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R. V. L. HARTLEY

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ULTRA HIGH FREQUENCY HARMONIC GENERATOR

Original Filed March 28, 1941

FIG. 1

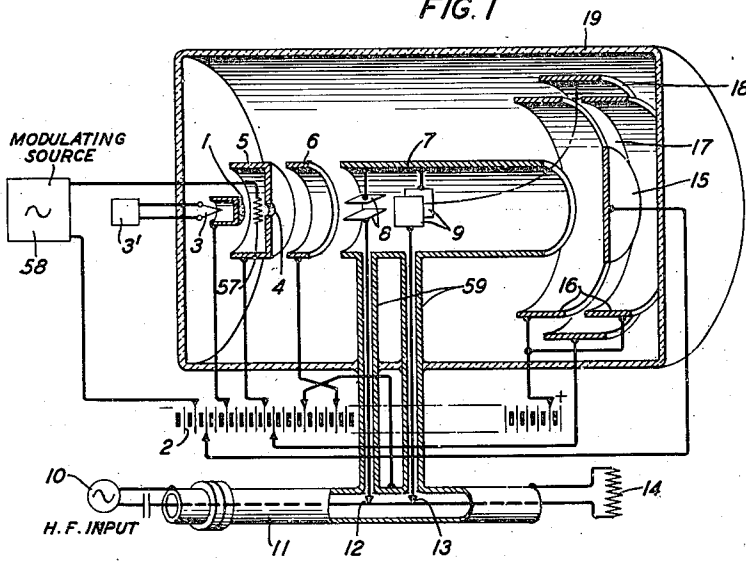


FIG. 2

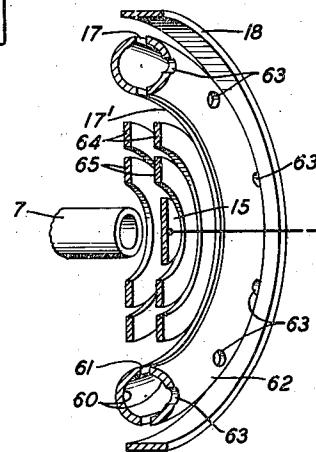


FIG. 3

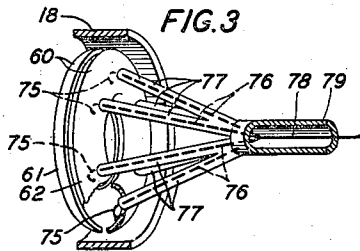
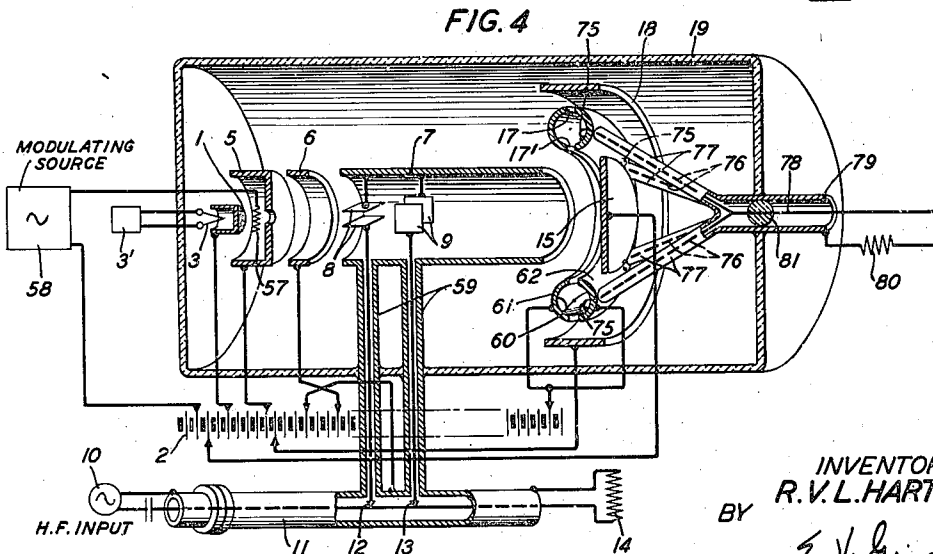


FIG. 4



INVENTOR
R. V. L. HARTLEY
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

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ULTRA HIGH FREQUENCY HARMONIC GENERATOR

Ralph V. L. Hartley, Summit, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Original application March 28, 1941, Serial No.
385,629. Divided and this application June 29,
1944, Serial No. 542,692

10 Claims. (Cl. 315-5)

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This invention relates to harmonic generators or frequency multipliers, particularly to such devices in which a beam of electrons is utilized to energize a hollow resonator at ultra-high frequency.

This application is a division of my copending application, Serial No. 385,629, filed March 28, 1941, and issued as United States Patent 2,381,539, August 7, 1945.

In most prior art devices of the space current type for generating ultra-high frequency waves, the space current delivers energy to the generated waves at a rate which varies during the cycle, instead of delivering energy to the wave at a constant rate. For example, in the case of waves generated in accordance with the velocity variation principle, the space current delivers energy in spurts of a duration not exceeding one-half a cycle of the generated wave. Similarly, in various forms of generators, the space current delivers energy impulsively, rather than a constant flow.

Because of the irregular transmission of energy by the space current, considerably higher space current voltages are required during intervals when energy is being supplied for the generation of waves of given power than would be the case if there were no irregularity. The relatively high voltage needed in any event for producing the space current, even without the irregularity of conversion of space current energy into the desired waves, results in relatively large losses of energy as well as transients and other objectionable phenomena at the anode, due to the high velocity of the electrons when striking the anode, and this difficulty is greatly increased by the irregular energy conversion. Because of the heat produced by the electron impacts, the power output of a given size of device is definitely limited by overheating and the accompanying destruction of the anode and adjacent parts of the generating device. Similar difficulties are experienced in various other ways because of the spasmodic, rather than continuous conversion of energy, in somewhat the same way that a reciprocating engine involves difficulties not experienced with a turbine.

Another serious problem from the standpoint of engineering and economics when converting space current energy into desired wave energy, particularly at ultra-high frequencies, is the complication of providing suitable transmission and coupling circuits between the electrodes of the space current device and the output terminals.

Some of the objects of the present invention

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are to reduce or avoid the above-mentioned difficulties, in whole or in part; to establish an efficient and convenient energy transfer relation between a beam of electrons and an electromagnetic wave field; to generate, modulate, or radiate high frequency wave energy in a simplified manner and with improved efficiency, to convert direct current energy into ultra-high frequency wave energy at a constant rate rather than at a variable rate during each cycle; to provide efficient space current devices and circuits of relatively simple construction for accomplishing any of the above-mentioned objectives; to distribute electron impact losses and so reduce heating at the anode; and to generate waves of exceptionally high frequency and power.

In accordance with the specific illustration of an ultra-high frequency generator of the harmonic generator or frequency multiplier type to be described, a continuous direct current, consisting of a beam of high velocity electrons, is cyclically deflected at an ultra-high frequency by rotating the beam about an axis substantially normal to the beam, like a single spoke in a rotating wheel. The rotating spoke-like beam is caused to pass, during its entire period of rotation, transversely through the space within a toroidal shaped resonator and thereby generate high frequency energy in the resonator.

One form of space current device adapted for this operation, may include a gun from which an electron beam is projected axially through an accelerating cylinder coaxial with the gun and containing polyphase deflector plates for deflecting the beam in a path which rotates around the gun axis. A retarding electrode outside the electron exit end of the cylinder, has such a potential and position that the electrons lose their velocity axially of the cylinder before reaching the retarding electrode. The electrons at a position in the beam after losing their velocity axially of the cylinder then constitute a continuously rotating virtual cathode of the general dimensions of the beam. Concentric with this cathode are one or more accelerating electrodes, preferably a pair of short cylinder electrodes of relatively large radius for highly accelerating the electrons from the virtual cathode radially outward toward a slot between the pair. Concentric with the slot and radially outside it, is an anode for collecting the spent electrons.

In arrangements described in the copending application of which this is a division rotation of that part of the electron beam projected from the virtual cathode by the pair of accelerating

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electrodes, causes that part of the beam to produce a high frequency electromagnetic wave which is so related to the electron beam producing it that the direction of the electric field of the wave at the beam, moves substantially in synchronism with the direction of the electron flow in the beam, the resulting reaction of the electric field of the wave on the beam being such as to oppose and reduce the velocity of the electrons to a maximum degree, thereby causing the electric field of the wave to continuously absorb energy directly from the beam throughout each cycle, and at a substantially constant rate throughout each cycle. The present arrangement differs from this in that the previously mentioned toroidal shaped hollow resonator is arranged so that the rotating beam passes through it. Within the resonator the opposing field of the generated electromagnetic wave is enhanced and the absorbed energy is increased so that substantially all of the high frequency energy generated by the rotating beam is produced within the hollow resonator. The resonator, being toroidal, is formed like a pipe bent into a continuous ring and its dimensions are such relatively to the frequency of rotation of the electron beam that harmonics of the frequency of rotation are generated and circulate progressively around within the pipe. Energy at the harmonic frequency may be taken through openings equally spaced around the toroid and that from the several openings may be combined together and transmitted to a common load. After the electrons have transferred to the high frequency wave a part of their energy of propulsion, they are collected at the anode. A relatively small increment of positive potential over that of the cathode is employed at the anode to further retard the electrons before their capture and so minimize the energy losses and heating from electron impact on the anode. Local heating of the anode is further minimized due to the fact that the electron impacts are cyclically distributed over the anode surface.

Modulation of the generated wave may be accomplished by applying the modulating wave to a grid for varying the amount of current in the electron stream while generating the ultra-high frequency waves.

The invention is described in greater detail hereinafter in connection with the accompanying drawings.

In the drawings:

Fig. 1 is a schematic diagram showing in partial axial section an ultra-high frequency wave generator of the space current type to illustrate particularly an arrangement for producing the rotating electron beam;

Fig. 2 is a diagram of certain details of a modification of Fig. 1 for producing waves of a frequency harmonic to a fundamental of high or ultra-high frequency;

Fig. 3 is a diagram of a modification of Fig. 2, employing an array of probes for leading off the harmonic waves; and

Fig. 4 is a diagram combining features of Figs. 1, 2 and 3 to show a complete harmonic generating device illustrative of the invention.

In Fig. 1 the cathode 1 is adjustably connected with a point near the negative end of the battery or other source of direct current energy 2. The element 3, heated by the source 3', causes cathode 1 to emit electrons which are projected through the beam defining aperture 4 on the axis of gun electrode 5, and then successively through

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the positively charged accelerating electrodes 6 and 7 of hollow cylindrical form, coaxial with electrode 5. The positive potentials of electrodes 5, 6, 7 are adjusted individually by a separate tap on source 2 for each electrode. Electrodes 6 and 7 have much higher positive potentials than electrode 5, and electrode 6 is usually made more positive than electrode 7 to provide with electrode 7 a converging lens in order to focus or concentrate the beam at a suitable point remote from cathode 1.

A pair of plate electrodes 8 for deflecting the electron stream in a vertical plane and another pair 9 at right angles thereto for deflecting the stream in a horizontal plane, are provided in well-known manner for connection with a two-phase source of waves derived from the source of high frequency excitation of the device, to cyclically deflect the stream in a path which rotates continuously about the gun axis, once for each cycle of the wave. One electrode of each pair 8, 9, is connected by way of cylinder 7 and the outer conductors of the coaxial cables 59 with a single adjustable tap on source 2 and with a terminal on the outer conductor of the coaxial cable 11 common to the two phases, the other electrode of each pair 8, 9, being connected respectively, by the inner conductors of the coaxial cables 59, with the other terminals of the two-phase source which differ in phase by 90 degrees. The amount of deflection of the beam and the length of the cylinder 7 are so chosen that the beam emerges from the cylinder near the periphery thereof but without striking it.

A convenient two-phase supply consists of a single phase source 10 of ultra-high frequency waves connected with a coaxial cable 11, the outer conductor of which forms the terminal common to the two phases, while the inner conductor is provided with two adjustable taps 12 and 13, differing in phase by 90 degrees. The cable is terminated with a surge impedance 14, for preventing reflection of waves back toward the source 10. Any other suitable form of two-phase source may be supplied in place of that shown. It will be understood that the leads from points 11, 12, 13, to plates 8, 9, should be of such length that they do not introduce any departure from the desired phase quadrature relation between the waves on plates 8 and 9.

The circular retarding electrode 15 of disc form, normal to and coaxial with the axis of gun 5, is positioned near to but spaced slightly beyond the end of electrode 7 through which the electron beam is projected, and is connected through an adjustable tap with source 2 at a point polarizing the electrode at a sufficiently negative potential with respect to cathode 1, to make all the electrons in the beam lose their axial velocity before reaching electrode 15. The motion of electrons along the gun axis toward electrode 15 is thus completely stopped, so that the beam is abruptly deflected or bent into a path positioned approximately in a radial plane of the gun axis, between electrodes 7 and 15, without suppressing the deflections of the beam radial to the axis. The electron beam, at the place where it loses its axial velocity, thus constitutes in effect a continuously rotating virtual cathode, having an emission surface area equal to the cross-section of the beam, the plane of rotation being normal to the gun axis around which the cathode rotates at the ultra-high frequency.

A hollow cylindrical accelerating electrode 16, of substantially larger radius than that of electrodes 7 and 15 and the virtual cathode, is preferably

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divided into two parts, constituting a pair of axially short rings, separated by a narrow slot 17, extending continuously around between the rings, concentrically with the point on the gun axis around which the virtual cathode rotates. Electrodes 13 are connected together to have the same potential and have an adjustable tap on source 2 for charging them to a sufficiently high positive potential to draw all the electrons radially out from the virtual cathode and accelerate them toward and through the slot 17, and to cause the electrons to traverse the radial distance in a small fraction of the period of the ultra-high frequency wave to be generated. The direction of the radius taken by a particular electron, is determined by the position at which the electron emerges from cylinder 7, and hence depends on the phase of the wave which deflects the beam. The radial beam therefore rotates once for each cycle of the deflecting wave. It will be seen that the energy of radial motion of the electrons in the beam is derived practically entirely from the source of direct current 2, and not from the deflecting wave.

The cylindrical electrode 18, disposed radially outside the slot 17, serves as an anode to terminate the electron stream, the anode having an adjustable tap connection on source 2 for polarizing the electrode with just sufficient positive potential to capture all the electrons passing through slot 17, the potential of electrode 18 being considerably less positive than rings 16. An envelope 19 of suitable insulating material, such as glass of low dielectric loss, is provided around the electrodes of the device for maintaining a suitably high vacuum for operation of the device.

The electron beam rotating in the radial plane about the axis of rotation which is the axis of the device, generates a circularly polarized electromagnetic wave which may be propagated along the axis of rotation and normal to the plane of rotation.

Since the electric field of the wave generated by the beam is in phase with the beam, it reacts on the electrons in the beam in directions opposing their radial outward flow, thus slowing their radial velocity and increasing the intensity of the electric field. The direct current energy of the beam is thus converted directly into radiated ultra-high frequency wave energy.

The high frequency energy thus drawn from the electron beam is proportional within limits to the strength of the high frequency electric field by which the motion of the electrons in the beam is opposed, or, in other words to the impedance of the load coupled to the electron beam. If the high frequency energy is radiated directly into free space the load impedance is low and the energy transferred will be relatively small. Consequently, it is desirable to utilize a resonator in which a standing wave may be produced to enhance the strength of the high frequency electric field where it interacts with the electron beam thus increasing the impedance of the load and allowing more energy to be given up by the beam to the high frequency wave with which the field is associated.

In order that the electric field of an electromagnetic wave may serve effectively at the rotating electron beam, as a means for increasing the radiation from the beam, it is necessary only that the beam rotate concentrically with the electric field of the wave, that the beam and the electric field rotations be of the same frequency, and that the beam and field be phased so that the field opposes the radially outward motion of the elec-

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trons. Under these conditions, all of the electrons traverse the maximum voltage developed across the load. Since all of the electrons traverse substantially the same retarding field, they reach the end of their radial path with the same velocity, and therefore may be retarded and captured at low velocity by the same increment of positive potential above the potential of the cathode 1.

The potential of electrode 6 is preferably adjusted so that the electrons come to a focus or are concentrated at a point near the slot 17, so that the electrons may readily pass through the slot. Since the potentials of cathode 1, accelerating electrodes 6, 7 and 16, anode 18, and retarding electrode 15, are substantially constant, the flow of direct current energy into the electromagnetic wave is continuous throughout the cycle of rotation, the energy flow being at a substantially constant rate throughout the cycle of the ultra-high frequency wave, as contrasted with the spurts of energy of maximum duration of one-half a cycle in generators of the velocity variation type. It is therefore possible to employ a minimum voltage for driving the space current through the device to produce a given amount of output power, as compared with prior devices wherein undesirably large spurts of energy are required in order to produce the same power averaged over the cycle. Since all of the electrons approach the anode 18 with the same velocity, they may be brought more nearly to rest before striking the anode than they can in devices where the velocity of the used electrons varies over the cycle, so that dissipation of energy at the anode is kept to a minimum and the heating of the anode may be made relatively small. The problem of dissipating the heat is further relieved by the fact that the place of impact of the electrons is continually moving away from the most heated spot, while the total heat radiating area is relatively large. Because of the simplified problem of heat dissipation, larger electron currents and higher voltages may be used than in devices having a fixed point of electron impact.

Since the circuits employed may be of the efficient resonant cavity type and the transfer of energy from the electron beam to the high frequency circuit is continuous throughout each high frequency cycle, a very high efficiency of conversion of direct current energy into ultra-high frequency wave energy is achieved.

For the purpose of modulating the generated high frequency wave the magnitude of the electron stream may be varied in accordance with the modulating wave by means of a grid 57, preferably located near the cathode 1, for example between the electrodes 1 and 5, as shown in Fig. 1. The modulating wave from the source 58, is impressed between the grid 57 and cathode 1, by way of an adjustable tap on source 2 for polarizing the grid negatively with respect to cathode 1.

The showing of Fig. 1 illustrates features of the invention involved in production of the rotating electron beam from which high frequency energy is continuously derived. The rotating beam of Fig. 1 produces a high frequency wave at a frequency corresponding to the frequency of rotation and in the previously mentioned copending application, Serial No. 385,629, various modifications of and additions to the Fig. 1 showing are described and claimed for enhancing and utilizing such a wave. The present

invention pertains to the production and utilization of high frequency energy at frequencies higher than and harmonic to the frequency of rotation of the electron beam through the agency of a toroidal shaped resonator in which the harmonic wave is generated such as is shown in Fig. 2.

Fig. 2 shows an arrangement of electrodes adapted for substitution in the device of Fig. 1 to permit the generation of waves which are harmonic to the frequency of rotation of the electron beam. The pair of ring electrodes 16 of Fig. 1 are replaced (as shown in Fig. 4) by a toroid 60 in the form of a metallic pipe bent into a continuous ring, concentric with the center of the rotating virtual cathode between electrodes 7 and 15. The toroid is interposed in the path of the radial beam of electrons, and has a circumferential slot 17, 17', where the radial plane of the toroid intersects the pipe, thus dividing the toroid into two rings, 61, 62, disposed respectively on opposite sides of the plane of rotation of the electron beam. The electron beam is projected radially through the slot in response to a high positive accelerating potential applied to the toroid through an adjustable tap on the source 2, as in the case of the rings 16, Fig. 1. The anode 18 collects the spent electrons as in Fig. 1.

In order that a plane polarized wave of the H_1 type may be set up to progressively circulate along the pipe of the toroid within the cavity of the pipe, the plane of the electric vector being parallel to the toroid, the frequency of such a wave should be high enough for the wave to be transmitted effectively by the pipe. Furthermore, the length of the pipe and the mean circumference of the toroid, should be made equal to an integral number of wave lengths of such a wave. The electrons passing through the slot 17, 17', of the pipe oppose the direction of the field of the waves set up in the pipe. By adjusting the frequency of rotation of the electron beam in the plane passing through the slot, so that the point of transit of the electrons rotates with the same speed as the wave travels in the pipe, the electrons will always pass through a point where they give up a maximum amount of energy to the wave. The frequency of the field at any point in the pipe will be a multiple of the high frequency of ultra-high frequency of rotation of the electron beam, and is determined by the number of wave lengths measured around the pipe. The electron beam in this manner can support a whole series of waves whose frequencies are in harmonic relation to the high frequency of rotation of the beam.

In order to select a desired one of the resulting harmonics and to suppress others, the energy to be withdrawn from the pipe is removed at properly selected points thereon. For example, in order to obtain an output wave having a frequency ten times that of the beam rotation frequency, ten points equally spaced around the toroid 60, are provided with circular holes 63, serving as openings through which desired energy may escape in the form of radiation or preferably through which probes may be inserted to remove the desired energy through coupling with the high frequency field within the toroid. Undesired harmonics adjacent to those being selected, are in such phase relation relatively to the openings that destructive interference takes place to oppose their transmission. If it is desired to draw off energy at all of the harmonics as from a "harmonic generator" a single coupling, for example a single one of the probes, may be used.

Any tendency to generate frequencies much below the desired harmonic, may be counteracted also by making the cut-off frequency of the toroid pipe only slightly lower than one desired frequency. The electrons in the beam should be accelerated to such a high velocity that they traverse the diameter of the pipe in a small fraction of the period of the desired harmonic wave.

By means of such an arrangement, the beam may be rotated at a high frequency below the ultra-high frequency range to generate ultra-high frequency waves as harmonics of the beam rotation frequency, or the beam may be rotated at an ultra-high frequency to generate much higher frequency waves, not readily obtainable by the usual types of generators. One of the advantages of this form of generator is that no metallic parts other than for coupling probes are required within the resonant chamber of the pipe.

A pair of flat focusing rings 64, of smaller radius than toroid 60, and another pair of similar rings 65 of smaller radius than rings 64, may be provided if desired, to improve the concentration of the beam and to direct it more effectively to pass through the slot 17, 17'. The rings in each pair 64, 65, are coaxial with cylinder 7 and are symmetrically disposed on opposite sides of and close to the radial path of rotation of the electron beam. Each of the rings 64, 65, has an adjustable tap connection (not shown) with source 2, to charge the rings positively at potentials which are intermediate between those of electrodes 7 and 60, the rings 65 being more positive than rings 64 when the adjustment of the beam calls for an electron lens system adapted to converge the beam toward the slot 17, 17'. It will be understood that the rings 64, 65, need not be provided unless improved focussing of the beam is desired.

High frequency energy radiated through the holes 63 may be directed into a resonant wave guide or cavity by placing the device coaxially in the guide or cavity as illustrated for the Fig. 1 device in Figs. 4 and 5 of the previously mentioned copending application, Serial No. 385,629. In this manner there may be generated within the guide a type of wave which has been termed the E_0 type, characterized by radially directed components of the electric field. In the preferred method of removing high frequency power from the toroid where it is not desired to use the holes 63, Fig. 2, as a means for directly radiating the output waves, the holes 63 may be utilized for the insertion of or be replaced by probes 75, Fig. 3, located at points selected similarly to the holes 63 around the toroid ring 62 and projecting into the space within the toroid. The probes 75 are connected by the central conductors 76 of coaxial line 77, of equal electrical length, with the central conductor 78 of the coaxial cable 79 which transmits the desired waves combined in phase with each other from all the probes.

Fig. 4 illustrates diagrammatically a complete harmonic generator combining features of Figs. 1, 2 and 3. The two portions 61 and 62 of the toroidal shaped resonator 60 of Fig. 2 take the places and functions of the two cylindrical accelerating electrodes 16 of Fig. 1. The electrodes 64 and 65 of Fig. 2 which, as mentioned, may or may not be used are not shown in Fig. 4 in order to keep the figure simple and clear. The output energy generated in the resonator at a frequency which is a multiple of the frequency of the input energy from the source 10 may be coupled through the

probes 75, the coaxial leads 76, 77 and the coaxial guides 78, 79 to any suitable load, for example the resistor 80. The insulating bead 81 through which lead 78 passes is a seal to maintain the vacuum within the envelope 19. The operation of the device of Fig. 4 has been fully explained in connection with the description of its components shown in Figs. 1, 2 and 3.

In the illustrations shown the axis of rotation of the electron beam is normal to the beam so that the surface generated by the end portion of the rotating beam is a flat plane. It is obvious that the axis of rotation may be at some other angle to the beam so as to make the surface generated conical rather than a flat plane without departing from the spirit of the invention. It is only necessary that the generated surface intersect the toroidal resonator so that the electron beam is always passing through the space within it. It is also evident that the slot 17 and electrode 18 of Figs. 2 and 4 may be omitted and the electrons collected on the inner surface of the toroid after passing through the resonator space rather than on the electrode 18. Other modifications will be apparent to those skilled in the art and it is intended that the invention be not limited to what has been specifically described but only by the scope of the claims.

What is claimed is:

1. In a space current device having an evacuated envelope, means for producing a beam of electrons, rotating field means positioned along the said beam for deflecting and rotating the beam around its undeflected axis at a predetermined frequency, electrode means remote from the emitter along the beam path for reducing to substantially zero the velocity of the electrons of the said beam in the direction of the said axis of the undeflected beam without suppressing the velocity normal to the said axis, the beam then forming a virtual cathode revolving at said predetermined frequency in a path lying substantially in a plane normal to the said axis, a pair of annular electron accelerating electrodes generally parallel to the said plane consisting of a toroid in the form of a pipe bent into a continuous ring concentric with the cathode and having a circumferential slot where the radial plane of the toroid intersects the pipe, the slot dividing the pipe into two rings disposed respectively on opposite sides of the plane of rotation of the cathode, the two rings constituting said pair of annular electrodes, the said slot being such as to permit passage therethrough continuously of a beam of electrons accelerated by said annular electrodes radially outward from the virtual cathode toward said slot, the length of the pipe being an integral multiple of the wavelength of a wave traveling circumferentially around the toroid within the pipe, the frequency of which is an integral multiple of said predetermined frequency, the toroid having a plurality of equally spaced coupling means disposed along the pipe for transmitting waves of a frequency harmonic to said predetermined frequency from the toroid.

2. Harmonic generating apparatus comprising a source of fundamental high frequency energy, an evacuated container enclosing a hollow electrical resonator of toroidal shape capable of supporting electromagnetic waves at a frequency harmonic to said fundamental frequency and having a circumferential slot providing access to the interior space of the resonator, means for producing a beam of electrons in coaxial relation to the said slot and in the evacuated space

which includes the said resonator space and rotating field means coupled to and adapted to be energized by said fundamental high frequency energy for deflecting and rotating the said beam of electrons about its undeflected axis whereby the beam generates a surface of revolution which passes uninterruptedly through said circumferential slot and said interior space of the resonator.

3. Harmonic generating apparatus comprising a source of fundamental high frequency energy, an evacuated container enclosing a hollow electrical resonator of toroidal shape capable of supporting electromagnetic waves at a frequency harmonic to said fundamental frequency and having a circumferential slot providing access to the interior space of the resonator, means for producing a beam of electrons in coaxial relation to the said slot and in the evacuated container which includes the said resonator space, rotating field means coupled to and adapted to be energized by said fundamental high frequency energy for deflecting and rotating said beam of electrons about its undeflected axis whereby the beam generates a surface of revolution which passes uninterruptedly through said circumferential slot and said interior space of the resonator and annular electrode means coaxial with said axis for imparting a radial component of acceleration to the electrons in the rotating beam.

4. Harmonic generating apparatus comprising a source of electrical energy of a given high frequency, an evacuated container enclosing a hollow conductive wave guide in the form of a pipe bent into a continuous ring, the pipe being of a length to support a plurality of cycles of a progressively circulating electromagnetic wave of a frequency which is a multiple of said given frequency, said wave guide having an annular slot concentric with said ring providing access to the space within the pipe, means for producing a beam of electrons in coaxial relation to the said ring and annular slot and rotating field means coupled to and adapted to be energized from said source of high frequency energy for deflecting and sweeping said beam along and through said annular slot and said space within the pipe continuously at a circumferential velocity equal to the phase velocity of the electromagnetic wave circulating within the guide, whereby energy may be transferred continuously from the said electron beam to an electromagnetic wave progressively circulating within the guide.

5. Harmonic generating apparatus comprising a source of electrical energy of a given high frequency, an evacuated container enclosing a hollow toroidal shaped electrical resonator capable of supporting an electromagnetic wave of a frequency which is a harmonic of said given frequency, said resonator having an annular slot around its periphery providing access to the interior space, means for producing a beam of electrons in coaxial relation to said resonator and annular slot and rotating field means coupled to and adapted to be energized from said high frequency source for deflecting and sweeping said beam laterally along and through said slot and interior space continuously while the beam is longitudinally projected through the slot and across the space.

6. Harmonic generating apparatus comprising a source of electrical energy of a given high frequency, an evacuated container enclosing an electron emitter, means for projecting a stream of electrons from said emitter, rotating field means positioned along the path of the stream adapted

to be energized from said source of high frequency energy for deflecting and rotating said electron stream to generate a conical surface of revolution about the axis of the undeflected stream, electrode means remote from the emitter for substantially stopping the motion of the electrons in the stream in the direction of said axis without stopping the deflection and rotation of the stream, annular electrode means coaxial with said axis for increasing the velocity of the electron stream in the directions of the deflections after said substantial stoppage of the axial motion, and a substantially closed toroidal shaped hollow electrical resonator capable of supporting a plurality of cycles of a progressively circulating electro-magnetic wave of a frequency which is a multiple of said given frequency, the resonator having an annular aperture around its periphery providing access to the interior space and being positioned coaxially with said axis whereby the rotating electron stream may enter said aperture and cross said interior space of the resonator continuously as it rotates whereby energy may be continuously transferred from the electron stream to an electromagnetic wave within the resonator having a frequency which is a multiple of said given frequency.

7. Harmonic generating apparatus comprising a source of electrical energy of a given high frequency, an evacuated container enclosing an electron emitter, means for projecting a stream of electrons from said emitter, rotating field means positioned along the path of the stream and adapted to be energized from said source of high frequency energy for deflecting and rotating said electron stream to generate a conical surface of revolution about the axis of the undeflected stream, annular electrode means coaxial with said axis for increasing the velocity of the electrons in the rotating stream, a toroidal shaped hollow electrical resonator capable of supporting a plurality of cycles of a progressively circulating electro-magnetic wave of a frequency which is a multiple of said given high frequency, the resonator having an annular aperture around its periphery providing access to the interior space and being positioned coaxially with said axis, whereby the rotating electron stream may enter said aperture and cross said interior space of the resonator continuously as it rotates, whereby energy may be continuously transferred from the electron stream to an electromagnetic wave within the resonator having a frequency which is a multiple of said given high frequency and means for coupling a load to said resonator to utilize energy of the multiple frequency wave.

8. Apparatus according to claim 7 in which the said load coupling means comprises a plurality of coupling means equally spaced around the periphery of the said resonator.

9. A high frequency electronic device comprising an electron emitter, means for projecting a beam of electrons from said emitter, deflecting means positioned along the beam for cyclically deflecting the beam in a path tracing a surface of revolution and having the axis of the undeflected beam at the center thereof, electrode means remote from the emitter along the beam path for reducing to substantially zero the velocity of the electrons of said beam in the direction of said axis of the undeflected beam without suppressing the velocity normal to said axis, the beam forming a

virtual cathode revolving about said axis at the place where the electron movement axially is stopped and the unsuppressed electron velocity normal to the axis causing a portion of the beam remote from the emitter to be directed radially outward from said virtual cathode as it is revolved about said axis, electrode means spaced radially outward from said electron stopping place for accelerating the beam electrons radially outward, the said accelerating electrode means consisting of two ringlike halves of a hollow toroid separated by an annular slot extending continuously around between the two halves of the toroid coaxially with the said axis of the undeflected beam and in the path of the said revolving radially directed portion of the beam, whereby the beam passes through the slot and the space of the toroid continuously as it revolves, the mean circumferential length of the toroid being an integral multiple of the wavelength of a wave traveling circumferentially within the space of the toroid, the frequency of which is an integral multiple of the frequency of revolution of said beam, the toroid having a plurality of equally spaced coupling means disposed around its circumference for extracting therefrom waves having a frequency harmonic to said frequency of revolution.

10. In combination, a direct-current source, a transmission path capable of guiding waves of a given ultra-high frequency, means comprising an electron emitter and electron accelerating electrodes remote from the emitter and energized from said direct-current source for converting direct-current energy from said source into a beam of high velocity electrons from said emitter, rotating field means positioned along the path of said beam of electrons for deflecting and rotating the beam at a subharmonic of said ultra-high frequency around the axis of the undeflected beam, hollow cavity resonator means comprising a toroidal shell symmetrically disposed about said axis and having its shell apertured in the path of the rotating beam to admit the beam into the toroidal space within the shell of the resonator continuously for converting continuously the direct-current energy of the beam into said ultra-high frequency waves, and a plurality of means coupled to said resonator at a plurality of points symmetrically disposed around said axis for collecting the resulting ultra-high frequency waves and transmitting them to said transmission path.

RALPH V. L. HARTLEY.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,200,745	Heyman	May 14, 1940
2,281,935	Hansen et al.	May 5, 1942
2,305,883	Litton	Dec. 22, 1942
2,368,328	Rosencrans	Jan. 30, 1945
2,368,329	Rosencrans	Jan. 30, 1945
2,408,437	McRae	Oct. 1, 1946

FOREIGN PATENTS

Number	Country	Date
468,185	Great Britain	June 30, 1937