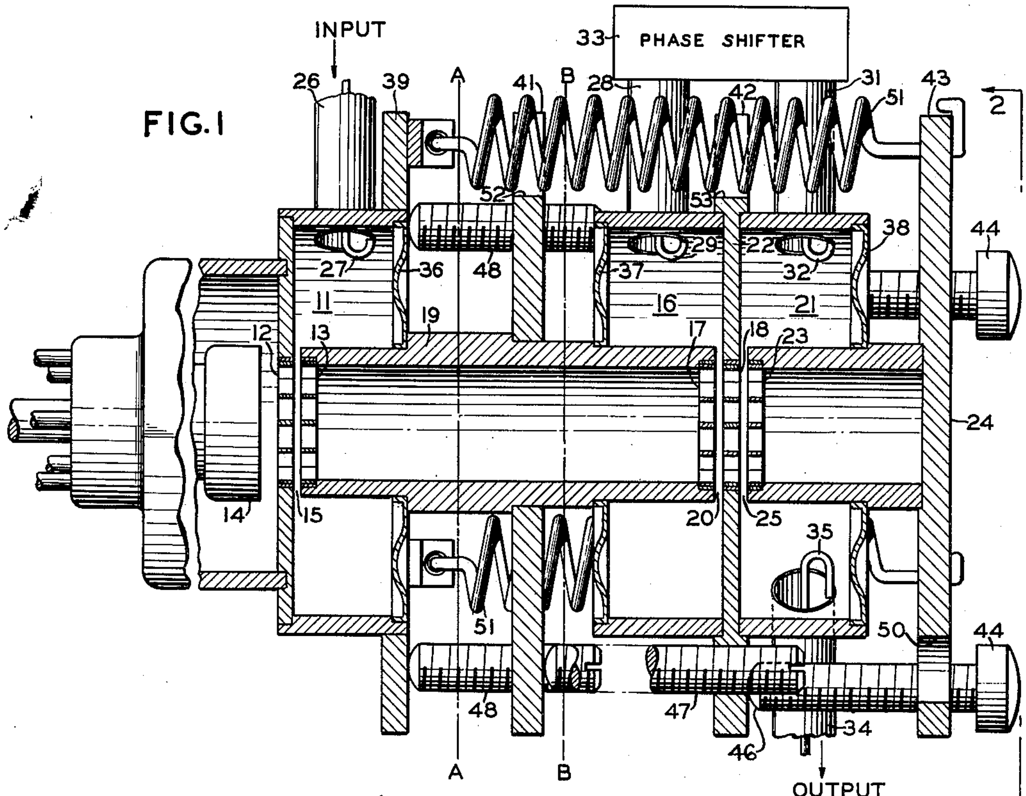
July 11, 1950 E. FEENBERG 2,514,383

HIGH-FREQUENCY CAVITY RESONATOR APPARATUS

Filed Aug. 25, 1944 2 Sheets-Sheet 1

FIG. 1



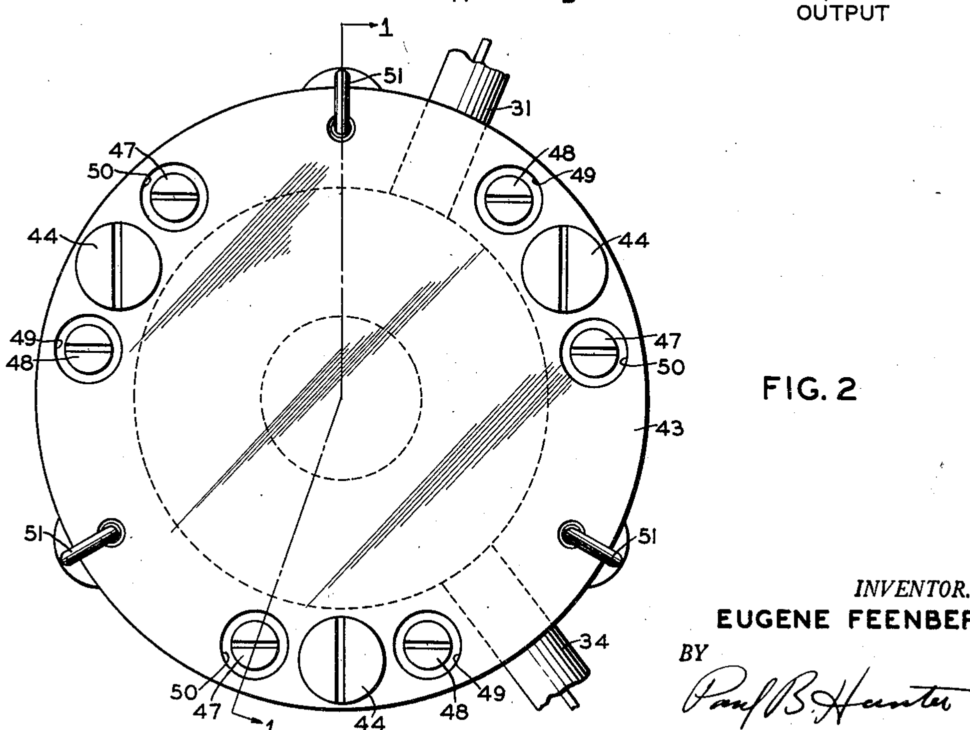


FIG. 2

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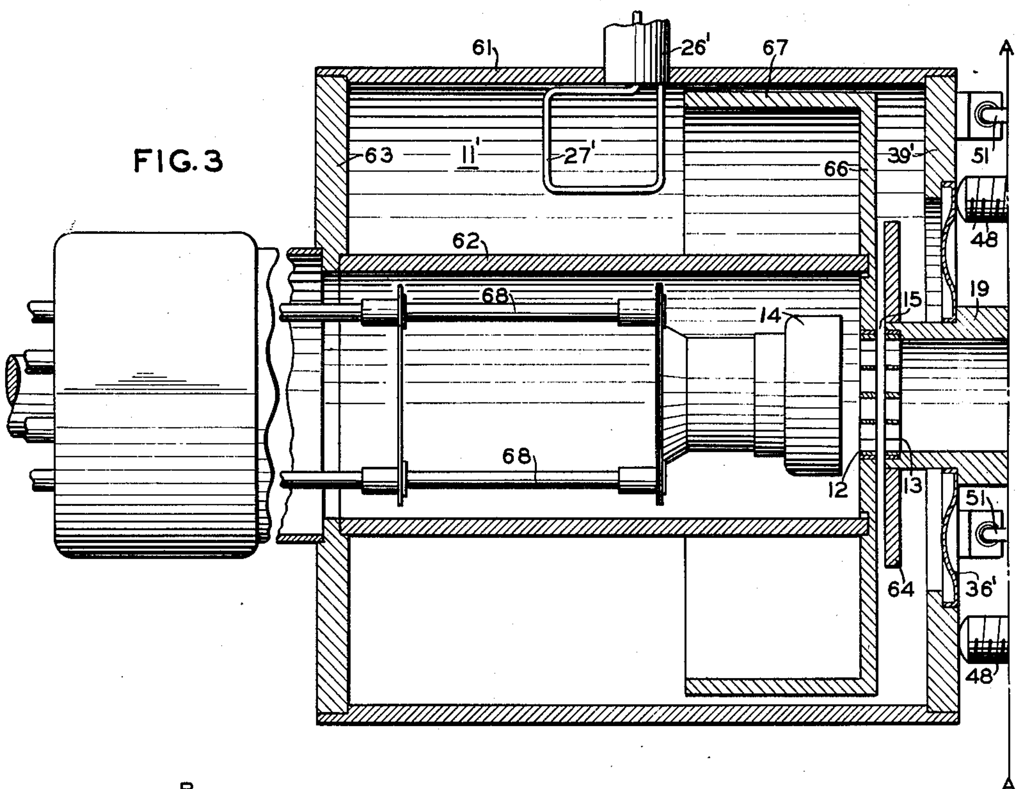
FIG. 3



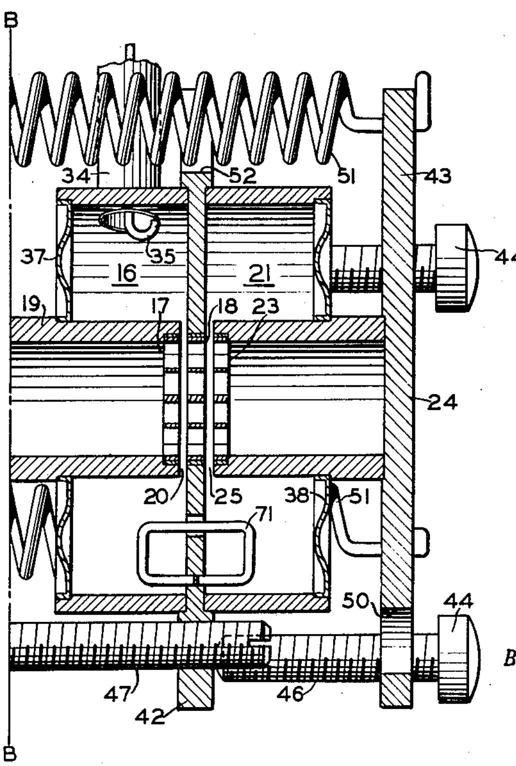


FIG. 4

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UNITED STATES PATENT OFFICE

2,514,383

HIGH-FREQUENCY CAVITY RESONATOR APPARATUS

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15 Claims. (Cl. 315—6)

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The present invention relates to the art including electron discharge devices, and especially such devices utilizing cavity resonators inductively coupled to electron streams.

Prior art devices of this general type are exemplified by Varian Patent No. 2,242,275 for Electrical Translating System and Method, issued May 20, 1941. In devices of this type, an electron stream is acted upon by an alternating high frequency electric field which velocity modulates the stream. The stream is velocity-grouped by subsequently traversing a field-free drift space and is thereby caused to periodically vary in amplitude at the field frequency and/or harmonics thereof. In this way, an alternating current component appears in the electron current which is of the same frequency as that of the impressed field, and may be accompanied by components of frequencies harmonically related to this frequency. This variable electron current or stream is then passed through an output or energy-extracting cavity resonator, which extracts high frequency energy from the stream at or near the resonant frequency of the extracting resonator. When this output resonator is tuned to the same frequency as that of the input field, the apparatus serves as an amplifier to amplify the input supplying the alternating field originally controlling the stream. However, when the extracting chamber is tuned to a harmonic of the input frequency, it serves to extract harmonically related energy, and the apparatus serves as a frequency multiplier, as described more in detail in Hansen and Varian Patent No. 2,281,935 for Modulation System, granted May 5, 1942.

The present invention is concerned with amplifier or frequency multiplier devices using output cavity resonators or other tuned circuits inductively coupled to an electron stream and having materially increased efficiency and power output. It is especially useful in devices wherein the input has very low power, resulting in alternating components of the electron stream which are of low amplitude compared with the average stream current.

According to the present invention, the electron stream after passing through the usual output resonant circuit is passed through a second output circuit closely adjacent the first output circuit, which extracts further energy from the stream. By properly coupling the two output resonant circuits in the manner taught by the present invention, a theoretical increase in output of 100 per cent is possible. In practical em-

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bodiments of the present invention, over 50 per cent increase in efficiency has been obtained.

Accordingly, it is an object of the present invention to provide improved electron discharge devices providing greatly increased efficiencies and power outputs.

It is another object of the present invention to provide improved electron beam devices having a pair of independent energy-extracting circuits coupled together to provide greatly increased output.

It is a further object of the invention to provide improved apparatus for extracting high frequency energy from a varying electron stream, whereby greater amounts of energy and greater efficiencies can be obtained.

It is still another object of the present invention to provide improved cavity resonator apparatus for extracting high frequency energy from periodically varying electron currents by the use of a pair of cavity resonators coupled to the stream at closely adjacent points, these resonators being adjusted to oscillate at the same frequency but with a relative phase shift corresponding to the average transit time of electrons of the stream between said resonators.

Other objects and advantages will become apparent from the following description and drawings, wherein:

Fig. 1 is a longitudinal cross-sectional view of one form of the present invention, the section being taken along line 1—1 of Fig. 2;

Fig. 2 is an end view of the apparatus of Fig. 1;

Fig. 3 shows a longitudinal cross-sectional view of a modification of the portion of Fig. 1 to the left of line A—A thereof; and

Fig. 4 shows a longitudinal cross-sectional view of a modification of the portion of Fig. 1 to the right of line B—B thereof.

Referring to the drawing, wherein like reference numerals are used in the several figures to designate similar elements in the respective figures, the present invention is illustrated in the form of an electron discharge device of the velocity modulation type, although the present invention is not restricted thereto. This device includes an electron velocity-modulating cavity resonator 11 having a pair of electron-permeable grids 12 and 13 at opposite walls thereof defining a narrow gap 15 through which an electron stream from a cathode arrangement 14 (which may be of any conventional type) may be projected under the influence of a suitable accelerating voltage connected between cathode 14 and the usually grounded entrance or accelerating grid

12 of resonator 11. An output or energy-extracting resonator 16 having an entrance grid 17 and an exit grid 18 defining a second gap 20 is spaced from the input resonator 11 by a tubular member 19 surrounding the path of the electron stream and providing a field-free drift space for the electrons of the stream after their passage through the gap 15.

A second output resonator 21 is provided having a common wall 22 with respect to resonator 16 and utilizing the same grid 18 as the entrance grid thereof, and having a further grid 23 as an exit grid, thereby defining a third gap 25.

In this way the gap 25 between grids 18 and 23 of resonator 21 is closely adjacent to the gap 20 between grids 17 and 18 of resonator 16. Desirably, in velocity modulation devices such as in Fig. 1, these two gaps 20 and 25 are located as closely together as is practical in order that the electron current flowing across both gaps may be in substantially the same bunched condition. The electron stream, after passage through gaps 20 and 25 is permitted to impinge on end wall 24, and is thereby collected, the energy of its electrons being dissipated in the form of heat.

Suitable high frequency energy, of the resonant frequency of input resonator 11 or differing therefrom but slightly in frequency, is supplied to input resonator 11 by way of the input coupling coaxial line 26 terminating within resonator 11 in coupling loop 27. A similar coupling line 28 and coupling loop 29 are provided for first output resonator 16, and a corresponding coupling line 31 and loop 32 are provided for second output resonator 21.

Resonators 16 and 21 are coupled together for purposes which will be described in detail below. Such coupling is effective partly as inherent coupling by virtue of the closeness of the gaps 20 and 25 and partly by a suitable phase shifter 33 of any conventional type which may be connected between the coupling lines 28 and 31 of resonators 16 and 21. Output energy is derived in Fig. 1 by a similar output coupling line 34 and coupling loop 35 coupled to resonator 21.

Apparatus is provided in the device of the present invention for independently tuning each of the three cavity resonators 11, 16, 21. For this purpose resonator 11 is provided with a flexible wall, which may be in the form of a circularly corrugated diaphragm 36. This wall 36 is effectively interposed between grids 12 and 13 to permit adjustment of the length of gap 15. Resonator 16 is provided with a similar flexible wall 37 permitting relative change of separation between grids 17 and 18 and adjustment of gap 20. Also, resonator 21 is provided with a corresponding flexible wall 38 permitting relative displacement between grids 18 and 23 to adjust gap 25.

A bearing plate member 39 is rigidly connected to grid 12 by virtue of its connection to the outer wall of resonator 11. A second plate member 41 is rigidly connected to grids 13 and 17 by its connection to the drift tube member 19 carrying these grids 13 and 17. A third plate member 42 is rigidly connected to grid 18 through its connection to the common wall 22 and outer walls of resonators 16 and 21. The collector electrode 24 is formed as part of a fourth plate member 43 fixed with respect to grid 23.

It will be understood, therefore, that a change in the spacing of plates 39 and 41 will correspondingly vary the length of gap 15, while variation of the spacing of members 41 and 42 will vary the gap 20, and variation in the spacing of members 42 and 43 will vary the gap 25. Such gap variations in these resonators cause corresponding changes in their resonant frequencies, producing tuning thereof.

For the purpose of adjusting the gap 25 and thereby tuning resonator 21, a set of tuning screws 44, shown in the present instance as three in number, are threadedly engaged in plate 43 and have rounded ends 46 bearing against bearing plate member 42. Similarly, a set of tuning screws 47 are provided threaded in plate member 42 and bearing against plate member 41. A corresponding set of tuning screws 48 are threaded in member 41 and bear against plate 39. In order to permit access to the tuning screws 47 and 48, the plate members 42 and 43 are suitably apertured in alignment with the screws 47 and 48, as shown at 49 and 50, permitting insertion of a screwdriver or other tool for changing tuning. In this way, by suitably adjusting the tuning screws 44, 47 or 48, the corresponding resonators 21, 16 and 11 may be individually tuned. Tension springs 51 are coupled between members 43 and 39 to take up any slack in the tuning system and to provide positive tuning control at all times for both directions of tuning variation. Members 41 and 42 are suitably apertured or cut away as shown at 52 and 53 to permit free passage of the spring 52 between members 39 and 43.

In operation, input resonator 11 is preferably tuned to the same frequency as that of the energy supplied thereto. In this manner the electron stream passing through the gap 15 between grids 12 and 13 is velocity modulated at this input frequency. Subsequent passage of the electrons of the stream through the field-free drift space provided by drift tube 19 serves to transform the velocity modulation of the stream into a periodic current variation having a current component of the input frequency. Preferably, the accelerating voltage applied between cathode 14 and entrance grid 12 is selected or adjusted in relation to the length of the drift tube 19 to provide substantially optimum bunching of the electrons of the stream as the electrons of the stream reach the gaps 20 and 25. Since these gaps are located closely adjoining one another, the bunching of the stream will remain substantially optimum during passage of the stream through both gaps.

The first output resonator 16 is also preferably tuned substantially to the input frequency and serves to extract high frequency energy from the stream as the stream passes through the gap 20 between the grids 17 and 18. The amount of energy thus derived from the stream is largely dependent upon the magnitude of the alternating current component of the electron stream and upon the effective alternating voltage across the gap 20 traversed by the stream. In a resonator such as 16, which is excited only by the stream, this voltage is dependent on the stream current and the effective shunt impedance of resonator 16. This shunt impedance is limited in value by the size of resonator 16 as determined by its frequency, and by the necessity of having the gap 20 relatively short to assure the passage of the electrons through the gap in a time interval of a smaller order of magnitude than one-half period of the input frequency. For this reason, the actual extraction of energy by a single resonator, such as resonator 16, produces an efficiency materially lower than the theoretical maximum limit of 58 per cent efficiency, especially where the alternating current component of the electron stream is of small amplitude.

Because of the high merit factor Q of the resonator 16, only a very small part of the energy it extracts from the electron stream is required to maintain resonator 16 in oscillation. The rest of the extracted energy passes over to resonator 21 through the inherent coupling between the two resonators 16 and 21, and through the coupling phase shifter 33. This inherent coupling necessarily exists because grid 18 cannot provide complete or perfect shielding between the two resonators while still permitting passage of the electron stream therethrough.

Especially where the alternating component of the stream current is small compared to the average current, the passage of the stream through the electric field in the gap 20 between grids 17 and 18 does not materially alter the magnitude of this alternating current component, although the electron velocities are changed somewhat. Accordingly, by passing this stream through the further output gap 25 between the grids 18 and 23 and having the second output resonator 21 tuned substantially to the input frequency, further energy can be extracted from the electron stream by resonator 21.

If resonator 21 were independent from resonator 16, it could extract only about the same amount of energy from the stream as resonator 16. However, resonator 21 is excited not only from the electron stream, as is resonator 16, but, in addition, is excited by energy from resonator 16, through their inter-coupling. Therefore, the effective high frequency voltage across gap 25 is much higher than that across gap 20 resulting in much higher energy extraction from the stream by resonator 21. The load coupled to resonator 21 is thus supplied with this enhanced energy extracted from the stream at gap 25, and also with energy extracted from the stream at gap 20 and transferred from resonator 16 to resonator 21.

As is well known, for optimum extraction of energy from an electron stream, the electric field acting on the electron stream should have its maximum retarding effect at the same instant that the electron stream has its maximum instantaneous current value. When an output resonator, such as 16, is exactly tuned to the frequency of the electron stream current and is not externally excited, this phase relationship is automatically maintained. However, if resonator 21 is also accurately tuned to the stream current frequency and is assumed to be not externally excited, the oscillations of the field in resonator 21 will be phase-shifted with respect to oscillations in resonator 16, since a finite time interval is required for the electron bunches or current peaks to travel from gap 20 to gap 25. This time interval is an appreciable part of one cycle; for example, at a wavelength of 10 cm. corresponding to a frequency of 3000 megacycles per second, an electron stream accelerated by 625 volts will travel only 0.5 cm. during one cycle. Even with a spacing of 0.1 cm. between gaps 20 and 25, this will produce a transit angle of 72 electrical degrees, which is a substantial phase shift.

Because of this phase shift, the addition of energy to resonator 21 from resonator 16 will ordinarily not result in purely arithmetic addition, but a vector resultant field will be produced in resonator 21 which no longer has the optimum phase relation with respect to the electron current variations, and the output is seriously reduced. For this reason, the phase shifter 33 is used. The phase shifter 33 is adjusted or selected to phase delay the energy traveling from resonator 16 to resonator 21 by the same phase shift as is produced by the transit time of the electron bunches between the two output resonators, or differing therefrom by a whole number of full cycles. In this way, the energy added to resonator 21 from resonator 16 will be in phase coincidence with that extracted by resonator 21 from the stream, resulting in maximum alternating voltage across gap 25 and greatly increasing the effectiveness of resonator 21 in extracting energy from the stream.

In this way, with both output resonators tuned to the stream current frequency, the proper phase relations are maintained for both resonators to remain at optimum operation, and markedly increased outputs and efficiencies are obtained.

For effectiveness of energy transfer between resonators 16 and 21, it is desirable that their coupling be quite tight. For this reason the inherent coupling through grid 18 is not in any way harmful, as it would be in other types of tubes, such as oscillator-buffers, but is actually desirable. Usually, however, the inherent coupling is not tight enough. Accordingly, phase shifter 33 is designed to provide tight coupling while retaining the necessary phase delay discussed above. For this reason, phase shifter 33 is provided with as little attenuation as possible. A preferred form of such phase shifter is merely an adjustable length coaxial transmission line, such as is well-known in the art.

The desired condition of optimum operation can be attained in another manner. As is known in the art, the phase of oscillation of a tuned circuit with respect to its driving voltage can be varied (within limits) by detuning the circuit slightly from a condition of true resonance. Accordingly, in Fig. 1 the relative tuning of resonators 16 and 21 can be adjusted by the tuning means described above so as to provide the required phase difference between their respective fields. This requires that one resonator be tuned above the frequency of the electron stream, while the other is tuned below by a corresponding amount. In this type of operation the phase shifter 33 is unnecessary and is omitted.

By either of these two modes of operation, both resonators 16 and 21 may operate at substantially optimum condition for extracting high frequency energy from the electron stream. The combined output, which may be derived from either one of two resonators, as described above, will be substantially larger than the output possible from prior art devices of the type shown in the above-mentioned Varian patent.

The present invention is not restricted to two output resonators. Three or more such resonators may be used, suitable means, such as described above, being provided for coupling the output resonator with proper phase delay. Thus, the first output resonator is excited by the stream, and serves to partially excite the second resonator in phase coincidence with the excitation of this second output resonator produced by the stream. The second output resonator in turn partially excites the third output resonator in similar phase coincidence. Each further output resonator is excited to higher amplitude of oscillation, until the desired output level is reached. The last output resonator is then coupled to the load circuit.

The apparatus of the present invention has a special advantage when the excitation of the input resonator 11 is of low level. Under these conditions, the high frequency variations in the electron stream are of low amplitude relative to the average electron current. This varying electron current is then able to excite a first output resonator such as 16 only with low amplitude of oscillation. This low amplitude of oscillation has but little effect upon the electrons of the stream during their passage across gap 20, and accordingly the stream may then serve to excite the second output resonator 21 or further output resonators with a substantal amplitude of oscillation. The addition of energy to resonator 21 from resonator 16 markedly increases the energy extraction by resonator 21. In this way, a substantial increase in output is derived. Such conditions of small variations of stream current may occur with low input levels in high frequency amplifier devices, such as shown in Figs. 1 and 2, and also occur generally in frequency multiplier devices, which inherently produce small amplitudes of high frequency current variation in the electron stream even for substantial input levels.

Such a multiplier device is illustrated in Fig. 3 which is intended to replace the portion of Fig. 1 to the left of line A—A thereof. Thus, instead of an input resonator 11 tuned to the same frequency as the output resonator 16 and 21 in Fig. 3, there is shown an input resonator 11′ which is tuned to a sub-harmonically related frequency. Resonator 11′ is formed by a pair of concentric tubular conductors 61 and 62 fixedly joined at one end by an end plate 63. At the other end of conductor 61 is the bearing plate 39′ which carries a diaphragm 36′ concentrically arranged therein. Plate 39′ serves the same function as plate 39 of Fig. 1; that is, it is a bearing plate for the tuning screws 48 and for connection to the springs 51. The drift tube 19 is sealed to and supported within the diaphragm 36′ and carries the grid 13 as in Fig. 1. Also carried at the end of the drift tube 19 is a capacity loading plate 64 which cooperates with the plate 66 coupled at the end of tubular member 62. Grid 12, forming the gap 15 with respect to grid 13, is carried at the center of plate 66. Plates 66 and 64 provide an effective lumped capacitance for the resonator 11′ which permits its physical size to be reduced while retaining its resonance at the sub-harmonic frequency. A cylindrical capacity-loading member 67 is fixed at the outer periphery of or may be integral with plate 66, and in association with the inner wall of tubular member 61 provides further capacity loading for the resonator to permit further reduction in physical size.

The cathode structure 14 is suitably supported on members 68 adjacent entrance grid 12, as in Fig. 1. A similar input coaxial line terminal 26′ and coupling loop 27′ are utilized for exciting the low frequency input resonator 11′. Tuning of resonator 11′ is effected in the same manner as for resonator 11, by varying the gap 15, as permitted by diaphragm 36′.

In operation, resonator 11′ is excited at or near its resonant frequency and produces a corresponding velocity modulation of the electron stream passing through the gap 15. Subsequent passage of the electron stream through the drift space provided by drift tube 19 produces bunching of the electrons so that at the time of their arrival at gap 21, the electron current will have impressed thereon periodic variations at frequencies harmonically related to the frequency input of resonator 11′. The resonators 16 and 21 are tuned to a desired harmonic of this input frequency. The operation of resonators 16 and 21 is then exactly the same as described above with respect to Fig. 1, and either by proper choice of phase shift between these resonators or proper choice of deturning thereof, will produce the greatly increased ouput of the present invention.

Fig. 4 shows a further modification of the invention intended to replace the portion of Fig. 1 to the right of line B—B. The apparatus of Fig. 4 may also be used with the device of Fig. 1 modified as described with respect to Fig. 3. In the form of apparatus shown in Fig. 4, the external phase shifter 33 is no longer used. Instead an internal coupling loop 71 is provided for tightly coupling resonators 16 and 21. By the proper choice of the size of the coupling loop, that is, of its encompassed area within each of the two resonators, the coupling thus produced between resonators 16 and 21 may be selected to have the desired tightness, producing optimum operation. The proper phase shift between the two output resonators may be obtained by relative detuning, as in Fig. 1. However, since the output is here derived from resonator 16 by way of output concentric terminal 34, energy flows from resonator 21 to resonator 16, instead of in the reverse sense as in Fig. 1. Therefore, the relative detuning must be in opposite sense, to phase advance the energy flowing from resonator 21 to resonator 16, to be in phase coincidence within resonator 16.

It is to be understood that, in Fig. 1 also (and in Fig. 1 modified as in Fig. 3), output energy may be derived from resonator 16 instead of 21. In such case, phase shifter 33 must provide a phase advance of the same amount as the transit time phase delay, instead of a phase delay as in Fig. 1 as shown.

Accordingly, by the present invention, there is provided improved high frequency apparatus from which, especially for low level input values, greatly increased efficiencies and output amplitudes may be derived.

As 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. High frequency apparatus comprising means for producing an electron stream and providing a path therefor, an input cavity resonator having an electron-permeable gap along the path of said stream for velocity modulating the electrons thereof, a drift tube surrounding said stream path beyond said input resonator for causing said modulated electrons to become velocity grouped, a first output cavity resonator having an electron-permeable gap along the path of said stream beyond said drift tube, a second output resonator having an electron-permeable gap along said stream path closely adjacent to said first output resonator gap to provide close inherent coupling therebetween, the distance between the gap of said first output resonator and the gap of said second output resonator being less than one-fourth the length of said drift tube, means further coupling said two output resona-

tors together, and means coupled to one of said output resonators for extracting high frequency energy therefrom.

2. High frequency apparatus as in claim 1, wherein said two output resonators are tuned substantially to the frequency of a component of said grouped electron current and said coupling means is adjusted to maintain a phase difference between the fields of said two output resonators corresponding to the average electron transit time between the gaps of said two output resonators.

3. Apparatus as in claim 1, wherein one of said output resonators is tuned slightly below resonance with respect to high frequency current variations in said stream and the other of said output resonators is tuned to a frequency slightly higher than said electron current frequency, to maintain a phase difference between the fields of said two output resonators.

4. Apparatus as in claim 1, wherein said input resonator is tuned to a predetermined frequency and wherein said output resonators are tuned respectively above and below said predetermined frequency.

5. Apparatus as in claim 1, wherein said input resonator is tuned to a predetermined frequency and wherein said output resonators are tuned respectively slightly above and below a harmonic of said predetermined frequency.

6. High frequency apparatus comprising means for producing an electron stream and providing a path therefor, an input cavity resonator having an electron-permeable gap along the path of said stream for velocity modulating the electrons thereof, a drift tube surrounding said stream path beyond said input resonator for causing said modulated electrons to become velocity grouped, a first output cavity resonator having an electron-permeable gap along the path of said stream beyond said drift tube, a second output resonator having an electron-permeable gap along said stream path adjacent to said first output resonator, the electron-permeable gaps of said first and second output resonators being located along said drift tube in the region in which said electrons attain substantially maximum velocity grouping, means further coupling said two output resonators together, and means coupled to one of said output resonators for extracting high frequency energy therefrom.

7. High frequency apparatus comprising means for producing an electron stream and providing a path therefor, means along the path of said stream for velocity modulating the electrons of said stream and causing said velocity modulated electrons to become density modulated at a predetermined high frequency, a pair of coupled tuned circuits positioned along said stream path in energy-exchanging relationship thereto, said tuned circuits being located along said path at the position at which said electrons reach substantially maximum density modulation, one of said tuned circuits being tuned slightly above said predetermined frequency and the other being tuned slightly below said predetermined frequency, and means coupled to one of said circuits for obtaining output energy from said apparatus.

8. Apparatus as in claim 7, wherein said coupled tuned circuits comprise a pair of cavity resonators having a common wall and a coupling loop extending through said wall and within each of said resonators for intercoupling the same.

9. High frequency apparatus comprising

means for producing an electron stream and providing a path therefor, means along said path responsive to an input electromagnetic wave for producing periodic current variations of said stream having a component of a predetermined frequency, a pair of tuned circuits positioned along said stream path in inductive energy-exchanging relationship thereto and tuned substantially to said frequency, said pair of tuned circuits being located along said path at the position at which said periodic current variations reach substantially maximum amplitude, and phase-shifting means coupling said two circuits for producing a phase difference between the oscillations of said two circuits corresponding to the average electron transit time between said circuits.

10. Appartus as in claim 9, wherein said predetermined frequency is harmonically related to that of said input wave.

11. The method of producing high frequency energy comprising the steps of producing an electron stream along a predetermined path, producing periodic current variations of said stream at a predetermined high frequency, exciting a first cavity resonator by said variable-current stream at a given point of said path, exciting a second cavity resonator by both a phase-shifted version of said first extracted energy and by said variable-current stream at a point of said path closely adjacent said first resonator excitation point, and supplying energy from said two resonators to a utilization device.

12. Apparatus for producing high frequency energy comprising means for producing an electron stream flowing along a predetermined path, means for causing said electron stream to become density modulated, and means for extracting high frequency energy from said stream, said last-named means comprising a pair of closely spaced cavity resonators having a pair of adjoining electron-permeable gaps, each gap being defined by a pair of electron-permeable electrodes located along the path of said stream and one electrode of one gap being common with one electrode of the other gap, the two gaps being located at the position at which said electron stream reaches substantially maximum density modulation.

13. Apparatus for producing high frequency energy comprising means for producing an electron stream flowing along a predetermined path, means for producing a high frequency current component in said stream, three closely spaced electron-permeable electrodes mounted successively along the path of said stream to produce a pair of adjoining gaps between successive pairs of said electrodes, and a pair of resonant circuits each coupled between the center of said electrodes and one of the outer ones of said electrodes.

14. The method of producing high frequency energy comprising the steps of producing an electron stream flowing along a predetermined path, periodically velocity-modulating the electrons of said stream by a high frequency wave, producing periodic density variations in said stream from said velocity-modulated electrons, extracting energy at a harmonic of the frequency of said high frequency wave from said stream at a first location along said stream, extracting further energy at said harmonic of the frequency of said high frequency wave from said stream at a second location along said stream, said first and second locations being closely adjacent and located in

the region in which said electrons attain substantially maximum density modulation, combining said first extracted energy with said further extracted energy, and conveying said combined energy to a utilization device.

15. The method of producing high frequency energy comprising the steps of producing an electron stream flowing along a predetermined path, periodically velocity-modulating the electrons of said stream by a high frequency electromagnetic wave, producing periodic density variations in said stream from said velocity-modulated electrons, extracting energy at a harmonic of the frequency of said high frequency wave from said stream at a first location along said stream, extracting further energy at said harmonic of the frequency of said high frequency wave from said stream at a second location along said stream, said first and second locations being closely adjacent and located in the region in which said

electrons attain substantially maximum density modulation, coupling said first extracted energy to said further extracted energy in in-phase relation, and conveying the combined extracted energy to a utilization device.

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