Feb. 1, 1949. W. W. HANSEN ET AL 2,460,288

RESONATOR APPARATUS

Original Filed Aug. 24, 1939

FIG. 1.

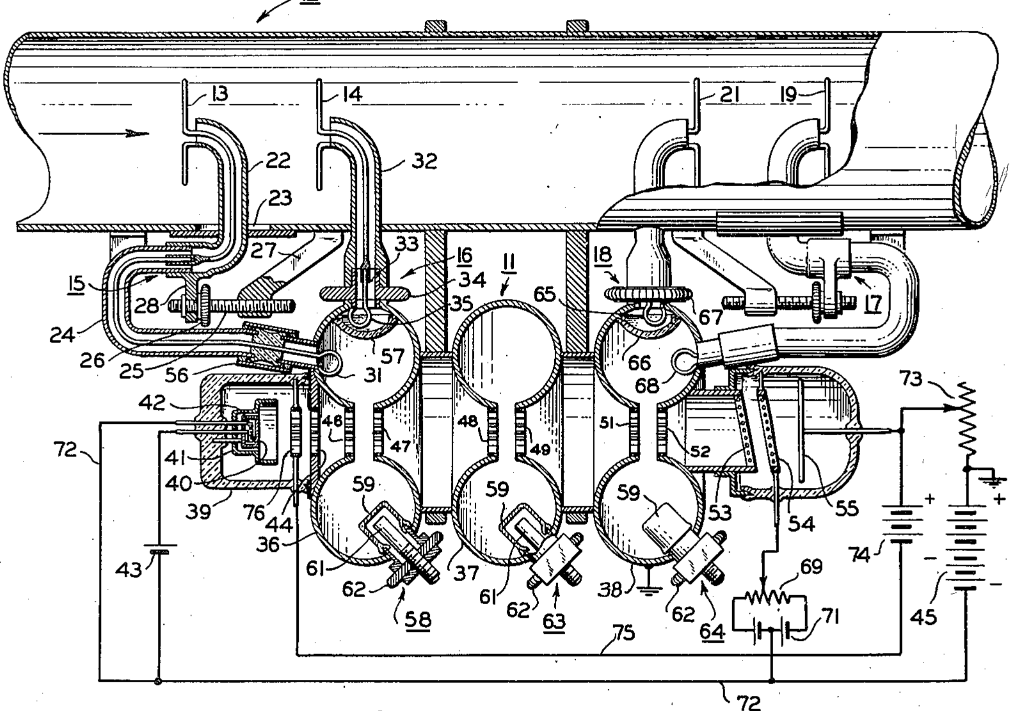
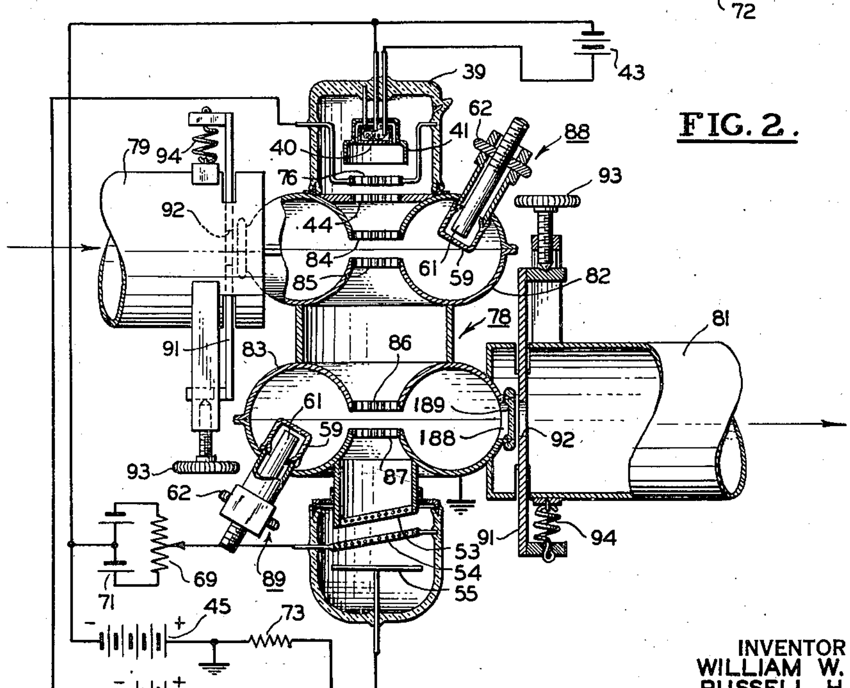


FIG. 2.



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RESONATOR APPARATUS

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7 Claims. (Cl. 178—44)

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This invention relates to hollow resonator apparatus and is particularly concerned with structural and circuit improvements in such apparatus.

This is a division of Serial No. 291,652, filed August 24, 1939, for Dielectric guide signaling, now Patent No. 2,375,223, granted May 8, 1945.

It is a major object of the invention to provide hollow resonator apparatus having novel control and/or energy coupling arrangements.

A further object of the invention is to provide novel hollow resonator apparatus wherein a suitable member is shiftably mounted in the electromagnetic field of a hollow resonator device having an evacuated section through which an electron beam is passed in such fashion that coupling of said member with the field may be controllably varied from outside the device without disturbing the vacuum seal.

A further object of the invention is to provide hollow resonator apparatus wherein a shiftable conductive member terminating a high frequency transmission line extends within a hollow resonator for variable coupling with the high frequency field within said resonator, that part of the resonator field with which said member is coupled being sealed off from the remainder of the resonator interior by vitreous or like wave energy permeable wall means permitting said coupling. Specifically the coupling member may be rotatable for changing the amount of energy transfer between the transmission line and said field.

A further object of the invention is to provide novel hollow resonator apparatus wherein an electron stream is passed through hollow resonator means and special detector and associated arrangements are provided for automatically controlling said electron stream, preferably for controlling the current strength of said stream.

It is a further object of the invention to provide hollow resonator apparatus wherein a hollow resonator device is connected in a novel manner between two wave guides.

A further object of the invention is to provide a novel amplifier section in a wave guide.

A further object of the invention is to provide novel arrangements for matching the impedance of a hollow resonator device with a wave guide.

Further objects of the invention will presently appear as the description proceeds in connection with the appended claims and the annexed drawings, wherein:

Figure 1 is a side elevation partly diagrammatic and partly in section of hollow resonator apparatus embodying the invention as used for amplifying signals projected along a dielectric wave guide; and

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Figure 2 is a side elevation of a further embodiment of the invention wherein wave guide sections are directly coupled to the resonators of an amplifier.

The term "hollow" as used herein in describing resonators and wave guides is of course intended to embrace all such resonators and wave guides regardless of whether the dielectric therein is air or some other medium.

Figure 1 illustrates relaying apparatus including a hollow resonator device 11 for picking up a signal traversing a wave guide 12 from left to right, amplifying the signal and then reradiating the same for continued transmission along the wave guide. This relaying apparatus includes directional discriminating means for receiving the signal to be relayed and for reradiating the signal after it has been amplified. The relaying apparatus is not responsive to signals coming from a direction opposite to its direction of sensitivity and hence will not cause interference with signals traversing the guide in that opposite direction. Ordinarily a similar relaying device with opposite directional characteristics is employed in the wave guide for relaying signals in the opposite direction, as described and claimed in said Patent No. 2,375,223.

Spaced signal receiving means 13 and 14, which may be of any suitable type such as the illustrated dipole antennae, are suitably located in wave guide 12. A phase shifter designated at 15 is supplied from antenna 13, while an amplitude adjuster designated at 16 is supplied from antenna 14. The outputs of the phase shifter and amplitude adjuster are combined as illustrated in hollow resonator device 11 which is a radio ultra high frequency amplifier. The output of amplifier 11 is supplied through a second phase shifter 17 and amplitude adjuster 18 to reradiating antennae 19 and 21.

Phase shifter 15, connected to receiving antenna 13, is illustrated as a concentric transmission line which is adjustable as to length. A concentric line portion 22 which is shiftable axially of wave guide 12 extends through an opening 23 provided in wave guide 12 and has dipole 13 connected with its upper end. The lower end of concentric line portion 22 is provided with a female socket for telescopically receiving the upper end of a relatively fixed concentric line portion 24. A screw 25 having a knob 26 is threaded into a bracket 27 fixed on wave guide 11. Screw 25 is rotatably mounted on a lug 28 integral with line portion 22, and is otherwise so connected with lug 28 that rotation of knob 26 varies the axial distance between dipoles 13 and 14, thereby varying the phase difference between these dipoles within the wave guide. The concentric line connecting dipole 13 to amplifier 11 is thereby changed in length so that rapid changes in phase of the outputs of the two dipoles as supplied to the amplifier may be effected by adjusting phase shifter 15.

Concentric line portion 24 terminates in a conductive loop 31 which is coupled to deliver energy to amplifier 11 as will be described.

Amplitude adjuster 16 comprises an upper concentric line portion 32 connected to receiving antenna 14 after extending through a suitable aperture in wave guide 12. The lower end of line portion 32 is formed as a female socket which is rotatably connected with the mated upper end of a short concentric line portion 33 having a manual operating knob 34. At its lower end concentric line portion 33 terminates in a conductive loop 35 which is coupled to deliver energy to amplifier 11 as will be described. Thus loop 35 is rotatably mounted with respect to the concentric line between antenna 14 and amplifier 11.

Amplifier 11 preferably is generally of the type disclosed in United States Letters Patent No. 2,280,824, issued April 28, 1942. Amplifier 11 comprises a plurality of aligned interconnected dielectric resonators 36, 37 and 38 that are evacuated. Within a vitreous insulating cup 39 at one end of the amplifier is provided a cathode 40 surrounded by a focusing shield 41, said cathode being indirectly heated by a heater coil 42 that is supplied from the battery 43. The electrons released by the cathode 40 are drawn in a columnar stream by a strongly positive grid 44, which grid is held positive with respect to the cathode by a battery 45. Note that the positive side of the battery 45 is grounded, which is also true of the casing of amplifier 11, to which casing grid 44 is connected. The electron stream drawn through grid 44 passes through subsequent pairs of grids 46, 47, 48, 49, and 51, 52, constituting grids of hollow resonators 36, 37 and 38, respectively. After leaving grid 52, the electron stream passes through additional inclined parallel grids 53 and 54 to a collector and detector plate 55.

Loops 31 and 35 are both disposed within input resonator 36, so as to be coupled in energy exchanging relation with the electromagnetic field of the resonator as will be described. A suitable vacuum tight sealed joint employing a body of vitreous material as indicated at 56 is provided where concentric line portion 24 is joined to resonator 36.

A partition 57 of vitreous material is provided within resonator 36 so as to seal off that section of resonator 36 within which rotatable loop 35 is disposed from the remainder of the resonator interior. Partition 57 is of course made of a material which is permeable to the resonator field and permits the resonator field to couple with loop 35. As illustrated, partition 57 provides an outwardly facing pocket accommodating loop 35.

Resonator 36 is also provided with a frequency control device indicated at 58 comprising a glass or like vitreous pocket or envelope 59, the closed end of which extends well into the interior of resonator 36. The open outer end of pocket 59 is sealed off along the edge of a suitable aperture in resonator 36, as illustrated, so as to be vacuum tight. A metal plug 61 is suitably mounted for longitudinal advance or retraction within pocket 59, as by rotation of nut 62. Similar frequency control devices 63 and 64 are provided on resonators 37 and 38, respectively.

Within output resonator 38, conductive loop 65 is disposed in a section of the resonator which is sealed off from the remainder of the resonator interior by a vitreous partition 66 similar to partition 57. Loop 65, like loop 35, is rotatable for variable coupling with the associated resonator field. Manual knob 67 of amplitude adjuster 18, which is structurally the same as amplitude adjuster 16, is provided for selective rotation of loop 65. Loop 65 is thus connected to transmitting antenna 21 in the same manner that loop 35 is connected to receiving antenna 13.

In like manner conductive loop 68 within resonator 38 is connected to transmitting antenna 19 through phase adjuster 17 which is identical in construction and operation to phase adjuster 15.

Thus in each of resonators 36 and 38, the electrically conductive inner surfaces of the resonators substantially define envelopes bounding the electromagnetic fields. The conductive loops and shiftable frequency control elements are all at least in part disposed within the physical confines of those envelopes, for coaction with the fields. The rotatable coupling loops are disposed in non-evacuated sections of the envelopes.

As illustrated loops 35 and 65 may be inserted into or withdrawn from their associated resonators without impairing the vacuum seal of the resonators.

During operation, the indicated wave energy traveling along wave guide 12 from left to right is picked up by receiving means 13 and 14 and delivered to resonator 36 in in-phase relation. This received energy serves to excite resonator 36 in such mode that an alternating current electric field is established within resonator 36 and between grids 46 and 47, the said electric field serving to alternately impart positive and negative accelerations to successive electrons of the stream passing therebetween, thereby causing the electrons of the stream to traverse the space between resonator 36 and the next resonator 37 with cyclically varying velocities. The faster electrons which passed through the electric field later than the preceding electrons will tend to overtake the latter in the interspace or drift space between resonator 36 and resonator 37, so that by the time the electron stream has arrived at grid 48, the stream will have a slight periodic variation in electron density at the frequency of the field between grids 46 and 47.

If intermediate resonator 38 is properly tuned, which is accomplished by tuning means 63 of the general type disclosed in United States Letters Patent No. 2,259,690, issued October 21, 1941, an alternating electric field will be established between grids 48 and 49, which is much stronger than that existing between grids 46 and 47, with the result that the successive electrons will receive much larger variations in velocity than that previously possessed, thereby effecting still greater bunching and corresponding increase in variation in electron density during passage through the space between resonators 37 and 38. Similarly, the entrance of the stream of variable electron density into resonator 38 establishes a strong alternating electric field between grids 51 and 52 which acts to retard the electrons so that they do work upon this field and thereby maintain the alternating electromagnetic field within resonator 38 and energy from the field is picked up by loops

68 and 65 and reradiated along wave guide 12 by transmitting means 19 and 21.

Grid 53, being at the potential of the positive side of battery 45, aids in maintaining the stream in columnar form, whereas inclined grid 54 is preferably maintained at a potential near that of the cathode. This is accomplished by use of potentiometer 69 and battery 71 connected to cathode lead 72. With grid 54 at this potential, most of the electrons are reflected back and to one side, and only the speeded up electrons will pass through this grid. Thus, as the change in electron velocity increases, more and more of the faster electrons will reach plate 55 beyond grid 54, while fewer of the slower electrons will reach this plate. The current therefore reaching plate 55 increases as the amplitude of oscillations in the hollow resonator device increases, so that said device as a whole serves as a cascade amplifier and detector.

The detected signal on the plate 55 is more negative the stronger the oscillations become. Looked at in another way, as the current through the plate circuit increases, the drop across a resistor 73 in the plate circuit increases, thereby lowering the potential at the plate, which is shown connected through a biasing battery 74 and lead 75 to a grid 76 positioned in front of emitter 40. Thus the potential of grid 76 is correspondingly lowered, effecting a decrease in the current passing through the device due to the repellent action of the grid 76 on the electron stream. Thus, since plate 55 becomes more negative as the signal intensity increases, grid 76 acts as an automatic volume control serving to cut down the current in the device and thereby the gain when the amplitude of oscillation increases.

As above described, the tuning devices supplied to each resonator consist of vitreous envelopes 59 that extend into the resonators and prevent the admission of air thereinto. The position in which the envelopes 59 and the associated metal plugs project into the resonators has an important bearing on the tuning. If the metal plug is positioned in a part of the resonant cavity containing essentially electric field, the same by its presence serves to increase the capacity of the circuit so that the resonant frequency will be decreased, whereas if this plug is inserted in a region containing mostly magnetic field, the same reduces the total volume of magnetic field since the plug contains no field, whereby the inductance will be decreased and the frequency will be increased. It is therefore possible to find an intermediate point where the mere presence of the plug will not affect the frequency. As illustrated in Figure 1, the metal plugs are located where the magnetic field is strong. As the plugs are moved in and out, controlled changes in the resonant frequency of the resonators is obtained, thereby allowing the various resonant chambers 36 to 38 to be tuned to the incoming signal.

Rotation of loop 35 by manipulation of knob 34 alters the number of magnetic lines of alternating current flux resonant in hollow resonator 36 that are enclosed by the loop, thereby varying the intensity of the signal that is set up in resonator 36 by a given signal passing along wave guide 12 from left to right. Similarly, rotation of loop 65 by rotation of knob 67 varies the intensity of the amplified signal delivered to wave guide 12.

Thus energy traveling from left to right along wave guide 12 is picked up by receiving antennae 13, 14 and delivered to cascade amplifier 11. The amplified signal is in turn reradiated in the original direction along wave guide 12 from antennae 19, 21. Suitable phase and amplitude adjustments are provided at both the input and output of amplifier 11, and an automatic volume control is provided for varying the amplification inversely to variations in amplitude of the received signal.

Receiving antennae 13 and 14 are preferably located about one-quarter wave length apart within wave guide 12; that is, they are spaced a distance apart such that the waves received by antennae 13 and 14 are substantially 90° apart in phase due to the time consumed by the wave in traveling this distance. Phase shifter 15 is adjusted by turning its control knob 26 so that the electromagnetic waves delivered therefrom to resonator 36 are in phase with the waves delivered to resonator 36 from the amplitude adjuster 16 when the received electromagnetic waves are traveling from left to right in wave guide 12. Thus, though the antenna 14 is displaced one-quarter wave length from antenna 13, the output of amplitude adjuster 16 is phased with the signal received from the phase shifter 15. Thus, the outputs of antennae 13 and 14 are combined additively for supplying ultra high frequency amplifier 11.

However, should a signal be received by antennae 14 and 13 coming from the reverse direction, that is, moving from right to left in Figure 1, then in that case the electromagnetic waves received at 13 will be 90° displaced later than those received at 14, and since phase shifter 15 and the connections shown act to retard the phase of the output of antenna 13 substantially 90° more, the output of the phase shifter 15 will be directly out of phase with that supplied resonator 36 from amplitude adjuster 16. Thus, these reversely moving signals will tend to cancel each other. If the amplitude of these reversely moving signals is made identical by adjusting the knob 34 of amplitude adjuster 16, the effect of the signal coming from the right at amplifier 11 will be zero due to the cancelling of the opposite signals. Thus, if receiving means 13 and 14 are approximately one-quarter wave length apart in the guide, their combined sensitivity in one direction, i. e., for signals moving from the left toward the right, will be substantially a maximum, whereas for signals moving in the opposite direction the combined signal will be zero. It is not essential that these receiver means be exactly one-quarter wave length apart, as some departure from this value will not appreciably affect the sensitivity of the system. Since it is necessary that the sensitivity of the apparatus to signals traversing the guide in the reverse direction should be as near zero as possible, the receiving means are set up, in practice, as near one-quarter wave length apart as convenient, or some odd multiple thereof. The final elimination of the sensitivity in the wrong direction is obtained by fine adjustment of the phase shifter knob 26 and the amplitude adjuster knob 34.

Phase shifter 17 acts to retard the phase of the waves emitted from antenna 19 substantially 90° in phase position relative to the waves emitted from antenna 21, which is spaced along wave guide 12 about one-quarter wave length therefrom, so that by the time the waves from antenna 21 have reached antenna 19, the combined waves are in phase for transmission along wave guide 12 toward the right. Antennae 19 and 21, on the other hand, are subtractive in their action so far as transmission to the left is concerned. Thus, radiation from antenna 19, upon reaching antenna 21, will be displaced 90° counter-clockwise from that which would be received at antenna 21 were phase shifter 17 not used, but since phase shifter 17 retards the phase by 90°, the net result is to establish an 180° out of phase condition between the signal emitted at 19 and that received at 21 from 19, so that these two signals cancel out and hence do not traverse the wave guide toward the left, i. e., in the wrong direction. Further action of the relaying and associated apparatus in connection with ultra high frequency energy transmission is disclosed and claimed in said Serial No. 291,652, now Patent No. 2,375,223, to which reference is made for further detail. The present invention is concerned mainly with above described features relating to the amplifier and associated arrangements.

In Figure 2 an electron beam excited hollow resonator device 78 is directly connected between wave guide sections 79 and 81 to relay and simultaneously amplify a signal passing from left to right along the wave guide.

Device 78 is here a two resonator amplifier, embodying a hollow input resonator 82 similar to input resonator 36 and an output resonator 83 similar to output resonator 38 in Figure 1. Resonator 82 is provided with spaced grids 84, 85, and resonator 83 is provided with spaced grids 86, 87. Tuning devices 88 and 89, similar to that at 58, are provided for resonators 82 and 83. As indicated by corresponding reference numerals, the various electrode and automatic volume control arrangements are the same in Figure 2 as in Figure 1. Device 78 has no intermediate cascade amplifier resonator such as that at 37 of Figure 1 and hence is constructed and operates similarly to the usual two resonator amplifier disclosed in United States Letters Patent No. 2,242,275.

Hence amplifier 78 is essentially the same as amplifier 11, except for details of coupling to the wave guide which will be described below.

Output resonator 83 is formed with an energy output aperture 188 sealed by a glass or like wall 189. The adjacent end of wave guide section 81 is slotted to permit passage of an apertured gate plate 91 having aperture 92 adapted to register with aperture 88. Thumb screw 93 opposing a spring 94 is adapted to adjust plate 91 vertically to thereby vary the portion of the area of aperture 92 that registers with aperture 88. Thus, by rotation of screw 93, the impedance of guide 81 may be matched with the internal impedance of amplifier 78.

A similar adjustable gate structure is provided between input wave guide section 79 and resonator 82, as indicated by the corresponding reference numerals, for matching the impedance of guide section 79 to the input impedance of resonator 82.

In operation, energy from wave guide section 79 is delivered directly to excite resonator 82 and cause velocity modulation of the electron stream. Energy extracted from the electron stream by resonator 83 is delivered directly to wave guide section 81. Proper impedance match for best operating conditions is attained by the adjustable gate structures, thereby insuring highly efficient performance. Hence signal energy traveling from left to right in Figure 2 is relayed and amplified at 78 with a minimum of losses.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a signaling apparatus of the type embodying a single continuous wave guide for conveying electro-magnetic wave signals therealong, the combination comprising input and output resonators independent from said wave guide, means for producing an electron stream for exciting said resonators, means for coupling both of said resonators to said guide, a detector responsive to the amplitude of oscillation of said output resonator, and means controlled from said detector for varying the output of said electron stream producing means to maintain the signal output intensity of said output resonator substantially constant.

2. Signal apparatus as defined in claim 1 wherein means are provided for varying the coupling of said resonators to said guide.

3. In signalling apparatus of the type embodying a single continuous high frequency energy conductor for conveying electromagnetic wave signals therealong, the combination comprising input and output resonators, means for producing an electron stream for exciting said resonators, means for coupling each of said resonators to said high frequency conductor, detector means responsive to the amplitude of oscillation of said output resonator and comprising an apertured electrode arranged to intercept the slower electrons of said stream and a collector electrode in the path of the faster electrons beyond said apertured electrode, and means controlled from said detector means for varying the output of said electron stream-producing means to maintain the signal output intensity of said output resonator substantially constant.

4. In signalling apparatus of the type embodying a single continuous high frequency energy conductor for conveying electromagnetic wave signals, the combination comprising an input resonator, an output resonator, means for producing an electron stream in energy-exchanging relation to both said resonators and means coupling said resonators to said conductor at respectively different points thereof, whereby said resonators and stream-producing means may serve to amplify energy flowing along said conductor.

5. High frequency repeater apparatus comprising a single continuous high frequency energy conductor adapted to convey electromagnetic wave signals from a source coupled at one end thereof to a utilization device coupled at the other end thereof, an input cavity resonator coupled to said conductor at an intermediate point thereof, an output cavity resonator coupled to said conductor at another intermediate point thereof, and means for producing an electron stream in energy-exchanging relation to both said resonators, whereby said resonators and stream-producing means may serve to amplify high frequency energy flowing along said conductor.

6. High frequency repeater apparatus comprising a single continuous hollow wave guide adapted to convey electromagnetic wave signals therein

between a source of such signals coupled at one end thereof and a utilization device for said signals coupled to the other end thereof, means for producing an electron stream, an input cavity resonator coupled in energy-exchanging relation to said stream, an output cavity resonator also coupled in energy-exchanging relation to said stream, and means coupling said resonators to said wave guide at respectively different points thereof intermediate its ends, whereby said resonators and stream-producing means may serve to amplify energy flowing along said wave guide.

7. Apparatus as in claim 6 further comprising means defining a drift space surrounding the path of said stream between said resonators, whereby velocity modulation of said electron stream produced by said input resonator is converted into electron current variations of said stream upon passage through said output resonator for amplification of the signal supplied to said input resonator from said wave guide.

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