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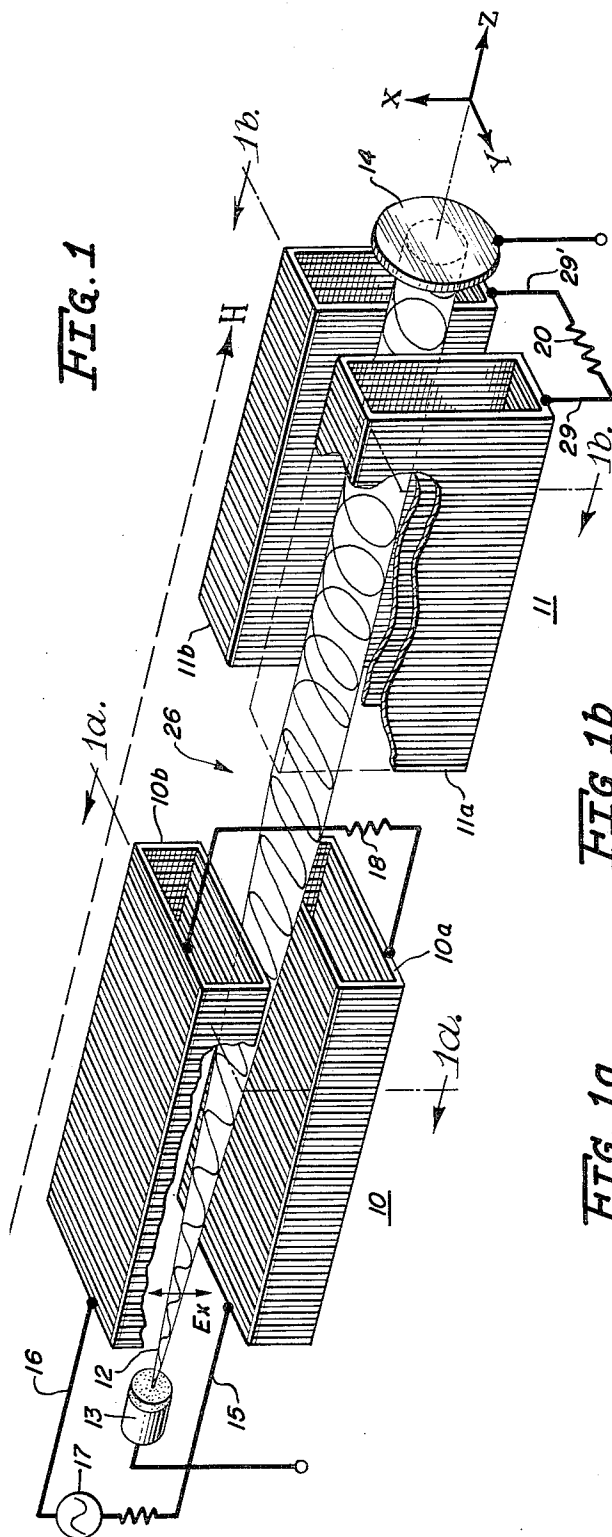
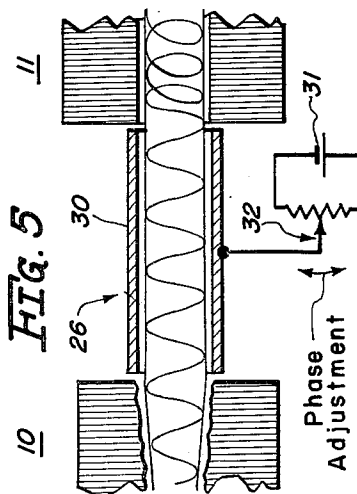
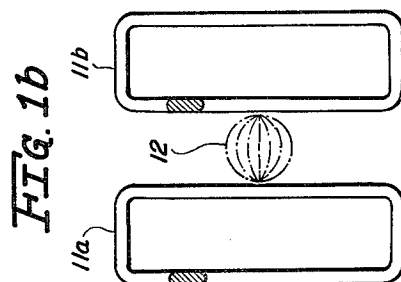
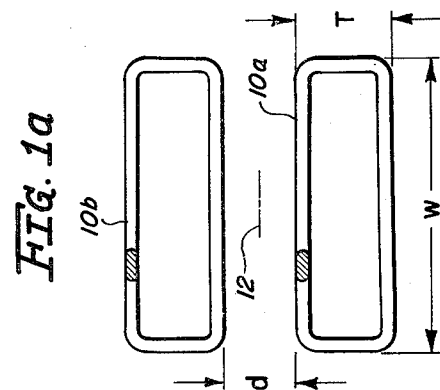
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ELECTRON BEAM DEVICES

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2 Sheets-Sheet 1



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ELECTRON BEAM DEVICES

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9 Claims. (Cl. 315—3)

This application is a continuation-in-part of the co-pending application of Robert Adler, Serial No. 119,931, filed June 27, 1961, for Electron Beam Amplifiers and Apparatus Therefor and assigned to the same assignee.

The present invention pertains to electron beam devices and more particularly to devices of the synchronous wave type.

That application specifically describes apparatus which interacts with and amplifies fast or slow cyclotron waves or, alternatively, synchronous waves. The detailed characteristics of synchronous waves are described in an article entitled "Waves on a Filamentary Electron Beam in a Transverse-Field Slow-Wave Circuit" by A. E. Siegman and appearing in the Journal of Applied Physics, volume 31, No. 1, pages 17-26 for January 1960. Synchronous wave energy appears in two different forms, the positive-energy carrying wave and the negative-energy carrying wave, measured with respect to the energy of an undisturbed drifting electron beam; for simplicity, these two waves will be referred to hereinafter as the positive and negative synchronous waves. A major difference between cyclotron and synchronous waves is that both forms of synchronous waves have the same phase velocity. Therefore, amplifiers of the synchronous wave type have unique design requirements.

It is a major object of the present invention to provide new and improved synchronous wave electron beam amplifiers.

A specific object of the present invention is to provide an amplifier of the above type having a wide frequency bandwidth.

A related object of the invention is to provide a new and improved phase shifter for electron beam waves of finite phase velocity.

Another object of the invention is the provision of a device for selectively coupling to synchronous waves on an electron beam.

In accordance with the above objects, a synchronous wave signal energy amplifier comprises means for projecting a stream of electrons along a predetermined axis and means for producing a magnetic field aligned parallel to that axis. An input coupler responsive to input signals produces an electric field aligned in a predetermined direction transverse to the axis and which has a velocity of propagation, in a direction parallel to the axis, substantially equal to the velocity of the electron stream to develop a beam synchronous wave representing the input signals. Output coupling means are provided for deriving amplified input signal energy from the synchronous wave energy on the electron stream.

In accordance with another aspect of the invention, a synchronous wave electron coupler associated with a magnetic field of predetermined polarity couples energy selectively to either a positive or negative synchronous wave on an electron stream. The coupler comprises means for projecting the stream of electrons along a predetermined axis at a predetermined velocity. A wave propagation circuit is coiled to helically encircle the electron stream and produces, in response to an input signal, a positive circularly polarized wave having a first phase velocity and a negative circularly polarized wave having a second phase velocity. The circuit couples energy to the positive synchronous wave on the electron stream when the stream velocity is equal to the second phase

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velocity and to the negative synchronous wave when the electron stream velocity is equal to the first phase velocity.

In yet another aspect of the invention, a wave-signal phase shifter comprises means for projecting a stream of electrons along a predetermined axis and means for producing a magnetic field parallel to the axis. An input coupler, having signal energy input means, produces an electron wave having a finite phase velocity at a predetermined frequency. An output coupler derives signal energy from the electron stream at the predetermined frequency. Means adjustable during operation of the phase shift intermediate the input and output couplers selectively controls the phase of the output signal with respect to the input signal.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is a perspective diagrammatic view, partially cut away, of a synchronous wave signal energy amplifier constructed in accordance with the invention;

FIGURE 1a is a sectional view taken along line 1a—1a of FIGURE 1;

FIGURE 1b is a sectional view taken along line 1b—1b of FIGURE 1;

FIGURE 2 is a graph useful in understanding the operation of the device of FIGURE 1;

FIGURES 3 and 4 are vector representations of the synchronous waves in the device of FIGURE 1;

FIGURE 5 is an enlarged fragmentary view of a portion of the device of FIGURE 1 modified to operate as a phase shifter; and

FIGURE 6 is a diagrammatic perspective view of another embodiment of the invention.

Referring to FIGURE 1, the device includes an input coupler 10 having rectangularly shaped halves 10a and 10b and an output coupler 11 having rectangularly shaped halves 11a and 11b. Each coupler half is identical in construction and is formed of a single conductor wound in a helical pattern. The opposing flat portions of each coupler half are placed parallel to each other on opposite sides of a Z axis (shown by the dashed line) along which a stream of electrons 12 is projected from a cathode 13 to a collector 14. Couplers 10 and 11 are biased to proper D.C. potentials for maintaining the electron stream at a predetermined velocity. Signal-energy input means includes an input signal source 17 connected to coupler halves 10a and 10b by conductors 15 and 16, respectively. An impedance 18 terminates the remote end of input coupler 10. From the respective halves of output coupler 11, conductors 29 and 29' are connected across an external load 20. In practice, the couplers are disposed in an evacuated envelope.

Electron stream 12 is subjected to a longitudinal magnetic field indicated by arrow H and which is parallel to the Z axis. It is usually most convenient to develop the magnetic field by means of a solenoid (not shown) within which the tube envelope is contained.

As shown in FIGURE 1, the electron stream follows a path along the Z axis of a Cartesian coordinate system which also contain transverse axes X and Y. These directions will be referred to throughout the remainder of this application.

Input coupler 10 produces an electric field transverse to the Z axis and which travels or propagates along that axis. More specifically, an electric field E_x (in the X direction) is produced across the axis, and substantially

all electric field vectors throughout coupler 10 lie in the X-Z plane. In other words, the electric field near the axis is linearly polarized. The electric field E_x varies in accordance with the frequency of signal source 17. The number of turns per inch of the windings, and the length of each turn, are the major factors which determine the velocity of propagation of the electric field along the Z axis.

In order to achieve the synchronous mode of operation required by the invention, the phase velocity of the electric field E_x is made substantially equal to the velocity of the electron stream 12 along the Z axis. The electron stream velocity is determined by the potential of coupler 10 with reference to cathode 13. In any case, coupler 10 must be designed to propagate electromagnetic waves at a velocity less than that of light, since the electron stream and consequently the synchronous wave can never reach that velocity.

The use of a linearly polarized electric field traveling synchronously with the electron stream causes the input signal from source 17 to produce on the stream a linearly polarized synchronous wave in the Y-Z plane. As shown in FIGURES 1 and 1a, this wave takes the form of a sine wave of gradually increasing amplitude, assuming a sinusoidal signal input. The wave lies in the Y-Z plane, having negligible amplitude in the X direction. With this stream configuration, no energy is supplied to the electron stream by the input signal, since work could be done on the stream by the electric field only if electrons were displaced in the direction of the electric field, i.e., in the X direction.

The linearly polarized wave may be explained in conjunction with FIGURE 3 which shows two vectors 21 and 22 rotating in opposite directions, as indicated by the arrows, with a frequency equal to that of the input signal; each of the vectors has an amplitude equal to one-half the maximum amplitude of the total synchronous wave. The rotating vectors have a vectorial sum only in the Y direction; the X directed components cancel each other. Thus a plane or linearly polarized wave is produced when the electric field of coupler 10 excites positive and negative synchronous waves of equal amplitude and frequency. These two waves carry equal and opposite amounts of kinetic power; the total power transferred to the stream in coupler 10 is zero.

The linearly polarized synchronous wave is produced by the combined action of electric field E_x in the X direction and magnetic field H in the Z direction. An alternative description of the process which occurs in the input coupler is as follows: because the stream travels in the Z direction at the same velocity as the electric field E_x , each electron is subjected to a continuous force in the X direction corresponding to the specific field intensity E_x at its position in the stream. In accordance with the well-understood behavior of electrons in crossed electric and magnetic fields, the electron moves in the Y direction with a velocity

$$V_y = \frac{E_x}{B}$$

Combined with the original velocity V_z along the Z axis, the electron thus moves along a straight line at an angle with the Z axis. The sinusoidal character of E_x with respect to distance brings about a corresponding sinusoidal electron pattern in the Y-Z plane.

Output coupler 11, downstream of the input coupler, derives energy from electron stream 12. In the preferred embodiment shown in FIGURE 1, it is similar to coupler 10 in construction except as to length but is rotated about the Z axis 90 degrees with respect to the input coupler. The significance of this 90 degree rotation will be explained below.

The linearly polarized synchronous wave, upon leaving input coupler 10, has its excursions in the Y direction. As this wave enters output coupler 11, it induces a current in coupler 11 which in turn generates a field in the

Y direction. This field then, in conjunction with magnetic field H, displaces the individual electrons in the X direction by a process similar to that discussed in connection with input coupler 10. However, the coupler field cannot change the electron displacement along the Y axis since it produces a force on the electrons only in the X direction.

The interaction in coupler 11 of the electric field generated by the induced current with the linearly polarized wave decreases the total drift energy of the electron stream. The coupler delivers output signal energy which is proportional to the energy loss caused by the decrease in drift energy. That output energy would be equal to the lost drift energy, were it not for ohmic losses.

Rotation of coupler 11 by 90 degrees with respect to coupler 10 permits it to respond to the electron wave in the Y-Z plane. Motion strictly in the X direction would not be detected by output coupler 11 since no current could be induced. Of course, some deviation from a 90 degree angle of rotation may also yield satisfactory coupling.

The electric field in coupler 11 interacts with the linearly polarized synchronous wave to transform this wave into a substantially circularly polarized negative synchronous wave as the wave enters collector 14. Since the wave is moving forward, it forms a helical pattern. FIGURE 1b illustrates the gradual change from a linear pattern through successive elliptical patterns into a circular pattern. From a vectorial point of view, referring to FIGURE 4, the final circularly polarized wave may be represented by a single negative synchronous wave vector 21'. In the amplification process the positive synchronous wave is stripped off of the stream by coupler 11 and the negative synchronous wave doubles its amplitude as shown in FIGURE 4. The circular polarization of the stream wave corresponds to a specific length of output coupler 11. Actually, the final wave shape may be elliptical. In that case, the vector diagram of FIGURE 4 would contain an additional smaller vector, representing a positive synchronous wave component, which would represent the formation of an elliptical locus.

The physical structure of output coupler 11 is determined by the same broad requirements as that pertaining to input coupler 10, i.e., it must respond to a linearly polarized electric field having a velocity of propagation substantially equal to the velocity of electron stream 12. In the preferred embodiment, couplers 10 and 11 are identical, except possibly for length, only for purposes of constructional simplicity.

The transformation from a linearly to a circularly polarized wave results in amplification of the input signal. This amplification mechanism can best be explained in conjunction with the graph of FIGURE 2. The left hand portion of FIGURE 2 represents the displacements off the Z axis, or amplitudes, of the positive and negative synchronous waves in the input coupler region of FIGURE 1. The right hand portion of the graph indicates the synchronous wave displacements or amplitudes in the output coupler region. This graph also depicts power, since the kinetic power of a synchronous wave is proportional to the square of the wave displacement or amplitude. The abscissa represents distance along the Z axis and the ordinate represents wave-displacement amplitudes, the convention chosen displaying waves with positive kinetic power above the Z axis and waves with negative kinetic power below the Z axis. In addition, the sketch shows the voltage present in the circuits of the couplers.

Initially at zero Z distance, no synchronous wave exists on the electron stream. When an input signal of constant amplitude is impressed on coupler 10, the voltage level in the coupler is uniform throughout and is indicated by line 23. This input signal causes a linear growth of the amplitude of both the positive synchronous wave 24 and the negative synchronous wave 25 until the field free

drift space 26 is reached where there is no further change in amplitude. Both synchronous waves have equal amplitudes throughout the input coupler region and the net power impressed on the stream is zero.

As the two synchronous waves reach the output coupler region, a Y-directed electric field is generated across coupler halves 11a and 11b, the field increasing linearly with distance. Coupling energy equally to both waves, this field causes a parabolic decrease in the amplitude of positive synchronous wave 24 from the previous level indicated by the dashed line, and also simultaneously causes a parabolic increase in amplitude (in the negative direction) of negative synchronous wave 25 from the dashed reference line. These two changes both correspond to a loss of power from the stream; a corresponding power output appears in the circuit of output coupler 11. The total power delivered to the output coupler is the sum of the power lost by the positive synchronous wave and the (negative) power gained by the negative synchronous wave. If the electron stream leaves the output coupler region at a point marked P in FIGURE 2, the amplitude of the positive synchronous wave will be reduced to substantially zero and the negative synchronous wave will be approximately doubled, in agreement with the previous discussion of FIGURE 4.

The length of output coupler 11 may be varied from the value shown in FIGURE 2. If the length of the coupler is increased, the positive synchronous wave varies as shown by extension 28 in FIGURE 2. The dashed construction indicates that it does not actually become negative, but merely reverses in phase. The power of the positive wave must always remain positive. Thus, increased gain may be achieved by increasing the length of coupler 11 past point P, until limits are incurred by undesirable side effects.

The double-helix coupler of the preferred construction eliminates fringe distortion of the electric field because of its two parallel surfaces. However, couplers of other configuration may be used with satisfactory results.

The following dimensions of the coupler shown in FIGURE 1a achieve exemplary performance when used in the present invention:

Helix width	W=.120 inch
Helix thickness	T=.040 inch
Distance between the two inner surfaces of the helices	d=.030 inch
No. turns of helix per inch	36

With a signal frequency of 3000 megacycles per second, the characteristic impedance of the helices is approximately 250 ohms. The ratio of phase velocity of the coupler to the speed of light is 0.07.

The gain of the amplifier, the output coupler of which terminates at point P, is given by the following expression.

$$\text{Power Gain} = \frac{1}{4} \frac{\omega \text{ sig.}}{\omega \text{ cyc.}} \frac{L^2 Z_O}{d^2 Z_B}$$

where $\omega \text{ sig.}$ is signal frequency, $\omega \text{ cyc.}$ is cyclotron resonance frequency, d is the distance between the two helices, L is the length of input coupler 10, Z_O is the characteristic impedance of the helices, and Z_B is the stream impedance. This equation is applicable only for the special condition described above.

In solving for a typical numerical gain, the ratio of $\omega \text{ sig.}$ and $\omega \text{ cyc.}$ can be assumed to be 1, $L=3$ inches, $d=.03$ inch, $Z_O=250$ ohms. Z_B is defined as the ratio of D.C. stream voltage to D.C. stream current. A typical value of Z_B is 30,000 ohms. Substituting the above values in the equation yields a power gain of approximately 21.

In operation, an input signal is amplified as described above and may vary in frequency from the special design frequency by a very large ratio. The enormous bandwidth of this device is achieved because of the fact that the

couplers maintain their characteristic phase velocity throughout the large frequency range.

Another feature of the present invention lies in the use of a phase shifting device for adjusting the phase between the output and input signals. As shown in FIGURE 5, a metal cylinder 30 is located intermediate couplers 10 and 11 and encompasses a portion of linearly polarized synchronous wave 12 in drift space 26. A variable unidirectional voltage is applied to cylinder 30 by a battery 31 and a potentiometer 32. The phase shift is achieved by varying the electron stream drift velocity.

The wavelength of the synchronous stream wave is directly proportional to drift velocity and, therefore, an incremental change in velocity causes an incremental change in wavelength in the drift space, resulting in a phase shift. The amount of phase shift, which is achieved by a given incremental increase or decrease of the voltage on cylinder 30, is proportional to the length of cylinder 30 along the Z axis and to the frequency of stream wave 12. In other words, the larger the number of cycles of stream wave 12 which are contained within cylinder 30 at any given time, the larger the phase shift for any given incremental voltage change.

Electron coupler 10 may also be modified to selectively couple energy to either a positive or negative synchronous wave on electron stream 12. As shown in FIGURE 6, an electron coupler 10' includes D-shaped halves 10'a and 10'b which are twisted about a Z axis along which is projected an electron stream generated by a cathode 13 and collected by an anode 14 similar to FIGURE 1. An input signal from source 17' is applied to one end of coupler 10' and a load resistance 20' is provided at its other end. A longitudinal magnetic field H is disposed along the Z axis.

As disclosed in copending application Serial No. 119,931, mentioned above, an electron coupler must be constructed to interact in two coordinate directions to selectively couple to a synchronous wave on an electron stream. Coupler 10 as shown in FIGURE 1 interacts only in one dimension throughout its length and thus couples equally to both positive and negative synchronous waves. To describe the action of coupler 10 in a more specific manner, the input signal wave which is propagated down the coupler circuit can be considered to be composed of positive and negative circularly polarized waves which may be represented as counter rotating vector components, as discussed above, each of which couple equally to respective synchronous waves on the electron stream.

The required interaction in two transverse directions is achieved in coupler 10' by modifying the coupler to give it at least one complete twist about the Z axis—that is, a twist of at least 360 degrees as illustrated by the distance $Q_1 Q_2$. The change from a rectangular to a D-shaped coupler half is for constructional purposes. The twisting of the coupler causes a variation in the phase velocities of the positively and negatively polarized circuit wave components of the input signal. Since one vector component is rotating in a positive direction and the other vector component is rotating in a negative direction, the direction of twist will either add to or subtract from the positive and negative waves. More specifically, when these circuit waves are viewed from a non-rotating reference frame, the phase velocity of one of the waves increases since the same number of wavelengths is now stretched over a longer distance because of the twist of the circuit. The other wave, correspondingly, will have a decreased phase velocity. For one major turn of the coiled propagating circuit, the number of wavelengths seen from the non-rotating reference frame decreases or increases by one, depending on the sense of polarization of the wave.

A circuit wave will couple to a synchronous wave on an electron stream only if the phase velocities are equal. In the case of the twisted coupler shown in FIGURE 6, the electron stream sees the two circuit waves with effective

tive phase velocities equal to those observed in a non-rotating reference frame, as discussed above. It is therefore possible for the stream to couple selectively to one or the other of the two waves. Because each of the two circuit waves has a specific sense of circular polarization, positive or negative, it can couple only to the synchronous wave having equal polarization: in the notation of the above-mentioned Siegman article, the positive circularly polarized circuit wave will couple only to a negative synchronous wave on the electron stream, provided their phase velocities are equal, and the negative circularly polarized circuit wave will similarly couple only to a positive synchronous wave.

The condition required for coupling can also be expressed in terms of wavelengths. The synchronous wavelength is the one observed in a non-rotating coordinate system or on the electron stream. If, on the other hand, one follows the twist of the circuit, a different wavelength is observed which is referred to as the physical wavelength. For effective coupling, the pitch of the coiled propagation circuit must be chosen to satisfy the following expression:

$$N_s = N_p \pm 1$$

where N_p is the number of physical wavelengths (measured by following the twist of the circuit) on one major turn of the circuit (the distance $Q_1 Q_2$ of the coiled helix) and N_s is the number of synchronous wavelengths on the electron stream within a corresponding distance. The sign in the above equation is determined by the sign of the synchronous wave to which one desires to couple.

The device just described can be employed in a traveling wave tube for amplifying negative synchronous waves. Its operation is similar to that of known traveling wave tubes in that interaction between the electron stream and the circuit wave on the helix causes a net transfer of energy from the electron stream to the load.

In the case of selective coupling to the positive synchronous wave, there is a periodic interchange of energy between the circuit wave on the helix and the positive synchronous wave on the electron stream. This phenomenon is analogous to the well-known Kompfer dip mechanism.

Thus, the present invention provides new and improved synchronous wave amplifiers of two related types, one of which is non-selective between positive and negative synchronous wave, and the other of which is selective. The non-selective amplifier exhibits very wide bandwidth and may be modified to shift the phase of its output signal with respect to the input signal.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A synchronous wave signal energy amplifier comprising:

means for projecting a stream of electrons along a predetermined axis;

means for producing a magnetic field aligned parallel to said axis;

input coupler means responsive to input signals for producing an electric field aligned in a predetermined direction transverse to said axis and having a velocity of propagation, in a direction parallel to said axis, substantially equal to the velocity of said electron stream to develop on said beam a synchronous wave representative of said input signals;

and output coupling means for deriving amplified input signal energy from the synchronous wave energy on said electron stream.

2. A synchronous wave signal energy amplifier comprising:

means for projecting a stream of electrons along a predetermined axis;

means for producing a magnetic field aligned parallel to said axis;

input coupler means responsive to input signals for producing an electric field aligned in a predetermined direction transverse to said axis and having a velocity of propagation, in a direction parallel to said axis, equal to the velocity of said electron stream to develop on said beam a synchronous wave representative of said input signals;

and output coupler means, having its stream interaction field aligned in a direction transverse to said axis and rotated about said axis substantially 90° with respect to the field of said input coupler means, for deriving amplified input signal energy from the synchronous wave energy on said electron stream.

3. A synchronous wave signal energy amplifier comprising:

means for projecting a stream of electrons along a predetermined axis;

means for producing a magnetic field aligned parallel to said axis;

first coupling means, including signal energy input means, for producing an electric field aligned transverse to said axis and creating on said stream a linearly polarized synchronous wave corresponding to said signal energy and said magnetic field;

and second coupling means, downstream of said first coupling means and having its interaction field aligned transverse to said axis but rotated about said axis substantially 90° from said field produced by said input coupler, for interacting with said linearly polarized synchronous wave to decrease the total drift energy of said electron stream, said coupling means delivering output signal energy which is proportional to the energy loss caused by the decrease in drift energy.

4. A synchronous wave signal energy amplifier, in which an electron stream is projected along a Z axis of a Cartesian coordinate system, comprising:

means for projecting said stream of electrons along said Z axis;

means for producing a magnetic field aligned in the direction of said Z axis;

first coupling means, including signal energy input means, for producing an electric field aligned transverse to said Z axis in the X direction and creating on said stream a synchronous wave linearly polarized in the Y-Z plane and corresponding to said signal energy and said magnetic field;

and second coupling means, downstream of said first coupling means and having its interaction field aligned transverse to said Z axis in the Y direction and rotated in the X-Y plane substantially 90° from the field produced by said input coupler, for interacting with said linearly polarized synchronous wave to decrease the total drift energy of said electron stream, said coupling means delivering output signal energy which is proportional to the energy loss caused by the decrease in said drift energy.

5. A synchronous wave signal energy amplifier, in which an electron stream is projected along a Z axis of a Cartesian coordinate system, comprising:

means for projecting said stream of electrons along said Z axis;

means for producing a magnetic field aligned in the direction of said Z axis;

first coupling means, including signal energy input means, for producing an electric field aligned transverse to said Z axis in the X direction and creating on said stream a synchronous wave linearly polarized in the Y-Z plane and corresponding to said signal energy and said magnetic field;

and second coupling means, downstream of said first coupling means and having its interaction field trans-

verse to said Z axis in the Y direction and rotated in the X-Y plane substantially 90° from the field produced by said input coupling means, for interacting with said linearly polarized synchronous wave to transform said wave to a substantially circularly polarized negative synchronous wave to decrease the total drift energy of said electron stream, said coupling means delivering output signal energy which is proportional to the energy loss caused by the decrease in said drift energy.

6. A wave-signal phase shifter comprising:

means for projecting a stream of electrons along a predetermined axis;

means for producing a magnetic field aligned parallel to said axis;

input coupler means having signal energy input means for producing on said electron stream an electron wave having a finite phase velocity at a predetermined frequency;

output coupler means for deriving output signal from said electron stream at said predetermined frequency;

and means adjustable during operation of the phase shifter intermediate said input and output coupler means for selectively controlling the phase of said output signal with respect to that of said input signal.

7. A synchronous wave-signal phase shifter comprising:

means for projecting a stream of electrons along a predetermined axis;

means for producing a magnetic field aligned parallel to said axis;

input coupler means having signal energy input means for producing on said electron stream a synchronous wave at a predetermined frequency;

output coupler means for deriving output signal from said electron stream at said predetermined frequency;

and means adjustable during operation of the phase shifter intermediate said input and output coupler means for selectively changing the drift velocity of said electron stream to controllably shift the phase of said output signal with respect to that of said input signal and in an amount proportional to the magnitude of drift velocity change selected at any given time.

8. A synchronous wave electron coupler, associated with a magnetic field of predetermined polarity, for coupling energy selectively to either a positive or to a negative synchronous wave on an electron stream, comprising:

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means for projecting a stream of electrons along a predetermined axis at a predetermined velocity; and

a wave propagation circuit coiled to helically encircle said electron stream and producing, in response to an input signal, a positive circularly polarized wave having a first phase velocity and a negative circularly polarized wave having a second phase velocity with said circuit coupling energy to a positive synchronous wave on said electron stream when said stream velocity is equal to said second phase velocity and to a negative synchronous wave when said stream velocity is equal to said first phase velocity.

9. A synchronous wave electron coupler, for coupling energy selectively to either a positive or to a negative synchronous wave on an electron stream projected along the axis of a longitudinal magnetic field of predetermined polarity, comprising:

means for projecting a stream of electrons along a predetermined axis; and

a wave propagation circuit, including input signal means, twisted to helically encircle said electron stream axis and having a pitch which produces the following equality:

$$N_s = N_p \pm 1$$

where N_p is the number of physical wavelengths at the input signal frequency between corresponding adjacent points of said twisted propagation circuit and N_s is the number of synchronous wavelengths on said stream corresponding to the distance between said adjacent points, the sign in the above equation depending on whether said circuit couples to said positive or to said negative synchronous wave.

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