Oct. 22, 1957 C. C. CUTLER 2,810,854

SERPENTINE TRAVELING WAVE TUBE

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FIG. 1

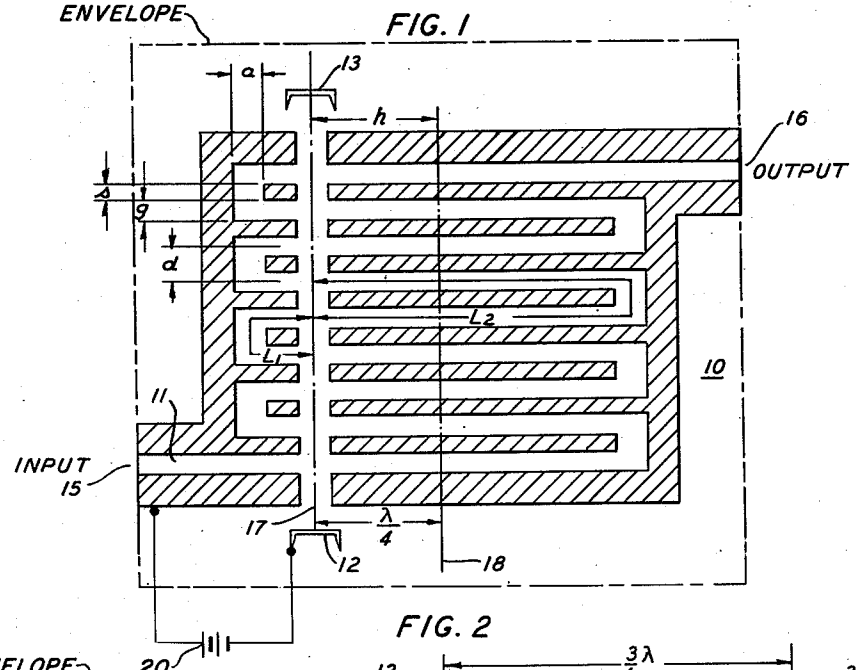
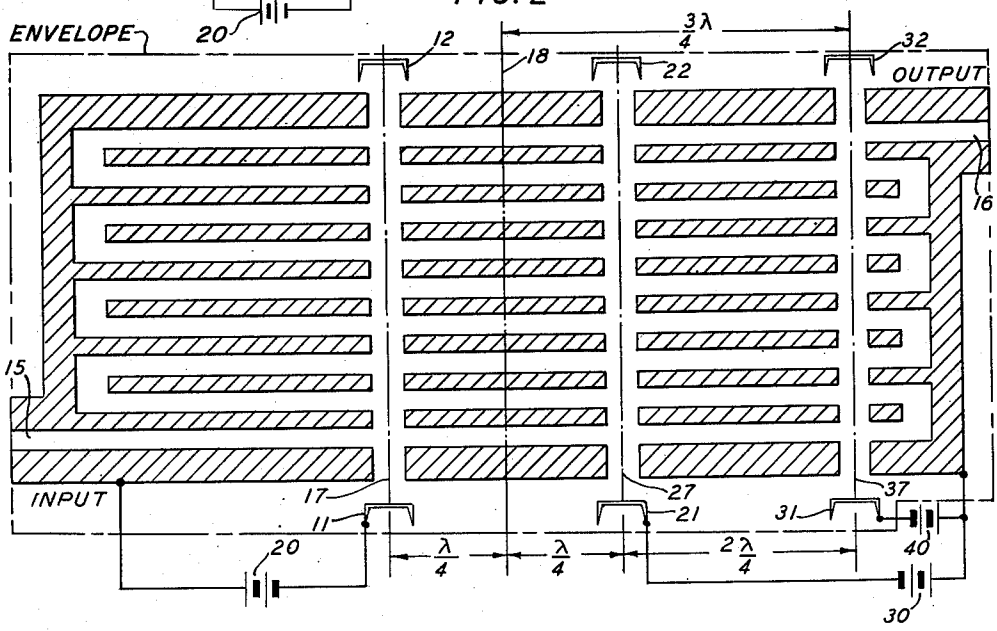


FIG. 2



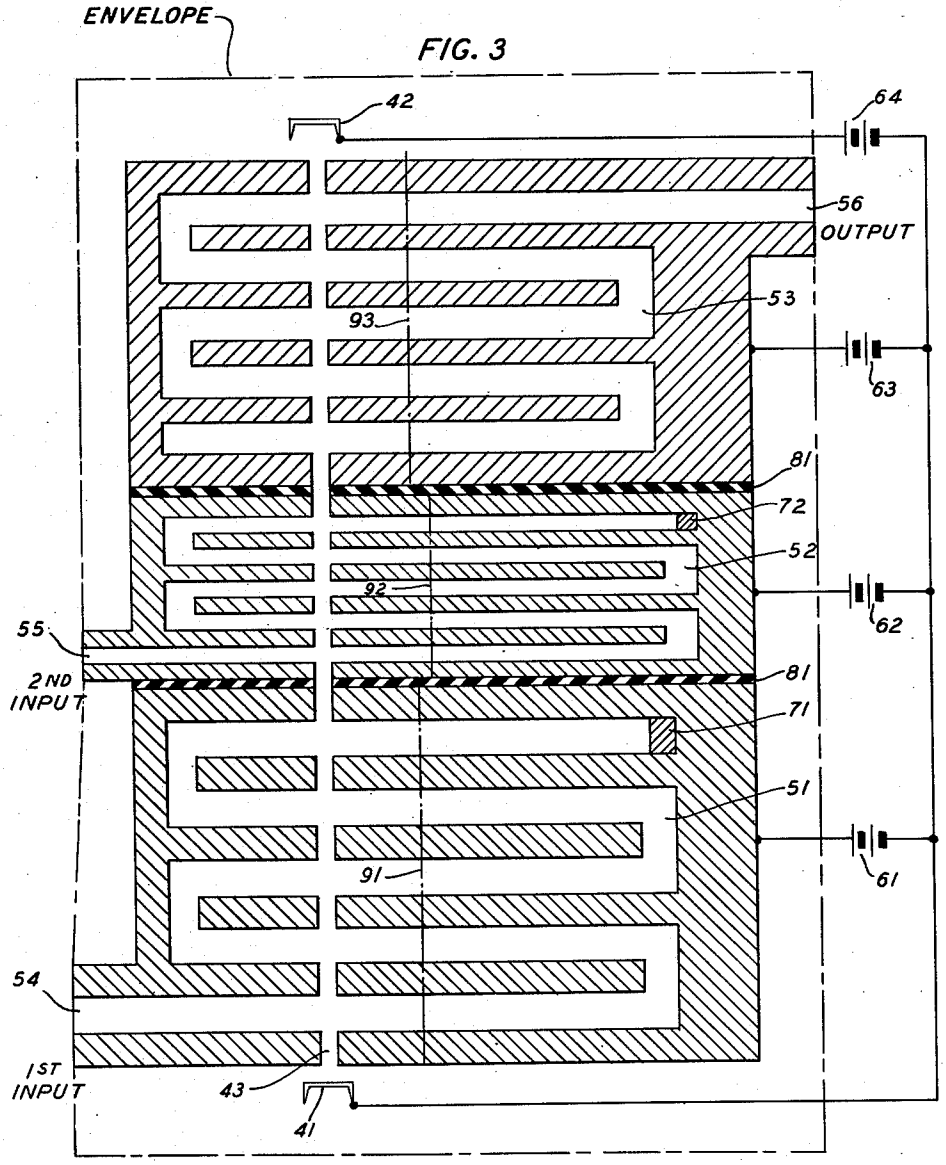
INVENTOR
C. C. CUTLER
BY Hugh S. Wertz
ATTORNEY

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FIG. 3



INVENTOR
C. C. CUTLER
BY
Hugh S. Wertz
ATTORNEY

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SERPENTINE TRAVELING WAVE TUBE

Cassius C. Cutler, Gillette, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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9 Claims. (Cl. 315—3.6)

This invention relates to microwave devices and more particularly to devices which utilize the interaction between an electron stream and a traveling electromagnetic wave to secure gain to the traveling wave.

In such devices, now generally known as traveling wave tubes, a wave circuit a plurality of operating wavelengths long propagates radio frequency electromagnetic waves therethrough at velocities slower than the velocity of light and an electron stream is projected in the direction of wave propagation through the electric field set up by the electric circuit. By proper adjustment of the velocities of the electron stream and the propagated wave, the two can be made to interact whereby the wave is amplified and the stream is density and velocity modulated. In operation, the radio frequency field of the wave circuit accelerates electrons in the stream, giving rise therein to an A.-C. velocity component which sets up an A.-C. convection current component. This in turn sets up a radio frequency field of its own which combines with the radio frequency field of the wave circuit. When the radio frequency wave and electron stream are properly synchronized, the cumulative action and reaction between the radio frequency field of the circuit and the A.-C. current component in the stream results in a wave which grows in magnitude as it travels along the circuit.

Various wave circuits have been proposed hitherto for providing wave propagation sufficiently slow for interaction with conveniently realized electron streams. Practical considerations usually favor an electron velocity no faster than one-tenth the velocity of light so that the velocity of the traveling wave in the direction of the electron stream must be adjusted proportionately. Some of these proposed circuits, such as the helix, although desirable from the standpoint of wide band and high gain characteristics, have poor dissipative properties which restrict their power handling capacity, are difficult of construction and assembly, and also pose formidable problems of impedance matching at input and output terminals. Others, such as those of the filter type, are disadvantageous from the standpoint of limited band width and low gain.

Accordingly, the primary object of the present invention is to provide a novel traveling wave tube of improved design particularly suitable for high power operation over a wide frequency band width.

One feature of the present invention is a wave circuit comprising a wave guide folded back and forth on itself a plurality of times forming a serpentine-like structure. This circuit has simplicity of structure, good dissipative properties, and wide band characteristics. Additionally, this structure facilitates the introduction and derivation of the wave signals, being particularly adaptable for the convenient admission of a plurality of signals from separate sources for mixing or modulating.

Another feature is a plurality of distinct electron streams, each projected along a separate electron path for traversing the serpentine wave circuit and interacting with the electric field therein. These various streams

may be operated either at the same velocity, thereby serving primarily to increase the size of the effective interacting electron stream and hence the gain, or at different velocities, staggered to provide a desired shaping either of the frequency-gain or the gain-level characteristics of the tube.

Another feature is the positioning of the regions of beam traversal of the folded wave guide approximately an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine wave guide structure to secure optimum phasing for the interaction. The term "axis of the serpentine wave guide structure" is used herein to denote a line transverse to the successive wave guide folds of the serpentine structure and equidistant from the two ends of each individual fold.

In an exemplary embodiment which illustrates features of the invention, the wave circuit comprises a serpentine wave guide folded back and forth on itself a plurality of times, and the successive folds are traversed by a plurality of electron streams each having a distinct electron path displaced an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine wave guide.

Various other features and secondary objects will be evident from the following more detailed description taken in connection with the drawings in which:

Fig. 1 shows schematically an embodiment of the invention which utilizes a single electron stream;

Fig. 2 shows schematically another embodiment which utilizes three distinct electron streams; and

Fig. 3 shows schematically an embodiment adapted for mixing two input signals.

With reference now to the drawings, in Fig. 1 there is shown a traveling wave tube 10 incorporating several features of the present invention. As the wave circuit, there is provided a wave guide 11 a plurality of operating wavelengths long, which, for example, can be rectangular in cross section, which is folded back and forth on itself in a serpentine fashion so that an electron stream may be directed transversely through successive folds. Wave energy is applied at the input end 15 which, for example, may be simply a continuation by way of a pressure-tight window of a wave guide which is part of a transmission system. The amplified wave is derived at the output end 16 which similarly may be made integral by way of a pressure-tight window with a wave guide of a transmission system. This arrangement makes possible a continuous path of travel for the wave energy and facilitates the introduction and derivation of wave energy to the tube, obviating the need for complex coupling elements. An electron gun 12 is provided beyond the first fold of the wave circuit for projecting an electron stream transverse to the folds of the wave guide. Although an electron gun customarily includes a heater element, an electron emissive cathode, and various focusing and accelerating electrodes, for purposes of simplicity these have not been shown in detail here. Beyond the last fold of the wave circuit and in target relationship with the electron gun, there is positioned the collector electrode 13 for collecting the spent electrons after their traversal of the wave circuit. In accordance with one feature of the invention, the electron path 17 defined by the electron gun and the collector electrode extends parallel to but displaced transversely approximately one-quarter the wavelength of the operating frequency from the axis 18 of the serpentine wave guide. Accurate alignment of the electron flow with the electron path is enhanced by providing an axial magnetic field by suitable magnetic flux producing means external to the tube (not shown here). To minimize disturbance of this axial magnetic field, the main tube con-

struction should preferably be of a suitable non-magnetic conductor, for example, copper.

The wave to the input **15** is applied to have a transverse electric field in which the electric lines of force have components transverse to the axis of the guide and in a direction to be parallel to the direction of electron flow. This same type of field is produced in the wave guide by the electron flow transverse through the guide. If the time required for the electrons to pass from the first to the last guide section is substantially the same as that required for the electromagnetic wave, and if successive wave guide traversals are properly phased, the two fields will interact in a manner to produce amplification of the wave in accordance with conventional traveling wave type interaction. The transit time of the electron stream is determined by the average electron velocity which is related to the accelerating beam voltage provided by the voltage source **20**. The transit time of the wave depends on the length of the serpentine path. By suitably relating the length and spacing of the folds and the accelerating beam voltage, the desired conditions for transit time can be satisfied.

For cumulative interaction it is of course necessary that each electron encounters substantially the same field phase condition in each successive region of wave guide traversal. This requirement is not automatically met both because the folding of the wave guide reverses the sense of the electric field of the wave guide with respect to the electron stream and because of the electrically long wave path between successive regions of beam interception. A solution to this difficulty is had by causing the wave transit time between successive regions of beam traversal to differ by one-half period from the transit time required by the electron stream. In accordance with one feature of the present invention, this is achieved by positioning the electron path substantially one-quarter of a wavelength of the midband operating frequency from the axis or center of the serpentine wave guide. As a result the time between successive traversals differs alternately by plus and minus one-half periods, so that there is no cumulative phase difference in traversing many sections and therefore amplification is realized over a wide band. It should be evident that substantially the same effect can be realized by making the time between successive traversals differ alternately by any odd multiple of a half period, in which case the electron path is positioned a corresponding odd number of quarter wavelengths away from the axis of the serpentive wave guide to secure the desired phasing.

As a condition for good broad-band amplification, it is important that the various wave guide bends do not introduce mismatch effects over the operating range. It can be shown that there is a particular choice of length a at the bends with square corners which permits a wide band match. In particular instances, it may be preferable in order to minmize mismatch effects of the bends to utilize other types of bends, such as curved bends, consistent with the principles set forth herein.

In order to obtain approximate synchronism between the wave and stream velocities certain circuit proportions must be satisfied. In particular, it is important that:

$$\frac{L_1+L_2}{2d}=\frac{v_g}{v_e}=\frac{\lambda_g}{\lambda_e} \qquad (1)$$

where L_1 and L_2 represent the lengths of two successive wave paths between successive traversals, d represents the center-to-center separation of successive traversals along the electron path, v_g and v_e are the wave and electron velocities, respectively, λ_g is the effective guide wavelength, and λ_e represents the free space wavelength multiplied by the ratio of the velocity of the electrons to the velocity of light.

To obtain proper phasing between adjacent gaps, it is then important that

$$L_2=n\lambda_g+L_1 \qquad (2)$$

where n is an odd integer. In the preferred embodiment shown, n equals 1, corresponding to a separation of electron path and serpentine wave guide axis of

$$\frac{\lambda_g}{4}$$

Equation 2 provides a definite lower limit for the value of L_1+L_2 and indicates that the time of transit between successive gaps is greater than one-half period. This further implies that the transit time for each gap is a large fraction of a wavelength and the effect of field strength variations during transit must be accounted for. In particular, from these considerations, it can be shown that a maximum energy per gap occurs for a gap length g equal to $.372\lambda_e$. The distance between gaps should be as short as possible consistent with Equation 1 to increase the effective average accelerating field. This means that for maximum gain L_1 and L_2 should be as short as feasible.

In general principles of operation, this circuit resembles other wave circuits proposed for traveling wave tubes. The signal to be amplified is applied to the tube by way of the input **15** and progresses along the wave circuit in a serpentine path. At the regions of beam traversal, the interaction with the electron stream produces amplification of the stream.

By taking advantage of the symmetry of this circuit and providing two distinct electron streams, the beam current interacting with the wave can be increased in a manner that avoids the space charge defocusing which usually serves to restrict the density attainable in a single stream. Fig. 2 illustrates a microwave device similar to that shown in Fig. 1 modified by the addition of two more electron streams. Elements having a counterpart in Fig. 1 have been designated by the same reference characters. The second and third electron streams are projected along the electron paths **27** and **37** which are defined by the electron guns **21** and **31** and the collector electrodes **22** and **32**, respectively. As, with the electron path **17**, electron paths **27** and **37** extend parallel to the axis of the serpentive wave guide and are separated odd multiples of a quarter of a guide wavelength therefrom. In addition to providing greater gain, the additional streams can be utilized to provide a particular shaping of the gain vs. frequency characteristic of the tube. In particular by providing different accelerating beam voltages to provide different stream velocities, it is possible to "staggertune" the circuit to give a flatter band pass characteristic than is possible otherwise, compensating for the effect of the waveguide velocity as a function of frequency on the gain frequency characteristic of the amplifier. Alternatively the beam velocities may be staggered to obtain flatter gain vs. level characteristics. If one beam is adjusted to the velocity of maximum interaction, and hence highest gain, and the others at successively greater velocities, the first beam would be the main contributor to gain at low levels. However, at high levels where this beam would be slowed down to a less efficient velocity, since it is characteristic that, at high level operation, the velocity of the electron beam is slowed by interaction with the traveling wave, the other beams, if properly adjusted, can be caused also to slow down in turn to the velocity of maximum interaction.

Similarly, additional distinct beams may be provided either for achieving additional power or for realizing particular response characteristics. In this case, each of the additional beams is projected along a separate electron path, provision being made that each electron path is parallel to and displaced an odd number of quarter wavelengths from the axis of the serpentine wave circuit.

Fig. 3 shows an illustrative embodiment of a tube which incorporates several features of the present invention for mixing two separate input signals and deriving therefrom a desired modulation product. The wave circuit in this case includes three separate sections 51, 52 and 53, each of which is a wave guide folded back and forth on itself as described above, the three sections being aligned with one another in a manner to permit their being electron coupled by a common electron stream which is projected between the electron gun 41 and the collector 42 along the electron path 43. In the arrangement shown, the three wave circuit sections are distinct and spaced apart by insulating material 81 to permit a different beam voltage and hence electron stream velocity through the separate sections, although arrangements are possible in which the electron velocity should be substantially the same in the various sections, in which case, the three sections may be made integral with one another and maintained at the same voltage. In the instant case, the different electron velocities are controlled by the voltage sources 61, 62 and 63 which provide the corresponding accelerating potentials. The first signal to be mixed is applied to the wave circuit section 51 by way of the wave-guide input 54 for travel therethrough. The parameters of section 51 are adjusted to provide the desired interaction with the electron flow in the manner described earlier for the tube of Fig. 1. In particular, this section is positioned to have the electron path 43 parallel to and spaced one-quarter the guide wavelength of this first signal from the serpentine wave guide axis 91. As a result of the interaction, modulation of the stream results and there is impressed on the stream the first input signal. To minimize undesirable reflection effects, the section 51 is terminated in an appropriate energy absorbing element 71, and the coupling between sections is effected primarily by means of the electron stream, since the energy transfer by way of the electron beam apertures in the guide walls is made small. The second input signal to be mixed is applied to the second wave circuit section 52 by way of the wave-guide input 55. In this case, the parameters of section 52 are chosen to provide interaction between the electron stream and this second input wave. In particular, section 52 is positioned so that the electron path is displaced substantially one-quarter the wave-guide length of this second input wave from the serpentine wave guide axis 92 of this second section. Since the two inputs to be mixed presumably will have different operating frequency bands, this will result in a displacement of axes 91 and 92 of the first two serpentine wave circuit sections. By way of example, there is shown the case where the frequency of the second signal is less. As a result of the interaction, the second signal will be impressed on the electron stream, which already has thereon the first signal, and cross modulation results. As before, the second section is terminated in an appropriate energy absorbing element 72 to minimize reflection effects. The modulated electron stream continues along the electron path and the A.-C. convection current in the stream excites a traveling wave in section 53 which travels therethrough in the manner of an input signal. By proper adjustment of the parameters of this third section, a predetermined modulation product of the two input signals present in the electron stream can be chosen for selective amplification. In particular this third serpentine wave guide section should be constructed to have its axis 93 displaced substantially one-quarter the guide wavelength of the desired modulation product. In this way, when the other conditions defined by Equations 1 through 3 above are satisfied in the desired operating range, cumulative interaction will occur between the selected wave and the electron stream which will provide amplification to the wave. At the output 55 of this third section, there will be available the modulated wave for utilization.

It can be seen that the principles illustrated by the above arrangements may be utilized in various other embodiments. In particular although the first two arrangements have been described as an amplifier, by suitable modification a portion of the output wave energy can be returned to the input for self-excitation and there is made available an oscillator. Additionally, it should be clear that the arrangement of Fig. 2 although described primarily as directed towards obtaining flatter gain characteristics, can be utilized to provide particular selective characteristics, both with respect to frequency and also with respect to level, as for compressors or expanders. Similarly the principles exemplified by the arrangement of Fig. 3 can be utilized in a variety of ways.

What is claimed is:

1. In a microwave device which utilizes the interaction between an electron stream and a traveling wave to secure gain, a wave circuit comprising a wave guide folded back and forth on itself a plurality of times forming a serpentine wave guide structure, and a plurality of electron sources, each forming and projecting an electron stream transverse to the folds of the serpentine wave guide structure and displaced an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine wave guide structure.

2. In an microwave device which utilizes the interaction between a traveling wave and an electron stream to secure gain, a wave circuit comprising a wave guide folded back and forth on itself a plurality of times forming a serpentine-like wave guide structure, a plurality of electron sources, each forming and projecting an electron stream displaced an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine wave guide structure, and means including a voltage source connected between said wave guide and each source for providing substantially the same velocity to each of the plurality of electron streams through said wave guide.

3. In a microwave device which utilizes the interaction between a traveling wave and an electron stream to secure gain, a wave circuit comprising a wave guide folded back and forth on itself forming a serpentine-like wave guide structure, a plurality of electron sources, each forming and projecting an electron stream through successive folds and along an electron path which is displaced an odd number of quarter wavelengths of the operating frequency on opposite sides of the axis of the serpentine wave guide structure, and beam accelerating means including a voltage source connected between each electron source and the wave guide for providing a different velocity to each of the plurality of streams.

4. In a microwave device which utilizes the interaction between an electron stream and a traveling wave, a serpentine wave circuit for propagating the traveling wave, and a plurality of electron sources each for projecting a distinct electron stream, the various electron streams being spaced apart to traverse the wave circuit along separate electron paths spaced an odd number of quarter wavelengths from the axis of the serpentine wave circuit.

5. In a traveling wave device, an electron source for forming and projecting an electron stream along an electron path, a first wave circuit along said electron path supplied with a first signal of a first frequency for modulating the electron stream, a second wave circuit further along said path supplied with a second signal of a second frequency for providing a traveling wave therethrough for further modulating the electron stream, a third wave circuit along said electron path wherein the modulated stream excites a traveling wave whose frequency is a desired modulation product of said first and second frequencies, and means for deriving said last-mentioned traveling wave for utilization, each of the first, second, and third circuits comprising a wave guide folded back and forth on itself a number of times to form a serpentine wave guide structure which forms with said path of electron flow a plurality of successive interaction regions at the regions where the electron path traverses

each fold of the wave guide, the axis of each of the serpentine wave guide structures being displaced from the path of electron flow an odd number of quarter wavelengths of the frequency of the wave propagating therealong defining short and long wave propagation paths between adjacent interaction regions, the length of each of said long paths in any one of said wave circuits being equal to the length of each of said short paths plus an integral number of wavelengths of the operating frequency in said one wave circuit.

6. In a microwave device which utilizes the interaction between an electron stream and a traveling wave to secure gain, a wave circuit consisting of one continuous wave propagation path folded back and forth upon itself a plurality of times forming a serpentine-like wave guide structure, an electron gun and a collector electrode positioned for defining an electron path transverse to the folds of the serpentine wave guide structure whereby a plurality of successive interaction regions are formed at the regions where the electron path traverses each fold of the wave guide, said electron path being parallel to and displaced an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine wave guide structure defining short and long wave propagation paths between adjacent interaction regions, the length of each of said long paths being equal to the length of each of said short paths plus an integral number of wavelengths of the operating frequency.

7. In a traveling wave device, an electron source for forming and projecting an electron stream along an electron path, a first wave circuit supplied with a first frequency signal transversely successively intersecting said electron stream at a group of first-signal electron-stream interaction points, a second wave circuit supplied with a second frequency signal transversely successively intersecting said electron stream at a group of second-signal electron-stream interaction points, a third wave circuit transversely successively intersecting said electron stream at a group of points where said electron stream induces in said third circuit a desired heterodyne modulation signal of the first and second signals, and means for connecting said heterodyne signal to an output, each of the first, second and third circuits comprising a wave guide folded back and forth on itself a number of times to form a serpentine wave guide structure, the axis of each of the serpentine wave guide structures being displaced from the path of electron flow an odd number of quarter wavelengths of the frequency of the wave propagating therealong defining short and long wave propagation paths between adjacent interaction points, the length of each of said long paths in any one of said wave circuits being equal to the length of each of said short paths plus an integral number of wavelengths of the operating frequency in said one wave circuit.

8. In a microwave device which utilizes the interaction between an electron stream and a traveling wave to amplify the wave, a wave circuit comprising a wave guide folded back and forth on itself a plurality of times forming a serpentine-like wave structure and an electron source and collector-electrode positioned for defining an electron path transversely through the plurality of folds of said serpentine structure whereby a plurality of successive interaction regions are formed at the regions where the electron path traverses each fold of the wave guide, said electron path being parallel to and displaced an odd number of quarter wavelengths of the operating frequency from the axis of the serpentine structure defining short and long wave propagation paths between adjacent interaction regions the length of each of said long paths being equal to the length of each of said short paths plus an integral number of wavelengths of the operating frequencies.

9. In a traveling wave type device, first, second and third wave circuits, each comprising a wave guide folded back and forth on itself a plurality of times forming a serpentine-like wave guide structure, input means to each of said first and second wave circuits for applying for propagation therethrough waves of a first and second frequency, respectively, and an electron source for forming and projecting an electron stream in turn through the folds of said three wave circuits for electron coupling thereof in the regions where the electron stream passes through the wave guide folds, the three wave circuits being positioned for providing an electron path through the serpentine wave guide structure of said first and second circuits parallel to and displaced from the axis of said serpentine structure approximately an odd number of quarter wavelengths of said first and second frequencies, respectively, and through the serpentine wave guide structure of said third circuit patrallel to and displaced from the axis of said serpentine structure an odd number of quarter wavelengths of a desired modulation product frequency of said first and second frequencies defining short and long wave propagation paths between adjacent regions of traversal of the beam in each of said first, second, and third circuits, the length of each of said long paths in any one circuit being equal to the length of each of said short paths plus an integral number of wavelengths of the operating frequency in said circuit.

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