

Oct. 26, 1948.

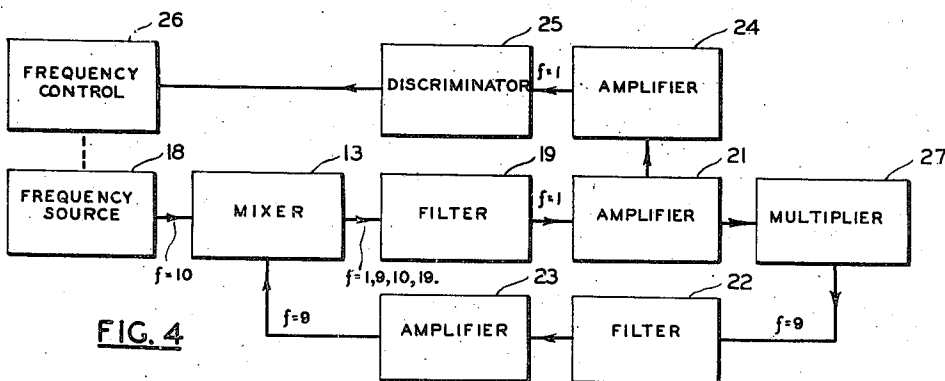
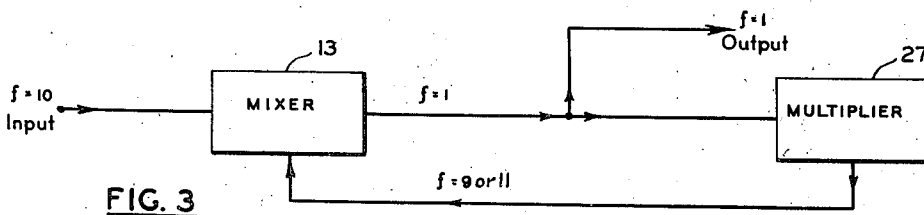
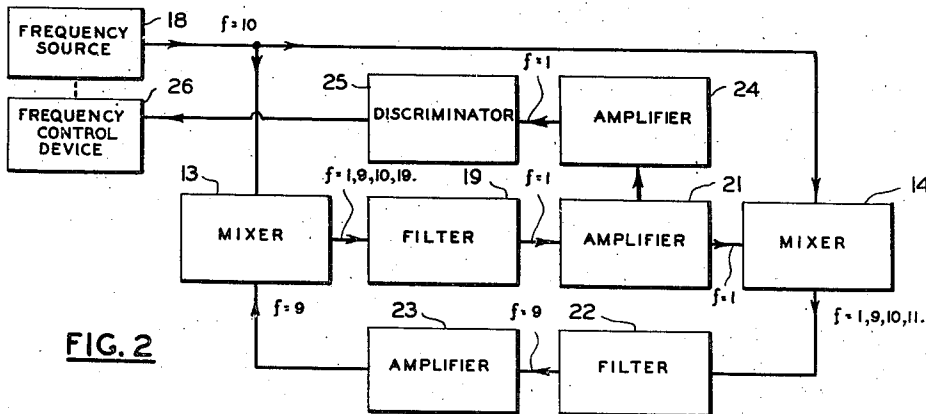
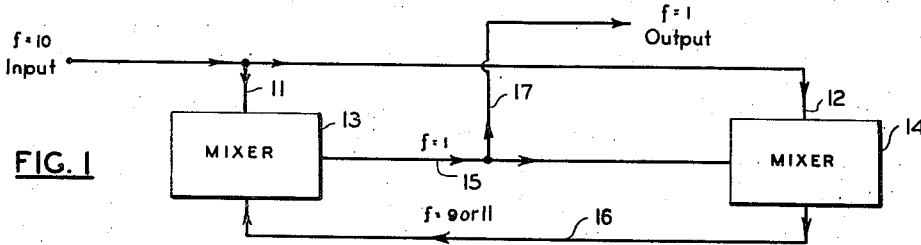
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2,452,048

FREQUENCY CONVERSION APPARATUS

Filed July 12, 1943

2 Sheets-Sheet 1



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FREQUENCY CONVERSION APPARATUS

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2 Sheets-Sheet 2

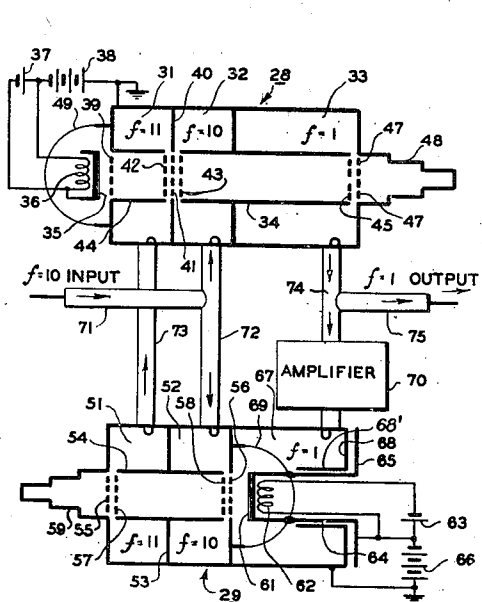


FIG. 5

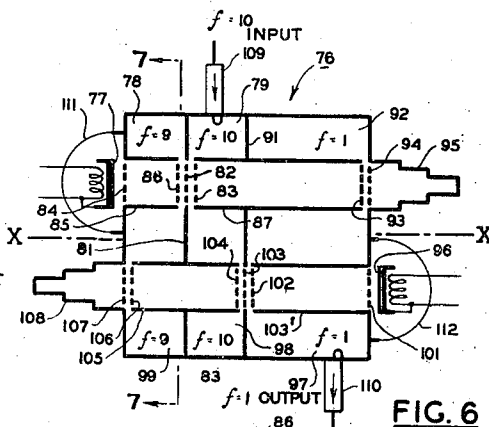


FIG. 6

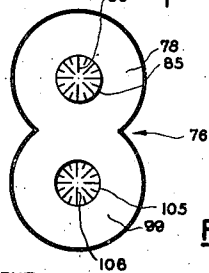


FIG. 7

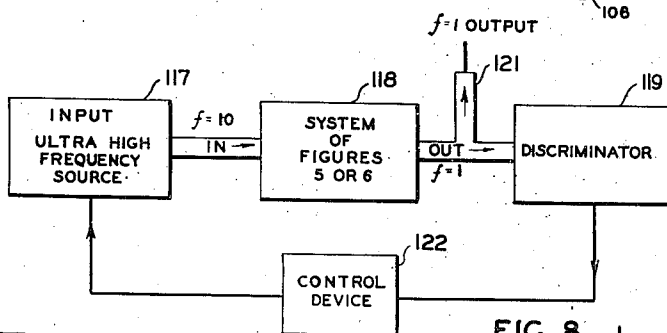


FIG. 8

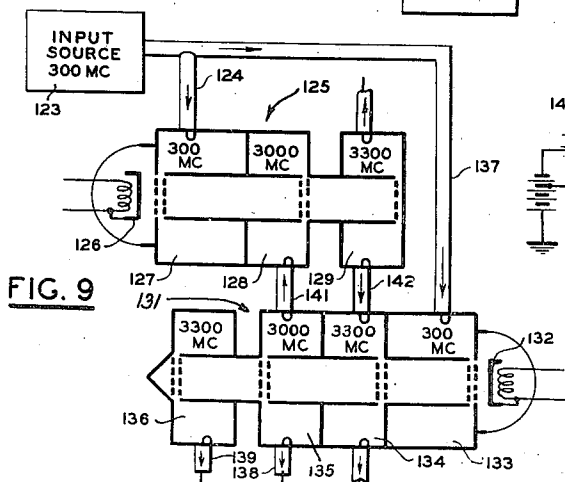


FIG. 9

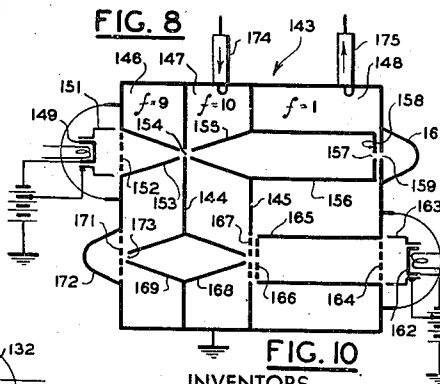


FIG. 10

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FREQUENCY CONVERSION APPARATUS

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Application July 12, 1943, Serial No. 494,284

25 Claims. (Cl. 250—36)

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The present invention relates to electronics and is especially concerned with frequency conversion methods and apparatus.

While various frequency multiplication arrangements have been suggested and employed for some electron discharge apparatus, no reliable frequency division devices are available for microwave apparatus to our knowledge. In the ultra high frequency field, wherein frequencies in the order of 3×10^8 to 3×10^9 cycles per second and higher are present, there is a growing need for such frequency division devices, and the present invention solves many of the attendant problems. As will appear, the invention is especially advantageous where stabilization of ultra high frequency output is difficult, and its principles are also applicable for frequency multiplication.

It is a major object of our invention to provide novel ultra high frequency division and multiplication methods and apparatus.

A further object of the invention is to provide frequency conversion apparatus embodying novel frequency mixing and feed-back arrangements.

It is a further object of the invention to provide novel frequency division apparatus embodying frequency multiplier and associated mixing arrangements.

A further object of the invention is to provide novel automatic frequency control arrangements embodying frequency division and multiplication methods and apparatus. In an important phase, this object is especially applicable to automatic frequency control of ultra-high frequency cavity resonator devices.

A further object of the invention is to provide novel ultra high frequency conversion apparatus of the cavity resonator type.

A further object of the invention is to provide novel ultra-high frequency cavity resonator structure.

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

Fig. 1 is a diagrammatic view illustrating certain basic principles of the invention;

Fig. 2 is a diagrammatic view illustrating practical application of the principles of Fig. 1 to an automatic frequency control system;

Fig. 3 is a diagrammatic view illustrating basic principles of a further embodiment of the invention employing a multiplier system;

Fig. 4 is a diagrammatic view illustrating practical application of the principles of Fig. 3 to an automatic frequency control system;

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Fig. 5 is a diagrammatic view illustrating principles of the invention of Figs. 3 and 4 as embodied in ultra-high frequency apparatus of the cavity resonator type having mixer-multiplier arrangements and adapted for automatic frequency control;

Fig. 6 is a diagrammatic view illustrating a variation of the apparatus of Fig. 5, employing different cavity resonator arrangements;

Fig. 7 is a section along line 7—7 of Fig. 6;

Fig. 8 is a diagrammatic illustration of an automatic frequency control embodying the systems of Figs. 5 and 6;

Fig. 9 is a diagrammatic view of ultra-high frequency multiplier apparatus embodied in a form of the invention; and

Figure 10 is a diagrammatic view of an embodiment of the invention similar to that of Figure 6 having special electron beam control arrangements.

According to the one phase of the invention, division of a relatively high source frequency to obtain a desired lower frequency is obtained by correlated frequency mixing and feedback arrangements to be hereinafter described in detail.

Referring now to Fig. 1, alternating voltage energy from any suitable ultra high frequency source is introduced by lines 11 and 12 into the mixer devices 13 and 14. The output of mixer 13 is introduced by line 15 into mixer 14, and the output of mixer 14 is fed back to mixer 13 by line 16.

Mixers 13 and 14 each may comprise any suitable device capable of associating two alternating voltages and delivering an output containing sum and difference frequencies.

Assume for purposes of explanation, that the high input frequency be designated as having an arbitrary value of ten, representing, for example, an absolute frequency of 3000 megacycles per second, and it is desired to obtain, for some purpose, a lower output frequency of one-tenth that value, or of the value one in our arbitrary scale. Hereinafter, whenever the frequency value ten is mentioned, such will be understood to represent a frequency in the neighborhood of 3×10^9 megacycles per second, and smaller frequency values will be proportional. We therefore introduce into mixer 13 on line 16 a voltage having a frequency of nine-tenths the value of the input frequency, or of the value nine. Disregarding other frequencies, including the side-band sum frequency of value eleven, the output of mixer 13 in line 15 will contain a side-band difference frequency of value

one, which may be extracted for use on line 17 as shown.

The comparison frequency on lead 16 is obtained by mixing in mixer 14 the input voltage having a frequency value of ten and the output of mixer 13 containing the side-band frequency of value one. This provides that, disregarding other frequencies, the output of mixer 14 will contain a side-band difference frequency of value nine, which is fed back into mixer 13 as illustrated.

The above explains one of the basic principles of this phase of the invention. By utilizing proper filters for eliminating undesired side-bands and other frequencies and realizing the below-mentioned conditions, accurate frequency division may be obtained.

The above selected frequency values, of course, satisfy the conditions required to maintain an integral 10 to 1 ratio in frequency. It might appear, however, that the apparatus may just as likely become stabilized to maintain any non-integral frequency division ratio which is within the range of the filters used in the system. For example, should the output of mixer 13 contain a frequency of value 1.1 instead of one, the output of mixer 14 will contain a frequency of value 8.9 instead of nine, and the mixing of the input frequency ten and comparison frequency 8.9 would tend to maintain stabilization with the output on lead 17 having a difference frequency of value 1.1. The frequency ratio 10 to 1.1 would then be non-integral and undesired.

This undesirable operation is, however, prevented by the non-linear characteristics of mixers 13 and 14, the outputs of which contain harmonics of the input frequencies, as well as the above-mentioned sum and difference frequencies and their harmonics. Should one of these harmonics of the input frequencies approximately coincide with a harmonic of the sum or difference side-band frequency, it will tend to pull the mixer into step with the harmonic frequency in the same way that an oscillator is pulled into step with a coercing frequency, so that the mixer output effectively contains only such side-bands as are related to the input frequencies by simple fractional relationships. Such a relation is herein termed a "rational" relation, which term also includes an intergral-multiple relation.

Fig. 2 illustrates this phase of the invention as embodied in an automatic frequency control system for controlling the input frequency source. Input frequency source 18 delivers a voltage of frequency value ten to mixers 13 and 14 which are the same as in Fig. 1. As indicated, a voltage having a frequency value nine is also fed into mixer 13. The output of mixer 13 therefore contains fundamental frequencies of values nine and ten, as well as rationally related sum and difference frequency side-bands of frequency values one and nineteen.

The output of mixer 13 is introduced into a suitable filter 19 which is designed to pass only the components having the frequency value one to amplifier 21 and reject the other frequencies. The output of amplifier 21 is introduced into mixer 14 where it is mixed with the original input frequency, and the output of mixer 14 contains fundamental frequencies one and ten, as well as rationally related sum and difference frequencies nine and eleven. A filter 22 filters out the components of all frequencies, except the difference frequency of value nine, from the output of mixer 14, and the latter frequency is amplified

at 23 for introduction into mixer 13. The system is thereby stabilized, voltages of lower frequencies of integral values one and nine being available for any desired purpose at amplifiers 21 and 23, respectively.

Assume, as exemplary of a use of the invention, that it is desired to utilize the lower frequency voltage available at amplifier 21 for automatically maintaining the input source frequency at a desired level. To this end, we extract a voltage of frequency value one from amplifier 21, further amplify it at 24 and feed it into the discriminator indicated at 25. This discriminator may be of any suitable type which is sensitive to changes in frequency of the voltage from amplifier 21, and which delivers a unidirectional output polarized according to the direction of departure of that frequency from the frequency value one.

The output of discriminator 25 is introduced into a frequency control device indicated at 26. This device 26 is cooperatively connected to vary the frequency of source 18, either mechanically or electrically, as indicated by the dotted line. Usually control device 26 is made integral with or a part of the source 18.

Both filters 19 and 22 are, for this embodiment of the invention, designed to pass frequencies within a normal control range including the above-mentioned frequency values, for reasons which will appear in further description of the operation.

In operation, were source 18 and the mixer components perfectly noise-free, there probably would be no output from either mixer and the apparatus would never automatically start into operation. However, this condition can never be realized, and the system always contains inherent disturbances which enable its operation to build up, since the system is a feed-back system and has sufficient gain to make it unstable. For example, such disturbances may be due to irregularities in the source voltage, thermal agitations in electronic discharge tubes, or the like. These disturbances are magnified by the regenerative circuit through filter 22 and amplifier 23 until a condition exists when the output of mixer 13 contains a frequency value of approximately one, as determined by the filters, or the output of mixer 14 contains a frequency value of approximately nine.

As the device approaches full oscillation, harmonics of the input frequencies appear in the output of mixer 14 and the output of the device locks into step with one of these harmonics as explained.

Thus, the system is started in operation simply by connecting source 18 to energize the mixers. An initial unstable condition prevails until the required frequency values appear in the mixer outputs, and then the system becomes a stable regenerative system producing the required integral frequency division.

The discriminator and frequency control circuits do not become effective until a voltage of the desired frequency is obtained from amplifier 21; that is, until the regenerative control system becomes substantially stable. Then, once stability of the control circuit is attained, any departure of source 18 from its desired frequency value ten will result in discriminator 25 exercising control to compensate for the departure and restore the desired frequency.

For example, should the output frequency of source 18 drop by one per cent, the output of

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amplifier 21 will now have a frequency value of only nine-tenths its former value one. The frequency sensitive discriminator is unbalanced and produces the necessary control signal for actuating device 26 to retune source 18, and restore it to the desired frequency ten. As soon as the desired source frequency has been restored, the control action obviously ceases.

United States Letters Patent No. 2,294,942 illustrates frequency discriminator and automatic frequency control arrangements with which the invention may be employed. Thus, discriminator 25 may include a source of reference frequency with which the output of amplifier 21 is compared, and the frequency control device responsive to the output of discriminator 25 may comprise a control electrode associated with the source, and/or motor-driven tuning mechanism such as illustrated in said patent.

It is to be further understood, moreover, that the invention is not limited to automatic frequency control, but is of broader scope and use as indicated above and in the appended claims.

Figs. 3 and 4 illustrate a further embodiment of the invention, Fig. 3 illustrating the principle thereof and Fig. 4 illustrating its use in an automatic frequency control similar to Fig. 2.

Referring to Fig. 3, the source frequency of value ten is mixed with the frequency of value nine in mixer 13 which is the same as in Figure 1. The output of mixer 13 contains a difference side-band frequency of value one that is fed into a frequency multiplier 27 which may be of any suitable type such as that disclosed in United States Letters Patent to Hansen et al. No. 2,281,935. For use of this phase of the invention with lower frequencies, any conventional frequency multiplier may be employed.

Frequency multiplier 27 is of such design that its output contains the harmonic frequency of value nine which is fed back to mixer 13, as in Fig. 1, for completing the regenerative circuit.

Referring to Fig. 4, the output of mixer 13 containing fundamental frequencies of value nine and ten, and sum and difference frequencies of value one and nineteen, is fed into filter 19 as in Fig. 2. The output of filter 19, which passes only frequencies within a normal control range near the frequency value one, is amplified in amplifier 21 and fed into multiplier 27.

The output of multiplier 27 contains the harmonic frequency of value nine, and several other harmonics of the introduced frequency of value one. These harmonics are eliminated by filter 22 which passes only frequencies within a normal control range near frequency value nine. The output of filter 22 is amplified at 23 and fed back into mixer 13 similarly to Fig. 2. Also, as in Fig. 2, this phase of the invention is illustrated as employed in an automatic frequency control system.

Aside from the fact that the system of Figure 4 employs a multiplier instead of mixer 14 of Figure 2, its operation and uses are essentially the same as above described in connection with Figure 2 except that it may be necessary to employ some external arrangement, such as shock excitation, for starting the system of Figure 4 into operation.

As indicated in Figures 1 and 3, and in the following embodiments, frequencies of value nine or eleven, as desired, may be mixed with the frequency of value ten to obtain the required frequency of value one.

Fig. 5 illustrates an embodiment of the inven-

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tion adapting principles of Figs. 3 and 4 to control of ultra-high frequencies in the order of 3×10^8 to 3×10^9 cycles per second, or higher. Here the frequency division system comprises a pair of suitably interconnected cavity resonator devices 28 and 29, one of which is a mixer and the other a mixer-multiplier device, which facilitates automatic starting of operation of the system.

One device 28 is a mixer and comprises a pair of hollow metal-walled cylindrical resonator chambers 31 and 32 connected to a third hollow-metal-walled cylindrical resonator chamber 33 as by cylindrical drift tube 34. A cathode 35, heated by filament 36 energized from battery 37, is designed to provide a beam of electrons to be projected axially through the cylindrical resonators and drift tube. The driving voltage for the electron beam is provided by a large battery 38 in series with filament battery 37. A smoothing or accelerator grid 39 is provided in the path of electron beam.

Resonator chambers 31 and 32 are separated by a common wall 40 having a central grid area 41 aligned with corresponding grid areas 42 on a reentrant portion 44 of resonator chamber 31 and grid area 43 on the end of tube 34 projecting within chamber 32. The essential feature of this arrangement, which is an important part of the invention, is that the electron beam is substantially simultaneously subjected to velocity modulation at two different frequencies. The exact nature or construction of the resonators or the like producing the adjacent field portions acting on the beam is not material. The other end of tube 34 projects within chamber 33, terminating in a central grid area 45.

A grid area 47 in the further end wall of chamber 33 is provided for permitting the electron beam to pass into a hollow cup-shaped collector electrode 48 comprising a series of stepped cylindrical sections decreasing in diameter remote from grid 47. This shape of electrode 48 is advantageous for preventing return of secondary emission into chamber 33, and for good heat dissipation of the received beam energy.

The resonator walls electrode 48 and a closure 49 for the cathode comprise an evacuated envelope. Collector electrode 48 may be integral with the walls of resonator 33, or may be a separate element sealed thereto.

The other cavity resonator device 29 is a mixer-multiplier and comprises a pair of hollow cylindrical metal-walled resonator chambers 51 and 52 separated by a common wall 53 apertured for mounting a drift tube 54 aligned with grid areas 55 and 56 on the opposite chamber walls. Grids 57 and 58, respectively, are provided on the drift tube ends opposite grids 55 and 56. A stepped cylindrical collector electrode 59, which may be integral with the walls of resonator 51 as illustrated, and which is preferably similar to electrode 48, is axially positioned to receive the electron beam from a suitable cathode surface 61.

Cathode 61 is heated by filament 62 energized from battery 63 and is carried by a cylindrical tube 64 having an annular outer flange 65. Battery 66 provides the driving voltage for cathode 61. Tube 64 projects through a cylindrical resonator chamber 67 formed by extensions of the other chamber walls and an annular end wall 68 parallel to flange 65. Cathode 61 is disposed well within chamber 67, being insulated therefrom by a vacuum tight insulating closure indicated at 69. Resonator 67 is not vacuum tight. Flange 65 and wall 68 are coextensive, thereby

providing a capacitative high frequency by-pass coupling between cathode 61 and resonator 67. Alternatively this capacitative connection may be provided between tube 64 and a concentric inward extension 68' of wall 68 employed with flange 65 as illustrated, or with flange 65 omitted, or in some equivalent manner. Physically, tube 64 and cathode 61 are supported by closure 69 which is sealed to tube 64 and resonator 52 as indicated. This arrangement also provides for convenient extraction of energy from chamber 67, if desired, without disturbing the evacuated condition of velocity modulation resonators 51 and 52.

Device 28 corresponds to mixer 13 of Fig. 3, while device 29 corresponds substantially to multiplier 27 of Fig. 3.

Ultra high frequency energy having a frequency value ten is introduced from source 71 into concentric line 72 by which chambers 32 and 52 are excited. Chambers 31 and 51, which are designed to resonate at frequency value eleven are inter-connected by coaxial line 73. Finally, chamber 33 is connected to chamber 67 as by a coaxial line 74 having a convenient output terminal 75. A suitable amplifier 70, preferably of the velocity modulation type, is employed in line 74.

Operation

Assuming both resonators 31 and 32 to be excited at their respective resonant frequencies eleven (or nine) and ten, the electrons in the beam passing therethrough are subjected to successive, adjacent substantially simultaneous velocity modulation by the resonator fields. The theory of velocity modulation of an electron beam by an oscillatory field is explained in Varian Patent No. 2,242,275. The resultant electron bunching which takes place along tube 34 is characteristic therefore of both resonator frequencies so that the amplitude of the bunches varies in accordance with the beat frequency between the two modulating frequencies. Resonator 33 is of such design as to be excited by the beam at a low frequency corresponding to that beat frequency, and to be unaffected by the other frequencies present. In this case, the resonant frequency of resonator 33 is of frequency value one.

Energy is extracted from the bunched electron beam by the oscillatory field of resonator 33 (for the general theory of such energy extraction see said Varian Patent No. 2,242,275) thus exciting resonator 33 at its resonant frequency of value one. Excitation of resonator 33 at frequency value one is made possible by the inherent debunching action which takes place in an electron-grouped beam and which is usually considered objectionable in cavity resonator devices. During travel of the electron-grouped beam along the drift passage, debunching of the electrons radially of the beam occurs due, for example, to mutual repulsion of the many negatively charged electrons in the groups. As a result of this debunching, considerable electrons from the debunched groups are collected by the drift passage walls, on which opposite charges are induced, so that the current densities of the electron groups are reduced. The electrons between the bunches, being of lower density, are not so collected.

This mixer action, which is similar to rectifier detector action, produces an available low frequency component of value one in the beam entering resonator 33, which low frequency would

not have been available without the mixing action effected by debunching. Coaxial line 74 in turn extracts some of this low frequency energy from resonator 33 and introduces some of it, after amplification by amplifier 70 (if needed), into chamber 67 which is resonant thereto.

The low frequency voltage of frequency value one introduced into chamber 67 modulates the electron beam current emitted by cathode 61, thereby producing electron grouping of the beam at frequency value one. The modulated beam enters resonator 52 which is excited to resonate at frequency ten by energy from line 72 as indicated. The resultant field within chamber 52 produces velocity modulation at frequency value ten of the already density modulated beam, and the result is that while passing along drift tube 54, the beam possesses electron grouping which is characteristic of both frequencies of value ten and one. Therefore, the beam current has a beat, or sideband frequency of value eleven (or nine) formed by these respective frequencies, and resonator 51, which is designed to resonate at that frequency value eleven, (or nine), is excited thereby.

Device 29 functions similarly to multiplier 27 in Figs. 3 and 4, and in addition functions as a mixer. It is not necessary to rely upon debunching for the mixing action in the operation of device 29 because the therein described manner of bunching is essentially a mixing or modulating action which renders the beat frequency of value eleven (or nine) available.

Resonator 51 of device 29 thus provides a source for exciting resonator 31 at the required frequency value eleven (or nine).

If desired device 29 may be simply a frequency multiplier, by eliminating resonator 52 or by disconnecting line 72 therefrom. Frequency value eleven, which is a harmonic of frequency value one, can be excited in resonator 51 according to known hollow resonator multiplier operation.

Both mixing and multiplication are desirable to provide improved operation of the device 29. In ordinary mixer action, the mixer output is very weak in higher harmonics, especially above the third and fourth. Special means, therefore, must be provided to obtain tenth and eleventh harmonics as are required for the above operation. This production of the higher harmonics has been provided by the special design of device 29, so that device 29 efficiently functions as both a mixer and a generator of the required relatively high harmonics. This novel construction and design of the device 29 is an important part of the invention.

Once the system of Figure 5 is set in operation, as through beam irregularities and the thermal or like disturbances above described, the system stabilizes itself, so that a reliable low frequency output may be continuously extracted as by concentric line 75. This output may be employed for any suitable purpose, such as for automatically regulating the input frequency source 18 as in Fig. 4 and as will be explained with regard to Fig. 8.

It will be observed that in the preferred embodiment of the invention the mixers operate with rationally related frequencies. This is preselected so that the frequency multiplication effects produced in substantially all cavity resonator devices helps the system to lock in at the desired operating frequencies.

If the input source coupled through transmis-

sion line 71 to line 72 is a crystal-stabilized oscillator of the usual low power type, device 29 can then be used as a stabilized high power source for any of the frequency values one, ten and eleven (or nine) to be extracted by suitable transmission lines, the whole system acting as a stabilized self-oscillator.

In Figs. 6 and 7 is illustrated a single duplex cavity resonator device 76 which has a central axis X—X. A cathode 77 projects an electron beam through cylindrical resonator chambers 78 and 79 which are separated by a common wall 81 formed with an apertured grid section 82. A smoother or accelerator grid 84 is provided in the wall of resonator 78 near cathode 77.

A hollow reentrant pole 85 extends from grid 84 into resonator 78 and is formed at its free end with a grid 86 near grid 82. Similarly, a hollow drift tube 87 extends from adjacent grid 82 through resonator 79 and common wall 91 into the interior of a third resonator chamber 92, terminating in a grid 93 adjacent a cooperating grid 94 in the resonator far wall. A grid 93 is formed in the end of tube 87 adjacent grid 82. A collector electrode 95 is mounted beyond grid 94. Grids 84, 86, 82, 83, 93 and 94, and collector 94 are aligned on the axis of the electron beam from cathode 77.

At the other side of axis X—X, the resonator construction is substantially reversed. A cathode 96 projects an electron beam through resonator chambers 97, 98 and 99, parallel to the beam from cathode 77, but in the opposite direction.

A smoother or accelerator grid 101 in the wall of resonator 97 near cathode 96 is aligned with a grid 102 on the end of a hollow pole 103 extending into resonator 97 from that wall. A grid 103 is formed in wall 91 opposite grid 102. A drift tube 105 extends from adjacent grid 103 through wall 81 into resonator 99, terminating in a grid 106 adjacent an associated grid 107 in the resonator wall. A grid 104 is formed on the drift tube end near grid 103. A stepped collector electrode 108 is secured to the resonator beyond grid 107. The opposite ends of drift tube 105 are in effect reentrant poles within the respective resonators 98 and 99. The structure of each resonator 78, 99 and 79, 98 is novel in that the spaced grid bearing poles extend from opposite end walls. Grids 101, 102, 103, 104, 106 and 107 are along the axis of the electron beam from cathode 96.

Coaxial lines 109 and 110 are provided respectively for introducing ultra high frequency energy into resonator 79 and extracting ultra high frequency energy from resonator 97. Cathodes 77 and 96 are suitably energized similarly to Fig. 5, and are located in insulating closures 111 and 112 which, together with collector electrodes 95 and 108, maintain the interior of the whole cavity resonator device vacuum tight.

As illustrated in Fig. 7, resonator chambers 78 and 99 are open to each other so that they contain a substantially common oscillating electromagnetic field. Chambers 79 and 98 are similarly open to each other, as are chambers 92 and 99.

In operation, the electron beam from cathode 77 is successively velocity modulated at the indicated frequencies of value nine and ten of resonators 78 and 79, and resonator 92 is excited at the difference frequency of value one by the bunched electron stream, similarly to the operation of Fig. 5. The electron beam from cathode 96 is successively velocity modulated at frequen-

cies of value one and ten, and excites oscillation of resonator 99 at the difference frequency value nine. The device of Fig. 6 is therefore similar in operation to that of Fig. 5 except that in Fig. 6 the resonator fields are substantially the same, and different relative frequencies are indicated. The resonator structure shown in Figs. 6 and 7 is an important part of the invention.

The resonator association with the beam from cathode 77 is essential the same as in device 23, so that the upper portion of device 76 functions as a mixer for producing the required low frequency one. The lower portion of device 76 is a mixer, reversed in direction but similar in operation to the upper portion. Instead of employing common resonators as illustrated the upper and lower portions of device 76 could be made separate cavity resonator devices similar to device 28 of Figure 5, with corresponding resonator chambers connected by coaxial lines similarly to Figure 5.

Fig. 8 illustrates diagrammatically a manner in which the systems of Figs. 5 or 6 may be used for automatically controlling the frequency of an ultra high frequency source 117. The high frequency output of source 117 is fed into system 118, which may comprise either of the systems of Figs. 5 or 6, and the output lower frequency from system 118 is fed into discriminator 119. A tap 121 is provided for any desired utilization of the lower frequency output of the system.

Discriminator 119 is preferably the same as discriminator 25 in Fig. 4, and delivers a control signal sensed to actuate control device 122 at a desired value. This control, as above explained, may be accomplished by the arrangements disclosed in said Letters Patent No. 2,294,942.

Fig. 9 illustrates further application of principles of the invention to ultra-high frequency multiplier apparatus wherein relatively stabilized ultra-high frequency outputs are desired. In the specific embodiment selected for explanation of this phase of the invention, it is desired to produce from a crystal-stabilized 300 megacycle per second source 123 two ultra-high frequency outputs of 3000 and 3300 megacycles per second separated by a maintained constant frequency difference of 300 megacycles per second.

Energy from source 123 is fed by coaxial line 124 into a frequency mixer device 125 of the cavity resonator type. Device 125 embodies a cathode 126 for projecting an electron beam through spaced resonators 127, 128 and 129. Resonator 127 is excited to resonance by 300 megacycle energy from source 123, and its oscillatory electromagnetic field initiates corresponding grouping in the electron beam.

Resonator 128 is designed to be resonant at the higher harmonic frequency of 3000 megacycles and produces further velocity modulation of the beam at that frequency when suitably excited. The required frequency of 3300 megacycles is thereby made available at resonator 129, device 125 functioning as a mixer similarly to device 28 above explained.

A second cavity resonator device 131 is provided for completing a stabilized system for producing energy at the required frequencies. A beam of electrons is passed from cathode 132 through successive apertured resonators 133, 134, 135 and 136.

Resonator 133 is excited at 300 megacycles by energy on line 137 from source 123, and causes velocity modulation of the electron beam at that frequency. Resonators 134 and 135 are designed

to resonate at 3300 and 3000 megacycles, respectively. Resonator 134 is excited at its frequency by energy introduced on line 142 from resonator 129. Resonators 133 and 134 thus produce characteristic velocity modulation leading to electron grouping in the beam from cathode 132, and energy at the beat frequency 3000 megacycles is extracted from the beam at resonator 135. This operation is similar to that of device 28. Resonator 135 serves as a source of 3000 megacycle energy for exciting resonator 128 through line 141. Resonator 136 is designed to resonate at 3300 megacycles and extracts energy from the grouped beam at that frequency. Output lines 138 and 139 provide the required spaced high frequencies for desired utilization. By this arrangement, the system is maintained relatively stable in operation similarly to that of Figure 5. If desired resonators 128 and 135 could comprise a common chamber, similarly to the structure of Figure 6, and resonators 129 and 134 could likewise comprise a common chamber. Resonator 136, moreover, serves as a buffer resonator for the 3300 megacycle output, being coupled to the device only by the electron beam, although if desired the 3300 megacycle energy is available at resonators 129 or 134 as illustrated.

Figure 10 illustrates a further embodiment of the invention generally similar to that of Figure 6 but including certain electron beam control features.

A cylindrical resonator body 143 is separated by walls 144 and 145 into three spaced resonator chambers 146, 147 and 148 designed to contain alternating electromagnetic fields having resonant frequencies of value nine, ten and one respectively.

A suitably energized cathode 149 is arranged to project an electron beam, collimated by electrode 151, through the resonators. The beam passes through a smoothing grid 152, a reentrant conical pole 153 within resonator 146, aperture 154 in wall 144, an oppositely facing reentrant conical pole 155 in resonator 147, a cylindrical tube 156 in resonator 148 forming with pole 155 a drift passage, and a relatively small aperture 157 in the center of a disc 158 otherwise closing the end of tube 156. A grid 159 and collector electrode 161 are arranged in the path of the beam beyond resonator 148.

The electron beam is a relatively small diameter concentrated stream of electrons for most efficient interaction with the high frequency fields within resonators 146 and 147. As in Figure 6 the beam is velocity-modulated by the fields of resonators 146 and 147 to produce electron concentrations along the beam characteristic of both frequency values nine and ten, so that the beam contains electron concentrations corresponding to the difference frequency value one for excitation of resonator 148.

As the electron concentrations pass along the drift passage 155, 156 radial debunching takes place due to space charge effects arising from mutual repulsion of the electron charges. Due to this debunching, the beam has fewer electrons near its axis in the regions of electron concentrations than in the regions between those concentrations. The electrons in the outer annulus of each concentration of electrons are intercepted by disc 158 which passes only the electrons in the central zone of the beam. These centrally located electrons so passed are disposed in periodic electron density concentrations which are inversely related to the original concentrations, but

which are so phased as to excite resonator 148 as desired. In addition, this construction is especially adaptable for utilization of the debunching feature for obtaining the above explained mixing action producing the required beat frequency for exciting resonator 148. Control of this mixing action may be had by terminating tube 156 in any desired size of aperture ranging from the small aperture 157 to the larger grid shown at 45 in Figure 5.

For further details as to the theory of operation of the above described general arrangement wherein the outer debunched electrons in the beam are intercepted, reference is made to the copending application of Varian and Relson Serial No. 490,962, filed June 16, 1943, now Patent No. 2,414,843, dated January 28, 1947.

A second cathode 162 projects an electron beam, collimated by electrode 163, through the resonators parallel and opposite to the beam from cathode 149. This second electron beam passes through a smoothing or accelerator grid 164, a cylindrical reentrant pole 165 extending into resonator 148, a grid 166 on the end of pole 165, a grid 167 in wall 145, a conical reentrant pole 168 extending into resonator 147 from wall 144, and an opposite conical reentrant pole 169 extending into resonator 146. A grid 171 and a collector electrode 172 are also arranged in the path of the electron beam.

The electron beam from cathode 162 is also a relatively small diameter concentrated electron stream. Poles 168, 169 serve as a drift passage, and pole 169 has a relatively small exit aperture at 173 whereby pole 169 functions similarly to disc 158 in intercepting the debunched electrons in the outer annulus of the electron concentrations passing therethrough.

The device of Figure 10 operates similarly to that of Figure 6. The high frequency of value ten, to be divided, is introduced into resonator 147 by coaxial line 174, and the low frequency output of frequency value one is extracted from resonator 148 by coaxial line 175. As above explained resonator 148 is excited at frequency value one by the beam from cathode 149. The electrons in the beam from cathode 162 are velocity grouped by the fields of frequencies of value one and ten, and then the difference frequency value nine excites resonator 146 to provide a source of frequency value nine for the initial mixing operation.

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. Apparatus for automatically controlling the frequency of an ultra-high-frequency oscillator, comprising means coupled to said oscillator for producing a signal at a relatively low frequency equal to a predetermined fraction of the ultra-high frequency of said oscillator, and means coupled to said signal-producing means and responsive to variations of said low signal frequency from a predetermined value for adjusting the tuning of said ultra-high-frequency oscillator to suppress said variations from said predetermined value, said means for producing said low frequency signal comprising a first mixer and a second mixer both coupled to said oscil-

lator to receive ultra high frequency energy therefrom, frequency selective means responsive to energy of a further frequency different from said ultra high frequency by an amount equal to said relatively low frequency and coupled to said first mixer to receive therefrom energy at said further frequency and also coupled to said second mixer for delivering thereto energy at said further frequency, and additional frequency selective means responsive to said relatively low frequency coupled to said second mixer for selectively receiving therefrom energy at said relatively low frequency, said additional frequency selective means being coupled to said first mixer for delivering thereto a portion of the energy at said relatively low frequency received from said second mixer.

2. Apparatus for automatically controlling the frequency of an ultra-high-frequency oscillator, comprising means coupled to said oscillator for producing a signal at a relatively low frequency equal to a predetermined fraction of the ultra-high frequency of said oscillator, and means coupled to said signal-producing means and responsive to variations of said low signal frequency from a predetermined value for adjusting the tuning of said ultra-high-frequency oscillator to suppress said variations from said predetermined value, said means for producing a signal at a relatively low frequency equal to a predetermined fraction of said ultra high frequency comprising a mixer coupled to said oscillator to receive ultra high frequency energy therefrom, frequency selective means coupled to said mixer to receive therefrom energy at said relatively low frequency, frequency multiplier means coupled to said frequency selective means for producing an output signal at a predetermined multiple of said relatively low frequency, and means for delivering said output signal from said multiplier to said mixer whereby said frequency multiplier output energy is mixed with said ultra high frequency energy to produce mixer output energy at said relatively low frequency.

3. Apparatus for automatically controlling the frequency of a high frequency source comprising means for mixing energy from said source with energy having a rationally related frequency for obtaining a lower frequency output, means controlled by said lower frequency output for providing said energy of said rationally related frequency, means feeding back said rationally related frequency energy into said mixing means, and means coupled to said lower frequency output and responsive to frequency changes thereof for controlling the frequency of said source.

4. Electronic apparatus comprising means defining a pair of adjacent electromagnetic fields oscillating at different frequencies, means for projecting an electron beam through said fields so that the electrons in said beam are subjected to velocity modulation by the respective fields, a third electromagnetic field coupled with said modulated beam for extracting energy therefrom having a frequency representing the difference between said frequencies, and means for obtaining energy from said third field.

5. Electronic apparatus comprising an associated pair of resonant chambers containing electromagnetic fields oscillating at different frequencies, means for projecting an electron beam through said fields so that said beam is subjected to successive velocity modulation by said fields, drift passage means wherein the electrons in

said beam become grouped as a result of said velocity modulation, a third resonant chamber adapted to receive said velocity-grouped beam and extract therefrom energy having a frequency equal to the difference of said frequencies, and means for obtaining energy from said third resonant chamber.

6. The apparatus defined in claim 5, wherein one of said fields is excited by an available source and energization of the other of said fields is controlled by the output of said third resonant chamber.

7. The apparatus defined in claim 5, wherein means are provided for excluding electrons from the third chamber in proportion to the degree of grouping in said beam.

8. The apparatus defined in claim 5, including a cavity resonator frequency multiplier device having an input resonant chamber coupled to the output of said third resonator, and means coupling the output resonator of said frequency multiplier device to excite one of said fields.

9. The apparatus defined in claim 5, including a cavity resonator device having three resonant chambers coupled respectively to said first-named chambers.

10. Electronic apparatus comprising a cavity resonator device embodying two cavity resonators adapted to contain oscillating electromagnetic fields having different frequencies, means for projecting an electron beam through said fields, said fields producing electron grouping in said beam, a third resonator in said device coupled to said electron grouped beam in energy interchanging relation therewith, a second cavity resonator device having a first resonator adapted to be coupled to the output of the third resonator of said first device, means for projecting a second electron beam through said first resonator of said second device, a second resonator in said second device coupled to said second electron beam in energy interchanging relation therewith, and means coupling said second resonator of said second device to one of said two resonators of said first device.

11. The apparatus defined in claim 10, wherein said coupled resonators have common electromagnetic fields.

12. Electronic apparatus of the cavity resonator type comprising means defining three spaced resonator chambers, means for projecting a pair of spaced electron beams in opposite directions through said chambers, means for coupling each of said beams for successive electron velocity modulation by the fields within two of said resonator chambers, and means coupling each of said modulated beams to excite its remaining associated resonator chamber.

13. Ultra high frequency apparatus comprising means providing two rationally related ultra high frequency fields, means for projecting a beam of electrons through said fields for producing an electron beam containing longitudinally spaced electron concentrations characteristic of the difference between said field frequencies, and means responsive to said beam providing an electromagnetic field oscillating at said difference frequency.

14. Ultra high frequency apparatus comprising means defining a pair of associated resonator chambers having different resonant frequencies, means for passing an electron beam through said chambers, means defining a third resonator chamber into which said beam is projected, said third chamber having a resonant frequency different

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from either of said other two chambers, and means providing a drift passage through which the beam passes between said pair of chambers and said third chamber.

15. Ultra high frequency apparatus comprising means defining a plurality of electromagnetic field regions having substantially harmonically related resonant frequencies, means passing an electron beam successively through said field regions for energy exchanging interaction therewith, means defining a plurality of further electromagnetic field regions having said substantially harmonically related frequencies, means passing a second electron beam successively through said further field regions for energy exchanging interaction therewith, and means for coupling one of said field regions to one of said further field regions having the same resonant frequency.

16. Ultra high frequency apparatus comprising means defining a plurality of cavity resonator chambers having different resonant frequencies, means projecting an electron beam through said chambers in energy exchanging relation with the fields contained by said chambers, means defining a plurality of further cavity resonator chambers having said different resonant frequencies, means passing a second electron beam through said further resonator chambers in energy exchanging relation with the fields contained by said chambers, and means for coupling the field within one of said first named resonator chambers to the field within that one of said further resonator chambers having the same resonant frequency.

17. Ultra high frequency apparatus comprising means producing a beam of electrons, mixer means providing a pair of resonant circuits having different frequencies arranged to substantially simultaneously interact with said beam for initiating electron grouping corresponding to said frequencies along the beam, and a third resonant circuit coupled to said grouped electron beam for extracting energy therefrom, said third circuit having a frequency which is a function of both said different frequencies.

18. The apparatus defined in claim 17, wherein each of said resonant circuits comprises a hollow resonator coupled to the beam through apertured walls, and wherein the apertures of the first two resonators are closely disposed.

19. The apparatus defined in claim 17 wherein said different frequencies are both harmonics of the frequency of said third circuit.

20. Electronic apparatus comprising means for producing an electron stream, electrode means positioned along the path of said stream and defining three gaps traversed successively by said stream, means defining a field-free drift space between the second and third of said gaps, means producing a first oscillating electric field of a first frequency at the first of said gaps, means producing a second oscillating electric field of a different frequency at said second gap, and output circuit means coupled to said third-gap-defining means and adapted to extract high frequency energy from said beam of a frequency different from both said first and second frequencies.

21. Ultra-high frequency apparatus comprising means for producing an electron stream, means for velocity modulating said stream at a first fre-

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quency, means for velocity modulating said stream at a second frequency, means defining a field-free drift space surrounding the path of said stream beyond said modulating means, and means beyond said drift space for inductively extracting energy from said stream of a frequency different from said first two frequencies.

22. Ultra high frequency apparatus comprising means providing an electron beam, means for imparting electron density modulation of two different frequencies to said beam, means providing a resonant circuit having a resonant frequency equal to the difference of said frequencies, means providing interaction between said modulated beam and said circuit, means providing a second electron beam, means actuated by said resonant circuit for imparting electron density modulation to said second beam of the frequency of said circuit, means for imparting density modulation to said second electron beam of a frequency equal to one of said first-named frequencies, means extracting energy from said second beam at the other of said first-named frequencies, and means utilizing said extracted energy for causing modulation of said first beam at said other frequency.

23. The apparatus defined in claim 22, wherein means are provided for excluding a part of said first beam from said resonant circuit in proportion to the combined amplitude of said two density modulations.

24. Electron discharge apparatus adapted to multiplication of ultra-high frequencies comprising means including a cathode for producing a stream of electrons, a grid mounted in the path of said stream adjacent said cathode, a resonator coupled between said grid and said cathode and tuned to a fundamental frequency, a second grid positioned along said stream path opposite said first electrode, and a second resonator tuned to a harmonic of said fundamental frequency and coupled to said pair of grids.

25. Apparatus as in claim 24, comprising a further cavity resonator positioned along said stream path for interaction with said stream at a position spaced from said pair of grids, said last-named resonator being tuned to a different harmonic of said fundamental frequency.

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