ABSTRACT

A traveling wave electron interaction device is provided having means for reducing intermodulation product amplitudes and cross-modulation in multisignal operation. An axial variation of a delay line phase velocity is introduced at substantially low levels of electron beam modulation to provide a positive velocity profile. The fundamental circuit wave of one signal is allowed to proceed with relative little gain while the space harmonic component of another signal is allowed to drop in magnitude thereby improving traveling wave tube linearity by desynchronizing of space harmonic interaction with the electron beam. The invention is suited for low power level communication type devices where signal distortion is a critical parameter.

4 Claims, 4 Drawing Figures
FIG. 1
SLOW VELOCITY CIRCUIT AND ATTENUATOR CIRCUIT
POSITIVE VELOCITY STEP

FIG. 2
PRIOR ART
TRAVELING WAVE TUBE LINEARITY CHARACTERISTICS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to traveling wave type electron interaction devices and, particularly, to means for minimizing intermodulation and cross-modulation signal distortion effects.

2. Description of the Prior Art

Traveling wave type devices incorporate a wave guiding circuit such as, for example, a helix for amplifying electromagnetic energy by extracting kinetic energy from an adjacent high power DC beam of electrons. The circuit wave typically travels along the propagating structure at a velocity less than that of light to establish a synchronous interaction relationship and produce AC density modulation of the beam. The electric and magnetic fields of the energy on the circuit induce perturbations in the electron beam to form electron packets or bunches having a fundamental frequency component at about the frequency of the circuit wave. Numerous space harmonic components are also present on the circuit and the beam which can result in a synchronous relationship. The beam of electrons is translated along the axial length of the propagating circuit with the parameters selected to retard the phase and group velocity of the circuit wave until the synchronous relationship is established to provide for a net exchange of energy. The electron bunches having a group velocity considered to be "in step" with the slowed electromagnetic fields of the circuit wave move at substantially the same phase velocity upon the establishment of the synchronous relationship. The electron beam, therefore, is simultaneously velocity and density modulated along the direction of travel until a saturation point is reached where the bunches become disarrayed and the kinetic energy can no longer be extracted. The synchronous relationship resulting in the interaction between the electrons and the circuit wave fields produces amplification or oscillation which may be characterized as being of the "backward or forward wave type."

In the backward wave devices the beam travels at a velocity which is synchronous with the phase velocity of a space harmonic component moving in a direction opposite to that of the waves along the circuit. Such harmonics have negative phase velocity while the group velocity is positive. In forward wave devices the electron beam and energy transport of the induced circuit waves travel in the same direction. A forward wave device is, therefore, provided with a propagating circuit whose phase velocity characteristic of the fundamental frequency is similar to that of the electron group velocity. In the art, the term "fundamental" generally refers to the component of an electromagnetic wave having the largest phase velocity which determines the operating characteristics of the device. The efficiency parameter of the subject devices is a measure of the energy converted from the kinetic energy on the DC beam to the RF energy in the wave traveling along the adjacent propagating circuit. This parameter is an arithmetic ratio of RF energy output to the input power and can run as high as 50 to 60 percent.

One of the prior art methods for increasing the efficiency of the applicable devices involves the optimizing or tailoring of the positioning of the electrons within the electron bunches to prolong the energy extraction. The pitch of the helix structure is varied to provide a negative velocity step which deliberately shifts the phase of the modulated electron bunches and introduces a desynchronization effect at relatively low levels of beam modulation, illustratively in the order of 0.1–1 percent of the DC beam power. The efficiency enhancement technique results in induced motion in the modulated beam bunches toward the forward portion of the deceleration fields of the circuit waves to increase the net overall energy transfer. An example of the negative velocity step technique is found in U.S. Pat. No. 3,614,517, issued Oct. 19, 1971, to Norman J. Dionne and assigned to the assignee of the present invention. Such techniques involve the use of computerized simulation models to provide the required circuit parameters for the desired interaction characteristics.

In certain communications systems utilized for guidance, the target information is received by a missile-borne monopulse antenna and then is time delayed, amplified and transmitted to a ground installation. On the ground the target information is analyzed and appropriate information is transmitted back to the acquisition source to effectively intercept the target. The method is complex since the missile monopulse antenna receives cluster signal inputs as well as target signals. Large clutter signals from the main lobe of the monopulse antenna and the smaller signals with differing Doppler frequency shifts from the side and back lobes produce intermodulation signals that can obscure the target signals unless appropriate measures are taken. Such clutter signals by their nature have large amounts of amplitude and phase modulation components. Cross-modulation of the target signals by the clutter signals will produce phase and amplitude variations in the target signals transmitted by the acquisition source with a resulting error in the guidance system. Traveling wave type electron interaction devices are typically used to amplify the signals received and retransmitted to ground installations. The intermodulation and cross-modulation phenomena, therefore, play an important role in the performance of the traveling wave tube devices in a multisignal communications system.

To minimize the intermodulation product amplitudes as well as cross-modulation the art has previously employed such techniques as operation at a power level far below saturation with the largest possible gain parameter (C) to approach linear traveling wave tube performance. For the purposes of the specification the term "linearity" is defined as the ratio of the fundamental current to the harmonic current components. In order to minimize intermodulation as well as cross-modulation of multisignals it is desirable that the harmonic components on the DC beam of one group of signals decrease in magnitude while the fundamental components of another signal proceed with minimum interference.

SUMMARY OF THE INVENTION

In accordance with the present invention the effects of intermodulation and cross-modulation components are substantially reduced by varying the wave guiding propagating circuit profile at a point well removed from the output end of the overall structure. A positive velocity step at low levels of beam modulation introduce a desynchronous effect which does little to im-
prove overall efficiency. Devices for a multisignal operation however such as low power level communication tubes having about 100 watts output are not adversely affected by the positive velocity step. The overall effect is a notable reduction of the intermodulation and cross-modulation products and amplitudes by increasing the circuit wave velocity to allow the fundamental component of one signal to proceed with relatively little gain while the space harmonic component of another signal rapidly dies off because of nonlinear bunching. Signal distortion is thereby reduced.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Details of the invention will be readily understood after consideration of the following description of a preferred embodiment and reference to the accompanying drawings, wherein:

FIG. 1 is a schematic representation of a traveling wave electron interaction device embodying the invention;

FIG. 2 is a graph of the velocity and attenuator profiles of the negative velocity step prior art embodiment;

FIG. 3 is a graph of the velocity profile and computerized simulation results of the fundamental and harmonic beam current related to the axial length of the illustrative embodiment of the invention; and

FIG. 4 is a graph of the velocity profile and computerized simulation of the embodiment of the invention showing the effect of second harmonic circuit interaction.

**DESCRIPTION OF THE PREFERRED EMBODIMENT**

Referring to FIG. 1, the exemplary embodiment of a traveling wave tube 10 for amplifying electromagnetic energy is shown. Circuit wave guiding means 12, such as a helix, extend along the longitudinal axis of a hermetically sealed envelope 14. The energy is coupled to the helix by an input conductor means such as a coaxial transmission line 16 and similar output means 18 are disposed at the opposing end adjacent to a collector electrode 20.

A directly-heated gun-type electron source 22 includes means for generating and directing a stream of electrons 24 along the longitudinal axis of the device to interact with the circuit wave energy. An emissive cathode 26 which may have a slight curvature to assist in the electron beam trajectory is provided with a heater coil 28. Leads 30 which extend through the envelope walls provide for the connection of all the components of the cathode structure to the DC voltage sources. Grid control electrode 32 is disposed adjacent to the cathode and is biased by a suitable DC variable control 34. Accelerator electrode 36 provides for beam focusing and is typically biased at a positive potential by a suitable DC voltage supply. Magnetic field producing means 38 which may include a high coercive force material such as samarium cobalt or platinum cobalt surround the tube envelope 14 and provide a longitudinal magnetic field parallel to the axis of the device to confine the electrons to the desired trajectory path. Electromagnetic magnetic field producing means such as a solenoid may also be employed.

The circuit wave guiding structure 12 includes a first slow velocity circuit section as well as the attenuator section 40 which is coupled to the input 16. An intermediate positive velocity step follows at a point where the electron beam modulation is at a relatively low level of illustratively 0.1 to 1 percent. A section follows having a fewer number of turns per inch to define a fast velocity circuit section 44 which extends toward the output means 18 for an axial distance greater than said slow velocity section 40. In an exemplary embodiment the first section 40 has a helix pitch of 22 turns per inch while the section 44 has 19 turns per inch. It is also known in the art that in order to change the phase velocity of the circuit wave, the diameter of the wave guiding means may be varied in lieu of a change in the number of turns. In transparent-type electron interaction devices which can be utilized as power boosters, no internal attenuator is necessary and the overall length of the device is therefore shorter. Such transparent-type devices are typically coupled to a traveling wave tube amplifier having a higher power output capability.

Referring now to FIG. 2, the teaching of the prior art relative to the provision of a negative velocity step to enhance efficiency will be reviewed. The velocity profile line 46 which is a plot of the V/C ratio has illustratively 22 TPI in the low level beam modulation area and a tighter pitch of 26 TPI in the rainder of the wave guiding means after a step which may have a slight taper. The purpose of the negative step is the preconditioning of the electron beam modulation before definitive bunching has definitive in order to introduce a desynchronization effect involving the shifting of the bunches further forward in the decelerating field to thereby provide for longer periods of beam energy extraction before saturation. Efficiencies of 50 to 60 percent have been realized with this velocity shift technique for single signal energy amplification applications. The variation in the wave guiding characteristic profile is provided with the velocity shift at a point well removed from the output end of the structure. This point may be determined by the computerized simulation model technique enumerated in the aforementioned U.S. Pat. No. 3,614,517. The profile of the attenuator characteristics is indicated by line 48. The RF current characteristics of both the fundamental and harmonic components are plotted in the lower section of this graph with the fundamental current indicated by the dotted line curve 50 while the harmonic current is indicated by the curve 52. An output of approximately 120 watts is obtained with the device having the characteristics plotted in FIG. 2. In the analysis of the inter-modulation as well as cross-modulation problem the computerized simulation model indicates that the fundamental and second harmonic beam currents as a function of the axial distance along the tube have an inherent exponential gain so that adjacent to the output end of the tube the second harmonic current amplitude is only approximately 3 dB down from the value of the fundamental current as indicated by the bracket 54.

In FIG. 3 the results of the positive velocity step profile of the invention are indicated by line 56. The relative attenuation with an internal attenuator is indicated by the profile line 58. The fundamental current is indicated by the dotted line curve 60 while the harmonic current is indicated by curve 62. The effect of the positive velocity step on the harmonic current is indicated by the bracket 64 near the output end of a tube having the same relative power output of 120 watts. The distance between the respective currents has now dropped to approximately -7 DB below the fundament-
tal or approximately a 4 DB reduction in harmonic current which represents approximately an 8 DB reduction in harmonic power. In multisignal operation it is the harmonic component which is coupled to one of the input signals while the fundamental is coupled to the other to create the intermodulation product amplitude as well as cross-modulation signal distortion. The effects of the reduction of the harmonic components of the modulated energy along the electron beam and circuit wave interaction path are even more significantly displayed in FIG. 4 where the velocity step section 66 of the profile line 68 is positioned even closer to the input section. The attenuator profile characteristics remain substantially the same as indicated by line 70.

In FIG. 4 the two harmonic current curves represent the performance of a dispersive circuit compared with that of a nondispersive circuit wherein harmonic interaction between the circuit and beam take place. The term "dispersive" as utilized in the art, refers to the ratio of the phase velocity and group velocity of the traveling waves and a nondispersive structure would be one in which the ratio is substantially equal to unity and interaction between the circuit and beam takes place. The results indicated for the fundamental current are shown by the dotted line curve 72. Interaction of the harmonic content with the electron beam is indicated by curve 74 while curve 76 shows the effect of the second harmonic without removal by the space charge waves of the electron beam. The results indicate that with interaction simultaneously at both the fundamental and harmonic frequencies the harmonic beam current is reduced by 3 DB with a circuit having a positive velocity step. In the fast velocity section, interaction of the fundamental frequency components with signals on the circuit wave guiding structure result in little change in bunching. Simultaneous interaction of the harmonic frequency component however results in a drop in magnitude due to nonlinear bunching. With significant reduction of the intermodulation and cross-modulation phenomena the linearity characteristics are improved and signal distortion problems are substantially reduced.

Since numerous modification and alternatives will be apparent to those skilled in the art a broad interpretation of the invention as set forth and described herein is intended.

I claim:

1. A traveling wave electron interaction device comprising:
   circuit guiding means for propagating multisignal electromagnetic wave energy;
   means for generating and directing an electron beam along a path adjacent to said guiding means to interact in energy exchanging relationship with the propagating waves; and
   means for increasing the phase velocity of said circuit means at substantially low levels of electron beam-wave interaction to substantially prevent interaction of the space harmonic frequency components of one propagated signal with said beam while permitting continued interaction of the fundamental frequency components of another signal with said beam.

2. A traveling wave electron interaction device comprising:
   circuit guiding means for propagating multisignal electromagnetic wave energy comprising a first slow velocity circuit section;
   means for generating and directing an electron beam along a path adjacent to said guiding means to interact in energy exchanging relationship with the propagating waves; and
   means for providing a positive velocity step and a second circuit section to increase the phase velocity characteristic of said circuit means at substantially low levels of electron beam-wave interaction to desynchronize the interaction of the space harmonic frequency components of one signal while continuing the synchronous relationship of the fundamental frequency components of another signal with said beam.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,758,811 Dated September 11, 1973

Inventor(s) Jeffrey Wong

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 12 - insert "i" in word "negative"
Column 4, line 17 - insert "p" in word "capa-"

Column 4, line 28 - insert "i" in "nitive" and change "definitive" to "arisen"
Column 4, line 32 - insert "i" in word "Efficiencies"

Column 6, line 1 - insert "i" in word "modification"

Add claims 3 and 4:

3. The device according to claim 2 wherein said positive velocity step commences at the point along the axial length of said circuit guiding means where the beam modulation level is in the order of about .1 to 1% of the total DC beam power.

4. The device according to claim 2 wherein said second circuit section has an axial length greater than said first slow velocity circuit section.

Signed and sealed this 19th day of March 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR. C. MARSHALL DANN
Attesting Officer Commissioner of Patents