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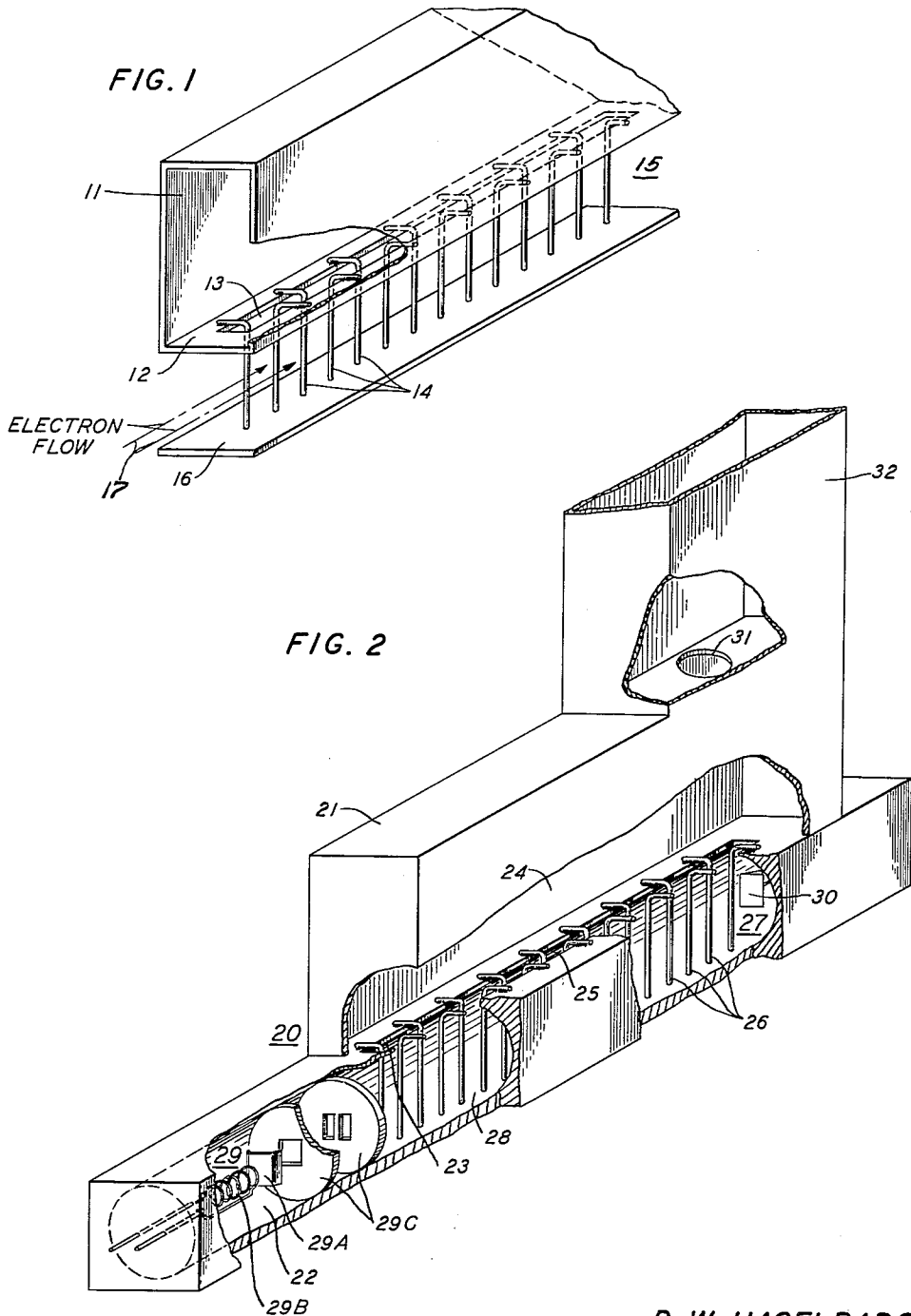
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2,745,984

MICROWAVE OSCILLATOR

Filed March 25, 1952

2 Sheets-Sheet 1



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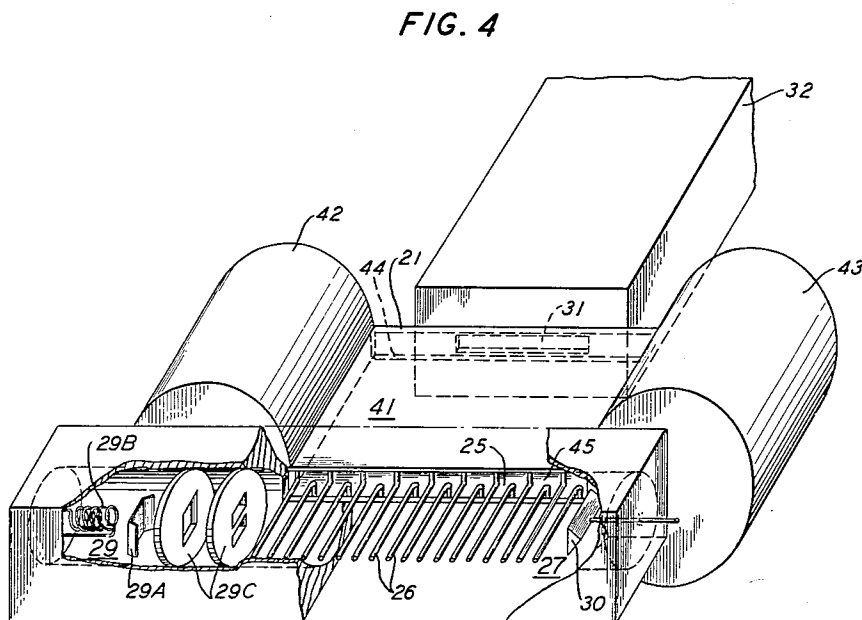
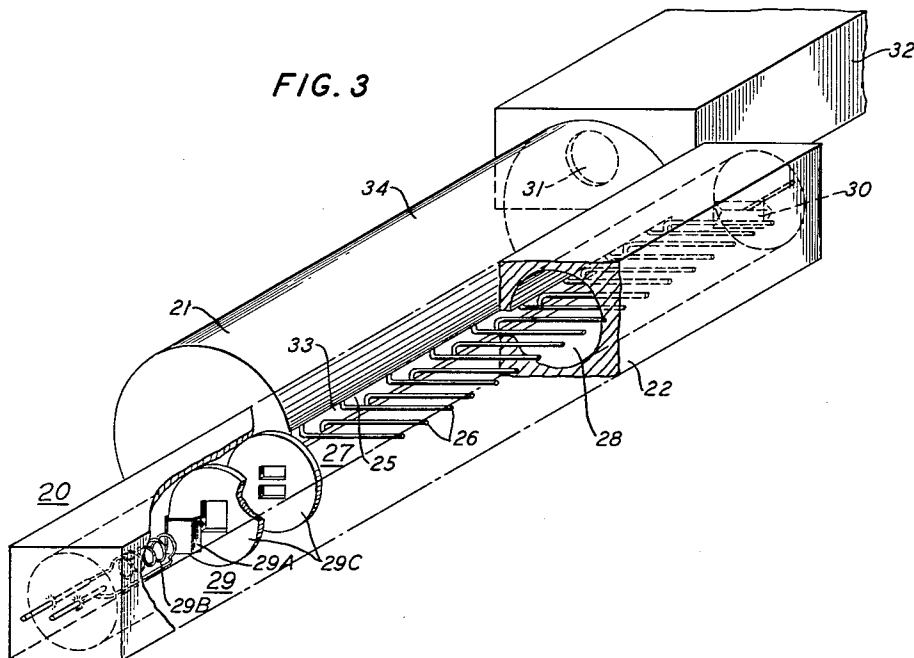
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1

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MICROWAVE OSCILLATOR

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Application March 25, 1952, Serial No. 278,323

16 Claims. (Cl. 315-4)

This invention relates to microwave oscillators and, more particularly, to such oscillators which utilize the interaction between electron streams and standing electromagnetic waves.

Hitherto, there has been developed a class of devices which utilize for gain the interaction between electromagnetic signal waves and electron streams. Generally in such devices, a suitable transducer transfers an input electromagnetic wave from an input wave circuit to a slow wave circuit which extends along the path of electron flow. The signal wave travelling on the slow wave circuit accelerates electrons in the stream, giving rise therein to an A.-C. modulation component. This in turn sets up an electromagnetic field of its own which combines with the field of the slow wave circuit. When the slow electromagnetic wave and electron stream are properly synchronized, the cumulative action and reaction of the circuit and the A.-C. modulation component result in a wave which grows in magnitude as it travels along the circuit and an A.-C. modulation component which grows in amplitude as it travels along the stream. In a copending application of L. R. Walker, Serial No. 278,322, filed March 25, 1952, there is described a microwave transducer suitable for effecting energy transfers between an input wave member and a slow wave circuit. In particular, there is described a transducer in which the wall surface of a conductively bounded wave transmission member is slotted in a direction transverse to the current flow in this surface induced by a wave traveling in the member and a linear array of conductive elements extends from this wall surface to a conductive base member positioned opposite thereto, successive elements of the array being supported from the wall surface on opposite sides of the slot. The electron stream is thereafter projected past the linear array of conductive elements. By this arrangement input waves traveling in the wave transmission member set up waves which travel along the linear array of elements and excite A.-C. modulations on the electron stream.

In the present invention, a basic coupling arrangement of the kind just described is modified for use in an oscillator in which the interaction between an electron stream and a standing wave is utilized to sustain oscillations. In accordance with the invention, a resonant wave member is cut along a wall surface to form a slot which extends transverse to the current flow induced in this surface by standing waves in the resonant wave member; successive spaced conductive elements are connected in a linear array from opposite sides of the slot in the apertured wall surface to a conductive base member positioned opposite thereto; and an electron stream is projected past the linear array of conductive elements. By a suitable choice of the dimensions and geometry of the resonant wave member and the conductive elements and of the velocity of the electron stream, oscillations are set up in the resonant wave member.

The invention will be better understood from the fol-

2

lowing more detailed description taken in connection with the accompanying drawings of which:

Fig. 1 shows the microwave transducer described in the above-mentioned Walker application, modifications of which are employed in the practice of the present invention; and

Figs. 2, 3 and 4 show illustrative embodiments of the invention, which utilize, respectively, as the resonant wave member, a section of rectangular wave guide, a section of circular wave guide, and a "dumbbell" or H type resonator.

With more particular reference now to the drawings, it will be convenient to describe first the microwave transducer disclosed in the Walker application and shown here as Fig. 1. A wave transmission element, for example, the rectangular wave guide 11, is cut along a narrow side wall 12 for forming the slot 13 extending in the direction of wave propagation so as to intercept the current flow across this wall induced by the wave propagation. Successive wire elements 14 of the linear array 15 extend from opposite sides of the slot 13 to a conductive base member 16 positioned opposite the wall 12. An electron stream 17 is projected by a suitable means, not shown here, past the linear array 15 in coupling relation with the electromagnetic fields associated with the wire elements resulting from current flow there-through. This current flow will be a maximum when the wire lengths are an integral number of half wavelengths long, in which case the current flow across this slotted side wall will be relatively undisturbed by the slot since the wires serve to short the slot. Alternatively, this current flow will be a minimum when the wire lengths are an odd number of quarter wavelengths since then the linear array of wires acts as a very high impedance to this current. As will be described below, a wire length intermediate these two extremes is usually chosen in the practice of the present invention. Additionally, to secure interaction between the electron stream and the fields associated with the wire elements resulting from the current flow there-through the velocity of the electron stream is adjusted so that the successive wire elements of the linear array are spaced apart along the stream approximately an integral odd number, usually one, of half electronic wavelengths, i. e. the wavelength on the electron stream which is the wavelength in free space multiplied by the ratio of the velocity of the electron stream to the velocity of light. By this arrangement just described, electromagnetic waves propagating in the wave guide 11 can be made to excite corresponding A.-C. modulations on the electron stream 17, and conversely, A.-C. modulations on the electron stream 17 can be made to set up electromagnetic waves for propagation through the wave guide 11. This action and reaction can be made cumulative, the A.-C. modulations on the stream acting to create electromagnetic fields which add to the fields in the wave guide and thereby increasing the fields acting to modulate the electron stream. It is this regenerative effect which is utilized in oscillators in accordance with the invention. By the substitution of a resonant wave chamber for the wave guide 11, there can be set up therein standing waves for interaction with the electron stream to sustain oscillations.

In Fig. 2 there is shown, in a perspective view which has been cut away in part, an illustrative embodiment of the invention. The evacuated envelope 20 which, for example, is of a non-magnetic metal such as copper, comprises essentially two sections 21 and 22 having a contiguous or common surface 23. The section 21 serves as a wave resonant chamber, being effectively a closed section of rectangular wave guide 24 of which one of the narrow side walls is the wall surface 23. This wall surface 23 is apertured to form the slot 25 which

3

extends in a direction transverse to the current flow to be induced in this wall surface by the standing waves to be set up in the resonant cavity 24. Wire elements 26 in a linear array 27 extend from the wall surface 23 to the opposite face 28 of the envelope section 22, successive elements being connected to the wall 23 on opposite sides of the slot 25 as described earlier. The envelope section 22 houses the electron stream which is projected past the linear array 27 of wire elements 26, and so is provided at opposite ends with an electron gun 29 and a target electrode 30. Such an electron gun comprises essentially an electron emissive surface 29A, a heater unit 29B, and various electrodes 29C for focussing and accelerating the stream. It is usually advantageous to provide a longitudinal magnetic field by appropriate flux producing means (not shown) to keep the electron flow straight contiguous to the linear array 27. The resonant wave chamber 24 is provided with suitable coupling, such as by way of the iris 31, to an external wave transmission circuit 32 so that oscillatory wave energy can be abstracted for utilization.

In operation, a number of modes can exist on the linear array 27 of wire elements, each corresponding to frequencies at which the slot 25 is approximately an integral number of half wavelengths long. Of these it is generally found that the one most readily tunable, i. e. the one most strongly coupled to the resonant wave chamber 24, is that for which the wires 26 are each approximately half a free space wavelength long and the slot approximately half a wave guide wavelength long, where the free space wavelength λ_0 , the resonant chamber cut-off wavelength λ_c which is fixed by the chamber dimensions in accordance with relationships well known to the art, and the wave guide wavelength λ_g , are related as

$$\left(\frac{1}{\lambda_0}\right)^2 = \left(\frac{1}{\lambda_c}\right)^2 + \left(\frac{1}{\lambda_g}\right)^2 \quad (1)$$

As a result, if the resonant cavity 24 is suitably dimensioned, there is set up a transverse electric standing wave of mode TE₁₀ in the resonant cavity 24.

The various other modes generally do not couple strongly to the resonant cavity 24 because the cavity modes to which they are coupled will be cut off in the cavity for the frequencies at which they occur if the cavity is adjusted for a TE₁₀ mode. For example, suppose there exists on the linear array 27 a mode having 8π radians phase shift along the slot. This tends to excite a TE₈₀ standing wave pattern in the resonant cavity but the cut-off frequency of such a wave is eight times the cut-off frequency of a TE₁₀ wave so that it will be cut off if the resonant cavity is designed for a TE₁₀ wave. As is well known in the microwave art, the resonant frequency of a cavity can be fixed by its dimensions and geometry and the resonant frequency varies for different modes.

Another degree of control is provided by the accelerating voltage acting on the electron stream which fixes the electron velocity. The electron velocity necessary is generally related to the spacing which it is convenient to provide between wires. This spacing in turn depends on the size and number of wires in the linear array along the slot. The size of wire used is primarily controlled by fabrication considerations and dissipation capacities desired. The number of wires should be sufficient to provide sufficient energy transfer from the stream to the circuit to sustain oscillations, this energy transfer increasing as the cube of the number of wires, while the losses in the circuit increase approximately only as the first power of the number of wires. As pointed out above for cumulative interaction, the modulations being impressed on the electron stream must cooperate with the fields associated with the wire elements. In the basic arrangement described with reference to Fig. 1, the fields associated with successive wires are shifted π radians and,

4

accordingly, for interaction the electron velocity needs to be adjusted so that the wire spacing corresponds to half an electronic wavelength. Since a standing wave will always exist in the resonant chamber, there are two traveling waves in the slot with phase shifts of

$$\pm \frac{n\pi}{m}$$

from one wire to the next, where n is the mode number, $n\pi$ the total phase shift along the slot, and m the number of wires in the linear array. Moreover, since the wire elements alternate between opposite sides of the slot, the phase difference between successive wires for these traveling waves are

$$\pm \left(\pi \pm \frac{n\pi}{m} \right)$$

Analysis of the electron interaction with the fields associated with the wire elements indicates roughly a maximum energy transfer when

$$\theta_e - \theta_\omega = \theta_0 - \pi \quad (2)$$

where θ_e is the transit angle of the modulations on the electron stream between successive wires and is controlled by the electron velocity, θ_ω is the phase shift per section of a wave on the linear array of wire elements, and is given by

$$\theta_\omega = \pm \left(\pi \pm \frac{n\pi}{m} \right) \quad (3)$$

and θ_0 is a constant which can be determined from the constants of the system.

Thus

$$\theta_e = \theta_0 \pm \frac{n\pi}{m} \quad (4)$$

Accordingly, the wire spacing and the electron velocities are adjusted so that the transit angle of the modulations on the electron stream between successive wires satisfies the relationship defined by Expression 4 for the mode desired.

Additionally it is usually found preferable if the wire elements are not made exactly a half free space wavelength long at the frequency of resonance. As is pointed out above, since the wire lengths determine the slot impedance the closer the wire lengths meet this condition, the more strongly coupled is the linear array of wire elements to the resonant cavity and the more readily is the oscillator tuned, as by varying the frequency of resonance of the cavity by some convenient tuning adjustment. However, it is also found that the more closely this condition is met, the greater the current flow in the cavity and the greater the loss of the system. Accordingly, it is generally advantageous to utilize a wire length which represents a compromise between these two considerations. In special cases, it may be desirable to have this wire length vary along the linear array.

It has been found usually more desirable to employ reflex operation which effectively doubles the number of wire elements acting to provide energy transfer since from Equation 3 above it is seen that the system is symmetrical with respect to the direction of electron flow. For such operation, the target electrode 30 is maintained at a voltage, negative both to the cathode emissive surface 29A and the wire elements 26 which in turn are maintained positive to the cathode emissive surface 29A. As a result, most of the electrons after passing the last wire of the array 27 are reflexed by the negative field of the target electrode 30 and redirected back towards the electron gun 29 in the manner characteristic of reflex operation.

It is, of course, possible to utilize alternative forms of resonant cavities for supporting the standing waves utilized in sustaining oscillations.

For example, in Fig. 3 there is shown an oscillator in which the wave resonant chamber 21 is a section of circu-

5

lar wave guide 34 which is slotted along a wall 33 contiguous with the electron stream housing 22. In other respects, this oscillator is similar to that shown in Fig. 2, and, accordingly, corresponding elements are designated by similar reference numerals.

Fig. 4 shows an oscillator in which there is incorporated a form of wave resonant chamber which is particularly well suited. In this case the resonant wave chamber is a dumbbell-type or H-type resonator 41 which comprises the two end members 42 and 43 of large transverse cross sections connected by the constricted bar portion 44. It is characteristic of such a resonator that the electric components of standing waves therein are uniformly high along the constricted bar portion and low at the end members. Accordingly, for the efficient utilization of the standing waves for oscillation, in this embodiment the constricted central bar portion is slotted in one side wall 45 to form the slot 25. In other respects, the oscillator is as described above, and accordingly, corresponding elements are again designated by like reference numerals. In this case, it is found convenient to abstract output wave energy by the coupling iris 31 in the constricted central portion 44.

It can be seen that various other resonant wave transmission elements which can support standing waves may be employed in accordance with the invention. For example, a slotted wall surface can be made to serve as the resonant member. Moreover, the wave resonant member can be operated at modes other than its dominant mode. Similarly, in place of the wire elements of circular cross section shown, wire elements of other shapes can be employed, as for example, a ribbon type wire having a narrow dimension transverse to the direction of current flow. Accordingly, it can be appreciated that the above-described embodiments are merely illustrative of the principles of the invention. Various other arrangements can be devised by one skilled in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. In a microwave oscillator, a wave resonant member having a wall surface apertured to form a slot therealong, a conductive base member positioned opposite said wall surface, a plurality of spaced conductive elements in a linear array, successive elements extending from opposite sides of the slot in the wall surface to the base member, means for forming and projecting an electron stream past the linear array in field coupling relation with the conductive elements, and means for abstracting energy from the wave resonant member for utilization.

2. In a microwave oscillator, a wave resonant member having a wall surface apertured to form a slot therealong, a conductive base member positioned opposite said wall surface, a plurality of spaced wire elements in a linear array, successive elements extending from opposite sides of the slot in the wall surface to the base member, means for forming and projecting an electron stream past the linear array in field coupling relation with the wire elements, and means for abstracting energy from the wave resonant member for utilization.

3. In a microwave device, a wave resonant member having a wall surface apertured to form a slot therealong, a plurality of spaced conductive elements in a linear array, successive elements extending in the same direction from the opposite sides of the slot in the wall surface, means for forming and projecting an electron stream past the linear array in field coupling relation with the conductive elements, and means for abstracting energy from the wave resonant member for utilization.

4. In a microwave device, a wave resonant member having a wall surface apertured to form a slot therealong, a plurality of spaced wire elements in a linear array, successive elements extending in the same direction from the opposite sides of the slot in the wall surface, means for forming and projecting an electron stream past the linear array in field coupling relation with the wire ele-

6

ments, and means for abstracting energy from the wave resonant member for utilization.

5. In a microwave oscillator, a conductively bounded wave resonant member having a wall surface apertured to form a slot therealong transverse to the current flow induced in the wall surface by a standing wave in said member, a conductive base member positioned opposite the apertured wall surface, a plurality of spaced conductive elements in a linear array, successive elements extending from the wall surface on opposite sides of the slot to the base member, means for forming and projecting an electron stream past the linear array in field coupling relation with the conductive elements, and means for abstracting energy from the wave resonant member for utilization.

6. A microwave oscillator in accordance with claim 5 in which the spaced conductive elements are wire elements spaced apart along the electron stream approximately half an electronic wavelength.

7. An oscillator according to claim 5 in which the resonant wave member is a closed section of rectangular wave guide.

8. An oscillator according to claim 5 in which the resonant wave member is a closed section of circular wave guide.

9. In a microwave oscillator, a cavity resonator having two end members and a constricted bar portion which is apertured along a wall of said bar portion to form a slot, a conductive base member positioned opposite said slot, a plurality of spaced conductive elements in a linear array, successive elements extending from opposite sides of said slot in said bar portion to the base member, means for forming and projecting an electron stream past the linear array in field coupling relation with the conductive elements, and means for abstracting energy from said cavity resonator for utilization.

10. In a microwave oscillator, a cavity resonator having two end members and a constricted bar portion which is apertured along a wall of said bar portion to form a slot, a conductive base member positioned opposite said slot, a plurality of spaced wire elements in a linear array, successive elements extending from opposite sides of said slot in said bar portion to the base member, means for forming and projecting an electron stream past the linear array in field coupling relation with the wire elements, and means for abstracting energy from said cavity resonator for utilization.

11. In a microwave oscillator, a conductively bounded wave resonant member having a wall surface apertured to form a slot therealong transverse to the current flow induced in said wall surface by a standing wave in the resonant member, a conductive base member positioned opposite the wall surface, a plurality of spaced conductive elements in a linear array, successive elements extending from the wall surface on opposite sides of the slot to the base member, an electron source and target electrode forming and projecting an electron stream from said source towards said target past the linear array, reflexing means for redirecting the electron stream from said target towards said linear array also past the linear array, and means for abstracting wave energy from the resonant member for utilization.

12. In a microwave oscillator, a conductively bounded wave resonant member having a wall surface apertured to form a slot therealong transverse to the current flow induced in said wall surface by a standing wave in the resonant member, a conductive base member positioned opposite the wall surface, a plurality of spaced wire elements in a linear array, successive elements extending from the wall surface on opposite sides of the slot to the base member, an electron source and target electrode forming and projecting an electron stream from said source towards said target past the linear array, reflexing means for redirecting the electron stream from said target towards said linear array also past the linear array, and

7

means for abstracting wave energy from the resonant member for utilization.

13. A microwave oscillator according to claim 11 in which the wave resonant member is a closed section of rectangular wave guide.

14. A microwave oscillator according to claim 11 in which the wave resonant member is a closed section of circular wave guide.

15. A microwave oscillator according to claim 11 in which the wave resonant member is a cavity resonator having a constricted central bar portion intermediate two end members of larger transverse dimensions, the bar portion being apertured to form the slot.

16. A microwave oscillator comprising a conductively bounded resonant cavity, means forming and projecting an electron stream exterior to said cavity, a conductive envelope surrounding said electron stream, said envelope and cavity being contiguous along one wall, and a slow wave

8

circuit comprising an array of wires extending from said wall into said electron stream for effecting energy exchanges between the electron stream and the resonant cavity.

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