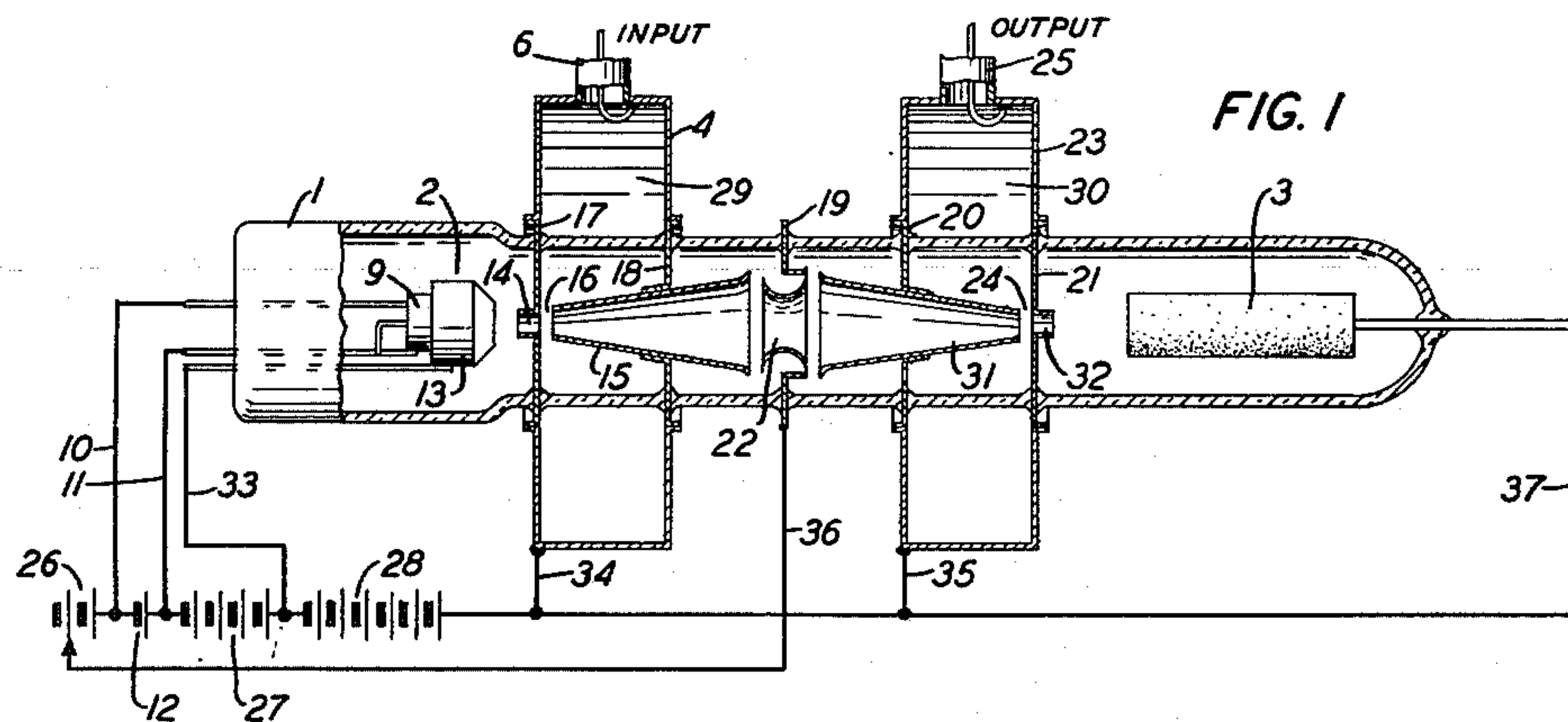
A. L. SAMUEL

2,405,611

ELECTRON BEAM AMPLIFIER

Filed June 26, 1942

2 Sheets-Sheet 1



INVENTOR
A. L. SAMUEL
BY
E. V. Briggs
ATTORNEY

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2 Sheets-Sheet 2

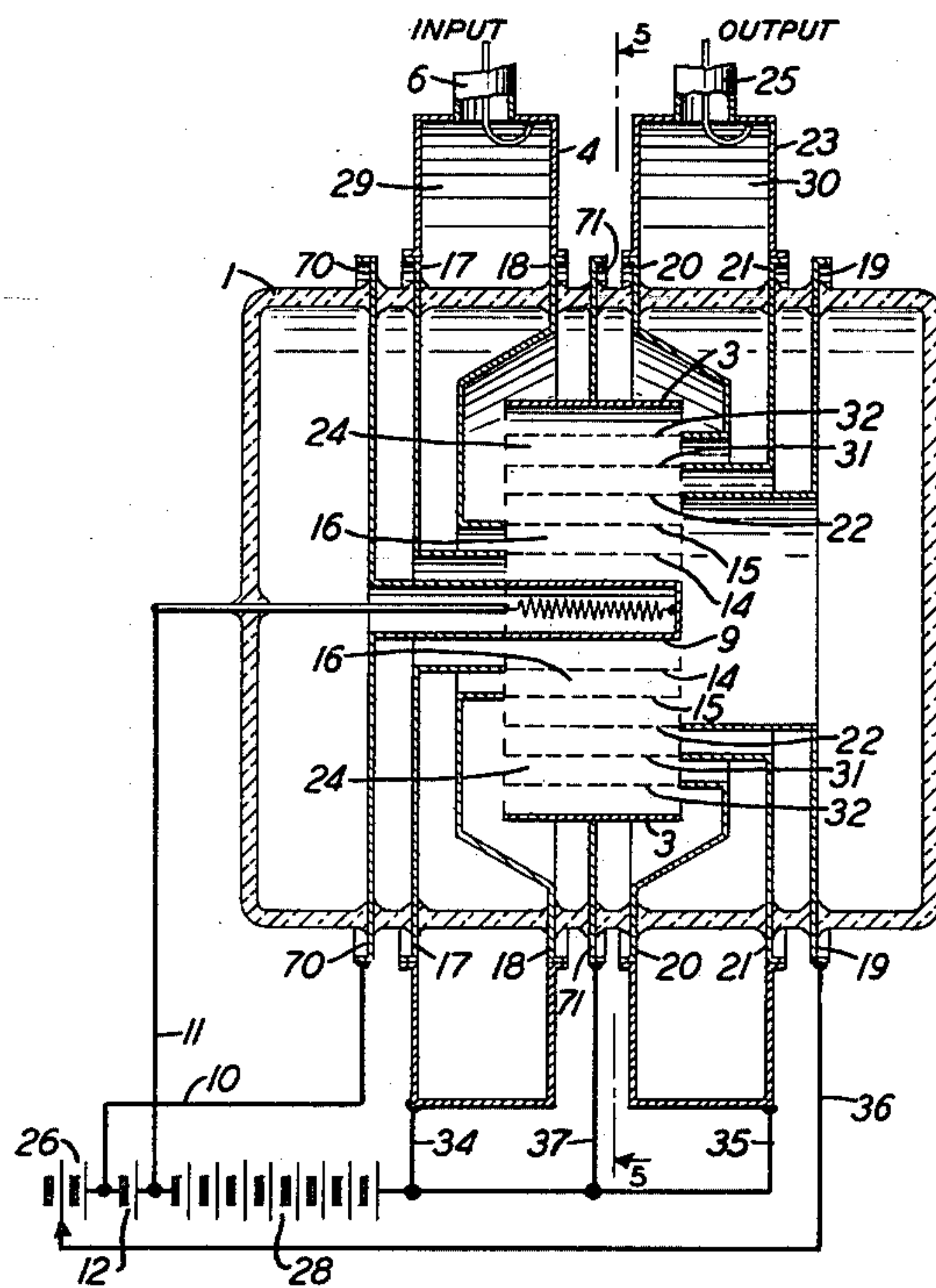


FIG. 4

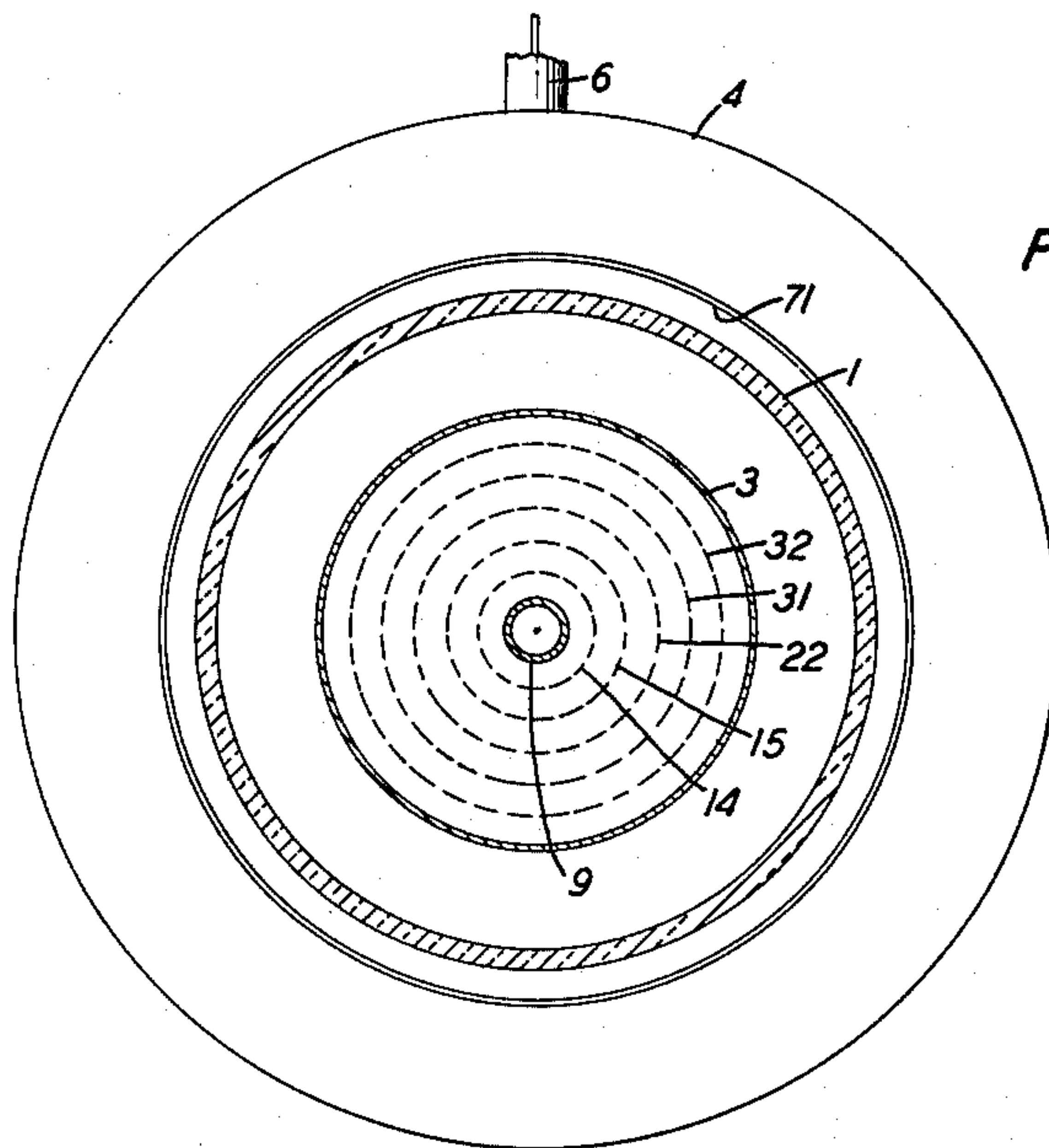


FIG. 5

INVENTOR
A. L. SAMUEL
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

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ELECTRON BEAM AMPLIFIER

Arthur L. Samuel, Summit, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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9 Claims. (Cl. 179—171)

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This invention relates to electron discharge devices of the velocity variation type, so termed because for translating purposes control of the electron stream is secured through the impression of variations upon the velocities of the electrons. The invention relates particularly to the use of such devices as amplifiers.

This application is a continuation in part of the applicant's copending application, Serial No. 412,067, filed September 24, 1941. Whereas that application relates to devices in which modulation and frequency conversion take place, such as in a superheterodyne receiving system, this application relates particularly to devices in which amplification without frequency conversion takes place.

A principal object of the invention is to provide in such a device a convenient method of converting electron velocity variations into electron density variations whereby electrical energy may be derived from the electron stream.

Another object is to make possible the design of such a device which is simple and compact.

Another object is to provide such a device in which the design is to a considerable extent independent of the intended frequency of operation.

Another object is to increase the transadmittance of such a device.

Another object is to increase the input impedance of such a device.

Another object is to reduce the transit angle required in such a device for conversion of a velocity varied electron stream to a density varied electron stream.

Another object is to provide such a device relatively easy of adjustment and incorporating efficient high frequency circuits.

Heretofore velocity variation devices employing electric circuits of the hollow resonator, or resonant cavity, type have converted electron velocity variations into density variations by allowing the velocity varied electron stream to traverse a drift space sufficiently long to allow grouping to take place due to faster electrons overtaking slower electrons. This, of course, requires the provision of a length of drift space in the electron path which adds to the total length of path and to the problem of preventing dispersion of the electron stream.

In the applicant's device to be described the velocity variations in the electron stream are converted into density variations by the action of a retarding field which turns back and thus eliminates from the stream the slower electrons leaving only the faster ones to excite the output circuit resonator. The elimination of groups of slower electrons from between groups of faster electrons by the retarding field is in effect an instantaneous conversion of electron velocity variations into the density variations necessary before

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the electron stream can excite an electrical circuit. Since no drift space is required for the conversion the electron path and therefore the discharge tube can be made shorter physically than if a drift space were required. Also, the drift space is eliminated as a factor in design and as a factor contributing to the dispersion of the electrons in the electron stream. Further, since the electron path can be made short the loss in transadmittance due to space charge degrouching along the path is largely eliminated.

Further objects and features of the invention will be apparent from the following detailed description and the accompanying drawings.

In the drawings:

Fig. 1 shows an amplifier arrangement illustrating features of the invention;

Fig. 2 is an alternative to Fig. 1 wherein the length of the electron path between the input and output circuits is minimized by placing the input and output resonators very close together;

Fig. 3 is another alternative arrangement illustrating the use of additional auxiliary electrodes to assist in the control of scattered and other electrons; and

Figs. 4 and 5 illustrate an alternative structure employing a central cathode with surrounding concentric control grids and anode.

More particularly, Fig. 1 illustrates an amplifier utilizing input and output hollow resonators (or resonant cavities) 29 and 30, respectively in conjunction with an electron discharge tube of which the insulating evacuated envelope is designated 1. The input resonator is excited from an input source by any suitable means 6, which couples with the electromagnetic field within the resonator and energy from the output resonator is transferred to a desired load circuit by any suitable means 25 which couples with the electromagnetic field within that resonator. The resonators are associated with electrodes within the envelope 1 by means of conducting annular discs 17, 18, 20 and 21 which are sealed into the envelope. These discs connect the separable external portions 4 and 23 of the resonators with the internal electrodes 14, 15 and 31, 32, respectively and form portions of the boundaries of the resonators. Also within the envelope 1 is an electron gun 2 with an emitting cathode 9 and an electron accelerating electrode 13. The cathode is heated by energy from source 12 through leads 10 and 11 and the accelerating electrode 13, which may be near to and concentric with the cathode, is maintained at a suitable potential positive with respect to the cathode by connection through lead 33 to potential source 27. The electrodes 14, 15, 31 and 32 are apertured for the passage of electrons from the gun 2 and define the gaps 16 and 24 in the input and output resonators. These electrodes close

the resonators except at the gaps and may be either connected to or made integral with the disc members 17, 18, 20 and 21. They are maintained at a suitably high potential positive with respect to the cathode by connections through leads 34 and 35 to potential source 28. The retarding electrode 22, which is also apertured for the passage of electrons, intercepts the electron stream from the gun 2 between electrodes 15 and 31 and is maintained at a potential which is the same as or only slightly different from that of the cathode by the connection of lead 36 to a suitable point on either of the potential sources 26, 12 or 27. The electron collector or anode 3 is polarized positively with respect to the cathode by the connection of lead 37 to a suitable point on potential source 28.

In operation the high potential positively charged electrodes 13, 14, 15, 31, 32 and 3 tend to cause an electron stream to flow from the cathode 9 through the gaps 16 and 24 to the collector 3 while the low potential electrode 22 tends to stop the electron flow and return the electrons toward the cathode. The initial adjustment of potentials may be such that with no excitation of the input resonator all of the electrons pass through the gap 24 to the collector 3 or it may be such that none of them pass through the gap 24 to the collector. In either case a density varied electron stream will flow through the gap 24 to the collector when the input resonator 29 is excited so that it varies the velocities of the electrons passing through the gap 16 toward the retarding electrode 22. In the first case certain of the electrons which are slowed in gap 16 will not be able to pass electrode 22 thus varying the density of the electron stream reaching the gap 24 and in the second case certain of the electrons will be speeded so that they are enabled to pass electrode 22 thus causing a varying number of electrons to reach the gap 24.

In accordance with the above therefore amplifier operation is had as follows:

The input resonator 29 is excited from the alternating current input source through means 6 such that an alternating electric field is produced across the gap 16 between electrodes 14 and 15 and thereby impressed upon the electron stream from the gun 2 passing through the apertures in the electrodes 14 and 15 and, if not stopped by the retarding electrode 22, through the apertures in electrodes 22, 31 and 32 to the collector 3. The alternating field across the gap 16 alternately increases and decreases the velocities of the passing electrons depending upon the phase of the field at the time an electron enters the gap so that the electron stream approaching the electrode 22 consists of alternate groups of faster and slower electrons. The retarding field between electrodes 15 and 22 due to the low biasing potential on electrode 22 tends to stop the electrons approaching it and the voltage adjustments are made such that electrons which have been slowed in gap 16 are stopped while electrons which have had their velocities increased pass through the electrode 22, are accelerated by electrode 31, pass through the gap 24 and on to the collector 3. The electrons passing through the gap 24 are in spaced groups due to the stopping of the slower electrons at electrode 22. In other words the electron stream passing through the gap 24 in the output resonator is density varied in accordance with the velocity variations impressed upon the elec-

tron stream in gap 16 in the input resonator. By virtue of the density variations in the electron stream passing through gap 24 an electromagnetic field is induced in the output resonator and energy associated therewith, which is in accord with the input excitation energy and represents an amplification thereof, may be conducted to an external load circuit by any suitable means such as 25.

Thus amplification of the input energy has been obtained utilizing the velocity variation principle and employing hollow electrical resonators with the advantages of their high electrical efficiency and their shielding qualities and at the same time other advantages as a result of this invention are had. The electron discharge tube is relatively simple. The tube is shorter and the design is more independent of the frequency of operation than it can be if dependence is placed upon a length of drift space to effect the conversion of electron velocity variations to density variations. (It will be noted that the external portions of the resonators are separable from the tube to facilitate using different sizes of resonators as required for different operating frequencies.) The fact that a relatively long drift space is not required makes possible the attainment of higher transadmittance because reduction in the transit angle of the conversion space reduces the space charge degrouing of the electrons in that space. In tubes with a long drift space or a large transit angle therein the attainable transadmittance is seriously limited by such space charge degrouing. Another advantage of a shorter electron path is that it allows a greater electron current without exceeding voltage limits which further contributes to the transadmittance. It may be pointed out in this connection that under some conditions such as where an electron stream of a large cross section is used and large apertures are therefore required in the electrodes at the gaps in the resonators it may be desirable to use grids instead of open apertures in order to effect a better coupling between the electric field of the resonator and the electron stream.

In the above discussion it was stated that the slower electrons were stopped and not allowed to proceed beyond electrode 22 toward the output gap 24. These stopped electrons may return through the input gap 16 and if adjustments are made so that they return to that gap after a period of approximately one-half cycle or an odd multiple of one-half cycle, they will again be retarded and so contribute energy to the input circuit which will partially compensate for the loss of energy to the accelerated electrons and for other losses in the tube. As a consequence the input impedance will be higher than is normally the case with drift space, or transit time, grouping.

Fig. 2 shows a modification of Fig. 1 to employ a minimum number of structural elements. This results in a device somewhat smaller and simpler mechanically though practically equivalent electrically. It will be observed that the input and output resonators 29 and 30 have been placed together with a common boundary (member 50 and disc 19) separating them and that the retarding electrode 22 is incorporated into this common boundary. This common boundary (member 50 and disc 19) is insulated from the other parts of the resonators for the direct current biasing potentials by spacing it from members 52 and 53 as shown. The openings resulting from this spacing are effectively closed electrically by member

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51 which is connected to member 50 and overlaps portions of the boundaries 52 and 53. Member 51 is closely spaced from members 52 and 53 so that the capacitances between the surfaces of 51 and 53 and between 51 and 52 form low impedance paths at the operating frequency and so make the boundaries of the resonators effectively continuous despite the spacing of the members to provide direct current insulation. The equivalent elements are polarized as described in connection with Fig. 1. The operation of the device of Fig. 2 is the same as described in connection with Fig. 1. However, in Fig. 2 the retarding field due to the low potential of electrode 22 exists in the gap 16 in the input resonator between electrodes 54 and 22, whereas in Fig. 1 it is apart from the input gap, being between electrodes 15 and 22. Also, in Fig. 2 the accelerating field following electrode 22 exists in the gap 24 in the output resonator between electrodes 22 and 55, whereas in Fig. 1 it is apart from the output gap, being between electrodes 22 and 31. This direct current retardation and acceleration of electrons in the gaps of the resonators is a somewhat undesirable feature of the simpler design of Fig. 2 because of the resulting sacrifice in the shortness of the transmit time in the gaps.

As in Fig. 1 the input resonator 29 is excited through means 6 and the resulting alternating electric field is impressed across the gap 16 where it varies the velocities of the electrons passing from the cathode 9 toward the collector 3. Electrons which enter the gap 16 in such phase of the alternating current field as to be retarded by it are further retarded by the retarding electrode 22 and stopped before they reach the gap 24 while electrons which enter the gap 16 in such phase of the alternating current field as to be accelerated by it are able to overcome the retarding field of the electrode 22 and pass on into the gap 24, are accelerated through the gap 24 by the accelerating electrode 55 and are collected at electrode 3. The electrons passing through the gap 24 are in spaced groups and so excite the output resonator 30 permitting energy which is an amplification of the input to be conducted to any desired lead through any means such as 25 as was described in connection with Fig. 1. A particular feature of Fig. 2 is the simplicity and compactness of the arrangement.

Fig. 3 illustrates another modification of Fig. 1 to provide auxiliary electrodes to collect stray electrons and to assist in maintaining the focus of the electron stream. Corresponding elements of Fig. 1 and Fig. 3 are similarly designated and the adjustment and operation of Fig. 3 is the same as described for Fig. 1. Fig. 3 differs from Fig. 1 in the provision of three additional apertured electrodes 60, 61 and 62 supported on the additional fused-in discs 63, 64 and 65. These electrodes through connection 66 to potential source 27 may be maintained at a potential positive with respect to the cathode and intermediate between the potential of the cathode and the accelerating electrode 13 of the electron gun. As mentioned, these additional electrodes function to collect scattered electrons and to assist in focussing the electron stream.

Figs. 4 and 5 illustrate an alternative structure utilizing concentrically arranged grid-like electrodes rather than apertured discs, cylinders or cones as illustrated in the previous figures. Fig. 4 is a sectional side view, while Fig. 5 is an end view to show the concentric arrangement of the electrodes. In these figures elements which cor-

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respond to and function the same as elements in Fig. 1 are designated the same as in Fig. 1 (even though they may be quite different in form in the two figures) so that the similarity of principle and operation can be readily seen.

The indirectly heated cathode 9 supported by disc 70 fused into the evacuated envelope 1 is centrally located and emits electrons in all radial directions toward the collector 3 which is supported by disc 71. The grids 14 and 15 bound the gap 16 in the input resonator 29 and impress an alternating electric field upon the electron stream as it crosses the gap to vary the velocities of the electrons in the same manner as the apertured electrodes 14 and 15 do in Fig. 1. The grid 22 supported by disc 19 functions the same as electrode 22 in Fig. 1 to prevent electrons which have had their velocities reduced in the gap 16 from proceeding into the output gap 24 and allows electrons which have had their velocities increased to pass through gap 24 and to the collector 3. The grids 31 and 32 bound the gap 24 in the output resonator 30 the same as the apertured electrodes 31 and 32 do in Fig. 1. Due to the elimination of the reduced velocity electrons by the action of grid 22 in turning them back toward the cathode the electrons crossing the gap 24 are in spaced groups which therefore induce an electric field in the gap and in the output resonator 30 and transfer energy thereto which may be conducted to a load circuit by any means such as the coaxial line 25. Thus there may be delivered to the output load circuit an amplification of the energy from the input circuit which through means such as the coaxial line 6 energizes the input resonator 29. It will be noted that the cathode is heated from source 12, that the accelerating grids bounding the gaps in the input and output resonators are maintained at a positive potential with respect to the cathode by source 28 and that the retarding grid 22 is maintained at a low potential near that of the cathode by connecting lead 36 to a suitable point on either source 26 or 12. Other equivalent arrangements of the components of Fig. 4 may obviously be used. For instance, the resonators may be disposed on opposite ends of the concentric grid assembly rather than surrounding it concentrically as shown. An advantage of the concentric grid arrangement in any such case is that the cross-sectional area of the electron stream is large so that a relatively large electron current is possible with relatively low electron density in the stream.

What is claimed is:

1. An amplifier comprising means for producing an electron stream, input and output circuits comprising hollow resonators having apertures to permit passage of at least portions of the electron stream through a portion of the electric field associated with the excitation energy of each of the resonators, means for exciting the input circuit whereby the interaction between the electron stream and the electric field of the input circuit resonator produces variations in the velocities of the electrons in accordance with the excitation energy, means at a point in the path of the electron stream following the place of its interaction with the field of the input circuit resonator (but in advance of the place of its interaction with the field of the output resonator) for producing a retarding field to turn back at least some of the electrons which have had their velocities reduced by the said interaction and allow other higher velocity electrons to pass on through

the said portion of the electric field of the output circuit resonator and transfer energy thereto in accordance with the excitation of the input circuit resonator.

2. An amplifier comprising an input circuit, an output circuit comprising a hollow electrical resonator, means for producing an electron stream, means for energizing the said input circuit, means for varying the velocities of the electrons of the said stream at a point along its course in accord with the excitation of the input circuit, means at a subsequent point along the course of the stream for setting up a retarding electric field to turn back lower velocity electrons while allowing higher velocity electrons to pass and excite in accord with the excitation of the input circuit the hollow resonator of the output circuit which is positioned at a point still farther along the stream.

3. An amplifier including an electron emitting cathode, an electron collector, means for producing an electron stream along a path from the cathode to the collector, a resonant cavity, means comprising a pair of electrodes bounding a gap in the resonant cavity and positioned along the path of the electron stream between the cathode and the collector for varying the velocities of the electrons traversing the gap between the electrodes, a second resonant cavity, means comprising a second pair of electrodes bounding a gap in the second resonant cavity and positioned along the path of the electron stream between the first-mentioned pair of electrodes and the collector whereby density variations in the electron stream traversing the gap between the second pair of electrodes may excite electrically the second resonant cavity, and means comprising a retarding electrode positioned along the electron stream and between the two said pairs of electrodes for producing a retarding field to turn back electrons which have had their velocities reduced during traversal of the gap in the first cavity while allowing higher velocity electrons to pass on and cross the gap in the second cavity whereby the electron stream traversing the gap in the second cavity is density varied and the second resonant cavity is excited thereby in accordance with the velocity variations impressed upon the electron stream as it traverses the gap in the first resonant cavity.

4. An amplifier including an electron emitting cathode, an electron collector, means for producing an electron stream along a path from the cathode to the collector, a resonant cavity, means comprising a first electrode and a second electrode positioned along the path of the electron stream between the cathode and the collector in the order named and bounding a gap in the resonant cavity for cyclically varying the velocities of the electrons traversing the gap between the electrodes, a second resonant cavity, means comprising the said second electrode and a third electrode, which is positioned along the path of the electron stream between the second electrode and the collector, bounding a gap in the second resonant cavity, the second electrode being common to the two said gaps, whereby density variations in the electron stream traversing the gap in the second resonant cavity may excite electrically that cavity, and means for maintaining the second electrode, which is common to the two gaps, at a direct current potential such that it produces a static retarding field in the gap in the first cavity to turn back electrons which by the

cyclic velocity variations have had their velocities reduced while allowing higher velocity electrons to pass on and cross the gap in the second cavity whereby the electron stream traversing the gap in the second cavity is density varied and the second resonant cavity is excited in accordance with the velocity variations impressed upon the electron stream as it traverses the gap in the first resonant cavity.

5. An amplifier according to claim 3 and including two additional electrodes positioned along the path of the electron stream one on each side of the retarding electrode and between it and the pairs of electrodes bounding the gaps in the resonant cavities, and means for maintaining the potential of each of these additional electrodes at a potential intermediate between the potentials of the electrodes on either side.

6. An amplifier according to claim 3 and including an additional electrode positioned along the path of the electron stream between the electrodes bounding the gap in the second cavity and the collector, and means for maintaining the potential of this additional electrode at a potential intermediate between the potentials of the collector and of the cathode.

7. An amplifier according to claim 3 in which the cathode, the electrodes and the collector are arranged concentrically with the cathode in the center, the electron stream is radially directed, and the electrodes are in the form of electron permeable grids.

8. In combination, a pair of hollow electrical resonators in close proximity having substantially a common boundary, aligned apertures in the common and other boundaries of the resonators suitable for projecting an electron stream there-through, means for projecting an electron stream through the said apertures such that it passes through a portion of the space of one of the resonators and thence through the aperture in the common boundary into a portion of the space of the other resonator, means external to it for energizing at high frequency the said resonator first traversed by the electron stream whereby the velocities of the electrons in the stream are varied at the high frequency and means for producing a retarding field to reduce the velocities of all of the velocity varied electrons and to turn back electrons having had a negative velocity variation permitting only those not turned back to pass through the aperture in the common boundary into the said other resonator thereby exciting it at the said high frequency.

9. In combination, a pair of hollow electrical resonators having apertures such that an electron stream may be projected through portions of the space of both resonators in series, means for projecting an electron stream therethrough, means external to it for exciting at high frequency the said resonator first traversed by the electron stream to produce variations in the velocities of the electrons in the stream, means for producing a retarding field to reduce the velocities of all of the velocity varied electrons and to turn back electrons having had a negative velocity variation permitting others to pass on into the space of the other resonator to excite it at the said high frequency, and a high frequency load circuit coupled to the said other resonator, the two resonators being placed adjacent to each other in such close proximity that effects of transit time of the electrons between them is negligible.

ARTHUR L. SAMUEL.

Disclaimer

2,405,611.—*Arthur L. Samuel*, Summit, N. J. ELECTRON BEAM AMPLIFIER. Patent dated Aug. 13, 1946. Disclaimer filed Feb. 21, 1948, by the assignee, *Bell Telephone Laboratories, Incorporated*.

Hereby enters disclaimer to claims 1, 2, 3, 4, and 8 of said patent.

[*Official Gazette March 30, 1948.*]