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TRAVELING WAVE COUPLER

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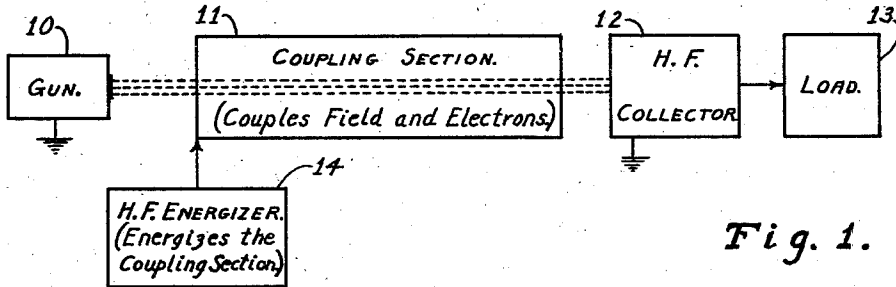


Fig. 1.

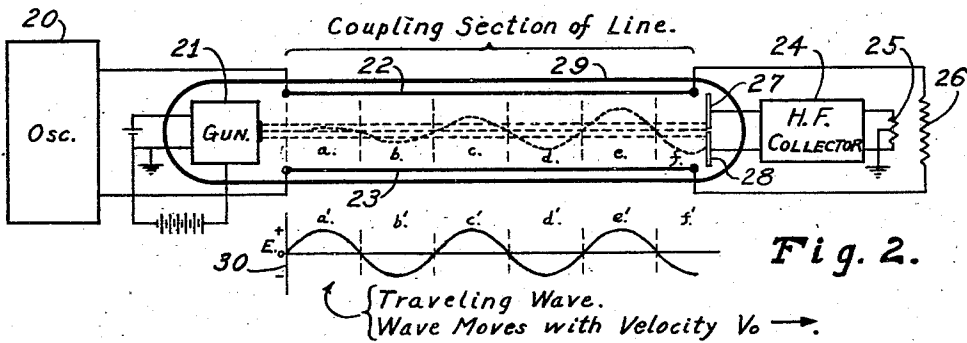


Fig. 2.

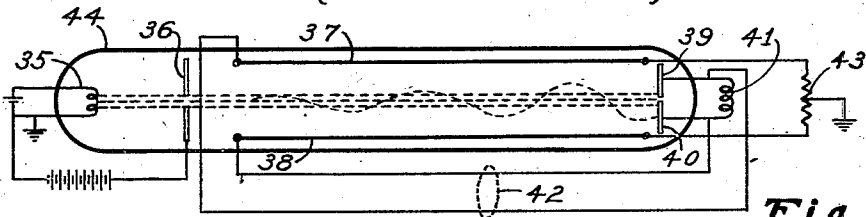


Fig. 3.

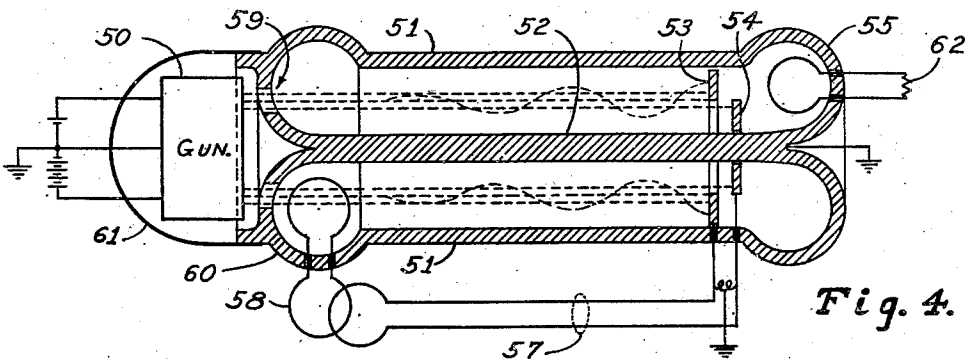


Fig. 4.

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TRAVELING WAVE COUPLER

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5 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 or grids. 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 time interval 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 lengthens the minimum oscillation period that may be applied to the 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 of generating high-frequencies at high powers, which consists essentially in directing simultaneously along a given path a suitable electromagnetic wave or field and a stream of charged particles, the orientation between the field and the stream being such as to permit deflection of the particles of the stream by the electrostatic field component of the wave. For example, a propagated electromagnetic wave may be directed along a given path, or guided by the use of a transmission line, in which the transmission line is conventionally constructed, such as by spaced parallel conducting members. Considering a transmission line constructed of two spaced parallel wires of infinite length, or what is electrically

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equivalent, terminated with a matched impedance, then a voltage disturbance applied to the head of the line will create an electrostatic field between the two wires which travels along the line in the form of an electromagnetic disturbance or wave having a given velocity. The velocity of propagation of the wave disturbance along the line depends upon the physical characteristics of the line, such as the wire diameter and the wire spacing, and the electrical properties of the wires and of the dielectric medium or media separating the wires or conducting members. Consequently, the velocity at which the electromagnetic wave is propagated along the line can be controlled by varying the properties of the line.

From the above, it follows that if a voltage of positive polarity is applied to the head of the line, that an electrostatic field of positive polarity will be propagated along the line. Similarly, if the applied voltage is of negative polarity, the electrostatic field resulting will also be of negative polarity. In general, if the head of the line is energized by an alternating voltage, the electrostatic wave moving along the line will consist of a sequence of fields of opposite polarity having a given velocity of propagation. Assuming a line thus energized with a traveling wave or field, then if a stream of charged particles is directed substantially parallel to the path of the transmission line and so positioned as to be in the field of the traveling wave and moving in the same direction, the fields of the traveling wave will act upon the charged particles to deflect them. It follows that if the velocity of the charged particles is substantially the same as the velocity of the traveling wave, the charged particles in the fields of positive polarity will be deflected one way, and those in the fields of negative polarity the other. When the traveling wave and the charged particles are both of the same velocity, it also follows that any given number of charged particles will always be in the same electrostatic field of the traveling wave, and consequently will be displaced in the same direction as long as the above conditions exist. By thus coupling the fields of the traveling wave with the stream of charged particles, each element of the stream is displaced in a direction and in an amount determined respectively by the polarity and the strength of the respective electric field of the traveling wave. The result is to produce a wave effect in the otherwise straight stream of charged particles. Once the stream of charged particles is thus "waved," it is possible to collect high-frequency energy therefrom by means well known

to the art. One such method of energy collection uses two collecting plates, one on each side of the middle position of the stream, so that when the waved stream of charged particles impinges upon the plates, it charges first one plate and then the other in alternate sequence. This alternating charging action can be used to energize an oscillating circuit.

The method of using the field of a traveling 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 traveling wave, the amplitude of deflection of the stream 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 traveling wave coupler used as an amplifier for generating high-frequency currents.

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

Figure 3 shows a diagram of a traveling 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 traveling wave coupled oscillator in which the conducting members which guide the traveling wave are shown as of the coaxial type.

Figure 1 is a block diagram showing the main elements of the 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 electrostatic field of the traveling wave and the electrons of the electron stream are coupled together, so that the wave field displaces the electrons. Block 12 represents a high-frequency collector for collecting high-frequency energy from the waved stream of 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 propagates a traveling wave of suitable mode through the coupling section 11. The high frequency energizer 14 may be an independent os-

cillator, or may be energized by the output of the high-frequency collector 12.

In the operation of the traveling wave coupler, the electron gun 10 directs a high velocity stream of electrons between the conducting members that form the transmission line of the coupling section 11. The transmission line consists of such members or medium as will serve to guide or propagate an electromagnetic wave along a given path so that the traveling wave, or transverse electrostatic field component thereof, can be coupled to the electron stream. A conventional type of transmission line consists of two spaced parallel wires. In order that a traveling wave should be formed when the transmission line is energized at the head of the coupling section, it is necessary that reflected waves be kept at a minimum. As is well known in the art, no reflected waves will occur if the transmission line is of infinite length, or if the line is terminated in a load impedance which is equal to the characteristic impedance of the line. In Figure 1, if the load impedance 13 is made equal to or matched with the characteristic impedance of the coupling section 11, the conditions of no reflection will be satisfied. By energizing the head of the coupling section 11 from an energizing source 14, an electromagnetic wave is caused to travel along the coupling section towards its terminating load. The voltages, and the fields that result, which are applied to the head of the coupling section are alternately of positive and negative polarity at some given frequency. The resulting electrostatic fields will be substantially perpendicular to the surfaces of the conducting members and perpendicular to the direction of motion of the traveling wave. By directing the electron stream in the direction of the traveling wave or between the conducting members which guide the wave, the electrons can be made to travel along the coupling section 11 at substantially the same velocity as the traveling wave, so that the traveling electrostatic field has a greatly increased interval of time to act upon and so displace the electrons laterally.

Still referring to Figure 1, if the high-frequency energizer 14 for the coupling section 11 is an oscillator, the transmission line can have a matched terminating impedance, while the output of the high-frequency collector 12 feeds directly to the load 13. Under such conditions, the apparatus is in the nature of an amplifier. If the output of the collector 12 is used to energize the transmission line, then all of the energy generated may be fed through the coupling section to the load 13 which is then matched to the transmission line, or only that amount of energy necessary to maintain the apparatus in operation may be diverted from load 13 to the coupling section. Under such conditions the apparatus is in the nature of an oscillator.

In general, the coupling section 11 is used for coupling a wave field with the electron stream in such a manner as will permit deflection of the electron stream. This application deals with the use of a traveling wave field for this purpose, but as disclosed in my application of serial #388,279, filed April 12, 1941, it is also possible to use a standing wave field.

Figure 2 shows a circuit diagram of the wave coupler used as an amplifier for 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 as is indicated by the horizontal dotted lines. The end of the coupling section 22—23 of the transmission line is terminated with a load impedance 26 matched to the characteristic impedance of the coupling section or transmission line. 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 to the gun 21 is provided for the current of the electron stream and electron gun 21. The tube casing 29 permits evacuation of the air from the region through which the electron stream is directed. The traveling wave is represented graphically by the voltage curve E shown at 30.

By reference to Figure 2 the operation of the wave coupler as an amplifier can be made clear. The coupling section of the transmission line 22—23 is energized by the oscillator 20 and the line so terminated by the load 26 as to permit traveling waves to traverse the coupling section 22—23. The electrostatic field set up by the traveling wave between the conductors 22—23 is illustrated graphically by the voltage curve E 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 *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. It is possible to make the velocity of propagation of the traveling wave and that of the electrons in the electron stream equal. The voltage curve 30 shows, for a given instant, the distribution of the fields in the traveling wave. It follows that the electrons in the segment *a* will be in a positive polarity electrostatic field, as indicated by the graph 30—*a'*. Also, the electrons in segment *b* will be in a negative polarity electrostatic field, as indicated by 30—*b'*. A similar inference can be drawn for the electrons in the remaining segments of the coupling section. Since the electrons in the segment *a* move along the line with the same velocity as the positive polarity wave pulse 30—*a'*, the electrons will be displaced more and more in a given direction as they and the wave pulse simultaneously reach successive positions along the line, such as at *c* and *e*. The electrons in a negative polarity field, as at *b* and 30—*b'*, will be displaced in the opposite direction. As a result, the electron stream will be waved into the shape indicated by the curved dotted line, which, it will be noted, tends to become graphically similar to the voltage curve E in the graph 30. 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 in the positive polarity field and thus displaced upwards will be collected on the upper plate 27, while those that were 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 energize them at a frequency which is proportionate to the number of pulses collected per second.

Figure 3 shows a diagram of the wave coupler used as an oscillator. The electron gun is represented by the cathode element 35 and the plate 36, each connected in the conventional manner to energizing sources. The coupling section is

formed by the spaced conductor elements 37 and 38. The electron stream is collected by the collector plates 39 and 40, and thereby energizes the collection circuit 41. High-frequency energy is fed from the collection circuit 41 through the line 42 to the head of the coupling section 37—38, the coupling section 37—38 being terminated in a matched load 43. A ground return is provided for the electron current. The tube casing 44 permits the air to be evacuated from the region through which the electron stream is directed.

The operation of the wave coupled oscillator is fundamentally the same as that of the amplifier in Figure 2. The variation lies in the use of the generated high-frequency energy collected in circuit 41 for energizing the coupling section 37—38. It will be noted that for the high-frequency energy to reach the load 43, it must pass from circuit 41 through the feed-back line 42 and then through the coupling section 37—38 to the load 43. Hence, all of the energy that is used in the load serves to wave the electron stream while passing through the coupling section 37—38, and so, with proper time and space phasing, maintains the device in a state of continuous oscillation. In order to stabilize the oscillations at some preassigned frequency, the collection circuit 41 may be tuned to some preassigned frequency by including the proper L. C. circuit elements. In order that oscillations may be sustained, it is necessary that the head of the coupling section 37—38 should be energized in the proper phase. The phase of the voltage delivered to the coupling section 37—38 can be readily controlled by any of the conventional phase shifting devices, and one method, easily applicable to the return transmission line 42, would be to adjust its length. The electron stream is indicated by the dotted lines and is shown in its normal state prior to being waved or deflected by the traveling wave.

Figure 4 shows a traveling wave coupler used as an oscillator, 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 feed it along the line 57 and 58 to the coupling toroid 60 at the head of the coupling section 51—52. The high-frequency terminating circuit 55 is shown as of the toroid 55 type; it is preferably matched to the coupling section 51—52 so as to reduce the setting up of reflected waves. The high-frequency energy in the toroid 55 is coupled to the load 62. The slotted openings 59 in the toroid 60 permit the electron stream to be directed into the coaxial coupling section 51—52. 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 65 coaxial tube and the casing 61 surrounding the electron gun 50. In the drawing, the electron stream is shown by the dotted lines and in its normal state prior to being waved.

The operation of the wave oscillator of Figure 70 4 is fundamentally similar to that of Figure 3, the main difference being that the traveling wave and its fields are guided by a coaxial line. High-frequency energy is collected from the electron stream by the ring plate collectors 53 and 54. This energy is fed back to the head of the cou-

pling section 51-52 by the transmission line 57 and 58, which is shown as of the two wire construction type. Obviously, the return line 57-58 could be of coaxial construction also, if desired. If symmetry of construction was desired, it would be possible to have one coaxial line inside of and concentric with the other, one serving as the coupling section, and the other as the return line. In the Figure 4 diagram, the ring collector plates 53 and 54 are placed in the coupling section 51-52, but if desired could be placed outside the toroid 55 by providing suitable slots in the toroid 55 for the electron stream to pass through, and by enclosing the collector rings in an air-tight casing. One advantage of such a construction would be to simplify the matching of the coupling section 51-52 to the toroid 55 and the load 62.

The above description serves to illustrate the general principles of the wave coupler when using traveling 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 propagated along the coaxial line. Many other patterns or modes are known to the art, and could be used in lieu of the radial pattern, as long as the electrostatic fields thereof can act upon the electron stream to deflect it, and if suitable collection means are employed.

For simplicity, it has been assumed that the velocities of propagation of the wave along the transmission line and that of the electron stream were equal, but this is not a necessary restriction. When the wave velocity and the electron velocity are equal, the coupling section can be of any length, and the total displacement of any displaced electron segment will be proportional to the coupling section length and the strength of the displacing field acting upon the electrons. If the electron velocity differs from that of the traveling wave, and the coupling section is long enough to permit a point of one shift one wave length (or an integral number of wave lengths) with respect to the other, it follows that the positive and negative polarities of the fields acting upon such electrons will in effect cancel one another, so that the emerging electron stream will not be waved. If differing velocities are used, it is preferable that the total shift resulting should not exceed one-half wave length, in order to prevent total or partial cancellation of the effectiveness of the acting fields.

In the 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 wave. 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 traveling 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 them. In the latter case, if the axis line was parallel to the transmission line elements 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 moving in a low pressure region, said coaxial transmission line being adapted to guide an electromagnetic traveling wave along a given path, means for energizing said section of said coaxial transmission line from a high-frequency energizing source to form a traveling wave having a transverse electrostatic field component along said path, means for maintaining a low pressure region along said path, means for directing said high velocity charged particles along said path and in the field of said electromagnetic wave, whereby charged particles of the stream are deflected by fields of the traveling wave, and means for collecting high-frequency energy from the deflected stream of charged particles.

2. In a high-frequency system including a coaxial transmission line and a stream of high velocity charged particles moving in a low pressure region, said coaxial transmission line comprising at least two dissimilar media adapted to guide an electromagnetic wave along a given path, means for maintaining a low pressure region along said path, means for exciting said coaxial transmission line with high-frequency energy, means for impedance matching at least one end of said coaxial transmission line to permit a flow of high-frequency energy along said line in the form of a traveling electromagnetic wave, said electromagnetic wave having an electrostatic field component substantially transverse to said path, means for directing said stream of high velocity charged particles along said path and in the field of said electromagnetic wave, whereby charged particles of the stream are deflected by fields of said wave, and means for collecting high-frequency energy from the deflected charged particles of the stream.

3. 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 terminated at each end by a conductive toroidal shell having an annular slot therein, the outer edge of each toroidal shell being conductively joined to the outer conductor of the said coaxial line, and the inner edge of each toroidal shell being conductively joined to the inner conductor of said coaxial line, one of said toroidal shells having at least one opening adapted to permit the directing of a stream of charged particles along said path and in the annular space within said coaxial line, two concentric annular collector rings adapt-

ed to fit coaxially within said coaxial transmission line and insulated therefrom, 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, means for energizing said coaxial transmission line with high-frequency energy, and means for collecting high-frequency energy from said annular collector rings.

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 terminated at each end by a conductive toroidal shell having an annular slot therein, the outer edge of each toroidal shell being conductively joined to the outer conductor of the said coaxial line, and the inner edge of each toroidal shell being conductively joined to the inner conductor of said coaxial line, one of said toroidal shells having at least one opening adapted to permit the directing of a stream of charged particles along said path and in the annular space within said coaxial line, two concentric annular collector rings adapted to fit coaxially within said coaxial transmission line and insulated therefrom, 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, means for collecting high-frequency energy from said annular collector rings, means for energizing said coaxial transmission line with said collected high frequency energy, and means for coupling a high-frequency load to one of said toroidal shells.

5. 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 terminated at each end by a matched resonating chamber, one of said resonating chambers having at least one opening adapted to permit the directing of a stream of charged particles along said path and in the annular space within said coaxial line, two substantially concentric annular collector rings adapted to fit coaxially within said coaxial transmission line and insulated therefrom, means for energizing said coaxial transmission line with high-frequency energy, 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 collecting high-frequency energy from said annular collector rings.

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