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2,866,115

TRANSIT TIME MODULATOR

Filed July 30, 1957

FIG-1

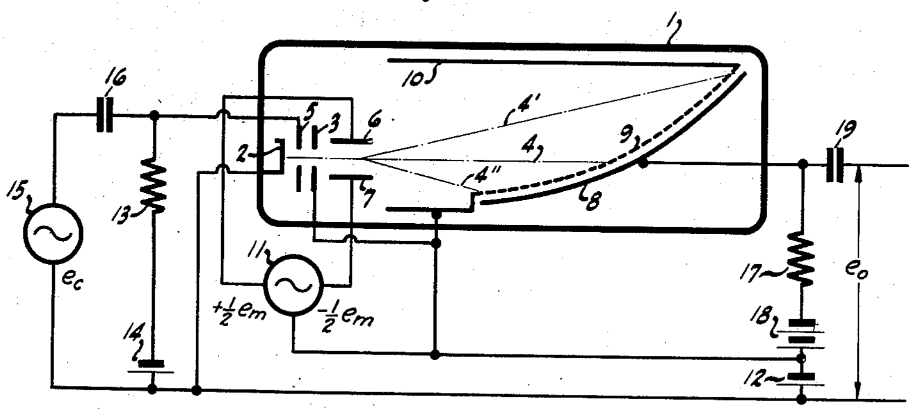


FIG-2

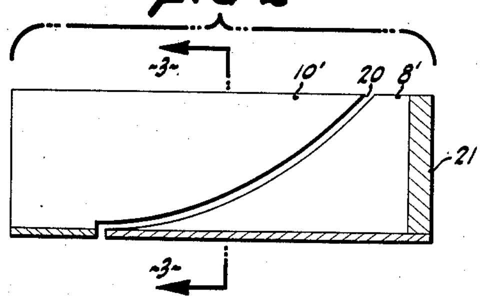
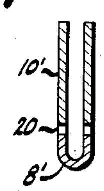


FIG-3



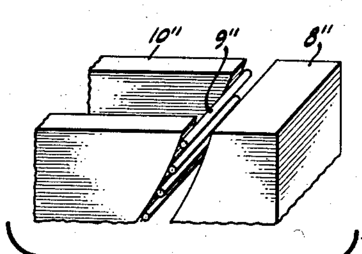


FIG-4

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TRANSIT TIME MODULATOR

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2 Claims. (Cl. 313—82)

This invention relates to apparatus for modulating the phase or frequency of an electric signal by varying the transit time or transmission delay of the signal through an electron tube.

Briefly stated, according to certain aspects of this invention, an improved transit time modulator comprises an electron tube having means for forming an electron beam, means for varying the intensity of the electron beam responsive to an input carrier signal, means for producing a variable transverse deflection of the electron beam responsive to an input modulating signal, and output means for producing an output electric signal responsive to the variations in the intensity of the electron beam. The output means is disposed in slanting relation to the beam so that as the beam is deflected transversely responsive to the modulating signal the effective length of the beam and the transit time of the signal passing through the tube are varied. Preferably the output means includes an electrode surface that lies along a segment of a parabola having its axis disposed perpendicular to the middle of the mean path followed by the electron beam between the deflection means and the output means. Also, means are provided for maintaining a substantially field-free drift space in which the electron beam moves at substantially constant velocity between the deflection means and output means.

The foregoing and other aspects of this invention may be better understood from the following illustrative description and the accompanying drawings. The scope of the invention is pointed out in the appended claims.

In the drawings:

Fig. 1 is a schematic diagram of an improved transit time modulator;

Fig. 2 is a longitudinal section showing one construction of a drift space shield and collector electrode for the improved transit time modulator;

Fig. 3 is a transverse section taken along line 3—3 of Fig. 2; and

Fig. 4 is a fragmentary perspective view showing another construction of the drift space shield and collector electrode.

Referring to Fig. 1, an improved transit time modulator employs a novel electron tube contained in an evacuated envelope **1**. A conventional electron gun comprising a cathode **2** and accelerating electrode **3** is operable to produce within envelope **1** an electron beam, represented in the drawing by broken line **4**. The electron gun also includes a conventional control electrode **5** for varying the intensity of the electron beam responsive to an input electric signal supplied between the control electrode and the cathode as hereinafter explained.

Conventional electrostatic deflection electrodes **6** and **7** are provided for producing a variable transverse deflection of beam **4** responsive to another input electric signal. Thus, the electron beam can be deflected through a range of angular directions. In the drawing, broken line **4** represents a mean or undeflected path of the electron beam while broken lines **4'** and **4''** represent the extreme upward and downward deflections of the beam, respectively.

A collector electrode **8** is disposed in slanting relation to the electron beam, as shown, so that deflection of the beam by the deflection electrodes moves the electron beam along the slant of the collector electrode and varies the length of the electron path between the control electrode **5** and the collector electrode **8**.

A substantially field-free drift space, through which the electrons move at substantially constant velocity, is provided between the deflection electrodes and the collector electrode. This field-free drift space may be defined, for example, by an electron permeable grid **9** disposed just in front of collector electrode **8**, as shown, and a lateral shield **10**. Grid **9** serves two principal purposes. First, it prevents variations in the potential of collector electrode **8** from having a substantial effect on the transit time of electrons traveling between the deflection electrodes and the collector electrode. Second, it improves the frequency response of the tube by providing an electrostatic shield between the collector electrode and the electrons approaching the collector electrode until such approaching electrons are closely adjacent to the collector electrode.

Preferably, collector electrode **8** and grid **9** which are closely adjacent to each other lie substantially along a segment of a parabola having its axis disposed perpendicular to the mean or undeflected path **4** of the electron beam between the deflection electrodes and the collector electrode.

Accelerating electrode **3**, grid **9**, and transverse shield **10** are electrically connected together and maintained at the same constant electric potential. Deflection electrodes **6** and **7** are maintained at the same average potential as accelerating electrode **3**. Consequently, except for the transverse deflecting potential applied between deflection electrodes **6** and **7** as is hereinafter explained, the space between accelerating electrode **3** and grid **9** is substantially field-free and electrons travel through this space at a constant horizontal velocity.

Balanced modulating potentials, $+\frac{1}{2}e_m$ and $-\frac{1}{2}e_m$, relative to cathode **3**, are applied to deflection electrodes **6** and **7**, respectively, by any source **11** of an input modulating electric signal. Consequently, a modulating voltage e_m is applied between deflecting electrodes **6** and **7** which deflects the electron beam transversely through the angle between broken lines **4'** and **4''**. Cathode **2** is maintained at a constant negative potential relative to accelerating electrode **3** by a conventional voltage supply **12**.

The voltage between electrode **3** and cathode **2** determines a constant horizontal component of electron velocity in the electron beam between electrode **3** and grid **9**. In addition, the electrons have a vertical component of velocity that is proportional to the deflecting voltage between deflecting electrodes **6** and **7** at the instant when the electrons pass between the two deflecting electrodes.

Control electrode **5** is connected through a resistor **13** to a negative bias voltage supply **14**, which biases control electrode **5** to a negative potential relative to cathode **2**. In addition, an alternating carrier voltage e_c, provided by any suitable source **15**, is supplied to control electrode **5** through a coupling capacitor **16**. Thus the input signal e_c, superimposed on the bias voltage provided by supply **14**, is applied between control electrode **5** and cathode **2** for modulating the intensity of the electron beam within envelope **1**. In other words, the intensity of the electron beam is varied as a function of the input carrier signal e_c and the transverse deflection of the electron beam is varied as a function of the input modulating signal e_m.

Collector electrode **8** is connected through a load resistor **17** to a voltage supply **18** which preferably maintains collector electrode **8** at a more positive potential than grid 9. Thus there is a voltage gradient between collector electrode 8 and grid 9 which quickly draws electrons into the collector electrode as they pass through gird 9. This produces an electric current flowing from supply 18 through load resistor 17 into collector electrode 8. Variations in this current produce variations in the voltage drop across load resistor 17 which in turn produces an alternating component of output voltage e_o, which is transmitted through coupling capacitor 19 to any desired utilization circuit.

For a better understanding of the apparatus, assume first that the modulating voltage e_m has zero amplitude. Then the electron beam within envelope 1 is undeflected and travels in a straight line between cathode 2 and grid 9 along the mean path represented by broken line 4. As the electrons pass through grid 9 they are quickly drawn into collector electrode 8 and produce a flow of electric current into the collector electrode through load resistor 17.

The intensity of the electron beam is modulated by the input carrier signal e_c. At each positive peak of the input carrier signal a relatively dense bunch of electrons passes through control electrode 5 of the electron gun. These electron bunches travel along the electron beam between electrode 3 and grid 9 at a velocity proportional to the square root of the voltage provided by supply 12. As each bunch of electrons travels down the beam it is electrically shielded from the collector electrode 8 until approximately the instant that the electrons pass through grid 9.

As each bunch of electron flows across the space between grid 9 and collector electrode 8 current flows into the collector electrode due to the positive charges induced thereon by the electrons flowing toward the collector electrode, which charges are neutralized as the electrons enter electrode 8. Therefore, provided that the transit time of electrons between grid 9 and electrode 8 is short compared to the period of the input carrier signal e_c, each bunch of electrons in the electron beam causes a momentary increase in the current flowing into collector 8 and the voltage drop across load resistor 17 contains an alternating component e_o that is substantially identical to the input carrier signal e_c delayed by the transit time of the electrons between control electrode 5 and collector electrode 8.

It will be noted that the frequency response of the tube is limited by the transit time of electrons traveling between grid 9 and control electrode 8. Therefore, a high frequency response can be obtained by providing a close spacing between collector electrode 8 and grid 9 and by providing a sufficient voltage at the collector electrode to draw the electrons quickly into the collector electrode as they pass through grid 9.

Now assume that there is supplied between deflection electrodes 6 and 7 a modulating voltage e_m of sufficient amplitude to deflect the electron beam repetitively back and forth between the paths represented by broken lines 4′ and 4″. As the electron beam is deflected back and forth the length of the beam varies considerably because of the slanting relation of collector electrode 8 and grid 9 to the beam. Furthermore, since the electrons travel between the accelerating electrode 3 and grid 9 with a substantially constant horizontal velocity the transit time of each electron bunch varies as a function of the length of the path which that bunch follows and therefore varies as a function of the instantaneous value of the modulating voltage e_m at the instant when that bunch of electrons passes between the deflection electrodes 6 and 7.

Assume that the instantaneous amplitude of the modulating voltage e_m is changing in a positive direction so that the electron beam is being deflected from the path 4″ toward the path 4′. It is evident that each bunch of electrons must travel a somewhat longer path than the preceding bunch and therefore has a somewhat longer transit time between control electrode 5 and collector electrode 8. Consequently, successive cycles of the output voltage e_o are spaced somewhat further apart than successive cycles of the input voltage e_c. Conversely, when the instantaneous values of the modulating voltage e_m are becoming more negative the beam is being deflected from path 4′ to path 4″ and successive cycles of the output voltage e_o are more closely spaced than successive cycles of the input voltage e_c. Thus, a type of modulation is produced which is somewhat similar to phase and frequency modulation. The technical name for this type of modulation is transit-time modulation and its characteristics are already known to those skilled in the art.

By making electrode 8 and grid 9 lie substantially along a segment of a parabola, as hereinbefore explained, the transit time is made to vary as a linear function of the instantaneous amplitude of the modulating voltage e_m. This is desirable to avoid distortion.

By proper configuration of the shielding electrode 10 the use of a physically present grid 9 of wires or the like can be avoided. This is illustrated in Figs. 2 and 3 which show a simple construction that may be employed for collector electrode 8 and drift-space shield 10. In Figs. 2 and 3 the collector electrode is identified by the reference numeral 8′ and the shield is identified by the reference numeral 10′. These two parts may be made from a single strip of metal folded to a U-shaped cross-section as is best shown in Fig. 3 and cut into two electrically separate parts 8′ and 10′ separated by a gap 20, as shown. The gap 20 is cut along a segment of a parabola so that the right edge of part 10′ corresponds in shape and position to grid 9 of Fig. 1 while the left end of part 8′ corresponds in shape and position to electrode 8 of Fig. 1.

The two flat sides of the U-shaped strip are just far enough apart for the electron beam to pass between them. Since these two flat sides are close together and are electrically conductive external electric fields can penetrate only a short distance into the space between the two flat sides of the metal strip. Consequently, substantially all of the space between the two flat sides of part 10′ is maintained at a substantially constant electric potential and electrons travel through this space at a substantially constant velocity. The principal effect of electric fields penetrating a short distance into the space between the two flat sides of part 10′ is that the effective electrical width of gap 20 is somewhat wider than its actual physical width. When the electrons reach gap 20 they are quickly drawn across the gap by the voltage gradient provided by maintaining part 8′ positive with respect to part 10′.

As the electrons cross gap 20 they induce positive charges on collector electrode 8′. Therefore, electrons may be considered to have been collected by electrode 8′ as soon as they have crossed gap 20 and whether the electrons immediately strike electrode 8′ or travel for some distance within a space that is substantially enclosed by the collector electrode is of little importance. Therefore, the frequency response of the tube depends only upon the transit time of the electrons across the electrical width of gap 20 which comprises the physical width of the gap plus some additional width due to the slight penetration of electric fields into the space between the two parallel flat sides of parts 10′ and 8′.

To prevent the escape of any electrons out the back end of collector electrode 8′ this end of the U-shaped metal strip can be closed by an insert 21, as shown, or by simply pressing the two sides of the U-shaped structure together at this end.

To increase the frequency response or to permit a wider space for the electron beam between the two flat sides of the U-shaped metal strip, or both, the alternative construction illustrated in Fig. 4 may be used. In this construction collector electrode 8″ has substantially the same exterior shape as collector electrode 8′ of Fig. 2 but in the construction illustrated in Fig. 4 the collector electrode is made from one solid piece of metal and has no hollow interior space. Therefore, the electrons strike the collector electrode immediately upon crossing the gap between the parts **10″** and **8″** and there can be no widening of the gap due to the penetration of electric fields into the collector electrode.

The shield **10″** may be substantially identical to part **10′** shown in Figs. 2 and 3 but, if desired, the two flat sides of part **10″** may be somewhat further apart than the two flat sides of part **10′** to provide more space for the passage of the electron beam. A plurality of parallel wires are welded or otherwise attached transversely across the right end of part **10″** extending between the two flat parallel sides and forming a grid **9″** close to but slightly separated from collector electrode **8″**. Grid **9″** corresponds to grid **9** of Fig. 1. The grid reduces the penetration of electric fields into the space between the two flat parallel sides of part **10″** and thus makes the effective electrical width of the gap between parts **10″** and **8″** more nearly equal to the physical width of the gap. This increases the frequency response of the tube and makes possible the use of the apparatus with higher carrier frequencies.

It is evident that the transit time modulators herein described can be used for a considerable variety of purposes. For example, if the size of the tube and the magnitude of the voltage supplied by supply **12** are made such that the transit time along path **4′** differs from the transit time along **4″** by one period of the carrier signal e_c then a full 360 degrees of phase modulation is easily obtained responsive to a modulating voltage e_m of moderate amplitude. Furthermore, by properly shaping the output means (essentially the gap between grid **9** and collector electrode **8** or its equivalent) into a parabolic segment as herein disclosed the instantaneous phase shift can be made linearly proportional to the instantaneous amplitude of the modulating voltage, thereby providing modulation of exceptionally low distortion which is difficult to obtain by other methods. If the modulating voltage e_m has a sawtooth waveform providing successive 360 degree phase shifts separated by relatively short flyback intervals low-distortion frequency translation can be achieved without resort to the heterodyne principle.

Numerous variations in construction are of course possible. For example, the electrostatic deflection electrodes **6** and **7** can be replaced with magnetic deflection means in a manner similar to the common use of magnetic deflection in television picture tubes. Where magnetic deflection is employed a slight reshaping of the collector electrode **8** and grid **9** may be desirable due to the well-known differences between the electron ballistics of electrostatic and magnetic deflection. However, such corrections will generally not be large and in practical cases will often be negligible.

It should be understood that this invention in its broader aspects is not limited to specific examples herein illustrated and described and that the following claims are intended to cover all changes and modifications within the true spirit and scope of the invention.

What is claimed is:

1. A transit time modulator comprising an evacuated envelope, an electron gun for producing an electron beam within said envelope, said gun including a cathode, a control electrode, and an accelerating electrode, means for supplying a first variable voltage between said control electrode and said cathode for varying the intensity of said beam, a collector electrode disposed in slanting relation to said beam, deflection means for producing a variable transverse deflection of said beam to move said beam along the slant of said collector electrode, and shielding means for maintaining a substantially field-free space through which the electrons of said beam travel at substantially constant velocity between said deflecting means and said collector electrode, said shielding means comprising a folded metal strip having a substantially U-shaped cross section.

2. An electron tube comprising within an evacuated envelope the combination of an electron gun operable to produce an intensity modulated electron beam, a conductive shield having two parallel flat sides disposed on opposite sides of said beam, and a collector electrode for receiving said beam, said colector electrode and said shielding means being separated by a gap having the shape of a segment of a parabola, said gap being disposed in slanting relation to said beam.

References Cited in the file of this patent

UNITED STATES PATENTS

2,071,382	Balsley	Feb. 23, 1937
2,290,587	Goldstine	July 21, 1942
2,401,740	Kilgore	June 11, 1946
2,519,443	Diemer	Aug. 22, 1950