

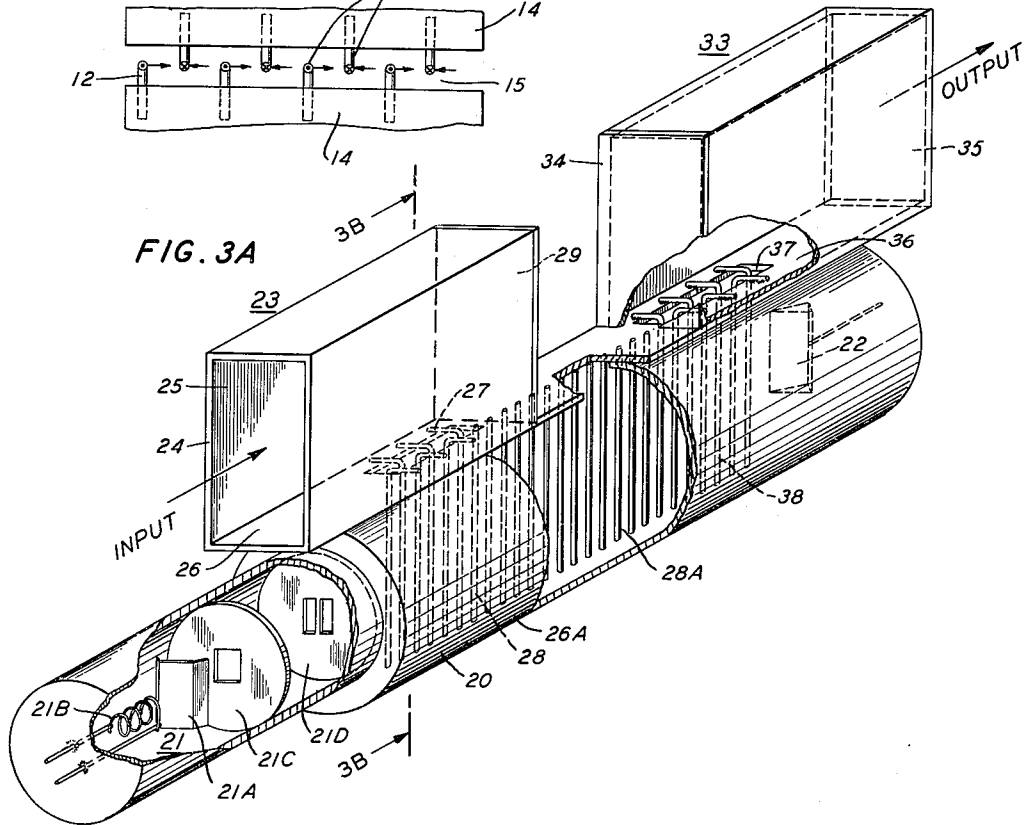
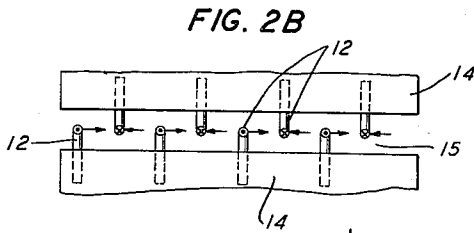
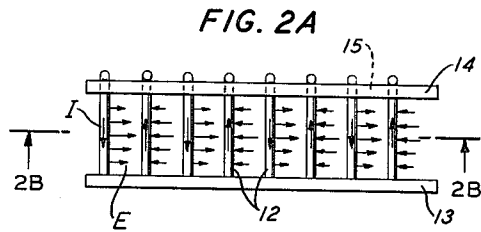
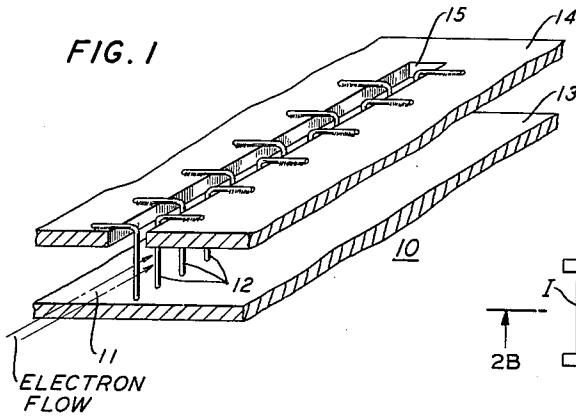
May 15, 1956

L. R. WALKER
DEVICE FOR COUPLING BETWEEN FREE
SPACE AND AN ELECTRON STREAM

2,746,036

Filed March 25, 1952

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3B

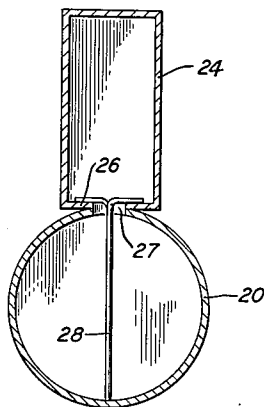
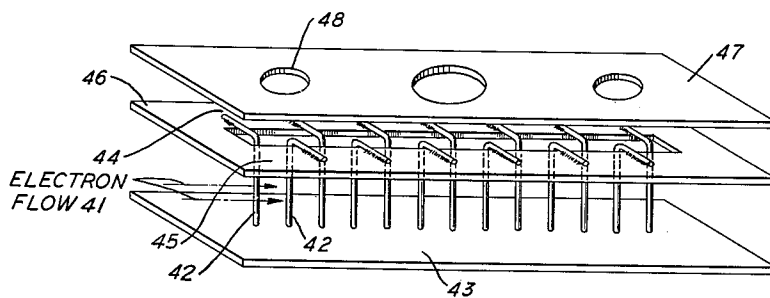


FIG. 4



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DEVICE FOR COUPLING BETWEEN FREE SPACE AND AN ELECTRON STREAM

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Application March 25, 1952, Serial No. 278,322

18 Claims. (Cl. 343—100)

This invention relates to microwave apparatus. In a particular aspect, the invention relates to coupling arrangements for energy transfers between electron streams on which are traveling space charge waves, as alternating current modulation components, at the velocity of the electron stream and wave transmission circuits in which electromagnetic waves are propagating at approximately the velocity of light.

There has been developed in recent years a number of space charge devices which utilize for amplification the growth of space charge waves in an electron stream. In these devices, velocity modulations are applied to the electron stream by input signal waves and the excitation is propagated along the stream as space charge waves. Various expedients are thereafter employed for the amplification of these space charge waves, as for example, the use of electron streams with distributed or different velocities.

In such space charge devices, it is important to secure over the frequency range of operation efficient coupling between the electron stream and the signal input and output wave members which are coupled thereto for exciting initially the space charge waves and abstracting the amplified output waves, respectively. Such devices generally involve conversions between waves traveling on the electron stream at electron stream velocities and waves traveling in wave transmission members at substantially the free space wave velocity which generally is appreciably faster than the electron stream velocities. For example, it is common to employ, as the input and output wave transmission elements, wave guides which are continuations of a wave transmission system and through which electromagnetic waves propagate at velocities comparable to the velocity of light. In such cases, it becomes necessary to introduce transducers for energy exchanges between the electron streams and the wave guides.

Various arrangements have been utilized hitherto for effecting these desired energy transfers. Generally, these have involved elements which are critical in geometry and positioning. Typical are the helix type transducers which involve wire conductors wound helically at a predetermined pitch with dimensions related to the operating frequency range. Such transducers do not lend themselves to efficient large scale fabrication and assembly, particularly at the higher radio frequencies.

Accordingly, one object of this invention is to provide microwave transducers for such energy transfers which can be made and assembled conveniently and with uniformity.

In a microwave transducer in accordance with the invention, a wall surface of a wave transmission member, through which are propagating electromagnetic waves, is slotted in a direction transverse to the current flow induced in the wall surface by the propagation of waves through the transmission member. Spaced conductive elements in a linear array along the slot extend between this wall surface and a conductive base member positioned opposite thereto, successive elements of the linear

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array being connected on opposite sides of the slot in the wall surface. Then, the electron stream to be coupled is projected contiguous to and along the linear array. The separations and lengths of the conductive elements and the average velocity of the electron stream are adjusted to secure interaction between the electron stream and the fields associated with the conductive elements.

In a specific illustrative embodiment for coupling an electron stream to a transverse electric wave traveling in a rectangular wave guide, one of the narrow side walls of the wave guide is slotted parallel to the direction of wave propagation, and successive wire elements, each approximately a half wave-length long extend across the electron stream, spaced apart therealong approximately half an electronic wavelength. Electronic wavelength is the distance between corresponding phases of two consecutive cycles of a space charge wave in an electron stream. Or, electronic wavelength is the distance traveled by an electron during one cycle of the signal.

The invention will be better understood from the following more detailed description taken in connection with the accompanying drawings in which:

Fig. 1 shows in perspective a basic coupling arrangement of the invention;

Figs. 2A and 2B are side and sectional views, respectively, of a number of adjacent wire elements of the arrangement of Fig. 1 for illustrating the directions of electric fields and currents associated therewith;

Figs. 3A and 3B shows a microwave amplifier in which there are incorporated as the input and output signal transducers modifications of the basic arrangement of Fig. 1; and

Fig. 4 shows a directive antenna array which also incorporates a form of the arrangement of Fig. 1.

With more specific reference now to the drawings, Fig. 1 shows schematically a basic arrangement for coupling in accordance with the invention. An electron stream 11, provided from some suitable source not here shown, is projected along a linear array of wire elements 12 which extend between two oppositely disposed conductive members, a base member 13 which can, for example, be a portion of the envelope enclosing the electron stream and a wall member 14, which can, for example, be a wall of a wave guide, cavity resonator, antenna or some other conductively bounded wave guiding element, above which exist, or are to be induced electromagnetic waves characterized by wavelengths long with relation to the corresponding electronic wavelengths. In the case to be first described, it will be assumed that the signal waves associated with the wall member are to be impressed as signal modulations of the electron stream. Subsequently, the converse case is to be briefly described in which signal modulations on the electron stream are made to set up electromagnetic waves for propagation above the wall member 14. This wall member is apertured to form the slot 15 which extends parallel to the electron flow. The orientation of the electron flow and the wall member is chosen originally so that the slot 15 will extend transverse to the current flow induced in the wall 14 by the electromagnetic waves associated therewith. Successive wire elements 12 extend normal to the direction of electron flow from opposite sides of the slot 15 to the base member 13, forming a linear array which proceeds in the direction of the electron stream. The length of the wires is chosen so that most of the current which formerly went across the slot will now proceed from one side of the slot down one set of alternate wires and up the other set of alternate wires to reappear on the opposite side of the slot in approximately the same phase as would be the case if the slot had not been cut. If this condition is met, the fields above the wall will not be appreciably disturbed by the presence of the slot. It can

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be seen that to satisfy this condition, the extra distance through which the current passes should be approximately an integral number of wavelengths. For wire elements of uniform length, this means that each wire is to be approximately an integral number of half wire wavelengths long. The wavelength along the wire elements is determined principally by the wire diameter and spacing and generally will be approximately the free space wavelength. As the wave advances past the slot and the current in the wires changes accordingly, the field between adjacent pairs of wires varies correspondingly.

It can be shown that by this arrangement the ratio of the velocity of the waves traveling along the wave transmission member 14 to the velocity of the corresponding waves traveling along the linear array of wire elements 12 is approximately equal to half the number of wire elements along one wavelength of the excitation along the wave transmission member 14.

Figs. 2A and 2B show the directions of the electric fields between adjacent wire elements and the currents along the wire elements when the wire lengths satisfy the above-described condition. As is shown, the current flow I is in opposite directions along adjacent wire elements 12 and accordingly, the electric field E reverses between adjacent elements. As is indicated vectorially, the electric fields between wire elements vary along the lengths of the wire elements, being a maxima at the centers and a minima at the ends. As is well known in the microwave art, for useful interaction between the electron stream and the electric fields set up by the signal waves (i. e. for amplification of the waves on the electron stream), the changes in direction of the electric fields should reinforce the bunching effect in the electron stream. In the present case since the electric field reverses direction between successive elements, for synchronism the center-to-center spacing between successive wire elements should correspond approximately to an integral odd number of electronic half wavelengths where the electronic wavelength is the free space wavelength of the signal excitation multiplied by the ratio of the average velocity of the electron stream to the velocity of light. Generally it is advantageous to adjust the electron velocity so that the center-to-center wire spacing is approximately one half an electronic wavelength. When the various conditions specified are sufficiently well satisfied, signal waves which induce flow in the wall member 14 are impressed on the electron stream 11 as waves which travel therealong.

It is also accordance with the invention to utilize this same structure to abstract power from an electron stream on which are traveling signal modulations. In this case, the signal modulations on the electron stream 11 induce currents in the linear array of wire elements 12 which circulate currents in the wall member 14 which set up waves above the wall member which correspond to the signal modulations.

Various other factors are to be considered in arriving at the particular configuration of the coupling arrangement which is most advantageous for a specific application. To intercept the maximum current flow induced in the wall member 14, the slot 15 should extend perpendicular to the direction of this current flow. The choice of exact location of the slot in the wall member is influenced by impedance matching considerations, various locations generally affording different impedance matches between the linear array and the slotted wall member. If the width of the slot is too narrow, the capacitance across the slot tends to short out the array of wire elements with a consequent loss in efficiency. If too wide a slot is provided, the radiation losses become excessive. The length of the slot and the number of wires in the array must also be adjusted to provide adequate energy transfers between the electron stream and the signal waves.

The choice of wire size is also governed by various

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factors. The finer the wire the greater the problems of fabrication, the less sturdy the structure, and the lower the power handling capacity. Moreover, for a given range of accelerating electron voltages, the larger the wire the closer the spacing if the center-to-center wire spacing is to be approximately half an electronic wavelength. However, since too close wire spacing results in too low a linear array impedance, upper limitations on the size of wire then exist. It is of course not necessary that the wire elements be circular in cross section, since ribbon-type or other forms can also be utilized. However, the ready availability of wire of circular cross section together with presently known grid winding techniques makes use of such wire generally advantageous.

The basic arrangement just described can conveniently be modified for incorporation in various microwave devices in which input wave signals are made to excite modulations in an electron stream which are thereafter amplified as they proceed along the stream to be thereafter employed to induce amplified waves into an output circuit. Figs. 3A and 3B are perspective and sectional views, respectively of a microwave amplifier which is particularly well suited for incorporating input and output transducers of the kind just described. Within an evacuated elongated tubular envelope 20, which, for example, can be of a non-magnetic metal such as copper, at opposite ends an electron gun 21 and a target electrode 22 define a path of electron flow. The electron gun can be of conventional structure including an electron emissive cathode surface 21A, a heater unit 21B, intensity control elements 21C, and various electrodes for collimating and accelerating the stream, which have been shown here schematically as the apertured plate 21D for the sake of simplicity. It is usually desirable to employ magnetic flux producing means (not shown here) external to the envelope to provide a longitudinal magnetic field to minimize transverse components of electron flow. Upstream along the flow, input waves are impressed as signal modulations on the electron stream by an input transducer 23 in accordance with the invention. In this embodiment, input transverse electric waves are applied by way of a rectangular wave guide 24, which for example, is a continuation by way of the pressure tight glass window 25 of a wave guide transmission system. The orientation of the various components is such that the narrow side wall 26 of the wave guide is contiguous or integral with the top surface of the tube envelope 20 and that the direction of wave propagation is in the direction of electron flow. With such an orientation, the side wall 26 serves conveniently the role of the wall member 14 referred to in the description of the basic arrangement of Fig. 1. The wall 26 is then apertured to form the slot 27 extending in the direction of electron flow which also corresponds to a direction transverse to the current flow induced in the wall 26 by transverse electric waves in the wave guide 24. Then spaced wire elements 28 are connected in a linear array along the path of electron flow from the wall surface 26 to the opposite surface 26A of the tube envelope, which in this way serves as the base member 13 referred to in the arrangement of Fig. 1. As in that arrangement, successive elements 28 of the linear array extend from opposite sides of the slot 27 to the base 26A. Moreover, it is advantageous that the successive elements be spaced apart approximately half an electronic wavelength, which relationship is most conveniently realized by an appropriate choice of velocity of electron flow after a convenient wire spacing has been chosen. Moreover, each wire element 28 should advantageously be approximately half a signal wavelength long, which relationship fixes the separation between the slotted wall 26 and the base surface 26A. The slot 27 is made of sufficient length so that the input waves applied to the wave guide 24 effect adequate modulation of the electron stream.

Since the electric field associated with the linear array

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of wire elements is generally strongest between the central portions thereof, falling off between the ends, it is advantageous to confine the electron flow to these central portions. To secure the maximum coupling and hence maximum effect, the stream should flow past the wire elements as closely as possible.

For the amplification of the impressed modulations, the amplifier shown employs as the amplifying means a linear array of resonant wire elements 28A similar to those employed in the input transducer 23 and past which the electron stream continues. These wire elements 28A, each approximately half a signal wavelength long, are also connected across the tube envelope, spaced apart along the direction of flow approximately half an electron stream wavelength. As is described in the copending application of J. R. Pierce, Serial No. 150,429, filed March 18, 1950, now Patent No. 2,708,236, dated May 10, 1955, amplification of the signal modulations on the electron stream is obtained from the interaction between the electron stream and the electromagnetic fields associated with these wire resonators. Beyond this amplifier section, energy is abstracted from the signal modulations on the stream by an output transducer 33 which resembles the input transducer 23. In this case, one of the narrow side walls of the output wave guide 34 serves as the wall member 36 which is apertured to form the slot 37. Then as before, wire elements 38, in a linear array, are connected across the tube envelope, successive elements extending from opposite sides of the slot 37 to the opposite surface of the tube envelope. By means of this output transducer, amplified output waves are set up in the wave guide 34 which can be a further continuation by way of a pressure tight glass window 35 of a wave transmission system.

It can be seen that various configurations are possible for input and output transducers for incorporation in an amplifier of the kind described. For example, the orientation of the input wave guide 24 can be rotated 90 degrees clockwise such that the end surface 29 becomes contiguous with the tube envelope for use as the slotted wall member. In this case, the slot is made to extend along the broad dimension of this end wall. As is known in the art, such a slot would intercept the current flow induced in the end wall by transverse electric waves being reflected by this end wall, and accordingly, such a configuration is possible for the practice of the invention.

The basic coupling arrangement shown in Fig. 1 can be further adapted for use as a directional antenna array, as shown in Fig. 4, for energy transfers between space charge waves on electron streams and waves radiating in free space. In this modification, as before, an electron source and a collector electrode (not shown) define a path of electron flow 41 along which are spaced wire elements 42 in a linear array. Successive elements are connected from a common conductive base member 43 alternately to one of the two conductive strips 44 and 45 which extend along the array. It is generally convenient to obtain these two strips by slotting a single conductive member 46, as shown here and as is characteristic of the basic arrangement of Fig. 1. Then, if the dimensions and spacing of the wire elements 42 is as described earlier, signal waves on the electron stream will induce oppositely directed currents in successive wire elements which will combine in the member 46 to set up a transverse current flow thereacross. Now by suitably positioning a conductive plate member 47, apertured for forming a succession of radiating slots 48, parallel to the member 46, there results an antenna which can be made directive by appropriate spacing of the slots 48 in the manner known in the antenna art.

An oscillator which incorporates a transducer arrangement of the kind described forms the basis of the copend-

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ing application, Serial No. 278,323 filed March 25, 1952, by D. W. Hagelbarger and L. R. Walker.

It is to be understood that the above-described arrangements are merely illustrative of the principles of the invention. Various other embodiments can be devised by a worker skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In microwave apparatus, a base member, a wave transmission member having a wall surface positioned opposite said base member and apertured to form a slot transverse to the current flow induced therein by waves propagating along said member, a linear array of spaced wire elements each having a length approximately an integral number of half wavelengths of said waves, successive elements extending from opposite sides of the slot in the wall to said base member, and means for forming and projecting a charge stream past said wire elements in the direction of extent of the linear array.

2. In microwave apparatus, means forming and projecting a charge stream, a conductive base member and a conductive wave transmission wall member on opposite sides of the electron stream, the wall member apertured to form a slot extending in the direction of the electron stream and transverse to the direction of the current flow induced in the wall member by waves propagating therealong, and a linear array of spaced conductive elements each having a length approximately an integral number of half wavelengths of said waves, successive elements extending from opposite sides of said slot in said wall member to said base member in field coupling relation with said electron stream.

3. In microwave apparatus, means forming and projecting an electron stream, a conductively bounded wave guiding member having a wall surface apertured to form a slot extending in the direction of the electron stream and transverse to the current flow induced in the wall member by waves propagating therealong, a conductive base member positioned opposite said apertured wall surface, and a linear array of spaced wire elements each having a length approximately an integral number of half wavelengths of said waves, successive elements extending from opposite sides of said slot in said wall surface to said base member in field coupling relation with said electron stream.

4. In microwave apparatus, a conductive base member, a conductive wave transmission wall member positioned opposite said base member and apertured to form a slot extending in a direction transverse to the current flow induced in the wall member by waves propagating therealong, a linear array of spaced conductive elements, each approximately an integral number of half wavelengths long, successive elements extending from opposite sides of the slot in the wall member to said base member, and means for forming and projecting an electron stream in field coupling relation along the linear array of conductive elements.

5. In microwave apparatus, means forming and projecting an electron stream, a conductive base member and a conductive wave transmission wall member on opposite sides of the electron stream, the wall member apertured to form a slot which extends in the direction of the electron stream and transverse to the current flow induced in the wall member by waves propagating therealong, and a linear array of spaced conductive elements, each approximately an integral number of half wavelengths long, successive elements extending from opposite sides of the slot in said wall member to said base member in field coupling relation with the electron stream and spaced apart along said stream approximately an odd number of half electronic wavelengths.

6. In microwave apparatus, means forming and projecting an electron stream, a conductive base member and a conductive wave transmission wall member on opposite

sides of the electron stream, the wall member apertured to form a slot along the direction of electron flow and transverse to the direction of current flow induced in the wall member by waves propagating therealong, and a linear array of spaced wire elements, each approximately half a wavelength long, successive elements extending from opposite sides of the slot in the wall member to the base member in field coupling relation with the electron stream and spaced apart therealong approximately half an electronic wavelength.

7. In microwave apparatus, a conductively bounded wave transmission member having a wall surface apertured to form a slot transverse to the current flow induced in said wall surface by waves propagating therein, a conductive base member positioned opposite said apertured surface, means for forming and projecting an electron stream along a path parallel to said slot intermediate between said base member and said apertured wall surface, and a linear array of spaced conductive elements, each approximately half a wavelength long, successive elements extending from opposite sides of the slot in the wall surface to the base member in field coupling relation with the electron stream and spaced apart therealong half an electronic wavelength.

8. In a microwave tube, an electron source and target electrode defining a path of electron flow, and transducer means, in an energy exchange relationship with said flow, comprising a conductively bounded wave guiding member slotted in one boundary surface along the direction of electron flow and transverse to the current flow induced in said wave guiding member by waves propagated therealong, a base conductive member separated from said slotted boundary surface by the path of electron flow, and a linear array of spaced conductive elements each approximately an integral number of half wavelengths long, successive elements extending from opposite sides of the slot in said boundary surface to said base member in field coupling relation with said electron flow.

9. In a microwave tube, an electron source and a target electrode defining a path of electron flow, and transducer means, in energy exchange relation with the electron flow, comprising a conductively bounded wave transmission member having a boundary surface apertured to form a slot transverse to the current flow induced in said boundary surface by waves in said member, the transmission member being disposed so that the slot extends in the direction of electron flow, a conductive base member positioned opposite the apertured boundary surface, and a linear array of spaced conductive elements each element approximately an integral number of half wavelengths long, successive elements extending from opposite sides of the slot in said boundary surface to said base member in field coupling relation with the electron flow.

10. In a microwave tube, an electron source and a target electrode defining a path of electron flow, and transducer means, in energy exchange relation with the electron flow, comprising a conductively bounded wave transmission member having a boundary surface apertured to form a slot transverse to the current flow induced in said boundary surface by waves in said member, said member being disposed so that the slot extends in the direction of electron flow, a conductive base member positioned opposite the apertured boundary surface, and a linear array of spaced conductive elements, each approximately half a wavelength long, successive elements extending from opposite sides of the slot in said boundary surface to the base member and spaced apart along the path of electron flow approximately half an electronic wavelength.

11. In a microwave tube, a conductive envelope, an electron source and target electrode defining a path of electron flow within said envelope, and transducer means in energy exchange relation with the electron flow comprising a conductively bounded wave guiding member having one boundary surface contiguous to said conductive envelope and apertured to form a slot extending in

the direction of electron flow and transverse to the direction of current flow induced in said boundary surface by waves propagating therealong, and a linear array of spaced conductive elements, each approximately an integral number of half wavelengths long, successive elements extending from opposite sides of the slot in said apertured boundary surface to the opposite side of the conductive envelope in field coupling relation with the electron flow.

12. In a microwave tube, a conductive envelope, an electron source and target electrode defining a path of electron flow within said envelope, and transducer means in energy exchange relation with the electron flow comprising a conductively bounded wave guiding member having one boundary surface integral with said conductive envelope and slotted in the direction of electron flow and transverse to the direction of current flow induced in said boundary surface by waves propagating therealong, and a linear array of spaced wire elements, each approximately half a wavelength long, successive elements extending from opposite sides of the slot in said boundary surface to the opposite surface of the conductive envelope in field coupling relation with the electron flow and spaced apart along said path approximately a half electronic wavelength.

13. In a microwave device, a conductive envelope, an electron source and target electrode defining a path of electron flow within said envelope, and transducer means in energy exchange relation with the electron flow comprising a conductively bounded waveguide having one wall integral with the conductive envelope and slotted in a direction transverse to the current flow induced in said wall by waves in said waveguide, said waveguide being disposed so that the slot extends in the direction of electron flow, and a linear array of spaced conductive elements, each approximately an integral number of half wavelengths long, successive elements extending from said wall on opposite sides of the slot to the opposite wall of the conductive envelope in field coupling relation with the electron flow.

14. A microwave device according to claim 13 in which the spaced conductive elements are wire elements spaced apart along the electron stream approximately half an electronic wavelength.

15. In a microwave device, an electron source and target electrode defining a path for an electron stream, a plurality of spaced wire elements, each transverse to the path of the electron stream, in a linear array along said stream, input transducer means for impressing input signals as modulations on said stream comprising a waveguide which is supplied with input signals having a wall apertured to form a slot transverse to the current flow induced in said wall by input signals supplied to the waveguide and extending in the direction of electron flow, successive elements of an upstream portion of said linear array being connected to opposite sides of said slot, and output transducer means for deriving output waves from signal modulations on said stream comprising an output waveguide having a wall apertured to form a slot extending along the direction of electron flow, successive elements of a downstream portion of said linear array being connected to opposite sides of said last-mentioned slot.

16. In a microwave device, a conductive base member, a slotted waveguiding member positioned opposite said base member, means forming and projecting an electron stream intermediate said base and waveguiding member, the slot in said waveguiding member being parallel to the direction of flow of the electron stream and transverse to the direction of current flow induced in the waveguiding member by waves propagating therealong, a linear array of wire elements each approximately an integral number of half wavelengths long extending between said base and waveguiding members in coupling relation with the electron stream, successive wire elements being connected to said waveguiding member on opposite sides of the slot therein, and an apertured con-

ductive plate positioned opposite said waveguiding member on the side remote from said base member.

17. In a microwave device, an apertured conductive plate, a slotted conductive wave transmission plate with the slot transverse to the direction of current flow induced in the plate by waves propagating therealong, and a conductive base member positioned parallel to one another in the order named, a linear array of wire elements each approximately an integral number of half wavelengths long extending between said slotted conductive plate and conductive base member, successive elements being connected to said slotted conductive plate on opposite sides of the slot therein, and means for forming and projecting an electron stream intermediate said slotted conductive plate and conductive base member along the linear array of wire elements.

18. A microwave device according to claim 13 in which the spaced conductive elements are spaced apart along the electron stream approximately half an electronic wavelength, where the electronic wavelength is the free space

wavelength of the signal excitation multiplied by the ratio of the average velocity of the electron stream to the velocity of light.

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