

Jan. 14, 1958

R. ADLER
ELECTRON BEAM WAVE SIGNAL FREQUENCY CONVERTER
UTILIZING BEAM DEFLECTION AND
BEAM DEFOCUSING

2,820,139

Filed Nov. 8, 1954

3 Sheets-Sheet 1

FIG. 1

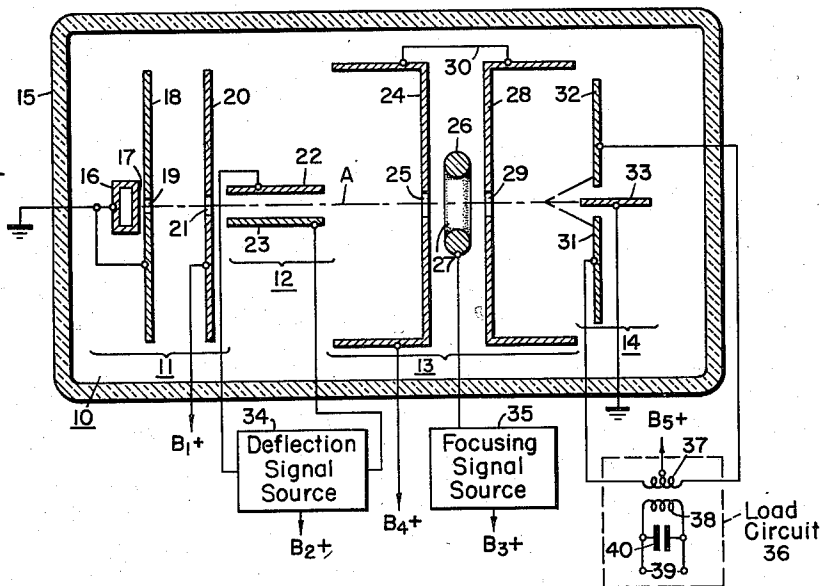
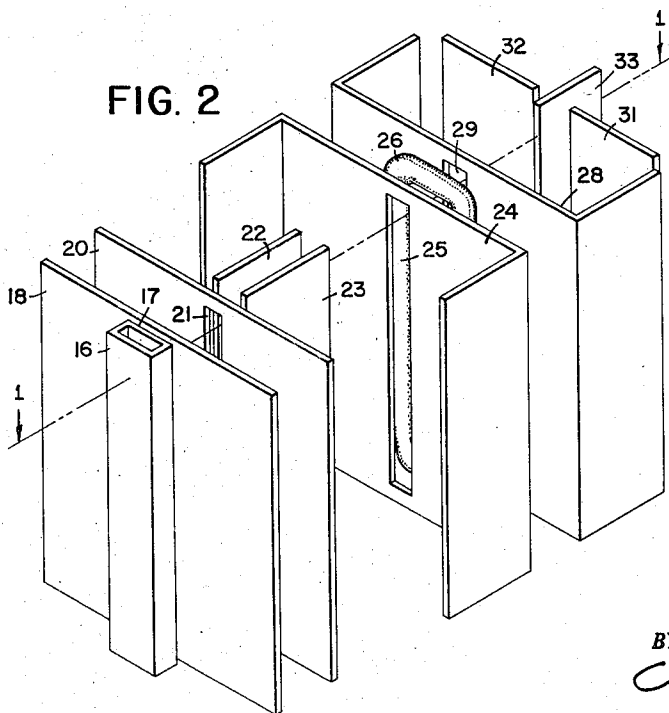


FIG. 2



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3 Sheets-Sheet 2

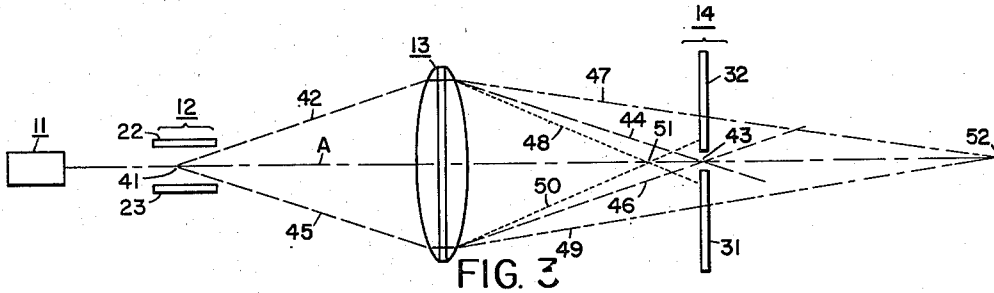
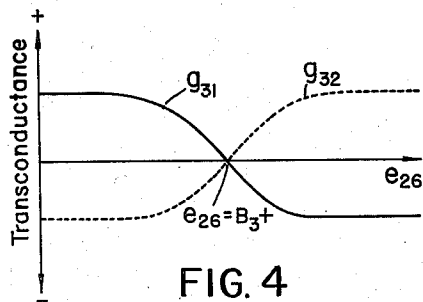


FIG. 4

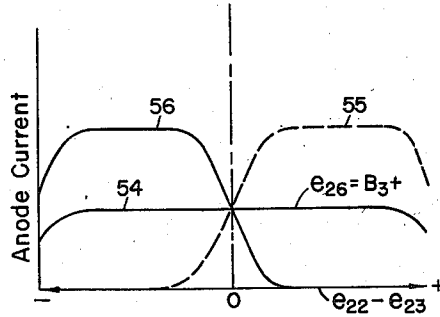


FIG. 5

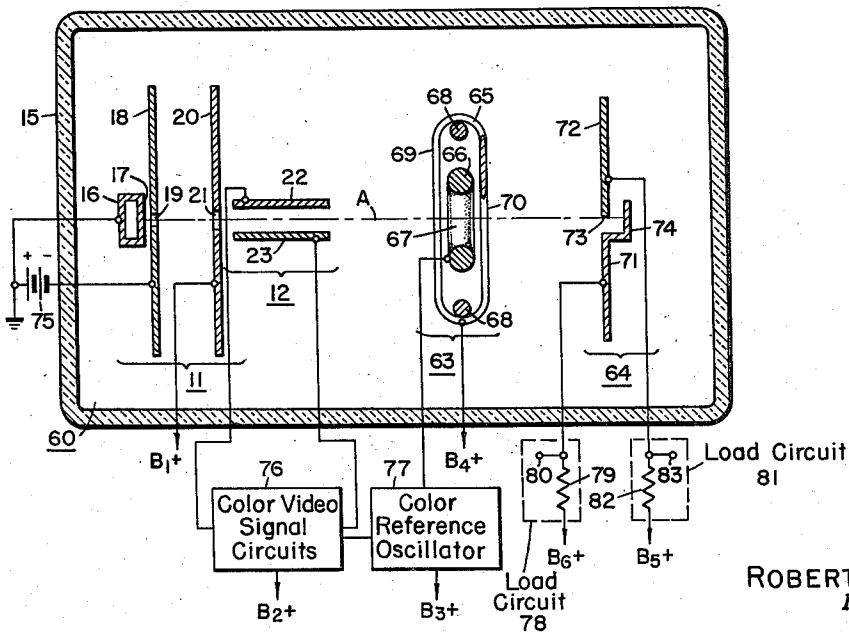


FIG. 6

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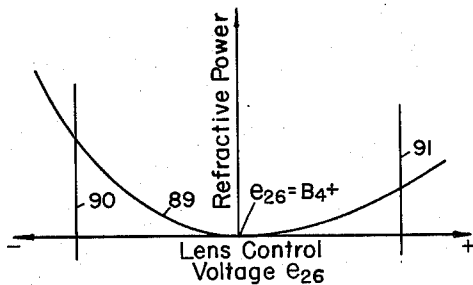
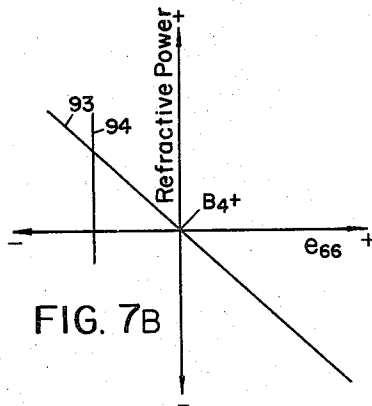
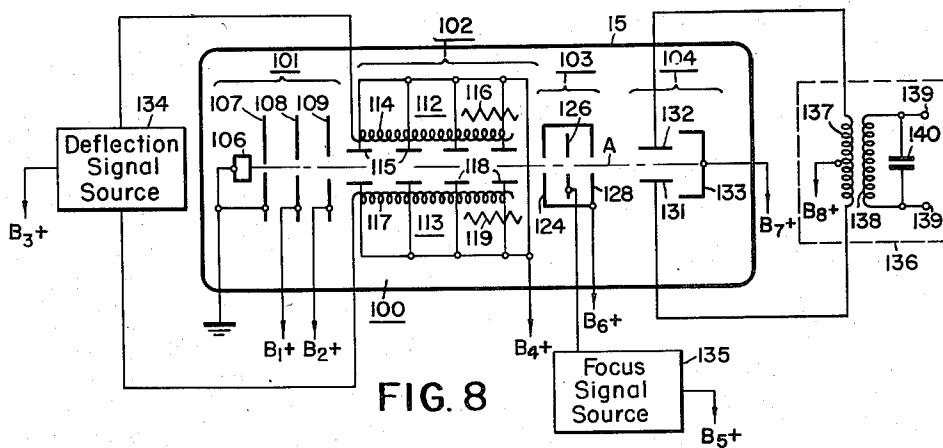
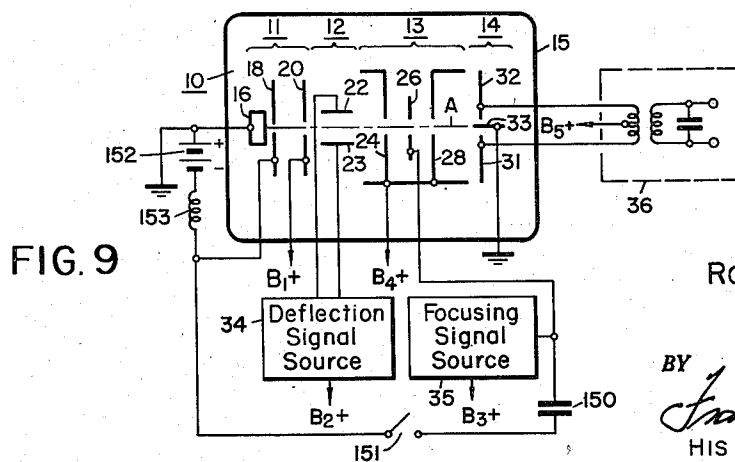
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3 Sheets-Sheet 3



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ELECTRON BEAM WAVE SIGNAL FREQUENCY CONVERTER UTILIZING BEAM DEFLECTION AND BEAM DEFOCUSING

Robert Adler, Northfield, Ill., assignor to Zenith Radio Corporation, a corporation of Illinois

Application November 8, 1954, Serial No. 467,621

17 Claims. (Cl. 250—20)

This invention is directed to new and improved electron-discharge devices and to wave-signal frequency converters employing those devices. More particularly, the invention is concerned with electron-discharge tubes in which a beam of electrons is subjected to deflection control and focus control, in that sequence, in accordance with two different input signals and with frequency converters utilizing tubes of this type to generate signals representative of the intermodulation products of two signals.

There are a relatively large number of known types of electron tubes suitable for use as frequency converters, modulators, and/or demodulators; generally speaking, these tubes may be grouped into three classifications. In the more common type of converter, a stream of electrons is intensity-modulated in accordance with two distinct signals and is intercepted by an anode coupled to a frequency-selective load circuit. The load circuit is made responsive to one of the intermodulation products of the two signals and develops a signal representative of that intermodulation product. Converters of this type are used in almost all commercially available radio and television receivers as well as in many other applications.

A somewhat less familiar type of converter tube combines intensity modulation with deflection modulation. In devices of this type, a stream of electrons is first modulated in intensity in accordance with one signal and is subsequently deflection-modulated in accordance with a second signal. An output electrode system, which usually comprises a pair of anodes disposed on opposite sides of the undeflected beam path, is employed to generate an output signal representative of a conversion product of the two signals. A specific example of this type of conversion or modulation system is described and claimed in the copending application of Robert Adler and John L. Rennick, Serial No. 355,476, filed May 18, 1953, now abandoned, and assigned to the same assignee as the present invention. Other lesser-known converter devices employ two stages of deflection control and specialized output electrode systems to provide the desired frequency conversion.

In all of these prior art converter arrangements, one of the principal difficulties and disadvantages results from the fact that it is virtually impossible to completely isolate the two signal-input electrode systems from each other; in addition, it is extremely difficult to prevent one or both of the input signals from appearing in unconverted form in the output signal. For example, in conventional modulators employing only intensity control, some degree of coupling between the two input signal circuits is almost inevitable. This coupling between the two input systems is highly undesirable in many applications, such as radio and television receivers, since it may cause variations in the local oscillator frequency or may lead to undesired radiation from the receiver antenna at the local oscillator frequency. On the other hand, although the presence of one or both

of the input signals in the output of the converter is not particularly disadvantageous in ordinary receiver applications, due to the relatively large differences in the frequencies of the desired intermodulation component and the two input signals, this effect may become extremely important in certain applications in which the desired output signal is in the same frequency range as one or both of the input signals.

It is a primary object of the invention, therefore, to provide a new and improved electron-discharge device, suitable for use in a frequency converter, which provides complete isolation of the input signals.

It is another principal object of the invention to provide a new and improved electron-discharge device and converter system which effectively avoid translation of the input signals to the output electrode system.

It is another object of the invention to provide a new and improved electron-discharge device which, when incorporated in a frequency converter, provides a relatively high conversion gain.

It is a further object of the invention to provide a new and improved electron-discharge device and frequency converter having a relatively high signal-to-noise ratio.

It is a corollary object of the invention to provide a new and improved electron-discharge device which is relatively simple and economical in design and construction.

An electron-discharge device constructed in accordance with one aspect of the invention comprises an electron gun for projecting a beam of electrons along a given reference path and a deflection-control system, responsive to an applied signal, for deflecting that beam transversely from its reference path as the beam passes through a predetermined center of deflection. The tube further comprises means including an electron lens for normally focusing the beam to form an image of the center of deflection at a preselected subsequent location on the reference path and for varying the location of that image along the path in response to a second signal. An output electrode system is coupled to the electron beam and is utilized to derive an output signal representative of transverse excursions of the electron beam from the aforementioned preselected image location.

The electron-discharge device of the invention may also be utilized in a dual-conversion system. In some applications, it is desirable to employ a signal oscillator for the conversion of a relatively wide range of received signal frequencies; thus, in the television field, it is desirable to employ a single oscillator for the conversion of received signals ranging in frequency from 54 to 890 megacycles. However, it is extremely difficult to obtain the requisite "repeatability" in an oscillator operating over such a wide range (approximately 100 to 930 megacycles for the usual intermediate-frequency); that is, it is extremely difficult to tune an oscillator consistently over such a broad band. Accordingly, a single electron-discharge tube adapted to operate as either a single-conversion or a dual-conversion device may be highly advantageous.

It is a further object of the invention, therefore, to provide a new and improved electron-discharge device and converter in which a single electron stream is modulated by three input signals and utilized to develop an output signal representative of an intermodulation product of all three of the signals.

It is a corollary object of the invention to provide a new and improved electron-discharge tube adapted to operate as either a single-conversion or dual-conversion device.

A dual-conversion electron-discharge device constructed in accordance with another aspect of the invention com-

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prises means for projecting a beam of electrons along a given reference path and means for subjecting that beam to intensity modulation, deflection modulation, and focus modulation, in the named sequence, in response to three individually applied signals. An output electrode system is included in the device to utilize the thrice-modulation electron beam to derive an output signal representative of an intermodulation product of all three signals. The three signals need not all be specifically different from each other; for example, the same signal may be employed for both intensity and focus modulation.

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

Figure 1 is a cross-sectional view of an electron-discharge device constructed in accordance with one embodiment of the invention; the figure also includes a schematic diagram of a simplified converter circuit for the tube;

Figure 2 is a perspective view of the electrode structure of the tube shown in Figure 1;

Figure 3 is an explanatory diagram employed to explain the operation of the tube of Figure 1;

Figures 4 and 5 are graphs illustrating certain operating characteristics of the tube of Figure 1;

Figure 6 illustrates, in cross section, an electron-discharge device constructed in accordance with another embodiment of the invention along with a simplified schematic diagram of the associated circuitry in a typical application;

Figures 7A and 7B are graphs which illustrate certain operating characteristics of the lens systems incorporated in the tubes of Figures 1 and 6 respectively;

Figure 8 is a schematic diagram of another embodiment of the invention; and

Figure 9 is a schematic diagram of a dual-conversion embodiment of the invention.

The wave-signal frequency converter illustrated in Figure 1 comprises an electron-discharge device 10 including an electron gun 11, a deflection-control system 12, an electron lens system 13 and an output electrode system 14 all mounted within the usual evacuated envelope 15. Each of the individual electrode systems 11-14 may be entirely conventional in form; it is the particular combination of these systems which forms the basis for the inventive concept.

Electron gun 11, for example, may include an indirectly-heated cathode 16 having an electron-emissive surface 17. Gun 11 further includes a focusing or control electrode 18, including an aperture 19 located opposite emissive surface 17, and an accelerator 20 having an aperture 21 aligned with aperture 19. Deflection-control system 12 includes a pair of conventional deflector electrodes 22 and 23 suitably disposed on opposite sides of the center plane A of the tube; it will be noted that all of the electrode systems in this particular embodiment of the invention are symmetrically arranged with respect to center plane A.

Electron lens system 13 includes three lens electrodes 24, 26 and 28 having individual apertures 25, 27 and 29 respectively, the apertures of these electrodes being substantially symmetrical with respect to center plane A. Electrodes 24 and 28 may be formed from sheet metal and are electrically connected to each other as by a lead 30. Electrode 26 may also be formed from sheet metal; in the illustrated embodiment, however, a simple U-shaped wire is used for this electrode. Output electrode system 14 comprises a pair of anodes 31 and 32 disposed on opposite sides of the center plane in symmetrical relationship thereto; preferably, a suppressor electrode 33 is positioned between the two output anodes.

Preferably, tube 10 employs a sheet-like beam of elec-

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trons; that is, the electron beam viewed in cross section, should have one dimension very much larger than the other cross-sectional dimension. As illustrated in Figure 2, the widths of the individual electrode apertures in tube 10 are very much smaller than the heights of those apertures, thus providing an electron beam having a width which is extremely small as compared to its height. A sheet beam of this type is preferred because it makes possible the control of large beam currents without requiring excessive control potentials or input signal levels. Figure 2 also gives a more complete picture of the general configuration and construction of the electrodes of tube 10; as indicated in Figure 2, virtually all of the electrodes for the tube may be formed from sheet metal or wire by simple stamping or bending techniques.

As shown in Figure 1, cathode 16 of electron gun 11 is connected to a plane of reference potential, here indicated as ground; in this embodiment of the device, focus electrode 18 is connected to the cathode within the tube envelope. Accelerator 20 is connected to a first source of positive unidirectional operating potential B_1+ . Deflectors 22 and 23 are coupled to a first input or deflection signal source 34 in push-pull manner and are also connected to a second source of positive operating potential B_2+ . Lens electrodes 24 and 28 are connected to an operating potential source B_4+ , whereas lens electrode 26 is connected to a second input or focusing signal source 35 and to an operating potential source B_3+ . Suppressor electrode 33 may be connected to ground, and output anodes 31 and 32 are connected to a utilization means comprising a load circuit 36. Load circuit 36 may, for example, constitute an output transformer including a primary winding 37 connected across the two anodes and a secondary winding 38 having output terminals 39. A tuning capacitor 40 may be connected across secondary winding 38. The electrical center of winding 37 is connected to a source of positive operating potential B_5+ to provide a suitable operating voltage for anodes 31 and 32.

In a typical application, deflection signal source 34 may constitute a source of a modulated carrier wave such as a radio or television transmission signal; thus, source 34 may constitute the antenna and associated input circuit, including the radio-frequency amplifier if any, of a television receiver. Focusing signal source 35 may comprise the local oscillator of such a receiver, and load circuit 36 may constitute a part of the input circuit of the first intermediate-frequency amplifier of that receiver. Operating potential sources B_1+ to B_5+ may comprise individual batteries or rectifiers; ordinarily, however, the individual operating potentials are provided by spaced taps on a voltage divider fed by a single source of positive operating potential.

When the wave-signal frequency converter illustrated in Figure 1 is placed in operation, a stream of electrons is emitted from cathode surface 17 and is focused into a beam as it passes through aperture 19 of electrode 18. The beam is accelerated and projected along a reference path centered about center plane A as it passes through aperture 21; disregarding any effect of applied signals, the beam continues along the reference path defined by plane A and thus passes between deflectors 22 and 23, through lens apertures 25, 27 and 29, and on toward suppressor 33. Because the suppressor electrode is held at cathode potential, the beam divides as it nears the suppressor and impinges equally upon output anodes 31 and 32.

The normal operating potentials on deflectors 22 and 23 are equalized so that, with zero signal from source 34, the electron beam is not deflected from path A. The operating potentials for lens electrodes 24, 26 and 28, on the other hand, are adjusted so that in the absence of a signal from source 35 the electron lens formed by these electrodes normally focuses the electron beam to form an image of the center of deflection of system 12 at a pre-

selected subsequent location on reference path A; for the illustrated embodiment, this image location should coincide with the plane of output anodes 31 and 32. Ideally, with no signal applied from sources 34 and 35, the electron beam divides equally between the two anodes; however, this ideal condition is by no means essential so long as each anode collects an appreciable portion of the beam current. Deflection modulation of the electron beam is effected by the signal applied to deflectors 22 and 23 from source 34. The focal length of the electron lens formed by system 13, on the other hand, varies in accordance with the signal from source 35.

Operation of the tube 10 as a converter may be more fully understood by reference to Figure 3, in which the various electrode systems of the tube are shown in schematic form. With no signal applied to either deflection system 12 or lens system 13, the electron beam from gun 11 is not diverted from reference path A and therefore cannot establish a potential difference between anodes 31 and 32. If the signal from source 34 instantaneously drives deflector 22 positive with respect to deflector 23, the electron beam is deflected transversely from reference path A as it traverses the center of deflection 41 of system 12; under these conditions, the beam follows a deflected path indicated by dash line 42. With lens system 13 adjusted to focus an image of deflection center 41 at a subsequent location on path A approximately in the plane of anodes 31 and 32, as indicated by point 43, the beam continues through the lens and follows the path indicated by dash line 44, passing through image location 43. The beam is still centered on the output anode system so that it develops no potential difference between the two anodes; thus, no output signal is generated. Similarly, if deflector 23 is instantaneously driven positive with respect to deflector 22, the beam traverses a path generally indicated by dash line 45 until it enters lens system 13 and is then redirected toward image location 43 along dash line 46; again, no difference in potential or current distribution is established between the output electrodes. It is thus apparent that the input signal supplied from deflection source 34 to system 12 cannot by itself generate an output signal in the load circuit 36 connected across anodes 31 and 32 (see Figure 1).

With no signal applied to deflection system 12, application of a focusing signal from source 35 to lens electrode 26 cannot change the potential difference or current distribution between the output anodes, provided the beam is properly centered to begin with. The only effect that this focusing signal can have, in the absence of any deflection signal, is to diverge or converge the beam; the focusing system cannot by itself change the direction of the beam and therefore cannot independently cause a signal to be generated in the output electrode system.

Simultaneous application of input signals to the deflection-control and electron lens systems, however, gives rise to the desired frequency-conversion action. If the beam is deflected from center 41 to follow path 42, and the focal length of the electron lens is changed substantially by varying the potential on lens electrode 26, the beam may be deflected over a range of different paths indicated by dash-dot line 47, line 44, and dash line 48. Similarly, if the beam is deflected to follow path 45, the resultant path as the beam emerges from the electron lens may be indicated by lines 49, 46 and 50, depending upon the focal length of the electron lens as determined by the signal applied from source 35 to electrode 26 (Figure 1). Looking at the combined effects of the two control systems from a different standpoint, the voltage on lens electrode 26 may be instantaneously varied from the normal operating potential supplied by source B_3+ so that the focus of the electron lens coincides with point 51 on reference path A; if the beam is then deflected between paths 42 and 45, the lens reverses the sense of the deflection in the plane of anodes 31, 32. On the other hand, with the lens adjusted to focus on point 52, the original sense of deflection

is preserved as the beam passes through the lens and continues on to the output electrodes.

Thus, the distribution of the beam in the plane of anodes 31 and 32 is a function of both the input signal applied to deflection system 12 from source 34 and the second input signal applied to lens electrode 26 from source 35. Two different intermodulation product signals are generated in the output electrode system; one of these signals has a frequency equal to the sum of the two input signal frequencies and the other has a frequency equal to the difference between the input signal frequencies. In most applications, however, only the lower of the two beat-frequency signals is utilized; accordingly, load circuit 36 may be tuned to this particular signal frequency so that the higher frequency intermodulation product is not translated to succeeding stages in the receiver or other device in which the converter is employed.

Certain of the operating characteristics of tube 10 are illustrated in Figures 4 and 5; in Figure 4, the transconductance of deflection system 12 with respect to the output electrodes 31, 32 is plotted as a function of the instantaneous voltage e_{26} on lens control electrode 26. As would be expected, the transconductance with respect to both anodes is zero when e_{26} is equal to the normal operating voltage applied to electrode 26 from source B_3+ , since this represents an operating condition in which no signal is applied to the lens electrode and the beam is focused to image the center of deflection at a point midway between anodes 31 and 32. As the voltage e_{26} is increased or decreased with respect to this normal operating potential, however, the focal length of the electron lens increases or decreases so that deflection of the beam gives rise to corresponding changes in the current distribution between the two anodes. Of course, any variation in focal length of the electron lens which causes the deflected beam to be diverted toward one of the anodes increases the current drawn by that anode and at the same time decreases the current to the other anode, so that the instantaneous transconductance of the deflection system with respect to one anode is opposite in polarity to the transconductance to the other anode. The transconductance g_{31} of deflection system 22, 23 with respect to anode 31 may be defined as

$$(1) \quad g_{31} = \frac{\partial I_{31}}{\partial (e_{22} - e_{23})}$$

the transconductance g_{32} for anode 32 is expressed as

$$(2) \quad g_{32} = \frac{\partial I_{32}}{\partial (e_{22} - e_{23})}$$

The transconductance characteristic for anode 31 is illustrated by solid line g_{31} and the transconductance characteristic for anode 32 is shown by dash line g_{32} in Figure 4; as indicated by these two curves, at any given instant the transconductances to the two anodes are equal in magnitude but of opposite polarity.

Figure 5 illustrates the changes in current distribution between the two anodes in response to changes in deflection voltage $e_{22} - e_{23}$ for given fixed values of e_{26} , the voltage on lens control electrode 26. With e_{26} equal to the normal operating potential from source B_3+ , of course, the current distribution between the two anodes is approximately equal no matter what the voltage distribution between deflectors 22 and 23, as indicated by solid line 54. With the lens control electrode at a higher potential than the normal operating voltage, the variations in current to anode 31 caused by changes in the deflection voltage is indicated by solid line 56. Under the same conditions, the current to anode 32 varies with changes in deflector voltage as indicated by dash line 55. When the signal applied to the lens control electrode decreases the potential e_{26} on that electrode below the normal operating potential supplied from source B_3+ , the operating characteristics of the two anodes are reversed so that curve 56 now represents the variations in current to anode

32 caused by changes in the deflector voltages whereas line 55 shows the current drawn by anode 31 with corresponding changes in the potentials on the deflectors.

The converter system of Figure 1 effectively isolates the two input signals from sources 34 and 35 from each other and at the same time prevents translation of either of the input signals to output electrode system 14. Deflectors 22 and 23 are shielded from the lens control electrode 26 by lens electrode 24, which is maintained at a constant potential, so that there can be no direct electrostatic coupling between the deflection-control and focus-control systems. Virtually none of the electrons of the beam are reflected from lens system 13 back toward deflection system 12, so that there can be no coupling by reflection; furthermore, there can be no space-charge coupling between lens control electrode 26 and deflection system 12. As indicated in the foregoing explanation of Figure 3, neither of the two input signals can generate any output signal in system 14 in the absence of the other, so that neither input signal can be translated in unmodulated form to anodes 31, 32. The converter utilizes both half cycles of the input signals, so that it is easily possible to obtain a relatively high conversion transconductance.

Figure 6 illustrates another embodiment of the electron-discharge device of the invention incorporated in a color converter or demodulator for a color television receiver. The color demodulator comprises an electron-discharge device 60 including an electron gun 11, a deflection-control system 12, an electron lens system 63 and an output electrode system 64 all mounted within the usual evacuated envelope 15. Gun 11 and deflection-control system 12 may be essentially identical in construction with the similarly-numbered systems in tube 10; accordingly, a detailed description of these portions of tube 60 need not be repeated.

Electron lens system 63 comprises a lens control electrode 66 which may be essentially similar in construction to lens electrode 26 of tube 10 and includes an aperture 67 aligned with the center plane A of tube 60. The lens electrode system further includes a helical grid 65 mounted on a pair of support rods 68 and encompassing lens control electrode 66. In effect then, the two sides 69 and 70 of grid 65 constitute two lens electrodes or lens grids disposed on the opposite sides of lens control electrode 66.

Output electrode system 64 of tube 60 comprises a pair of anodes 71 and 72 disposed on opposite sides of center plane A. Anode 72 is mounted so that one edge 73 coincides with the center plane; the other anode 71 includes a projection 74 which extends behind anode 72 across center plane A.

The cathode 16 of tube 60 is connected to ground and focus electrode 18 is maintained at a potential slightly negative with respect to the cathode by means of a battery or other source of unidirectional potential 75. As in the previous embodiment, accelerator 20 is connected to a first source of positive unidirectional operating potential B_1+ . Deflectors 22 and 23 are coupled in push-pull relationship to the color video signal circuits 76 of a color television receiver and to a second source of positive operating potential B_2+ . Circuit 76 may include any group of conventional devices for intercepting and detecting a color television broadcast to generate a composite color signal including the usual color synchronizing components and a carrier color signal. Lens control electrode 66 is coupled to the usual color reference oscillator 77 and to a suitable source of positive operating potential B_3+ ; reference oscillator 77 is also coupled to color video signal circuits 76. Lens grids 69 and 70 are connected to a source of positive DC potential B_4 . Anode 71 is connected to a first load circuit 78; load circuit 78 may include a load resistor 79 interconnecting anode 71 and a source of positive operating potential B_5+ , the output from the load circuit being obtained from an output terminal 80. Anode 72 is connected to a second load circuit 81 comprising an output terminal 83 and a load resistor 82

interconnecting the anode 72 and an operating potential source B_5+ .

The operational characteristics of the converter of Figure 6, including tube 60, are essentially similar to those of the apparatus of Figure 1. As in the previously described embodiment, electron gun 11 generates and projects a focused stream of electrons along a center plane A between deflectors 22 and 23, through grid 69, aperture 67, and grid 70, to impinge upon the two output electrodes. For normal operation, the operating potentials on the various electrodes are adjusted so that the beam is divided equally between anodes 71 and 72 and the electron lens formed by system 63 focuses the beam to form an image of the center of deflection of system 12 at edge 73 of anode 72.

Application of a deflection signal to system 12 cannot by itself produce any output signal in the utilization means comprising load circuits 78 and 81, since electron lens system 63 effectively obliterates the deflection-modulation applied to the beam in system 12 by redirecting the beam so that it is divided between anodes 71 and 72 in the same ratio as when no deflection signal is present. On the other hand, variations in the focal length of the electron lens do not give rise to any output signal in the absence of a deflection signal, since the beam continues to be centered about path A and impinges upon the two anodes in the same ratio as if the lens remained unchanged. Thus, the demodulator illustrated in Figure 6 effectively precludes translation of either of the input signals from circuits 76 and 77 to load circuits 78 and 81 and effectively limits the output signal to the intermodulation products of the two input signals. In the illustrated embodiment, deflection-control system 12 is made responsive to the carrier color signal component of the received color telecast whereas the focal length of the electron lens formed by system 63 is varied in accordance with the usual color reference signal generated by oscillator 77 and controlled in phase and frequency by the color synchronizing signals included in the received composite color signal. The complete isolation of the output electrode system from both the input signals is particularly valuable in this application, since the input signals are not widely separated in frequency from the desired color-difference output signals. In addition, as in the apparatus of Figure 1, the two input signals are completely isolated from each other so that the color reference signal cannot be reflected back into video circuits 76 and the carrier color signal is not applied to oscillator 77.

There are, however, some differences between tube 10 of Figure 1 and tube 60 of Figure 6. The principal difference between these two devices results from the different types of electrodes employed in lens systems 13 and 63. Each of these structures, it is true, comprises what is commonly called a unipotential lens system; that is, the lens system includes two electrodes maintained at a common potential and located on opposite sides of a third lens electrode which is maintained at a different potential. The electron lens formed by system 13 is always a convergent lens, however, whereas lens electrode system 63 may form either a convergent or a divergent electron lens.

In Figure 7A, the refractive power of the electron lens formed by lens system 13 is plotted as a function of the voltage e_{26} on electrode 26. As would be expected, the refractive power of the lens is zero when e_{26} is equal to the voltage applied to electrodes 24 and 28 from source B_4+ , since under those conditions no effective electron lens is formed. As e_{26} is increased or decreased from that particular value, an electron lens of increasing refractive power is developed; the resulting curve 89 showing refractive power of the lens versus voltage e_{26} is similar in configuration to a parabola. In order to provide a useful operating range for the lens, the normal potential on electrode 26 supplied from source B_3+ is established

either substantially lower than the potential from source B_4+ , as indicated by line 90, or is made considerably higher than the potential of source B_4+ , as indicated by line 91. If the normal operating potential of the lens control electrode is established at the value indicated by line 90, any increase in e_{26} caused by the signal from source 35 reduces the refractive power of the lens and increases its focal length, whereas decreasing voltage e_{26} shortens the focal length of the lens. With a higher value for B_3+ , as indicated by line 91, increases in lens control voltage e_{26} increase the refractive power of the lens and shorten the focal length of the lens, whereas any decrease in the control voltage increases the focal length of the lens.

Figure 7B provides a graph of the refractive power of the lens formed by system 63 of tube 60 plotted as a function of the voltage e_{66} on lens control electrode 66. As in the case of lens system 13, of course, the refractive power of the lens is zero whenever voltage e_{66} is equal to the voltage applied to grids 69 and 70 from source B_4+ , since when there is no potential difference between these elements no lens is formed. As indicated by line 93, the refractive power of the lens formed by system 63 may be either positive or negative and is an essentially linear function of lens control voltage e_{66} ; in other words, the electron lens formed by system 63 may be either a convergent or divergent lens depending upon the potential of electrode 66 as compared to the voltage on grids 69 and 70. Usually, it is preferable to adjust the voltage from source B_3+ to some value lower than that from source B_4+ so that the normal operating condition for the lens is indicated by line 94, thus forming a normally convergent lens. The signal voltage applied to electrode 66 from oscillator 77 may then be utilized to shorten the focal length of the lens by reducing the total lens electrode potential e_{66} or to increase the focal length of the lens by increasing voltage e_{66} .

For some applications, lens electrode system 63 is somewhat more advantageous than lens system 13 since changes in the focal length of the lens are a linear rather than a parabolic function of the applied control voltage and the lens is somewhat more sensitive to voltage changes, which may permit the use of a focusing signal source having a lower output amplitude. On the other hand, in other applications, lens system 13 may be preferable since it introduces less partition noise in the output signal and slightly less loss of gain due to current drawn by the lens electrodes. Both lens electrode systems, however, are quite satisfactory for most applications.

Figure 8 illustrates a further embodiment of the invention in which deflection control is obtained by use of a transverse-mode traveling-wave structure. The frequency converter tube 100 comprises an electron gun 101, a traveling-wave deflection-control system 102, a lens electrode system 103, and an output electrode system 104 positioned in that order within a conventional evacuated envelope 15. Gun 101 may include a cathode 106, a focusing electrode 107, an accelerator 108 and a beam-limiting electrode 109; electrodes 107—109 each include an aperture symmetrically encompassing the center plane or beam reference path A of the tube. Deflection-control system 102 comprises a pair of low-velocity wave-transmission lines 112 and 113 arranged on opposite sides of center plane A. Transmission line 112 may include a helical conductive winding 114 and a plurality of guiding field electrodes 115 interposed between winding 114 and reference path A. A terminating resistance element 116 may be disposed closely adjacent the end of winding 114 opposite electron gun 101. Wave-transmission line 113 is of similar construction and includes a helical conductive winding 117, a plurality of guiding field electrodes 118, and a resistance load element 119 corresponding to components 114, 115 and 116 of line 112 respectively.

Lens electrode system 103 is essentially similar to lens

system 13 of tube 10 (Figure 1) and includes a pair of apertured lens electrodes 124 and 128 disposed on opposite sides of lens control electrode 126. In this particular embodiment, lens electrodes 124 and 128 comprise opposite sides of a conductive box surrounding lens electrode 26. Output electrode system 104 includes a pair of receptor electrodes 131 and 132 disposed on opposite sides of reference path A closely adjacent to the reference path. The output electrode system further includes a collector electrode 133.

Cathode 106 of gun 101 is connected to ground, as is focus electrode 107; in any given tube design, it may be desirable to operate the focus electrode slightly above or slightly below the potential of the cathode in which case the focus electrode should be provided with a separate external lead. Accelerator 108 is connected to a first source of positive unidirectional operating potential B_1+ and beam-defining electrode 109 is connected to a second source of D. C. potential B_2+ . The ends of conductive windings 114 and 117 adjacent gun 101 are connected in push-pull to a deflection signal source 134; the two transmission-line windings are also connected to a source of positive operating potential B_3+ . Guiding field electrodes 115 and 118 are all connected to each other and to a source of positive operating voltage B_4+ .

The connections for lens system 103 are essentially similar to those for the previously described lens system 13; lens control electrode 126 is connected to a focus signal source 135 and to an operating potential source B_5+ , whereas lens electrodes 124 and 128 are connected to a source of positive operating potential B_6+ . In output electrode system 104, collector 133 is connected to a source of D. C. potential B_7+ . The two receptor electrodes 131 and 132 are coupled to the opposite ends of a primary winding 137 of an output transformer included in a load circuit 136. Load circuit 136 further includes a secondary winding 138 which may be tuned by means of a capacitor 140; the terminals 139 of winding 138 comprise the output terminals for load circuit 136. The electrical center of primary winding 137 is connected to a D. C. operating potential source B_8+ to provide suitable unidirectional operating potentials on receptors 131 and 132.

In many respects, the converter illustrated in Figure 8 operates in the same manner as the apparatus of Figures 1 and 6. In electron gun 101, a stream of electrons emitted from cathode 106 is focused, accelerated, and limited in width to form a beam of electrons projected along reference path A. As the beam enters the portion of the reference path bounded by transmission lines 112 and 113, it is subjected to a transverse field controlled by a signal applied to windings 114 and 117 from source 134. As the beam passes the first part of the wave-transmission lines, it absorbs signal energy from the lines and is deflected transversely from path A in response to that signal energy. The transverse excursions of the beam in turn induce a signal back in the wave-transmission lines as the beam continues along its path; mutual interaction between the beam and the signal wave on the lines substantially amplifies the input signal. The electron beam is confined between the transmission lines by a periodic electrostatic lens field established by maintaining electrodes 115 and 118 at a substantially different operating potential from the operating potential applied to the conductive windings. Thus, the deflection system 102 functions as a transverse-mode traveling-wave device of the type described and claimed in the copending applications of Robert Adler, Serial Nos. 394,797 and 394,798, both filed November 27, 1953, and assigned to the same assignee as the present invention. The operation of a traveling-wave system of this type is explained in detail in those two applications and need not be examined at great length here. For the purposes of this application, it is sufficient to indicate that the overall effect of deflection system 102

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upon the beam is to deflect it transversely from path A in response to the signal from source 134; the effective center of deflection of the system is very close to the ends of transmission line 112 and 113 adjacent lens system 103. The deflection system may be constructed to provide very favorable noise properties, as compared to conventional deflectors, and is therefore highly advantageous in a converter utilized as a first detector in a television receiver or similar apparatus. The resistive elements 116 and 119 are employed only to load the lines sufficiently to prevent reflections of signal energy back along the wave-transmission lines; no signal output is taken from the conductive windings.

Lens system 103 operates in exactly the same manner as system 13; it focuses the electron beam to form an image of the center of deflection of system 102 approximately at the center of output electrode system 104. As in the previously described embodiments, the focal length of the electron lens formed by system 103 is varied in accordance with an input signal from source 135 so that the position of the beam as it traverses the space between receptors 131 and 132 is a function of an intermodulation product of the two input signals from sources 134 and 135. The output electrode system in turn generates a signal representative of transverse excursions of the beam from the image location on path A and supplies that signal to the utilization means comprising load circuit 136. Receptors 131 and 132 are inductively coupled to the beam; the collector 133 is employed as the terminal electrode of the system. While anodes such as electrodes 31 and 32 (Figure 1) might be employed in place of receptors 131 and 132, it has been found that the receptors provide somewhat less noise in the output signal when employed in combination with a properly constructed traveling-wave tube deflection system such as system 102 or with a composite electrostatic deflection system of the type described and claimed in the copending application of Robert Adler, Serial No. 452,620, filed August 27, 1954, and assigned to the same assignee as the present invention.

The embodiment of Figure 8 retains all of the advantages of the converters described in connection with Figures 1 and 6 and may also provide an improved signal-to-noise ratio in the output signal as compared to conventional intensity-control converters and devices utilizing ordinary deflectors. Because amplification of the signal wave traveling down the transmission lines does not contribute directly to the output signal, the transmission lines may be made substantially shorter than in traveling-wave tubes in which the output signal is derived from the conductive windings; it is only the transverse excursions of the beam which have any effect upon the ultimate output signal. Although tube 100 is somewhat more complicated in construction than the previously described embodiments of the invention, it may nevertheless be economically advantageous for particular applications where noise problems and low input signal levels are important factors.

Figure 9 illustrates another embodiment of the invention comprising a two-stage or dual-frequency converter. This dual-conversion system includes an electron-discharge device 10 which may be essentially identical in construction with the tube illustrated in Figure 1 and may comprise an electron gun 11, a deflection-control system 12, a lens electrode system 13, and an output electrode system 14 all mounted within evacuated envelope 15. As before, gun 11 includes a cathode 16, a control electrode 18, and an accelerator 20. Deflection system 12 includes a pair of deflectors 22 and 23 disposed on opposite sides of the reference path A of the tube and lens system 13 comprises a lens control electrode 26 positioned between a pair of lens electrodes 24 and 28. As before, the output electrode system includes a pair of anodes 31 and 32 disposed on opposite sides of reference path A; preferably, a suppressor electrode 33 is positioned between the two anodes.

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The circuit connections for tube 10 are also quite similar to those of Figure 1; cathode 10 is grounded, accelerator 11 is connected to D. C. source B_1+ and deflectors 22 and 23 are coupled to a deflection signal source 34 and to a second source of positive operating potential B_2+ . Lens electrodes 24 and 28 are connected to each other and to an operating voltage source B_4+ , whereas lens electrode 26 is coupled to focusing signal source 35 and to D. C. source B_3+ . As before, suppressor 33 is grounded and anodes 31 and 32 are connected to load circuit 36 and to operating potential source B_5+ .

The principal difference between the embodiment of Figure 9 and that of Figure 1 results from the fact that a lead for control electrode 18 is brought out separately from the lead on cathode 16 and the control electrode is coupled to focusing signal source 35 through a coupling capacitor 150. A switch 151 is interposed in the circuit interconnecting source 35 and control electrode 18, and a source of bias potential, indicated by battery 152 and choke coil 153, is utilized to return the control electrode to cathode 16. In a typical application, deflection signal source 34 may comprise the antenna and input circuits, with or without a radio-frequency amplifier, of a television receiver and focusing signal source 35 may constitute the local oscillator for the receiver, tube 10 being employed as the converter or first detector of the receiver.

With switch 151 open, the converter of Figure 9 operates in exactly the same manner as the apparatus illustrated in Figures 1 and 6. Gun 11 generates and projects a beam of electrons along path A; the beam is deflected transversely from the reference path, as it traverses the center of deflection of system 12, in response to the signal applied to deflectors 22 and 23 from source 34. The operating potentials on the electrodes of lens system 13 are adjusted to establish an electron lens which focuses the beam to form an image of the center of deflection at a subsequent location on path A approximately in the plane of anodes 31 and 32 so that the beam normally divides equally between the two anodes. The signal applied to lens electrode 26 from source 35 varies the focal length of the electron lens, and output electrode system 14 utilizes the deflection-modulated and focus-modulated beam to generate an output signal comprising the intermodulation products of the signals from sources 34 and 35. This output signal appears in load circuit 36 and, in a typical receiver application, is supplied to the subsequent intermediate-frequency stages of the receiver.

In a television receiver adapted for operation in both the V. H. F. (54-216 megacycle) and U. H. F. (470-890 megacycle) bands, the converter of Figure 9 may be operated as a single-conversion device in the V. H. F. range. However, if it is desired to use a single local oscillator as focusing signal source 35, it becomes highly desirable to reduce the frequency range required for the oscillator. For operation in the U. H. F. band, therefore, switch 151 is closed to complete the circuit coupling focusing signal source 35 to control electrode 18. Under these conditions, the electron beam is first intensity-modulated by the local oscillator signal from source 35, then deflection-modulated by the received television signal from source 34, and subsequently focus-modulated by the local oscillator signal from source 35. The thrice-modulated electron beam is intercepted by anode system 14 which develops an output signal representative of the intermodulation components of the three signals.

The dual-conversion action of the converter of Figure 9 with switch 151 closed may be shown by considering the effect of the individual signals. In the absence of any signal on deflection system 12 and lens system 13, intensity-modulation of the beam by the signal applied to control electrode 18 from source 35 cannot produce any output signal in electrode system 14, since anodes 31 and 32 still intercept the same relative proportions of the electron beam, and no change in current distribution or potential difference between the two anodes is established.

As indicated by the foregoing description of operation of the deflection-control and electron lens systems, the signals applied to those systems cannot independently develop an output signal in system 14. With all three signals supplied to tube 10, however, the beam approaches anodes 31 and 32 from a direction determined by the conjoint effect of the deflection signal applied to electrodes 21 and 22 and the focusing signal applied to lens control electrode 26; at the same time, the beam is modulated in intensity by the signal applied to control electrode 18. Thus, the output signal developed by system 14 is a product of all three of the input signals.

In order to indicate more explicitly the advantages of the dual-conversion arrangement shown in Figure 9 with regard to the frequency range required for signal source 35, U. H. F. channel 69, having a carrier frequency of 801.25 megacycles, will be considered as a specific example. If the usual intermediate-frequency of 41.25 megacycles is to be employed, the oscillator frequency utilized in conventional signal conversion systems is 842.50 megacycles. For the dual-conversion system shown in Figure 5, however, a local oscillator frequency of 421.25 megacycles may be employed. Using this frequency, the beat between the television carrier and the local oscillator signal in the intensity and deflection modulation systems produces an intermodulation component having a frequency of 380 megacycles and the beat frequency between this intermodulation component and the local oscillator signal applied to lens system 13 produces an ultimate intermodulation product having a frequency of 41.25 megacycles. Thus, the oscillator frequency required for conversion of the channel 69 signal to the desired intermediate-frequency signal is effectively cut in half, and an oscillator having an operating range of approximately 100 to 465 megacycles may be employed to cover the full V. H. F.-U. H. F. television range instead of one having a range of about 100 to 930 megacycles as would be necessary with a single-conversion system. The device retains all of the isolation advantages obtained when used in a single-conversion system; the possible coupling between lens electrode 26 and control electrode 18 is quite harmless since they are connected to the same signal source.

In order to facilitate a more complete understanding of the electron-discharge devices of the invention, the dimensions and electrical parameters for a specific tube corresponding to tube 10 of Figures 1 and 9 are set forth hereinafter. This data is presented merely by way of illustration and in no sense as a limitation upon the tube structure.

Dimensions

	Inch
Height of tube electrodes.....	.563
Width of slot 19.....	.015
Width of slot 21.....	.015
Spacing between deflectors 22, 23.....	.024
Width of slots 25, 29.....	.025
Width of slot 27.....	.033
Spacing between anodes 31 and 32.....	.035

Figure 1 is drawn approximately to scale.

Operating voltages

Cathode 16.....	ground
Control electrode 18.....	volts— 1
Accelerator 20.....	do— 250
Deflectors 22, 23.....	do— 74
Lens electrodes 24, 28.....	do— 135
Lens electrode 26.....	do— 51
Anodes 31, 32.....	do— 250
Suppressor 33.....	ground

Operating currents

Accelerator 20.....	milliamperes— 0.5
Lens electrodes 24, 28.....	microamperes— 160
Lens electrode 26.....	do— 17
Anodes 31, 32.....	milliamperes— 1.5

This particular tube has been successfully operated as a first detector for a television receiver.

Electron-discharge devices and converter systems constructed in accordance with the invention are relatively simple and convenient in construction and present marked advantages as compared to more conventional devices. Complete isolation between the input signals is easily obtained and, in the single-conversion embodiments, no individual input signal is separately translated to the output electrode system. Relatively high conversion gains are obtainable in all of the illustrated embodiments of the invention. The devices of Figures 8 and 9 present particular advantages with respect to noise reduction and oscillator range respectively.

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

I claim:

1. A wave-signal frequency converter comprising: means for projecting a beam of electrons along a given reference path; means for subjecting said beam of electrons to deflection modulation and to focus modulation, in the named sequence, in response to two individual signals; and an output electrode system for utilizing the twice-modulated electron beam to derive an output signal representative of an inter-modulation product of the two input signals.

2. A dual-conversion electron-discharge device comprising: means for projecting a beam of electrons along a given reference path; means for subjecting said beam to intensity modulation, deflection modulation, and focus modulation, in the named sequence, in response to three individually applied signals; and an output electrode system for utilizing the thrice-modulated electron beam to derive an output signal representative of an intermodulation product of all three signals.

3. A dual-conversion wave-signal frequency converter comprising: means for projecting a beam of electrons along a given reference path; an intensity-control electrode, a deflection-control system, and an electron lens system disposed in the order named along said reference path; means for applying a first input signal to said deflection-control system to deflection-modulate said beam; means for applying a second input signal to said intensity-control electrode and to said electron lens system to intensity-modulate and focus-modulate said electron beam; an output electrode system, coupled to said electron beam, for deriving an output signal from said thrice-modulated electron beam; and utilization means, responsive to a dual-intermodulation product of said first and second input signals, coupled to said output electrode system.

4. An electron-discharge device comprising: an electron gun for projecting a beam of electrons along a given reference path; a deflection-control system, responsive to an applied signal, for deflecting said beam transversely from said reference path as said beam passes through a predetermined center of deflection; an output electrode system, coupled to said electron beam, for deriving an output signal representative of transverse excursions of said beam from said path at a preselected image location spaced from said deflection system; and means for varying the effective transconductance of said deflection system with respect to said output electrode system over a predetermined range including values of opposite polarity, said means comprising an electron lens system interposed between said deflection-control system and said output electrode system for normally focusing said beam to form an image of said center of deflection at said preselected image location and for varying the position of said image along said path in response to a second signal.

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5. An electron-discharge device constructed in accordance with claim 4 in which said electron lens system comprises three lens electrodes arranged in sequence along said reference path.

6. An electron-discharge device constructed in accordance with claim 4 in which said electron lens system comprises three lens electrodes arranged in sequence along said reference path with the first lens electrode in said sequence electrically connected to the last lens electrode in said sequence to establish a unipotential electron lens.

7. An electron-discharge device constructed in accordance with claim 4 in which said electron lens system comprises a pair of apertured lens electrodes each substantially encompassing a predetermined portion of said reference path.

8. An electron-discharge device constructed in accordance with claim 4 in which said electron lens comprises a first lens grid, an apertured lens electrode, and a second lens grid arranged in the order named along said reference path.

9. An electron-discharge device constructed in accordance with claim 4 in which said output electrode system comprises a pair of beam-intercepting anodes symmetrically arranged on opposite sides of said reference path adjacent said preselected image location.

10. An electron-discharge device constructed in accordance with claim 4 in which said output electrode system comprises a pair of receptor electrodes symmetrically arranged on opposite sides of said reference path adjacent said preselected image location in inductive coupling relationship to said beam.

11. An electron-discharge device constructed in accordance with claim 4 in which said electron gun comprises a control electrode for varying the intensity of said beam in response to an applied signal.

12. An electron-discharge device constructed in accordance with claim 4 in which said deflection-control system comprises a pair of low-velocity wave-transmission lines disposed on opposite sides of said reference path.

13. A wave-signal frequency converter comprising: an electron gun for projecting a beam of electrons along a given reference path; a deflection-control system, responsive to an applied signal, for deflecting said beam transversely from said reference path as said beam passes through a predetermined center of deflection; an output electrode system, coupled to said electron beam, for deriving an output signal representative of transverse excursions of said beam from a preselected image location on said reference path spaced from said deflection-control system; means for varying the effective transconductance of said deflection-control system with respect to said out-

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put electrode system over a predetermined range including values of opposite polarity, said means comprising an electron lens system interposed between said deflection-control system and said output electrode system for normally focusing said beam to form an image of said center of deflection at said preselected image location and for varying the position of said image along said path in response to a second signal; means for applying a first input signal to said deflection-control system; means for applying a second input signal to said electron lens system; and utilization means, responsive to an intermodulation product of said input signals, coupled to said output electrode system.

14. A wave-signal frequency converter constructed in accordance with claim 13, in which said output electrode system comprises a pair of output electrodes coupled to said electron beam and in which said utilization means comprises a resonant load circuit, tuned to the frequency of said intermodulation product, interconnecting said pair of output electrodes.

15. A wave-signal frequency converter constructed in accordance with claim 13, in which said output electrode system comprises a pair of beam-intercepting anodes and in which said utilization means comprises a pair of load circuits individually interconnected to said anodes.

16. A wave-signal frequency converter constructed in accordance with claim 13, in which said electron gun includes a control electrode for controlling the intensity of said electron beam, said converter further including means for applying a third input signal to said control electrode, and said utilization means being responsive to an intermodulation product of said three input signals.

17. A wave-signal frequency converter constructed in accordance with claim 13, in which said electron gun includes a control electrode for controlling the intensity of said electron beam, said converter further including means for applying said second input signal to said control electrode as well as to said electron lens system, and said utilization means being responsive to a dual-intermodulation product of said input signal.

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