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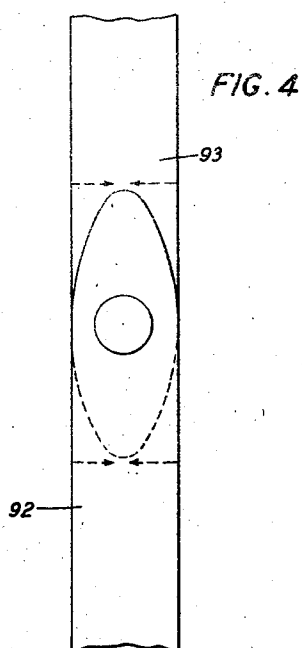
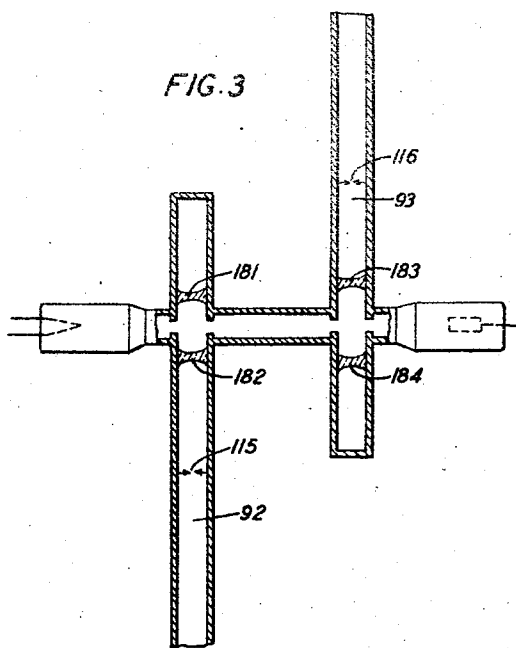
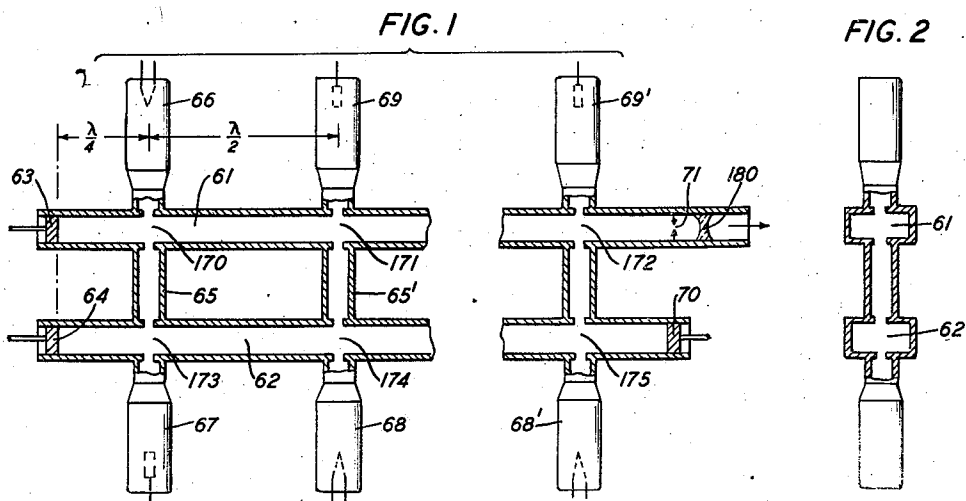
A. E. BOWEN

2,458,556

COUPLED CAVITY RESONATOR AND WAVE GUIDE APPARATUS

Original Filed April 8, 1941

2 Sheets-Sheet 1



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FIG. 5

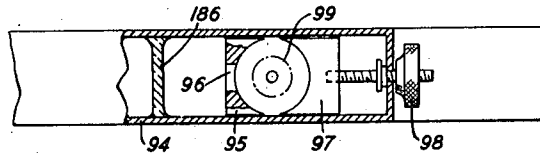


FIG. 6

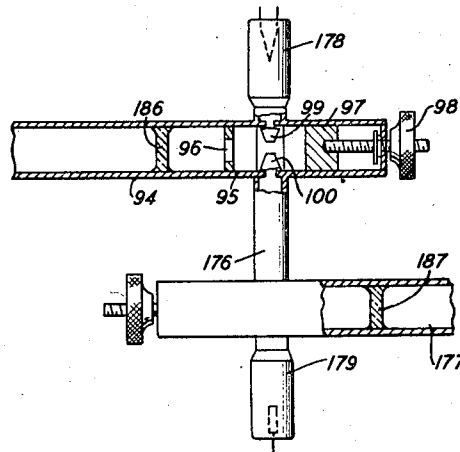
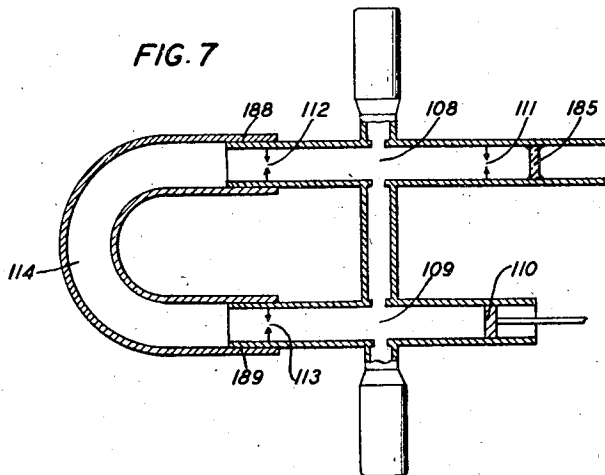


FIG. 7



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COUPLED CAVITY RESONATOR AND WAVE GUIDE APPARATUS

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13 Claims. (Cl. 315-6)

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This application is a division of my copending application Serial No. 387,432, filed April 8, 1941, and now Patent No. 2,408,409, granted October 1, 1946.

The invention relates to arrangements for facilitating the interchange of energy between an electron stream and an electromagnetic field, particularly in a resonator of the cavity type, and to arrangements for coupling such a resonator to a wave guide for energy transmission or reception. The wave guide may be of any suitable form, as, for example, a hollow conductive tube containing air, or a rod of dielectric material, etc.

The invention is more particularly applicable to systems in which velocity variations are impressed upon an electron stream and the stream is thereupon subjected to conditions which promote the development of electron current density variations in the stream to correspond to the impressed velocity variations. Electromagnetic waves or currents are induced by suitable means under the influence of the electron current density variations and supplied to a transmission line, wave guide or load circuit as the case may require. Excitation of the system is usually effected by employing an electromagnetic wave to develop a varying potential difference across a definite space, conveniently designated an input gap, traversed by the electron stream and associated with a resonating chamber. In its passage across the input gap, each electron of the stream on the whole either takes energy from or gives energy to the electromagnetic field in the resonating chamber depending upon the phase of the field during its transit across the gap. The velocities of the respective electrons are varied in accordance with the energy exchange in well-known manner. The electrons are next passed through a passageway or tube, usually termed a drift tube and preferably free from alternating electromagnetic fields, wherein a grouping or bunching effect takes place, those electrons which have lost energy and have as a consequence been slowed down, being overtaken by other electrons entering later, which have gained energy and thus have been speeded up. Consequently, at points in the stream at some distance beyond the input gap, the electrons are traveling in more or less well-defined groups. At such a point a second or output gap is usually provided, also traversed by the electron stream and associated with a resonating chamber. In the output gap, the bunches of electrons, if the length of the drift tube and the average speed of the electrons have been adjusted correctly, may be moving in op-

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position to the force of the electromagnetic field, thus contributing energy to the field, in greater amounts than are absorbed by the thinly distributed electrons which may cross the output gap during the unfavorable phase of the field.

A form of resonator which is particularly well adapted for coupling between a wave guide, e. g., a hollow conductive tube, and an electron stream is formed by partitioning off a section of the wave guide of proper length to serve as a resonator at the desired operating frequency. The section partitioned off and the section comprising the remainder of the wave guide may be said to have a portion of their boundary in common. Wave guides of either rectangular or circular cross section are most conveniently used although the invention is not limited to any particular shape or size of guide. The resonator and the main portion of the wave guide may be coupled by way of an aperture in the partition wall or common boundary portion and the amount of the coupling may be made adjustable by means of an iris diaphragm or other means of varying the size of the aperture. Openings for the passage of an electron stream are generally best provided at voltage antinodes of the electric field in order to secure the maximum interchange of energy. In some arrangements a plurality of electron streams are established at successive points of maximum voltage along an extended section of wave guide where standing waves are maintained.

A feature of the invention is an adjustable resonator comprising a space between curved faces of a fixed and a movable conductive block fitted within a hollow conductive tubular or rectangular shell.

The invention is applicable generally to amplifiers, oscillators, modulators, detectors and the like, particularly at ultra-high frequencies, wherever it is desired to effect direct interaction between an electromagnetic field and an electron stream.

The invention is described with reference to a number of illustrative examples.

In the drawings:

Figs. 1 and 2 show side and end views, respectively, partially in section, of an oscillation generating arrangement employing rectangular wave guides and providing for the parallel operation of a plurality of electron streams;

Figs. 3 and 4 show, respectively, a side view partially in section and a plan or elevational view of an amplifying arrangement in which rectangular wave guides are employed, a portion of

each wave guide being partitioned off by means of a wall having an aperture or iris diaphragm, the partitioned section having curved walls forming a resonator;

Figs. 5 and 6 show a top view and a side view, respectively, partially in section, of another amplifying arrangement including a cavity resonator consisting of a compartment partitioned off from the main portion of a wave guide, the compartment having two semicircular walls one of which is slidably mounted for tuning purposes; and

Fig. 7 shows an oscillator employing a wave guide which is formed into a U-shape in order to intercept an electron stream at two points, the arrangement including two resonating chambers with coupling apertures.

In Figs. 1 and 2, the reference numerals 61 and 62 designate two substantially parallel wave guides each having a width somewhat greater than one half the free space wave-length of the frequency to be generated, that is, one half the wave length of a wave of this frequency as propagated in open air or free space. The width of the guide here is the dimension perpendicular to the plane of the drawing in Fig. 1 or the horizontal dimension in Fig. 2. It is known from the theory and practice of transmission over wave guides that the width of the guide must exceed a certain value comparable to the half wave-length in free space before free transmission of the waves lengthwise of the guide is possible. The left-hand end of the guide 61 is closed by an adjustable piston 63 and the left-hand end of the guide 62 by an adjustable piston 64. At a distance from the pistons 63 and 64, equal to approximately one quarter of the wave-length at the operating frequency, arrangements are provided to direct an electron stream across both of the wave guides through a connecting tube 65. Here the wave-length referred to is not the free-space wave-length hereinbefore mentioned, but the wave-length in the wave guide as determined by the wave transmission properties of the wave guide. The tube 65 forms part of an otherwise conventional electron beam vacuum tube assembly having end sections 66 and 67 containing respectively an electron source or electron gun of any suitable type and an electron collecting electrode or collector, the electron stream in this case being directed vertically downward along the axis of the tube 65 through suitable apertures in the walls of the wave guides 61 and 62. At distances in each case equal to some integral number of half wave-lengths from the first electron stream, other electron streams are introduced. The second electron stream shown is maintained by an electron gun assembly 68, directed upward through an interconnecting tube 65' and collected by a collector at 69. As many additional electron tube assemblies 68', 69' with electron streams as desired may be provided and they may be uniformly spaced at half wave-length intervals along the wave guides. The right-hand end of the guide 62 is closed off by a tuning piston 70 at approximately a quarter wave-length beyond the last of the series of electron beam tubes while the right-hand end of the guide 61 is partitioned off by an iris diaphragm indicated schematically at 71. If in the particular embodiment employed, there are capacitive loading effects, or other disturbing factors, the actual spacings herein referred to as one quarter and one half wave-lengths, respectively, may depart somewhat from the theoretical values speci-

fied. The actual spacings in a given case may best be determined by trial. A vacuum-tight seal 180 of dielectric material such as glass may be inserted in the wave guide 61 between the group of tubes 68', 69' and the outgoing section of the wave guide to complete the closure of the vacuum chamber in which the electron beams operate.

In the operation of the system of Figs. 1 and 2, an accidental irregularity of electron flow in any one of the electron streams will suffice to start a traveling electromagnetic wave in the interior of one or both of the wave guides 61 and 62. Supposing for example, that a wave is thus started at the gap 173 in the guide 62 by the electron stream from the electron gun at 66, the wave will be propagated along the guide to the gaps 174 and 175 successively. At the gap 174 the wave will impress a velocity variation upon the upwardly directed electron stream from the electron gun at 68. The electron drift action in the connecting tube 65' whereby the faster electrons overtake the slower ones will cause an electron density variation to appear in the electron stream at the gap 171 the effect of which is to start a wave in the guide 61 which will be propagated in both directions. The part of this wave which reaches the gap 170 will effect an electron velocity variation in the electron stream from the electron gun at 66. The electron drift action in the tube 65 will cause an electron density variation to appear at the gap 173 and if the velocities of the respective electron streams have been properly adjusted so that the new electron density variations are in proper phase relation to the wave set up by the original disturbance, a fresh supply of energy is given to the wave by the electron stream and the oscillation is maintained. The waves traveling along the guides 61 and 62 will affect the whole series of electron beam tubes successively. In general one feedback tube 66, 67 should supply sufficient energy to drive several oscillating tubes 68, 69 although more than one feedback tube can be used, if desired.

Figs. 3 and 4 illustrate an amplifying system employing an electron stream and a pair of rectangular wave guides 92 and 93. The nearby ends of the respective wave guides may be closed by any suitable reflecting closures for setting up a standing wave system. Parabolic cylindrical closures are shown, but straight ends, fixed or movable, as for example pistons like 63 and 64 in Fig. 1 may be used instead. Means are provided for directing an electron stream through a region of relatively great intensity of electric field in each guide. In the form illustrated, the electron stream is directed along a line constituting a focal line which is common to the two parabolic surfaces.

The arrangements of Figs. 3 and 4 may be extended to accommodate any desired number of electron streams according to a plan similar to that shown in Figs. 1 and 2. It should be noted, however, that when the system is used as an amplifier, all the electron streams may be directed in the same direction, viz., from the input guide towards the output guide. A wave to be amplified may be introduced at the lower end of the guide 92 and the output may be taken from the upper end of the guide 93 by any suitable means in each instance. Resonant end sections may be partitioned off by means of iris diaphragms indicated schematically at 115 and 116, respectively, and the vacuum chamber may have its closure completed by means of a plurality of

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vacuum-tight seals 181, 182, 183 and 184 of dielectric material.

Figs. 5 and 6 show an arrangement similar to that of Figs. 3 and 4 including as an added feature a substantially cylindrically walled resonant chamber, adjustable for tuning and having apertured conical electrodes to accommodate the passage of an electron stream. The walls of the input wave guide are shown at 94. One end of the resonant chamber is formed by a block 95, stationary with respect to the wave guide and having a cylindrical concavity at the right-hand side as viewed in Fig. 5 which figure shows the top of the input wave guide partly broken away. An aperture 96 in the block 95 communicates between the main portion of the wave guide and the resonant chamber. The other end of the resonant chamber is closed by means of a slidably mounted block 97 which has a cylindrical concavity at the left-hand side as viewed in Fig. 5. The block 97 may be adjusted in position by any suitable means such as a screw-threaded device operated by a handle 98. Conical apertured electrodes 99 and 100 are set into the upper and lower walls of the input wave guide as viewed in Fig. 6 near the center of the approximately circular cylindrical enclosure between the blocks 95 and 97. The gap between the electrodes 99 and 100 as shown constitutes an input gap but the same structure may be used both for the input gap and for the output gap. The tuning feature of the resonator is particularly advantageous when it is desired to operate a system at a selected frequency within a predetermined range of frequencies. A drift tube 176 interconnects the input wave guide with the output wave guide 177. The electron beam tube is completed by an end section 178 containing an electron source and an end section 179 containing an electron collecting electrode. The vacuum chamber may be sealed off by means of vacuum-tight dielectric seals 186 and 187.

Fig. 7 shows an oscillator in which a wave guide is formed into a U-shape so as to intercept an electron stream at two points such as may be determined by gaps 108 and 109. A piston 110 and an iris diaphragm 113 are adjusted to positions approximately one quarter wave-length either side of the gap 109 to form one resonating chamber and iris diaphragms 111 and 112 are placed at approximately quarter wave-length distances either side of the gap 108 to form another resonating chamber. With proper adjustment of the electron transit time between the gaps 108 and 109 an interaction can be produced between the wave guide system and an electron stream at the gaps 108 and 109. It has been found that when the iris apertures are small and the conduction losses in the walls of the wave guide are small, a standing wave of very high amplitude is readily maintained either between 111 and 112 or between 110 and 113. By adjusting the position of the piston 110, the two resonating chambers may be made to have the same frequency. The bent section 114 serves to couple the two resonators and constitutes a feedback line or guide. A substantially pure traveling wave with practically no reflection or attenuation is set up in the section 114 and sustained oscillations are readily maintained in the system. The section 114 may be of any convenient length and is preferably adjustable as by means of trombone-type sliding joints 188, 189 so that the relative phases of the oscillations in the input and output stages can be given a suitable value. Closure of the vacuum

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chamber may be completed by means of a vacuum-tight dielectric seal 185.

What is claimed is:

1. An ultra-high frequency electronic amplifying system comprising, two wave guides, a plurality of tubes each interconnecting a pair of corresponding points in said respective wave guides, said points in either wave guide being spaced substantially at half wave-length intervals with reference to a predetermined operating frequency, said wave guides being provided with a plurality of groups of apertures aligned with said respective pairs of corresponding points, each group of aligned apertures being for the passage of an electron stream through both wave guides and through one of said interconnecting tubes, and beam forming means providing paths extending to direct a plurality of electron streams through said respective groups of aligned apertures.

2. An oscillator, comprising two substantially closed resonators, means to project an electron stream successively through both of said resonators, means defining a drift space for the electron stream between said resonators, and means to project a second electron stream successively through both of said resonators in the reverse order from said first mentioned electron stream to provide an electronic feedback coupling between said resonators.

3. A resonator having two spaced regions wherein the electric intensity of a system of standing electro-magnetic waves capable of being maintained in the said resonator has a series of respective maximum values, and means to maintain a pair of electron streams, the path of each said stream passing through one of said regions of maximum intensity, said paths permitting said streams to flow through said resonator in opposite directions.

4. An ultra-high frequency electronic oscillator, comprising, two wave guides, a plurality of tubes each interconnecting a pair of corresponding points in said respective wave guides, said points in either wave guide being spaced substantially at half wave-length intervals with reference to a predetermined operating frequency, said wave guides being provided with a plurality of groups of apertures aligned with said respective pairs of corresponding points, each group of aligned apertures being for the passage of an electron stream through both wave guides and through one of said interconnecting tubes, beam forming means providing paths extending to project a plurality of electron streams through a plurality of respective groups of aligned apertures, said paths permitting said streams to flow through the said two wave guides in the same order, and beam forming means providing a path extending to project another electron stream through another group of aligned apertures, said latter path permitting said last-mentioned stream to flow through said two wave guides in the reverse order to serve as a feedback path.

5. In a coupling system, two wave guides each closed at one end and having their closed ends in proximity to each other, means defining a half-wave resonator in each of said wave guides at the respective closed end, means for positioning said wave guides with the regions of maximum electric intensity of the respective resonators substantially adjacent, beam forming means providing a path through said resonators for projecting an electron stream through the said resonators of both of said guides, and spacing

means comprising a hollow member separating said guides and surrounding said electron path to provide a drift space for said electron stream between said respective resonant end sections.

6. Two wave guides each terminated in a resonator for developing standing electromagnetic waves therein, beam forming means providing a path for projecting an electron stream successively through said respective resonators of said wave guides, and a drift tube interposed between said wave guides, said tube enclosing said electron path and defining a drift space for said electron stream.

7. An adjustable cylindrical resonator comprising a hollow conductive wave guide rectangular in cross-section, a stationary conductive block within said wave guide, said block having a concave cylindrical face and said block being provided with an aperture communicating with the main portion of the wave guide, and a movable conductive block positioned within said wave guide near said stationary block, said movable block having a concave cylindrical face opposed to the concave cylindrical face of said stationary block to form a cylindrical resonator between said opposed concave faces, said resonator being coupled to the main body of the wave guide through said aperture.

8. An oscillating system comprising input and output resonators, means to project an electron stream successively through said input resonator and into said output resonator whereby a system of standing electromagnetic waves may be set up in said output resonator under the control of another system of standing electromagnetic waves existing in said input resonator, a hollow pipe transmission line connecting the interior portions of the said input and output resonators, and a pair of apertured diaphragms located respectively between the input resonator and the said transmission line and between the output resonator and the said transmission line, whereby a substantially pure traveling wave may be maintained in said feedback line by energy from said standing wave system in said output resonator and utilized to feed energy back to the standing wave system in said input resonator.

9. An oscillating system in accordance with claim 8 together with a section of adjustable length in said hollow pipe transmission to regulate the phase of the feedback with respect to the phase of the said standing wave system in said input circuit.

10. An oscillating system in accordance with claim 8 in which the said input and output resonators each contain a further plurality of aper-

tures all of which latter apertures are aligned with one another to accommodate the passage of the electron stream through both resonators.

11. An oscillating system in accordance with claim 8 together with an output wave guide and an apertured diaphragm between the said output resonator and the said output wave guide.

12. An ultra-high frequency electronic amplifying system, comprising two wave guides, beam forming means providing paths for a plurality of electron streams each of said paths passing through both of said wave guides in the same order whereby each of said streams may be acted upon by a system of standing electromagnetic waves in one and the same guide and may energize a similar system of standing electromagnetic waves in the other of said guides, each of said paths intersecting said guides at a pair of corresponding points in said respective guides and said points in either wave guide being spaced substantially a half wave-length apart with reference to a predetermined operating frequency.

13. Electron discharge apparatus comprising first and second hollow resonators having two sets of aligned apertures, means for producing a main electron beam, means for directing said main electron beam through one set of aligned apertures in the direction from said first resonator to said second resonator so that the said beam is velocity modulated in traversing said first resonator and is bunched on arrival at said second resonator, and yields energy thereto, and means for producing an auxiliary electron beam and for directing it through the other set of aligned apertures in the direction from said second resonator to said first resonator whereby said auxiliary electron beam is velocity modulated and feeds back energy from said second resonator to said first resonator.

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