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STANDING WAVE COUPLER

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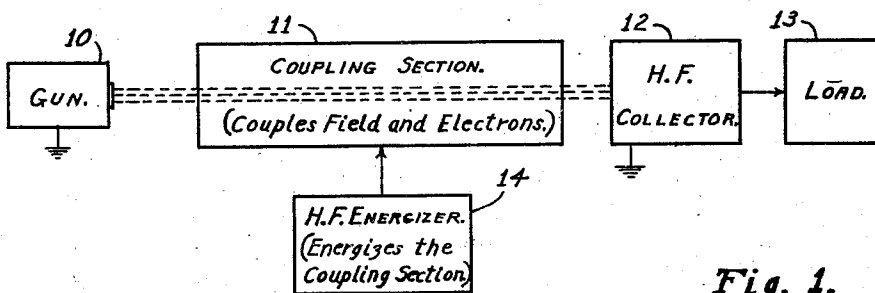


Fig. 1.

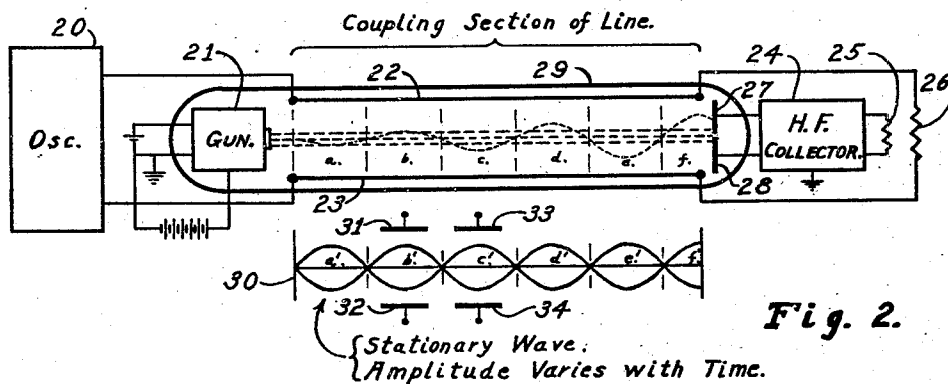


Fig. 2.

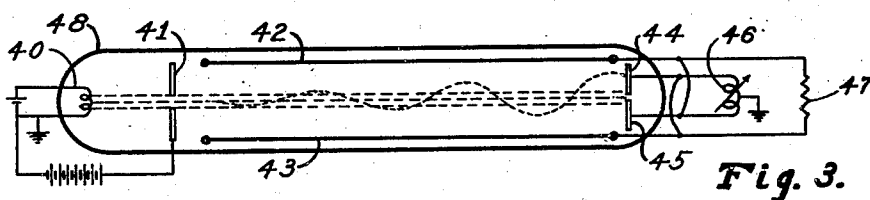


Fig. 3.

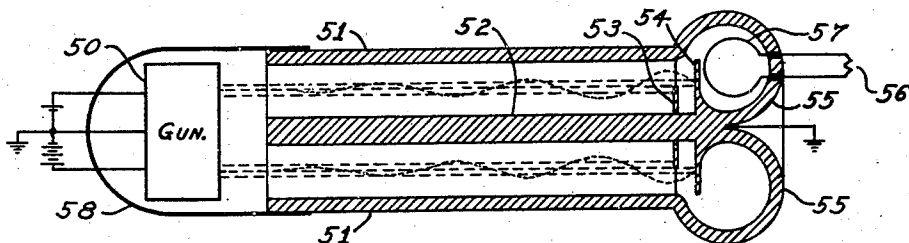


Fig. 4.

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STANDING WAVE COUPLER

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4 Claims. (Cl. 250—36)

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This invention relates to a high frequency generating system of the type which is energized by successive groups of charged particles moving through space, wherein the groups are obtained by deflecting a stream of charged particles.

The object of the invention is to provide improved method and means for generating high-frequency currents of high power and for controlling the deflection mode of a high velocity stream of charged particles.

In conventional methods of utilizing high velocity streams of charged particles for high-frequency generation, the stream is either interrupted into groups, or deflected from side to side by energizing a fixed pair of deflector plates. In the latter case, collection of the deflected stream is effected in such a manner as to charge first one side and then the other of some oscillating circuit. There are certain limitations imposed when using the conventional stream deflection methods. For one thing, the high velocity charged particles can only be acted upon by the deflecting field during the interval of time it takes each of them to pass the fixed deflecting plates, and the higher the velocity the shorter is this time interval. Increasing the length of the deflector plates will increase the time interval it takes a charged particle to pass through the field between them, thus giving a greater amplitude of deflection, but also increases the minimum oscillation period that may be applied to the deflector plates, so that increased amplitudes of deflection of the stream are obtained at the expense of a decrease in frequency. Because of the above and other difficulties, the known conventional methods of utilizing high velocity streams of charged particles for high powered high-frequency generation are limited in their practical application.

This invention relates to an improved method for generating high-frequencies at high power which consists essentially in directing along a given path a stream of high velocity charged particles and providing along the path a series of changing deflecting fields whose polarity is so coordinated with the velocity of the charged particles that a given segment of the stream of charged particles is acted upon by a field of substantially the same polarity throughout the length of the given path. For creating the desired type of deflecting field, it is proposed that a transmission line which is adjusted and energized so as to set up electromagnetic standing waves be used. As is well known to the art, traveling waves can be set up in any of the conventional transmission lines, such as, for example,

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the open wire type or the coaxial type. A standing wave is the resultant of an incident traveling wave and its reflected traveling wave traveling in opposite directions over the same transmission path. The conditions for terminating the line so that reflected waves will result is well known to the art, and consists in general of a mismatch termination. When a transmission line is thus energized with a standing wave, at any given instant the successive one-half wave length sections of the line will be of alternate positive and negative polarity, while the field intensity in any one given section will vary sinusoidally with time. That is, successive one-half wave length sections of the line will have a phase difference of 180° , while varying periodically with time. Assuming such a standing wave existing along the given path, then if a stream of charged particles is directed along this path with such a velocity that a given particle traverses a one-half wave length section of the line in a time interval of one-half a period of the exciting frequency, then it follows that some given charged particle will always be acted upon by a field of the same polarity throughout the length of the path. That is, if a charged particle is just entering a one-half wave length section as its transverse deflecting field is turning positive, the field of the following section will just be turning negative in polarity; by the time the charged particle traverses the first section, it will just be turning to negative polarity while the following section will just be turning positive as the particle enters it. The maximum amplitude of deflection of the waved stream will occur when the moving charged particle can traverse a wave length section of the given path in a time period of the frequency coordinated with the given wave length. The amount of deflection that any one charged particle will receive for each wave length section depends upon its instant of phase entry into the field coupling section; if it enters at the instant of zero field or phase, it will receive maximum positive deflection; if it enters at the one-quarter or three-quarters instant, due to subsequent cancelling fields it will receive zero deflection; and if it enters at the one-half phase instant, it will receive maximum negative deflection. As a result, the emerging stream of charged particles will have a "waved" shape, and the positively and negatively deflected loops of the waved stream can be used to energize an oscillating circuit.

When the velocity of the charged particles is such that they traverse one wave length section in the period of one cycle, the maximum ampli-

tude of deflection of the resulting waved stream is obtained. However, the velocity of the charged particles may be greater or less than the above assumed optimum value. For a given phase instant of entry into the coupling section, it is possible to make the displacement amplitude of the waved stream on emerging to be either zero, or some positive or negative value, depending upon what fraction of the optimum velocity is selected.

In this method of creating a series of varying fields along a given path a transmission line, which by definition is made up of distributed electrical constants or parameters, is used to create a standing wave field. It would be possible to approach this result by using properly phased lumped constants for each one-half wave length section of the given path forming the coupling section. For practical application, the use of the transmission line has greater advantages.

It will be noted that the wave coupled oscillator or amplifier using a standing wave on a resonant transmission line can be excited from either end of the line, whereas the wave coupled oscillator or amplifier using traveling waves as disclosed in application having Serial Number 388,280 and filed April 12, 1941 must be so excited that the traveling wave and the electron stream are both moving in the same direction.

The method of using the fields of a standing wave to deflect moving charged particles gives many advantages over known systems. Brief reference to some of these advantages may be made. It will be noted that for a given strength of field in the standing wave, the amplitude of deflection of the stream for a given velocity can be made as large as desired simply by increasing the length of the coupling section of the transmission line. Also, the amount of power that can be controlled is not limited by the usual considerations of physical size of the apparatus. Further, very high frequencies can be generated or amplified without encountering the many difficulties inherent in other systems wherein the physical size of the apparatus imposes severe limitations. Other advantages of the invention will be evident from the more detailed description that follows.

More particularly, the invention consists in the system and method hereinafter described, illustrated in the accompanying drawing and defined in the claims hereto appended, it being understood that various changes in form, arrangement and details both of circuits and of method within the scope of the claims may be resorted to without departing from the spirit or sacrificing any of the advantages of the invention.

A clearer understanding of the operation of the invention and its improvement over known methods can be obtained by reference to the following figures and the descriptions relating thereto.

Figure 1 shows a block diagram of the principal elements of the standing wave coupler used as an oscillator or as an amplifier.

Figure 2 shows a circuit diagram of a high-frequency amplifier embodying the principles of the invention, with a graphical representation of the standing wave in the coupling section.

Figure 3 shows a diagram of a standing wave coupled oscillator, wherein the output energy of the oscillator is also used to energize the coupling section.

Figure 4 shows a circuit diagram of a standing wave coupled oscillator in which the conducting members which guide the initial and reflected traveling waves that form the resulting standing

wave pattern are shown as of the coaxial type.

Figure 1 is a block diagram showing the main elements of the stationary wave coupler. Block 10 represents a gun for creating high velocity charged particles, such as electrons. In what follows, it will be assumed that the charged particles used are electrons, although it will be obvious that this is not a necessary restriction. Block 11 represents the coupling section, wherein the fields of the standing wave and the electrons of the electron stream are coupled together, so that the wave fields deflect or displace the electrons therein. Block 12 represents a high-frequency collector for collecting high-frequency energy from the waved stream of emerging electrons. Block 13 represents the load which utilizes the energy collected by the high-frequency collector 12. Block 14 shows the high-frequency energizer which energizes the transmission line of the coupling section 11, and thus forms the stationary wave pattern therein. The high-frequency energizer 14 may be an independent oscillator, or may be energized by a portion of the output energy of the high-frequency collector 12.

In the operation of the wave coupler, the electron gun 10 directs a stream of electrons along the path in the coupling section 11 where the standing wave field pattern is set up. A transmission line can be used to direct the path of the wave. Conventional transmission lines consist of such members or media as will tend to guide electromagnetic waves along a given path. One conventional type of transmission line consists of two spaced parallel wires. In order that standing waves shall be formed when the transmission line is energized, it is necessary that traveling waves moving in opposite directions be set up in the transmission line and coupling section. If one end of the line is energized from a high-frequency source and the other end terminated in such a manner as to create a reflected wave, the desired standing wave field will result. As is commonly known in the art, such reflected waves will be set up if the end of the line is mismatched as by being open-circuited or short-circuited. The standing wave will form a series of one-half wave length sections along the coupling section 11 whose fields are alternately of positive and negative polarity, and wherein the field of each section varies sinusoidally with time at the frequency of the energizing source 14. By directing electrons of given velocity through the standing wave transverse electrostatic fields of the coupling section the action of the fields on the passing electrons of the stream serve to deflect the stream into a "waved" pattern.

Still referring to Figure 1, if the high-frequency energizer 14 is an independent oscillator energizing the coupling section 11, all of the output energy of the collector 12 goes to the load 13. Under these conditions, the standing wave coupler serves as an amplifier. However, by diverting part of the output of collector 12 to the coupling section 11, the standing wave coupler serves as an oscillator. In the matter of the frequency at which the oscillator will operate, it is to be remembered that a transmission line setting up standing waves is in the nature of a resonant line, and that the resulting resonant frequency is a function of the length of the resonant line, in which the fundamental or harmonic frequencies may be used.

Figure 2 shows a circuit diagram of the standing wave coupler used as an amplifier for

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high-frequency currents. The exciting oscillator 20 energizes the transmission line 22—23 of the coupling section, which includes two spaced parallel conducting members 22 and 23. The electron gun 21 directs a stream of high velocity electrons through the coupling section 22—23 as is indicated by the dotted lines. The end of the coupling transmission line 22—23 is terminated with an impedance 26 which may have an infinite or zero value in order to favor the forming of standing waves in the coupling section. High-frequency energy is collected from the waved electron stream by the collector plates 27 and 28 and the high-frequency collector circuit 24 transfers the energy to the load 25. A ground return circuit from the collector 24 to the electron gun circuit 21 is provided. The tube casing 29 permits evacuation of the air from the region through which the electron stream is directed. The standing wave formed in the coupling section of line 22—23 is represented graphically by the voltage curve shown at 30. The condenser plates 31—32 and 33—34 indicate where one-half wave length sectional fields could be set up if a series of such condensers were energized in proper phase.

By reference to Figure 2 the operation of a wave coupler using standing waves and operating as an amplifier can be made clear. The coupling section 22—23 of the transmission line is energized by the oscillator 20 and the line so terminated as to create standing waves. The electrostatic field set up between the conductors 22—23 by the stationary waves is illustrated graphically by the voltage curve in graph 30. The transmission line is shown as marked off in one-half wave lengths to correspond with the voltage curve, and the one-half wave length segments are indicated by the letters *a*, *b*, *c*, *d*, *e*, and the remainder by *f*. The primes of the above letters indicate the corresponding regions of the graph. The electron gun 21 directs a high velocity stream of electrons along the straight dotted lines shown. The voltage curve 30 shows the range of values that the standing wave goes through for a complete period or cycle. It will be observed that the zero nodes are successive stationary points at one-half wave lengths along the line, whereas the loops vary with time between maximum positive and negative values. For any given instant, say, the loop 30—*a'* will be positive, 30—*b'* negative, 30—*c'* positive, and so on throughout the coupling section used. One-half a period or cycle later, however, the polarity of the respective segments will be reversed. If a stream of charged particles is directed through the standing wave field with such a velocity that each particle traverses a one-half wave length section in one-half a period of time, the amount of deflection that a charged particle will receive for each wave length section it traverses will depend upon the phase of the standing wave at the instant of entering the wave length section. A particle, for example, entering 30—*a'* at the instant of zero phase, will be entering just as the field 30—*a'* is turning positive, and will be leaving just as it is turning negative; consequently, it will be entering the next section 30—*b'* just as it is turning positive, and similarly throughout the rest of the path. As a result, a particle entering the coupling section at the instant of zero phase will receive a maximum deflection in the positive direction. By a similar line of reasoning, a particle entering the coupling section 30—*a'* at the instant of 180°

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phase, will receive a maximum deflection in the negative direction. It follows that particles entering at the instants of 90° and 270° phase will receive zero deflection for each complete wave length traversed, since the fields in say, 30—*a'* and 30—*b'* will change polarity while the particles are traversing them, and thus substantially cancel out any deflections. Particles entering the coupling section at phase instants between those mentioned will receive intermediate amounts of deflection, so that the final emerging stream of charged particles or electrons will leave the coupling section "waved" into a sinusoidal wave form. After being waved in the coupling section, the electron stream impinges upon the collector plates 27 and 28. It will be observed that those electrons that were for the most part in the positive polarity field and were thus displaced upwards will be collected on the upper plate 27, while those that were for the most part in the negative polarity field will be collected on the lower plate 28. The result will be to alternately charge the upper and lower plates with electrons, and so energize them at a frequency which is proportionate to the number of pulses collected per second.

It is to be observed that the standing wave pattern in the coupling section 22—23 as illustrated by the standing wave graph 30 could be duplicated by the use of individual lumped impedance oscillating circuits spaced in series along the path of the electron stream. For example, the field in the section 30—*b'* could be duplicated by a pair of condenser plates 31—32 energized by an oscillating circuit. Likewise, the field in section 30—*c'* could be set up between the condenser plates 33—34 by energizing them from an oscillating circuit having the proper phase relationship. It follows that a properly spaced and energized series of such pairs of condensers would set up a series of fields approximating the standing wave field pattern set up by the coupling section of the transmission line 22—23. In comparing the two methods, it is evident that the wave propagation properties resulting from the distributed electrical constants inherent in the transmission line construction provides a simpler means of producing the desired field pattern.

Figure 3 shows a diagram of a wave coupler using standing waves when used as an oscillator. The electron gun is represented by the cathode element 40 and the plate 41, each connected in the conventional manner to energizing sources. The coupling section is formed by the spaced conductor elements 42 and 43. The electron stream is collected by the collector plates 44 and 45, and thereby energizes the collection circuit 46. The circuit 46 may be tuned to some desired frequency, and energy is fed therefrom to the load 47 and the coupling section 42—43. The connections between the coupling section 42—43 and the collector circuit 46 must be of the proper phase necessary to maintain oscillation of the wave coupler. The head end of the coupling section line 42—43 is shown open-circuited, thereby reflecting waves and creating a standing wave field along the coupling section. A ground return is provided from the circuit 46 to cathode 40 for electrons of the stream. The tube casing 48 permits the air to be evacuated from the region through which the electron stream is directed.

The operation of the wave coupled oscillator using standing waves is fundamentally the same as that of the amplifier in Figure 2. It differs

mainly in that it uses its own developed high-frequency energy to energize the coupling section. Also, the coupling section 42—43 is energized from the collector end 46, instead of from the electron gun head end. It is to be noted that a wave coupled oscillator using a traveling wave only must be so energized that the electromagnetic wave and the stream of charged particles are both moving in substantially the same direction, whereas in the wave coupled oscillator using a standing wave this restriction does not apply. With regard to the frequency at which the wave coupled oscillator operates, this can be stabilized by a proper choice of L. C. constants in the high-frequency collector circuit 44—45—46, which frequency may be the fundamental or a harmonic of the resonant line coupling section 42—43. In the diagram the electron stream from the gun 40—41 is shown as three straight dotted lines in its unexcited position, whereas the single waved dotted line indicates the waved electron stream after excitation.

Figure 4 shows a wave coupled oscillator utilizing standing waves, but in which the coupling section transmission line is depicted as of the coaxial type. The electron gun 50 directs a circular ring of electron streams into the coaxial coupling section of the transmission line which has an outer cylindrical conductor member 51 and an inner conductor member 52. The collector ring plates 53 and 54 collect the high-frequency energy and thereby energize the toroid oscillating circuit 55. The load 56 is coupled to the fields set up in the toroid by the loop 57. The coaxial line coupling section 51—52 is energized from the toroid 55 end of the line. The end of the line is shown as open-circuited, which will give the reflection of traveling waves necessary for setting up standing waves in the coupling section. For the purpose of permitting evacuation of any air in the region through which the electron stream is directed, an air tight surface can be formed by the outer coaxial member 51, the toroid 55, and the casing 58 surrounding the electron gun 50. The paths that the streams of electrons follow in their normal and in their waved form are shown by the dotted lines.

The operation of the wave coupled oscillator of Figure 4 is fundamentally similar to that of Figure 3, the main difference being that the fields used are guided by a coaxial line. High-frequency energy is collected from the waved electron stream by the ring plate collectors 53 and 54. In the matter of choice of operating frequency, the toroid 55 and the line 51—52 can be designed to operate at some particular frequency, or means employed for varying the L. C. constants of the toroid 55 and also of the length of the resonant coaxial line 51—52. As an illustration, the head end of the coaxial line 51—52 could be short-circuited by a movable piston to permit varying the length of the resonant line, proper provision being made, of course, for the entrance of the electron stream.

The above description serves to illustrate the general principles of the wave coupler when using standing waves, and particularly as applied to amplifiers and oscillators. In the illustrated coaxial type of coupling section, it was assumed that a radial pattern of electrostatic field was being generated along the coaxial line. Other patterns are known to the art, and could be used in lieu of the radial pattern, as long as the electrostatic fields thereof can act to deflect the elec-

tron stream and suitable collection means are employed.

The displacement amplitude of the waved electron stream that emerges from the coupling section will be some function of the velocity of the electrons. The amplitude of displacement will be a maximum when the electron velocity is such that an electron can traverse a wave length section of the line during the time interval of a period or cycle of the exciting frequency. Changes of electron velocity from this optimum value will result in a decrease in amplitude, due to the fact that successive fields acting upon a given electron during its passage through the coupling section may not all be of the same polarity. The displacement amplitude for given conditions of electron velocity, standing wave pattern, and coupling section length can be derived by mathematical means well known to the art.

It is to be observed that the velocity of propagation of the traveling waves along the transmission line depends upon the value of the distributed constants of the transmission line. If the propagation velocity of the transmission line is lowered, then for a given exciting frequency the corresponding space length of the wave-length along the line is likewise reduced, as is also the electron velocity required to give the maximum displacement amplitude of the waved electron stream.

In coupling sections referred to in the drawing, the dielectric medium separating the conductor members is assumed to be space. However, as long as a path is provided for the electron stream, regions of the separating dielectric can be of material substances, such as of glass. For a given spacing of conductors, the introduction of a glass dielectric would increase the capacity per unit length of the coupling section, and so modify the velocity of the propagated traveling waves, incident and reflected. It follows that the glass dielectric used could also serve for the casing of the tube, so that in effect the conductors for the coupling section could be placed outside the tube walls. In some applications of the wave coupler, this form of construction might have physical or technical advantages.

With regard to the particular form that the coupling section may assume, it is to be noted that considerable variation is possible as long as the basic requirements of an electromagnetic standing wave having an electrostatic field component capable of deflecting an electron stream are fulfilled. If the two wire transmission line and the electron stream, such as is illustrated in Figure 2, are taken as a basic element, it can be used to trace out other forms, as by displacing it laterally along a line perpendicular to the plane of the basic element pattern, or by revolving it laterally around a given line serving as an axis to create a surface of revolution. In the former case, the coupling section would have the form of two spaced parallel conducting sheets, with a moving sheet or stream of electrons directed between. In the latter case, if the axis were parallel to the transmission line element and the radius was constant, the coupling section would be similar to the concentric circular cylinders of a coaxial transmission line, substantially as illustrated in Figure 4.

I claim:

1. In a high-frequency generating system including a section of a coaxial transmission line and high velocity charged particles, said coaxial

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transmission line being adapted to set up an electromagnetic standing wave having an electrostatic field component transverse to the annular space within said coaxial line when energized by a high-frequency source, means for terminating one end of said transmission line with a resonanting chamber, means for energizing said transmission line with high-frequency energy, means for maintaining a low pressure region within said coaxial transmission line, means for directing a stream of said high velocity charged particles into said coaxial transmission line and in the field of said standing wave, whereby charged particles of the stream are deflected by fields of the standing wave, and means for collecting high-frequency energy from the deflected stream of charged particles.

2. In a high-frequency generating system including a section of a coaxial transmission line and a source of high velocity charged particles in a low pressure region, said coaxial transmission line being adapted to guide an electromagnetic wave along a given path, said section of said coaxial transmission line being open circuited at one end and terminated at the other end with a substantially toroidal shell having an annular slot therein, the outer edge of said slot being conductively joined to the outer conductor of said coaxial line, and the inner edge to the inner conductor of said coaxial line, two substantially concentric annular collector rings adapted to fit coaxially within said coaxial line, the outer annular collector ring being conductively joined to the inner conductor of the coaxial line, and the inner annular collector ring being conductively joined to the outer conductor of the coaxial line, means for directing said high velocity charged particles along said path toward said collector rings, means for maintaining a low pressure region along said path, and means for coupling a high-frequency load to said terminating toroidal shell.

3. In a high-frequency generating system including a section of a coaxial transmission line

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and a source of high velocity charged particles in a low pressure region, said coaxial transmission line being adapted to guide an electromagnetic wave along a given path, said section of said coaxial transmission line being open circuited at one end and terminated at the other end with a resonant chamber which joins the inner and outer conductors of said coaxial line, two substantially concentric annular collector rings adapted to fit within said coaxial line and having transposed connections to the inner and outer conductors of said coaxial line, means for directing said high velocity charged particles between the coaxial conductors and toward said collector rings, means for maintaining a low pressure region along said path, and means for coupling the generated high frequency energy to a load device.

4. In a high-frequency generating system including a section of a coaxial transmission line and a source of high velocity charged particles in a low pressure region, said coaxial transmission line being adapted to guide an electromagnetic wave along a given path, said section of said coaxial transmission line being open circuited at one end and terminated at the other end with a conductive toroidal shell having a substantially annular slot therein, the outer edge of said slot being conductively joined to the outer conductor of said coaxial line, and the inner edge to the inner conductor of said coaxial line, two substantially concentric annular collector rings adapted to fit coaxially within said coaxial line and having the outer annular collector ring conductively joined to the inner conductor of the coaxial line, and the inner annular collector ring conductively joined to the outer conductor of the coaxial line, means for directing said high velocity charged particles into said coaxial line and toward said collector rings, means for maintaining a low pressure region along said path, and means for coupling a high-frequency load to said terminating toroidal shell.

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