Oct. 22, 1946.   A. E. ANDERSON   2,409,608

ULTRA HIGH FREQUENCY DETECTOR

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FIG. 1

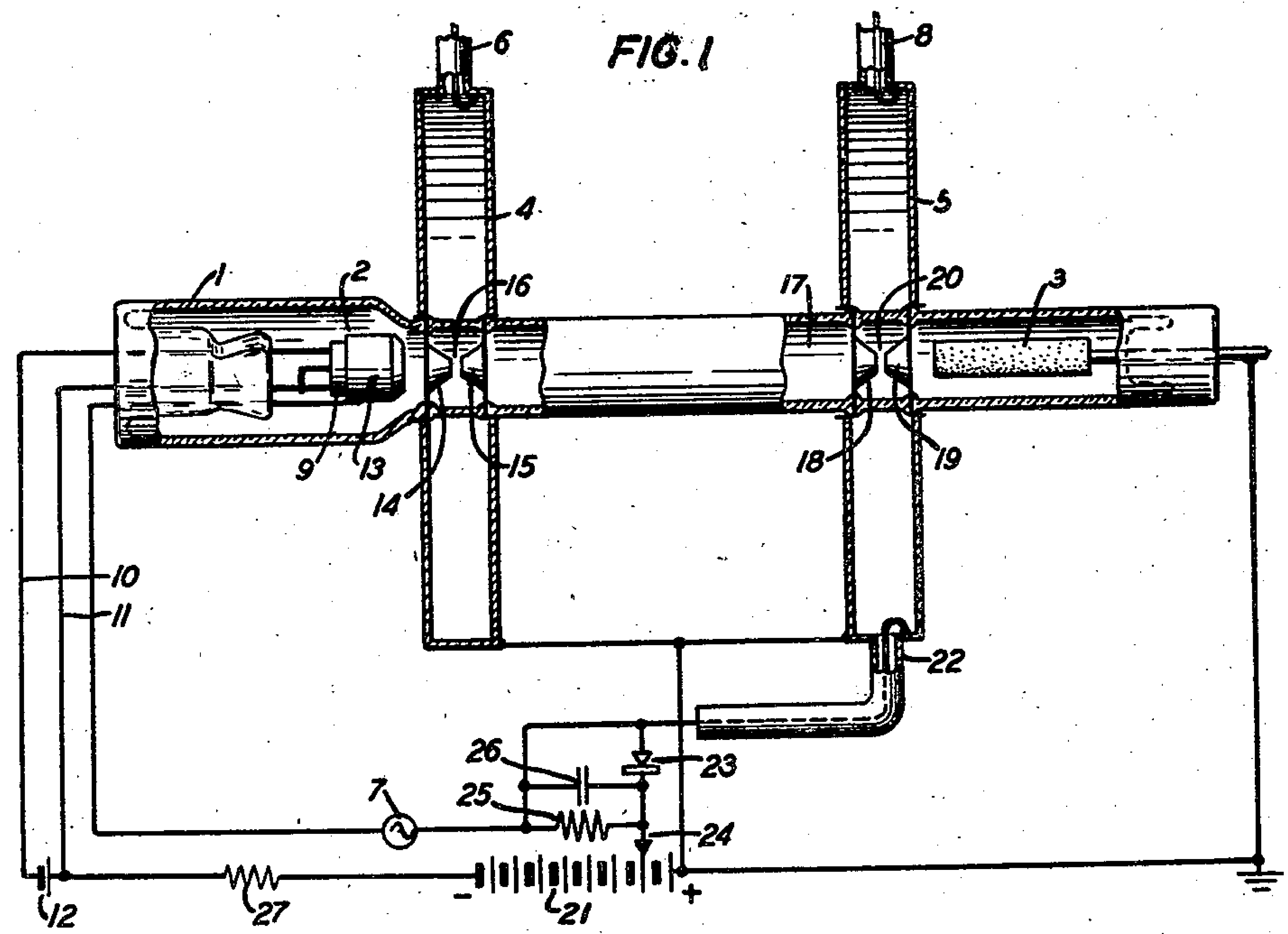

FIG. 2

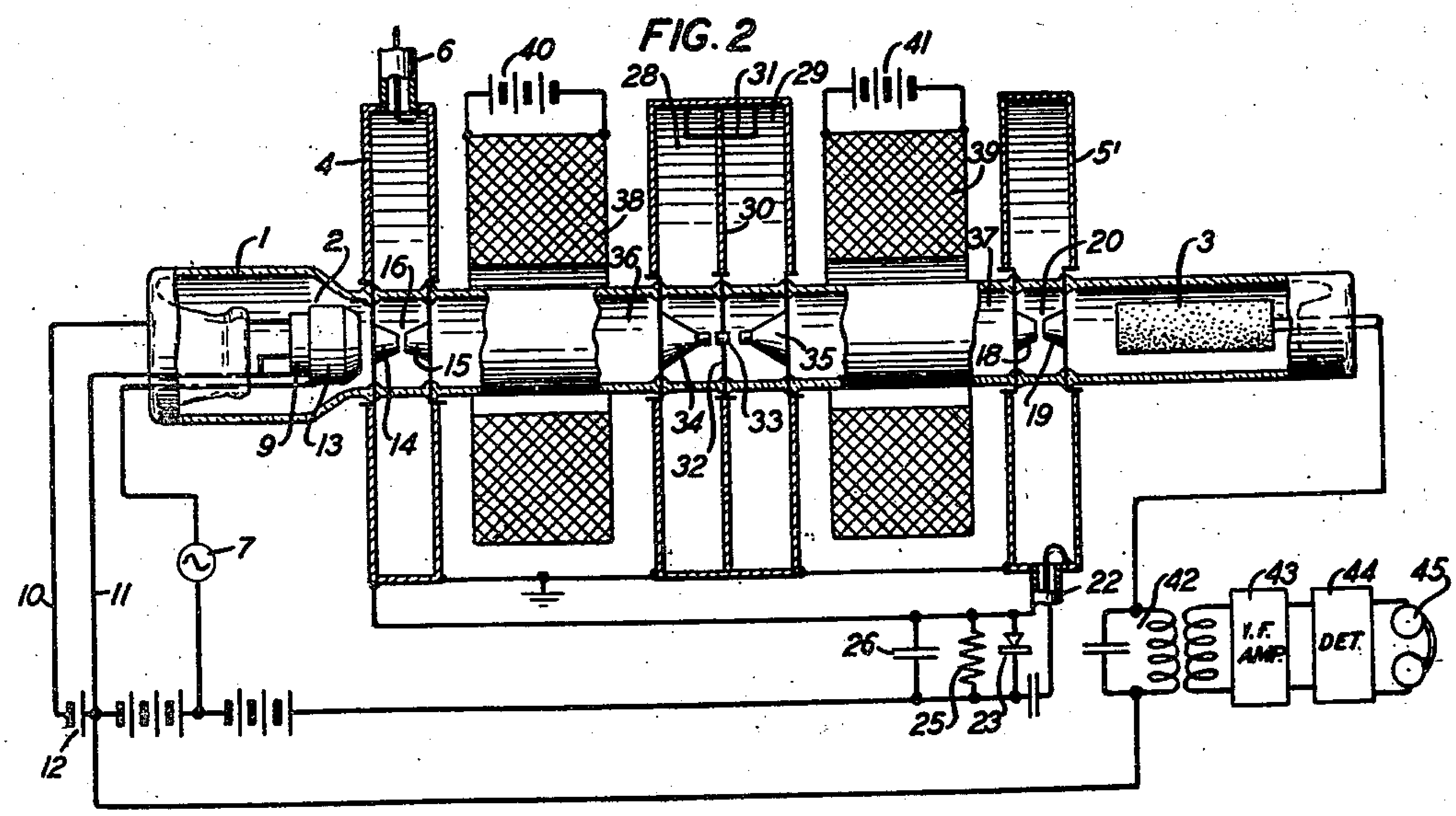

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FIG. 3

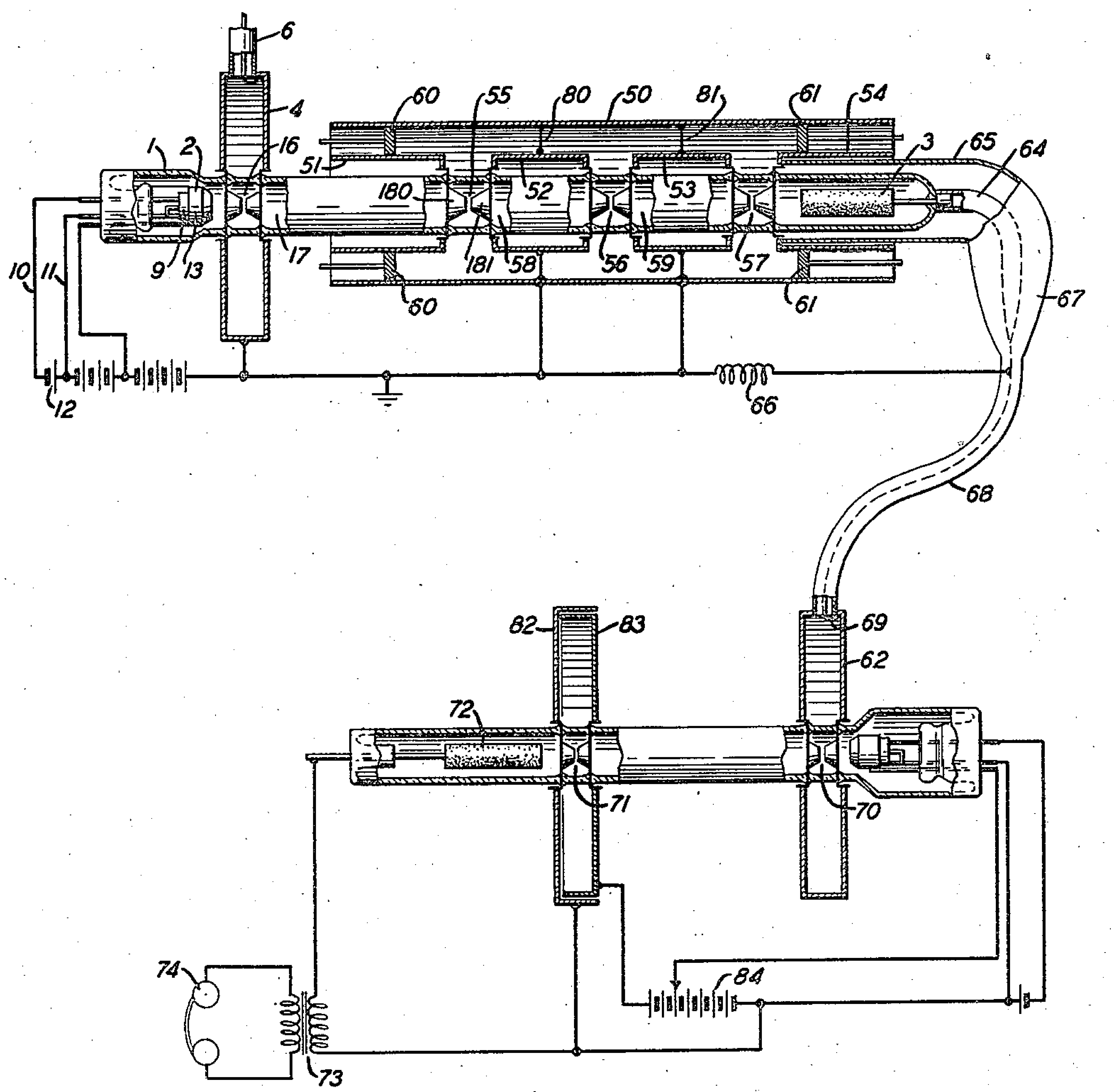

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FIG. 4

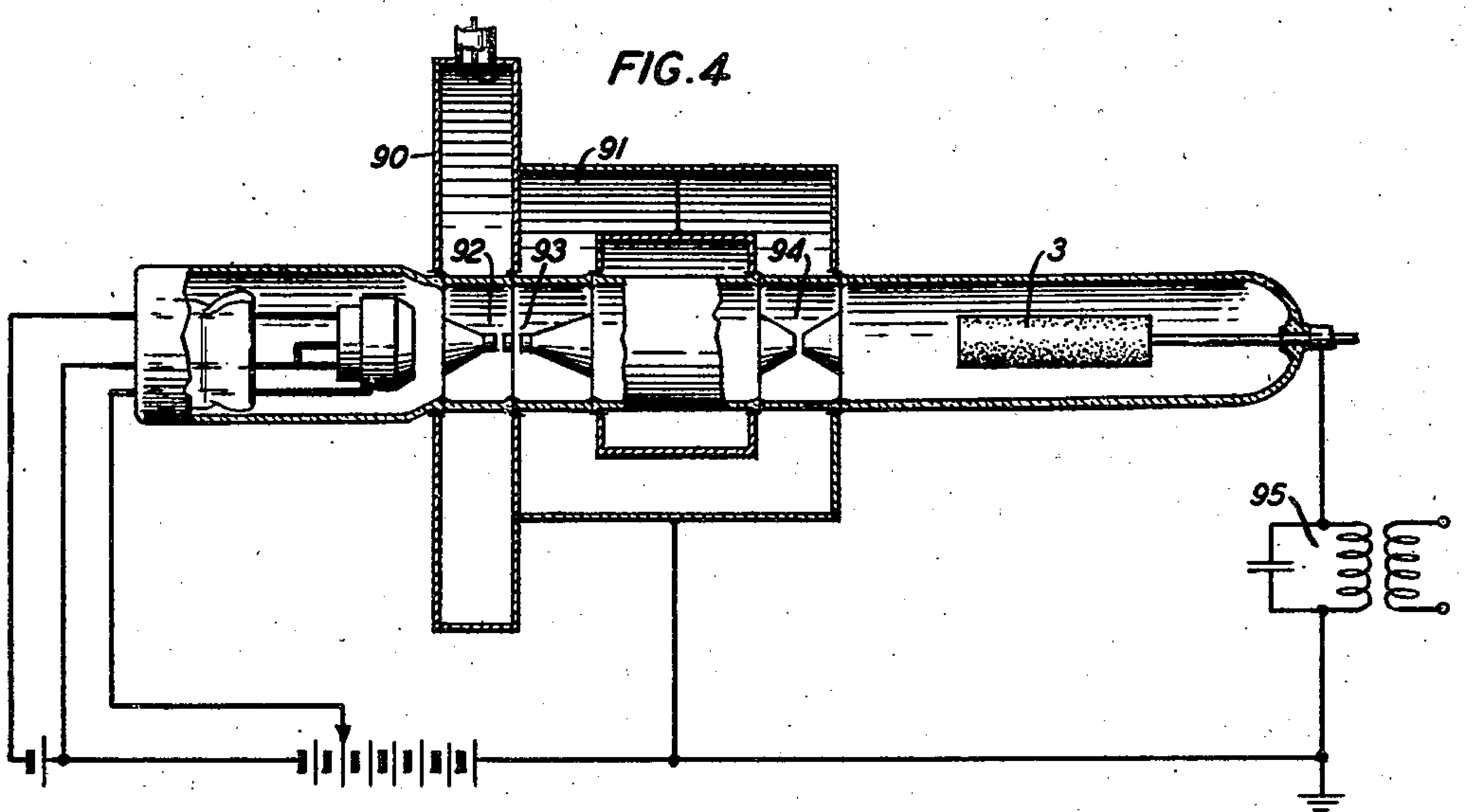
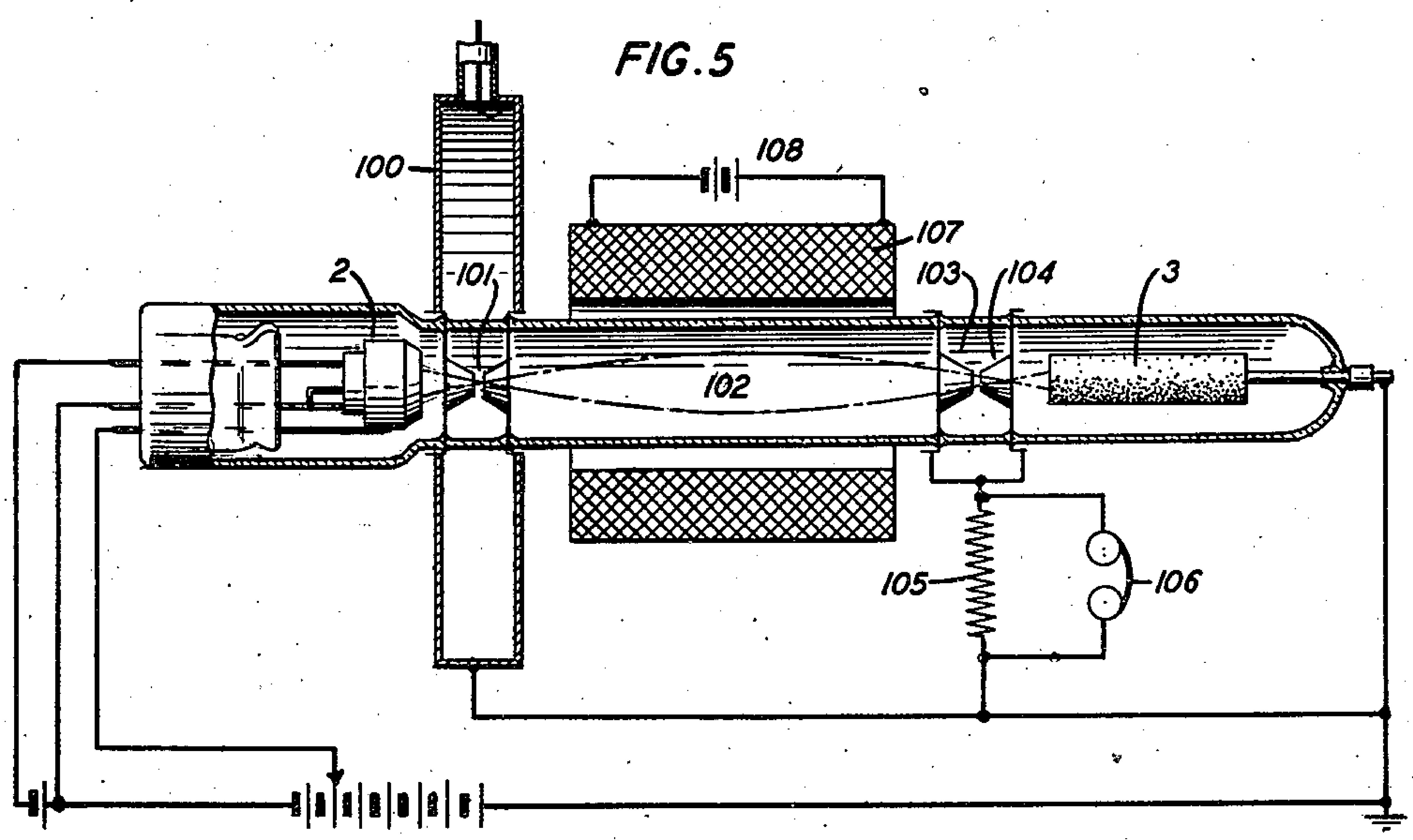


FIG. 5



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UNITED STATES PATENT OFFICE

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ULTRA HIGH FREQUENCY DETECTOR

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Application September 24, 1941, Serial No. 412,065

1 Claim. (Cl. 250—20)

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This invention relates to electron beam devices, particularly for operation at ultra-high frequencies.

An object of the invention is to intermodulate wave energies by virtue of non-linear actions in electron beams associated with a plurality of electrodes, particularly for use in frequency shifting arrangements for radio repeaters, first and second detectors in superheterodyne receiving systems, and the like.

Another object is to improve and stabilize the operation of electron beam devices.

A feature of the invention is a method of frequency conversion employing combinations of velocity variation and density variation effects in an electron stream with the aid of resonating chambers.

A further feature is a detector making use of a varying electron current intercepted by an apertured electrode, the amount of current intercepted being varied as the result of the shifting of a focal point of a focussed electron beam.

Another feature of the invention is an automatic volume control employing variable electron velocities.

Still another feature is the coupling of two resonators through a common wall thereof, both resonators being also coupled to a common electron beam.

Further objects and features of the invention will be apparent from the following detailed description and the accompanying drawings, while the scope of the invention is defined in the appended claim.

In the drawings,

Fig. 1 shows an arrangement for shifting from one ultra-high frequency to another, as for example in a radio repeater;

Fig. 2 shows a superheterodyne receiving system employing features of the invention in connection with the first detector stage;

Fig. 3 shows another form of superheterodyne receiving system employing features of the invention in the first and second detector stages;

Fig. 4 shows an alternative form of first detector; and

Fig. 5 shows a detector employing a focussed electron beam with variably displaceable focal point.

In the arrangement of Fig. 1 an envelope 1 of insulating material is shown enclosing a plurality of elements including an electron gun shown generally at 2 and an electron intercepting or collecting electrode 3 referred to hereinafter as the collector. A pair of resonating en-

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closures or chambers 4 and 5 are associated with certain electrodes within the envelope 1. The resonating chamber 4 is designated as the input resonator and is provided with any suitable means 6 for the introduction thereinto of an incoming electromagnetic wave. A source 7 of electromotive force of relatively low frequency is associated with one of the elements of the electron gun 2. The resonator 5 is provided with means 8 for leading away therefrom developed or amplified energy in the form of an electromagnetic wave. The electron gun 2 is provided with an electron emitting cathode 9 which is associated with any suitable heating means energized, for example, through leads 10 and 11 by a source 12 of electromotive force. Associated with the cathode 9 is an electrode 13 for use in regulating and varying current of the electron beam and commonly known as an accelerating electrode. It may be adjacent to and coaxial with the cathode. A pair of suitably shaped electrodes 14 and 15 which may be fused into the walls of the envelope 1, define an input gap 16 and serve to close the resonator 4 except for suitable apertures left in the electrodes for the passage of an electron beam or stream from the gun 2. The walls of the envelope 1 serve to separate the resonators 4 and 5 by a desired distance and to determine a suitable drift space 17. A pair of electrodes 18 and 19 define an output gap 20 associated with the resonator 5. The resonators 4 and 5 may be conductively connected together and to the collector 3, making a system which is maintained at a substantially constant potential difference from the cathode 9 by a source 21 of electromotive force, the negative terminal of which is connected to the cathode. A supplemental output means 22 is associated with the resonator 5, preferably in the form of a coaxial line, the inner conductor of which is connected to an intermediate point 24 of the source 21 through a rectifier 23. The rectifier is shunted by a parallel combination of a resistor 25 and a condenser 26, the unit formed by the elements 23, 25 and 26 being serially inserted in circuit with the source 7 and the accelerating electrode 13. A stabilizing resistor 27 may be provided in the cathode lead.

The arrangement of Fig. 1 is adapted to effect a transfer of modulated energy from one high frequency wave to another, both of which may be in the ultra-high frequency range. In the operation of the system an incoming wave of the frequency to which the resonator 4 is tuned, is introduced through the input means 6 with the consequent setting up of a high frequency alternating potential between the electrodes 14 and 15 in the input gap 16. The source 7 is arranged to operate at a frequency equal to the difference which it is desired to introduce between the frequency of the incoming wave and the frequency of the outgoing wave. The resonator 5 is tuned to the frequency of the outgoing wave. The function of the source 7 is to superpose variations of the above-mentioned difference frequency upon the potential of the electron accelerating electrode 13 to regulate the space charge effect in the tube and consequently to produce corresponding variations in the current or electron density of the beam. The beam, in traversing the input gap 16, has superimposed upon the above-mentioned current variations from source 7, a succession of electron velocity variations impressed by the incoming wave. It is further contemplated that the incoming wave will carry amplitude modulations corresponding to a signal which is to be repeated. The electron beam, thus modulated in density in accordance with the oscillations of the local source 7 and in velocity in accordance with the variations of the incoming wave, is allowed to traverse the substantially field-free drift space 17 to permit further grouping of the electrons to take place. In the absence of the density variations impressed upon the electron beam by the source 7 but in the presence of velocity varying potentials across the gap 16, the velocity variations tend to produce approximately proportional electron density variations at the output gap 20. The effect of the superposed density variation in the beam current is to produce a variation in the number of electrons per unit time which are subjected to the velocity variation at the input gap. As a result, the electron density variation at the output gap 20 tends to be proportional to the product of the two superposed variations, thereby introducing components corresponding to intermodulation products, such as combination frequencies according to well-known principles. Any desired modulation product may be accentuated by dimensioning or tuning the resonator 5 to resonate at the frequency of the selected modulation product. For example, the component of frequency equal to the incoming frequency minus the frequency of source 7 may be selected by making the critical dimensions of the resonator 5 somewhat greater than those of the resonator 4 in such proportion as to tune the resonator 5 to the desired output frequency. With proper tuning, an electromagnetic wave of the selected frequency will be sustained in the resonator 5 and delivered to the ouput means 8. By making the resonator 5 somewhat smaller than the resonator 4, on the other hand, the frequency component equal to the incoming frequency plus the frequency of source 7 may be selected. Of particular interest in the use of the arrangement of Fig. 1 as a radio repeater, the difference between the input and output frequencies is utilized to avoid undesirable reaction of the output upon the input which would otherwise cause self-oscillations or "singing" in the repeater.

Automatic stabilization of the intensity of the output wave is provided by taking a sample of the output wave from the resonator 5 through the coupling means 22 and applying the sample wave to the rectifier 23. The time constant of the resistor-condenser combination 25, 26 is preferably adjusted to a suitable value to smooth out rapid variations of the rectified current, leaving slow changes of current to produce a varying potential difference across the elements in series with the steady biasing potential impressed upon the accelerating electrode 13. The circuit is so arranged that the potential difference across the resistor 25 opposes the potential of the source 21 in determining the resultant potential of the electrode 13. In the well-known manner of automatic control systems of this type, changes in the amplitude of the output wave due to variations of the input wave are minimized. If it is desired, instead, to emphasize amplitude changes to secure a volume expansion effect, the polarity of the rectifier 23 may be made the reverse of that shown.

Stabilization of the system against power supply fluctuations associated with the source 21 is provided by means of the resistor 27 in the cathode return lead. Changes in the cathode return current affect the potential difference across the resistor 27 inherently in the proper sense to minimize such current changes by controlling the effective voltage between the cathode on the one hand and the system comprising the resonators 4 and 5, collector 3, and associated electrodes on the other hand.

Arrangements for maintaining an electron beam in any other suitable manner may be substituted for the electron gun 2. Any suitable resonators and electrodes may be substituted for the corresponding elements illustrated provided only that means are present for superposing an amplitude or current density variation and an electron velocity variation upon an electron beam which beam is thereafter subjected to suitable conditions or manipulation which results in a regrouping of the electrical charges in the beam in some manner adapted to produce intermodulation of the original variations. The automatic control features and stabilizing elements may, of course, be either omitted or included, as desired.

Fig. 2 illustrates certain features of the invention embodied in a superheterodyne radio receiver. The facilities for producing the electron beam, the envelope 1, the collector 3, and the input and output resonators and associated arrangements are substantially the same as in the system of Fig. 1, except that the output resonator 5' is tuned to the same frequency as the input resonator 4. Intermediate between the input and output resonators are two auxiliary chambers 28 and 29 having a common wall 30. The interiors of the chambers are shown coupled by means of a coupling loop 31 passing through an aperture in the wall 30. Alternatively, the loop 31 may be omitted and the aperture itself may be suitably dimensioned to provide the coupling. If desired, an iris or other suitable arrangement may be used to secure a variable coupling. Conductively connected with the wall 30 is an electrode 32 comprising a disc with an axial aperture surrounded by a short tube 33. The resonators 28 and 29 are provided with electrodes 34 and 35 respectively having apertures aligned with the aperture in the disc 32. Drift spaces 36 and 37 respectively are provided between the resonators 4 and 28 and the resonators 29 and 5'. Electromagnetic focussing coils 38 and 39, respectively, may conveniently be placed adjacent to the drift spaces 36 and 37 and energized by sources 40 and 41 of electromotive force. Alternatively, suitably designed permanent magnets may be substituted for the electromagnets. The collector 3 is connected by way of a tuned circuit 42 to the cathode 9. An intermediate frequency amplifier **43**, a detector **44** and a translating device **45**, such as a telephone receiver, are coupled in tandem arrangement with respect to the tuned circuit **42** in the conventional manner of a superheterodyne receiving system. The control elements **23**, **25** and **26** may be coupled to the output device **22** in a manner similar to that shown in Fig. 1. In this case, however, the control is shown applied to the potential of the resonating system instead of the electron accelerating electrode.

The operation of the system of Fig. 2 in its broad aspect is similar to that of any superheterodyne receiver. An input wave is impressed upon the resonator **4** through the input coupling **6** to impress velocity variations upon the electron stream which has also been given an electron density variation through the action of the local source **7**. The operation of the system differs from that of Fig. 1 among other particulars, in that the essential intermodulation of the local and incoming waves is effected in a somewhat different manner. Intermodulation according to the scheme described in connection with Fig. 1 may also occur in the drift space **36** of Fig. 2, but by tuning the resonator **28** to the frequency of the incoming wave the intermodulation at this point may be subordinated to amplification of the incoming wave, the latter process being brought about by electron density variations serving to set up forced oscillations in the resonator **28**. A portion of the energy of these oscillations is transmitted to the resonator **29** by means of a coupling loop **31** to produce a second and relatively intense velocity variation of the electron beam in the gap between electrodes **33** and **35**. By electron drift action in the drift space **37** a further amplified electron density variation is produced in the gap **20**, causing forced oscillations in the resonator **5′**. The amplified oscillations in the resonator **5′** will impress a new and still further amplified velocity variation upon the electron beam before the beam enters the space between the electrode **19** and collector **3**.

To obtain the desired intermediate frequency component which may be at the frequency of the difference between the incoming wave and the source **7**, velocity sorting of the electrons is effected by subjecting the beam to a retarding or reflecting field. The field is conveniently produced by connecting the collector **3** to the cathode **9** as illustrated, thereby placing the collector **3** at a potential considerably negative with respect to the potential of the electrode **19**. Due to the reflecting field, the slower electrons passing electrode **19** are unable to reach the collector **3** and are turned back, but the faster electrons are able to enter the collector **3** and induce a pulsating current in the return circuit. The intermediate frequency component of the pulsating current is resonated by the tuned circuit **42**, thereby supplying an input to the intermediate frequency amplifier **43**. Intermediate frequency amplification and final detection as well as translation of the signal are accomplished in the usual manner as in any superheterodyne receiving system.

It is contemplated that the frequency of source **7** will be relatively low compared to the frequency of the wave incoming at the coupling **6**, in which case the difference frequency will lie within the transmission band of the resonators **4**, **28**, **29** and **5′**. If desired the transmission band may be widened by detuning slightly one or more of the resonators or by increasing the degree of coupling between resonators **28** and **29**.

The system of Fig. 2 may be employed simply as a high frequency amplifier if desired, in which case, the high frequency output may be taken from the resonator **5′** by any suitable output means such as the coupling **8** illustrated in Fig. 1 and the collector may be connected to the positive terminal of the source of biasing potential. Elements **42**, **43**, **44** and **45** and source **7** may then be omitted.

The automatic control arrangement of Fig. 2 is shown as operating to control the average electron velocity at the electrode **14** thereby controlling the electron transit time through the drift spaces **36** and **37** and consequently controlling the gain of the device as a high frequency amplifier. With the rectifier **23** polarized in the direction indicated by the arrow the control is such as to minimize volume changes. If instead, it is desired to emphasize the volume changes to give a volume expansion effect, the polarity of the rectifier should be reversed.

Fig. 3 shows a superheterodyne receiving system employing two electron beam devices in a tandem arrangement. In the first tube, shown at the top of the figure, the incoming wave is impressed upon the resonator **4** by means of the coupling **6** to produce a velocity variation in the electron beam at the gap **16**. Conversion of the velocity variations into current density variations is provided for in the drift space **17**. The local oscillations are generated in a resonant chamber of concentric structure having an outer wall **50**, and inner walls **51**, **52**, **53** and **54**, of which **52** and **53** are conductively connected with the outer wall by wires **80** and **81**, respectively. The wires are preferably of sufficiently small dimensions not to interfere materially with the transmission or oscillation of electromagnetic waves within the enclosure. The wires preferably extend radially or substantially perpendicular to the electrical lines of force normally existing therein. Three gaps **55**, **56** and **57** are provided along the course of the electron beam separated by additional drift spaces **58** and **59**. The electrode **180** together with an electrode **181** defines the gap **55** and the gaps **56** and **57** are defined by similar pairs of electrodes. The ends of the resonating chamber are closed by means of annular pistons **60** and **61**, which are slidable for purposes of tuning the resonant chamber. The collector **3** is conductively connected to the inner conductor **64** of a concentric transmission line of which a tube **65** of conductive material connected conductively with the walls of the resonanting chamber is the outer conductor. The conductor **64** is connected to the tuning chamber and to ground through a high frequency choke coil **66**. The concentric line **64**, **65** is connected to another concentric line **68** of smaller diameter through a tapering section **67**.

A second electron beam tube serving as an amplifier and second detector is shown in the lower portion of the figure and has an input resonator **62** coupled to the transmission line **68** by means of a coupling loop **69** inside the resonator. The wave impressed upon the resonator **62** produces a velocity variation of the electron beam at an input gap **70**. Velocity sorting is effected in the output gap **71** due to the steady difference of potential maintained between insulated portions **82** and **83** of an output resonator by the electromotive force of a biasing source **84**. The slower electrons of the beam are turned back and only the faster electrons continue, finally striking a collector **72**. A coupling transformer **73** is provided for repeating the alternating portion of the pulsating current in the collector lead and a translating device such as a telephone receiver 74 is connected to the secondary of the transformer 73.

In the operation of the system of Fig. 3 the incoming oscillations and local oscillations are combined in the first or upper tube to produce a wave of somewhat lower frequency corresponding to the usual "intermediate frequency" wave. The wave so produced is amplified by the second or lower tube and the signals are detected by the velocity sorting process above described. The local oscillator is substantially a two-stage amplifier with coupling between the output and input. The relative voltages impressed upon the input gap 55 and the output gap 57 may be adjusted by proper setting of the tuning pistons 60 and 61, a movement of both pistons in the same direction an equal amount having substantially no effect on the resonant frequency. If it is desired to operate the lower tube at a much lower frequency, e. g. in the ordinary intermediate frequency range, the second tube may be replaced by a conventional intermediate frequency amplifier.

Fig. 4 shows another arrangement for the first detector of a superheterodyne receiving system. A resonant chamber 90 is tuned to the incoming frequency. Another resonant chamber 91 having a wall in common with the resonator 90 is tuned to the frequency desired for the local or beating oscillator. A gap 92 is provided within the resonator 90 and gaps 93 and 94 within the resonator 91. The collector 3 is connected to the biasing potential source through a tuned circuit 95 which may be tuned to the difference frequency.

In the operation of the arrangement of Fig. 4 the electron beam receives a velocity variation in accordance with the incoming waves at the gap 92. The beam receives a second electron velocity variation at the gap 93 in accordance with the local oscillations. The electron path between the gap 93 and the collector 3 is essentially a drift space and due to the non-linear character of the drift space action, difference frequency components are set up in the electron density variations effected by the drifting of the electrons. The gap 94 is provided for the purpose of extracting enough energy from the electron stream to support continuous oscillations in the resonator 91. The intermediate frequency wave may be of sufficiently low frequency to be handled with ordinary tuned circuits, and any desired utilization device, such as an intermediate frequency amplifier, may be coupled to the tuned circuit 95 in well-known manner.

Fig. 5 shows an alternative form of detector which may be used either as a first or second detector in a superheterodyne receiving system or as a simple detector for the direct conversion of an ultra-high frequency wave to recover the original signals in a single step of detection. A resonator 100 is provided for the input wave and is associated with a gap 101. Separated from the first gap by a space 102 are a pair of connected electrodes 103 and 104, which may be like the electrodes shown herein for the accommodation of a resonating chamber, but with the chamber omitted. The electrodes 103 and 104 are connected to the positive terminal of the biasing potential source through a resistor 105 which is shunted by a translating device such as a telephone receiver 106. A single electron-permeable electrode of any suitable type may be used instead of the connected electrodes 103 and 104. Focussing means such as an electromagnet 107 energized in any suitable way as for example by a battery 108 is provided to bring the electron beam to a focus near the electrodes 103 and 104.

In the operation of the system of Fig. 5 the incoming wave is resonated in the chamber 100 and by means of the gap 101 impresses a velocity variation upon the electron beam. The electron gun 2 is preferably of a type which focusses or concentrates the electron beam, and arranged to establish a focal point in the gap 101. The focussing coil 107 normally produces a point of concentration of the beam in the neighborhood of the electrodes 103 and 104. The electron velocity variation impressed upon the beam is arranged to be sufficient to cause a shifting of the point of concentration axially with respect to the electrodes 103 and 104 in accordance with amplitude modulations of the incoming wave. The electrodes 103 and 104 are thus caused to intercept a variable portion of the electrons of the beam, thereby producing a pulsating current through the resistor 105 and receiver 106. If desired, the resistor 105 may be replaced by a tuned circuit resonant to a desired intermediate frequency and the voltage variations in this tuned circuit may be employed to excite an intermediate frequency amplifier.

What is claimed is:

A modulating system comprising an electron beam-type tube, a plurality of resonating chambers arranged in succession along the path of the electron beam, one of said resonating chambers having two electron permeable electrode portions in opposite walls, in alignment with the electron beam to permit the beam to traverse said resonating chamber, another of said resonating chambers being located beyond said first-mentioned resonating chamber and enclosing a drift tube and having two electron permeable electrode portions in opposite walls, said electrode portions and the axis of said drift tube being in alignment with the electron beam, said second-mentioned resonating chamber being resonant at a frequency different from the resonant frequency of the first-mentioned resonating chamber, a source of electro-magnetic waves coupled to said first-mentioned resonating chamber to excite forced oscillations therein and to impress an electron velocity variation upon the electron beam at the frequency of said forced oscillations as the beam traverses the resonating chamber, a substantially field-free drift space between said first and second-mentioned resonating chambers for converting the said velocity variation of the electron beam into a corresponding electron density variation, means including the said electron permeable electrode portions of said second-mentioned resonating chamber and the said drift tube enclosed within said resonating chamber for generating self-oscillations in said second mentioned resonating chamber and for impressing upon the said density varied electron beam at a point ahead of said enclosed drift tube, a second velocity variation at the frequency of said self-oscillations and means including the said enclosed drift tube for converting the compound variation of the electron beam so produced into a second electron density variation comprising an intermodulation of said forced oscillations and said self-oscillations.

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