Sept. 29, 1964 M. H. CROWELL 3,151,272

MODULATING DEVICE FOR CATHODE RAY DISPLAY TUBE

Filed Dec. 18, 1962

FIG. 1

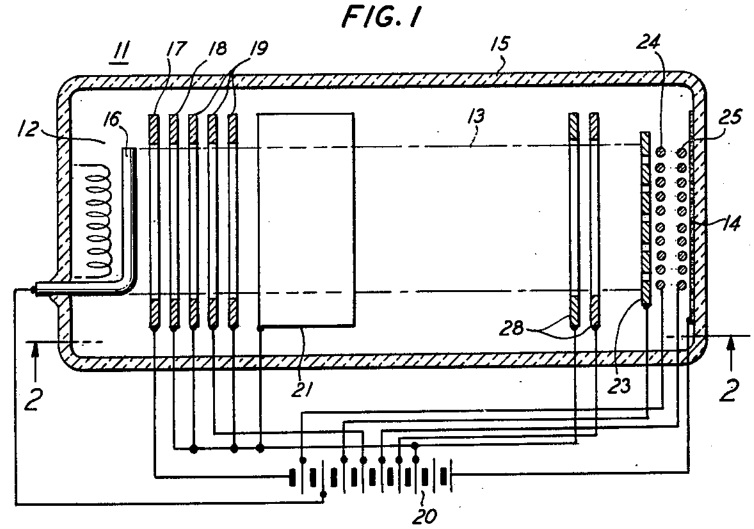
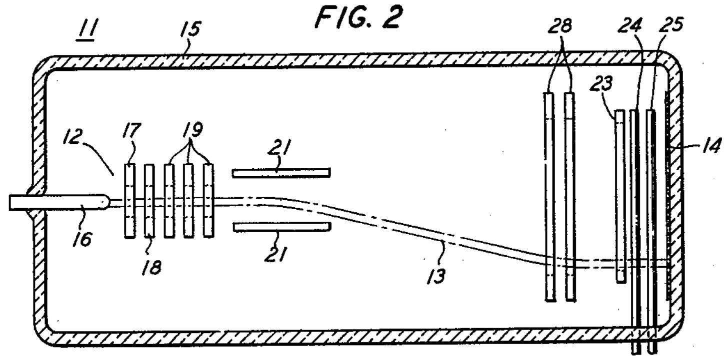


FIG. 2



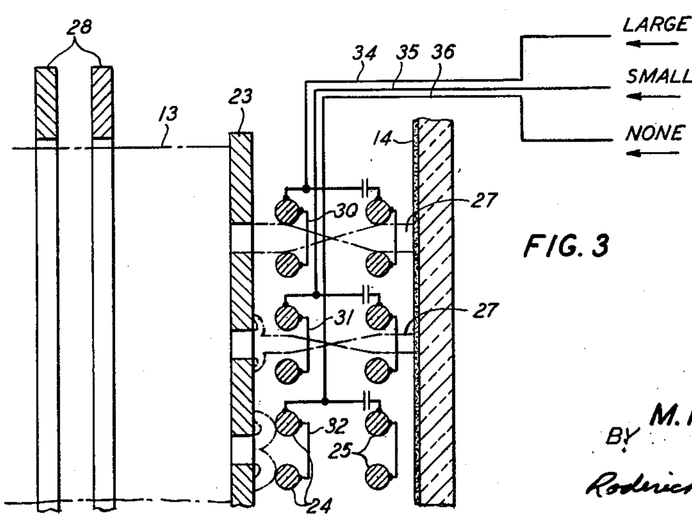


FIG. 3

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MODULATING DEVICE FOR CATHODE RAY DISPLAY TUBE

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9 Claims. (Cl. 315—30)

This invention relates to cathode-ray tubes and, more particularly, to apparatus for modulating the electron beams of cathode-ray display devices.

The copending application of R. J. Beck, Serial Number 219,343, filed August 24, 1962, discloses a unique system for displaying information from a plurality of sources simultaneously on a single cathode-ray tube screen. A ribbon electron beam is swept periodically across a shield plate containing a number of elongated slots which are perpendicular to the plane of the beam and are parallel with its direction of deflection. The beam is thereby divided into a number of segments. A modulating wire in front of each of the slots is connected to a signal source and controls the electron flow through the slot. Those electrons that flow through the slot impinge upon a phosphor screen, leaving a visible trace. The intensity of each trace is proportional to the modulating signal on the corresponding modulating wire.

One convenient use for this display system is the simultaneous display of the outputs of a plurality of directional radar antennas, each of which is directed at a different elevation angle. With the horizontal deflection of the beam synchronized with the transmission of a radar pulse, the horizontal position of the beam at the time of reception of any reflected pulse is a function of the range of the target. Each antenna is connected to a different modulating wire in order according to elevation angle so that the vertical position of any spot on the screen indicates elevation angle while its horizontal position indicates target range.

The use of higher microwave frequencies, and other refinements, have made radar antennas so highly directional that it may be feasible to use more than 100 antennas in one system of the type described above. However, for practical reasons, the single cathode-ray tube of the Beck system is incapable of displaying that many channels simultaneously. For example, if the ribbon beam were ten inches wide, provision for 100 modulation channels would require that each beam segment would be separated by less than one-tenth of an inch, depending on the thickness of the individual segments. Adjacent beam segments of the Beck modulation system will overlap if they are that closely spaced. Further, differential divergence of the various beam segments affects their intensity and therefore impairs the accuracy of the modulation.

Accordingly, it is an object of this invention to modulate accurately the segments of a segmented ribbon electron beam.

It is another object of this invention to increase the number of segments of a normal ribbon electron beam that can be individually modulated.

These and other objects of the invention are attained in an illustrative embodiment thereof comprising an electron gun for forming and projecting a ribbon electron beam toward a phosphor screen. A pair of deflection plates periodically deflects the ribbon beam in a direction transverse to its plane. Before striking the screen the beam is divided into a plurality of segments by being directed through a beam forming structure having a plurality of parallel elongated slots. Each segment is then individually intensity modulated by a separate signal source.

It is a feature of this invention that a collimation lens be included between the deflection plates and the beam forming structure. The lens has a converging focal length which is equal to its separation from the center of deflection of the deflection plates. Under these conditions, the velocities of all the electrons will be parallel as they approach the beam forming structure, regardless of the extremes of their deflection. This is desirable because it avoids the discrepancies in modulation that invariably accompany deviations in direction of electron flow.

It is another feature of this invention that the intensity of each beam segment be modulated by two rod-shaped modulating electrodes on opposite sides of the segment. The electrodes are maintained at a quiescent direct-current voltage which is barely sufficient to repel all, or most, of the incoming electrons. The modulation signal is directed to both electrodes and drives them positively so that the quantity of electrons that are permitted to pass between the modulating electrodes varies in proportion to the modulating voltage.

It can be shown that the two modulating electrodes constitute an electron lens which focuses the beam segment to a crossover point. After crossover, in the absence of other apparatus, the electrons will diverge and overlap on adjacent segments. Accordingly, it is still another feature of this invention that two rod-shaped lens electrodes be located on opposite sides of each beam segment between the phosphor screen and the modulating electrodes. The two lens electrodes are conductively connected, and like the modulating electrodes, constitute an electron lens. A predetermined voltage on each pair of lens electrodes is maintained such that the focal length of the modulating electrodes plus the focal length of the lens electrodes is approximately equal to the distance between the lens electrodes and the modulating electrodes. Under these conditions, the electrons will leave the lens electrodes along approximately parallel lines, rather than overlapping onto other beam segments.

Each pair of lens electrodes can be coupled to its corresponding pair of modulating electrodes so that its voltage follows the modulating voltage. In this way the above relationship of local lengths can be insured. Alternatively, the lens electrode can be maintained at a constant voltage such that the sum of the focal lengths of the lens and modulating electrodes are equal to the distance between the lens and modulating electrodes at the average modulating voltage.

These and other objects and features of my invention will be better appreciated from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a sectional schematic view of a cathode-ray tube employing the principles of the invention;

FIG. 2 is a view taken along lines 2—2 of FIG. 1; and

FIG. 3 is an enlarged view of part of the electron beam modulation structure of the device of FIG. 1.

Referring now to FIGS. 1 and 2 there is shown a cathode-ray tube 11 having an electron gun 12 for forming and projecting a ribbon electron beam 13 toward a phosphor screen 14. The beam is maintained within a vacuum by an envelope 15 which is typically made of glass. The electron gun comprises, by way of example, a cathode 16, a control electrode 17, an accelerating electrode 18 and a focusing lens 19, of the type known in the art as an Einzel lens. These elements are connected in a known manner to a battery 20. A pair of deflection plates 21 deflects the beam in a direction transverse to the plane of the beam as best seen in FIG. 2.

The deflecting plates sweep the beam across modulation apparatus comprising a beam forming structure 23, a plurality of modulating electrodes 24 and a plurality of lens electrodes 25. The beam forming structure 23 is essentially an electron shield plate containing a plurality of elongated slots. As the beam sweeps the structure 23, those electrons that flow through the slot define a beam segment 27 as shown in FIG. 3. To compensate for differences of velocity direction due to deflection, a beam collimation lens 28 is included between the deflection plates and the beam forming structure. As will be explained later, the electrons travel in substantially parallel lines normal to the screen 14 as they leave the collimation lens.

The quantity of electrons that finally reach phosphor screen 14 is controlled by modulating electrodes 24. Referring to FIG. 3, electrodes 24 are arranged in pairs with the electrodes of each pair being conductively connected together and situated on opposite sides of the path of an individual beam segment 27. Each pair of modulating electrodes is connected to a separate input signal line. For example, modulating electrode pairs 30, 31, and 32 are respectively connected to signal input lines 34, 35, and 36. As shown in FIG. 1, all of the modulating electrodes are maintained at a negative direct-current voltage with respect to the cathode 16. Hence, in the absence of an input signal, they repel the beam segment against beam forming structure 23. However, an input signal drives the modulating electrodes to a more positive voltage which tends to propel electrons toward the phosphor screen 14.

Referring again to FIG. 3, there is no signal on input line 36 so that modulating electrode pair 32 repels its beam segment against beam forming structure 23. A large input signal on input line 34 propels all of the electrons of its beam segment toward screen 14. A smaller signal on input line 35 propels some of the electrons of its segment toward the screen. Hence, each beam segment is effectively intensity modulated by its respective modulating electrode pair. The source of modulation signals and the deflection control circuit are not shown; these elements are part of a system such as that shown in the aforementioned Beck case, into which the present invention may be incorporated.

Each pair of modulating electrodes acts as an electron lens and therefore tends to focus its respective beam segment. It can be shown that the focal length of this modulating electrode lens is given by

$$\frac{1}{f_M}=\frac{V_L'-V_{BF}'}{2V_M} \qquad (1)$$

where f_M is the focal length of the modulating electrodes under consideration, V_L' is the potential gradient at the adjacent lens electrodes 25, V_{BF}' is the potential gradient at the beam forming structure 23, and V_M is the voltage of the modulating electrodes under consideration. Assuming that the electrons approach the modulating electrodes in parallel lines, they will cross-over at the focal point, a distance f_M beyond the modulating electrodes, and thereafter diverge. It should be pointed out that Equation 1 presupposes that the modulating lens is a thin lens. The modulating electrodes define an electrical modulating plane while the beam forming structure defines a beam forming plane and the lens electrodes define a lens plane. Other structures that define thin electrical planes could alternatively be used.

The purpose of lens electrodes 25 is to eliminate or reduce electron divergence so that adjacent beam segments do not overlap. To do this, the lens electrodes effectively converge or focus the incoming beam segments to compensate for their divergence, as illustrated in FIG. 3. It can be shown that if the distance between the modulating electrodes and the lens electrodes is equal to the sum of the focal lengths of the modulating electrodes and the lens electrodes, the lens electrodes will precisely compensate for diverging effects of the modulating electrodes. This criterion is stated algebraically as

$$f_M+f_L=d_2 \qquad (2)$$

where f_L is the focal length of the lens electrode and d_2 is the distance between the modulating plane and the lens plane. The focal length f_L of the lens electrodes can be given by an equation similar to Equation 1:

$$\frac{1}{f_L}=\frac{V_P'-V_M'}{2V_L} \qquad (3)$$

where V_P' is the potential gradient at the phosphor screen and V_L is the voltage of the lens electrode. Using Equations 3 and 1 the condition of Equation 2 can be expressed as

$$\frac{2V_M}{V_L'-V_{BF}'}+\frac{2V_L}{V_P'-V_M'}=d_2 \qquad (4)$$

To a first order Equation 4 can in turn be expressed in terms of voltages on the various electrodes as

$$\frac{2V_M}{\left[\frac{V_L-V_M}{d_2}\right]-\left[\frac{V_M-V_{BF}}{d_1}\right]}+\frac{2V_L}{\left[\frac{V_P-V_L}{d_3}\right]-\left[\frac{V_L-V_M}{d_2}\right]}=d_2 \qquad (5)$$

where V_{BF}, V_M, and V_L are the voltages on the beam forming structure, the modulating electrodes, and the lens electrodes, respectively, d_1 is the distance between the beam forming structure and the modulating electrodes, and d_3 is the distance between the lens electrodes and the phosphor screen. It is usually desirable that the phosphor screen be "aluminized," as is known in the art, to facilitate maintenance of the desired voltage on it.

Equations 2, 4, and 5 are different representations of the same condition. Even if this condition is met, however, the electrons will leave the lens electrodes in parallel lines, and therefore make a well-defined trace on the phosphor screen, only if they approach the modulating electrodes in parallel lines. The collimation electrodes 28 are therefore important in that they force all electrons to follow paths parallel with the tube axis regardless of the extremes of their deflection; see FIG. 2. The condition for this action is that the focal length of the collimation lens must equal the distance between the collimation lens and the center of deflection of deflecting plates 21.

In FIG. 3 the width of the beam segment leaving the lens electrodes is shown as being the same as that between the modulation electrodes. This may be desirable because if the beam is originally divided into more than 100 segments, a large change in width may cause adjacent segments to overlap or make individual segments extremely thin. Unaltered beam segment width is accomplished by making the focal length of the modulating electrodes equal to the focal length of the corresponding lens electrodes. If the two focal lengths are not equal but still fulfill the condition of Equation 2, the electrons leaving the lens electrodes will be parallel, but their beam segment width will be larger or smaller than that at the modulating electrodes.

As described above, individual beam segments are modulated by varying voltages on individual pairs of modulating electrodes. Equation 5 can be fulfilled for varying values of modulating voltage V_M without changing the voltages of the phosphor screen V_P or the beam forming structure V_{BF} if the voltage of the corresponding lens electrodes V_L is changed in a predetermined proportion to changes in V_M. The exact proportion, of course, depends on the direct-current voltages on the electrodes and the separation between them.

One method for varying the lens electrode voltage in accordance with the modulation voltage is shown in FIG. 3 wherein each pair of lens electrodes is connected to its corresponding pair of modulating electrodes through a capacitor. The capacitor permits the lens electrodes to be maintained at a higher direct-current voltage than the modulating electrodes as is usually advantageous for convenient fulfillment of Equation 5. When a voltage pulse is transmitted to any of the modulating electrodes, the voltage of the corresponding lens electrodes is raised in some predetermined proportion depending on the impedance of the capacitor. Resistors may also be advantageously included in the input lines wherever desired to proportion the input voltage between the lens and modulating electrodes.

For many applications, it is unnecessary to make any compensating changes of the lens electrode voltage. For example, it may be convenient to maintain modulating electrodes 24 at a quiescent direct-current voltage of −3 volts, the lens electrodes at +550 volts, and the phosphor screen at 10,000 volts, each with respect to a cathode voltage of zero volts. With such a large lens electrode voltage comparatively small modulation voltages can intensity modulate the beam segments without unduly upsetting the equality of Equation 2 since the sum of the average focal lengths of the lens and modulating electrodes will equal the distance between the modulating plane and the lens plane. The lens electrodes still sufficiently compensate for the diverging effect of the modulating electrodes to permit a 10 inch wide electron beam to be divided into more than 100 segments without overlapping.

It can be seen that a fair degree of design flexibility is inherent in the described device. For example, the exact electrode voltages and spacings that are most conveniently employed in a particular tube depend on the requirements that are to be met by the tube. The various electron trajectories that result from different designs are easily determinable by known principles of electron optics. Although the modulating electrodes and lens electrodes are shown as being rod-shaped, other structures are readily conceivable for defining an electrical modulating plane and lens plane. Numerous other modifications can be made by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A cathode-ray tube comprising:
means for forming and projecting a ribbon electron beam;
a pair of deflecting plates for deflecting the beam;
a collimating lens adjacent the deflecting plates;
an indicating screen;
a beam forming structure between the collimating lens and the screen for dividing the beam into a plurality of segments;
means for individually intensity modulating each beam segment comprising two parallel modulating rods on opposite sides of the path of each segment and means for applying a modulating voltage to the rods;
each pair of modulating rods constituting a first electron lens having a first focal length;
means for individually focusing each segment comprising two parallel lens rods on opposite sides of each segment between the modulating rods and the screen;
the lens rods constituting a second electron lens having a second focal length;
the distance between the pair of modulating rods and the pair of lens rods of each beam segment being approximately equal to the sum of the first focal length and the second focal length;
and the first and second focal lengths being approximately equal.

2. A cathode-ray device comprising:
means for forming and projecting a beam of electrons which is appreciably wider in one dimension than in the other;
a pair of deflecting plates for deflecting the beam;
means for dividing the beam into a plurality of segments;
means comprising a plurality of first electron lenses for intensity modulating each beam segment;
means for indicating the impingement of each beam segment;
and a second electron lens located between each of the first lenses and the indicating means for focusing each of the beam segments;
the distance between the first electron lens and the second electron lens being substantially equal to the sum of the focal lengths of the first and second electron lenses.

3. A cathode-ray tube comprising:
means for forming and projecting a ribbon electron beam;
a pair of deflecting plates having a center of deflection for deflecting the beam;
a collimating lens for focusing the beam;
the distance between the center of deflection and the collimating lens being substantially equal to the focal length of the collimating lens;
an indicating screen;
a plurality of modulating lenses for selectively intensity modulating different parts of the beam;
a focusing lens between each of the modulating lenses and the indicating screen for focusing each of the said different parts of the beam;
the distance between any modulating lens and its corresponding focusing lens being approximately equal to the sum of their focal lengths.

4. In a cathode-ray tube of the type having an electron gun for forming and projecting a beam of electrons toward an indicating screen, a modulating device for controlling electron impingement comprising:
means included between the electron gun and the indicating screen for defining a beam modulating plane;
means included between the beam modulating plane and the indicating screen for defining a lens plane;
and means included between the electron gun and the modulating plane for defining a beam forming plane;
the potential gradients along the beam path at its intersections with the planes being substantially given by

$$\frac{2V_M}{V_L'-V_{BF}'}+\frac{2V_L}{V_P'-V_M'}=d_2$$

where V_M' is the potential gradient at the modulating plane, V_L' is the potential gradient at the lens plane, V_{BF}' is the potential gradient at the beam forming plane, V_P' is the potential gradient at the indicating screen, V_M is the voltage at the modulating plane, V_L is the voltage at the lens plane, and d_2 is the distance between the modulating plane and the lens plane.

5. In a cathode-ray tube of the type having an electron gun for forming and projecting an electron beam toward an indicating screen on which indications are made in response to the impingement of electrons, a modulating device for controlling electron impingement on the indicating screen in response to an input signal from a source comprising:
a pair of modulating electrodes both connected to the signal source and located between the electron gun and indicating screen on opposite sides of a predetermined portion of the electron beam;
a pair of lens electrodes located between the modulating electrodes and the indicating screen on opposite sides of the beam portion;
the modulating electrodes constituting a first electron lens having a first focal length;
the lens electrodes constituting a second electron lens having a second focal length;
the distance between the first lens and the second lens being approximately equal to the sum of the first focal length and the second focal length.

6. In a cathode-ray tube of the type having an electron gun for forming and projecting an electron beam toward an indicating screen on which indications are made in response to the impingement of electrons, a modulating device for controlling electron impingement on the indicat-

ing screen in response to an input signal from a signal source comprising:

a modulating electrode connected to the signal source and located between the electron gun and the indicating screen;

a lens electrode between the modulating electrode and the indicating screen;

a beam forming electrode between the modulating electrode and the electron gun;

first means for applying an electrical voltage to the beam forming electrode;

second means for applying an electrical voltage to the lens electrode;

the electrical voltages on the electrodes and the separation between the electrodes being substantially given by

$$\frac{2V_M}{\left[\frac{V_L-V_M}{d_2}\right]-\left[\frac{V_M-V_{BF}}{d_1}\right]}+\frac{2V_L}{\left[\frac{V_P-V_L}{d_3}\right]-\left[\frac{V_L-V_M}{d_2}\right]}=d_2$$

where V_M is the voltage on the modulating electrode, V_L is the voltage on the lens electrode, V_P is the voltage on the indicating screen, V_{BF} is the voltage on the beam forming electrode, d_1 is the distance between the beam forming electrode and the modulating electrode, d_2 is the distance between the modulating electrode and the lens electrode, and d_3 is the distance between the lens electrode and the indicating screen.

7. A cathode-ray tube comprising:

means for forming and projecting a ribbon electron beam;

means for deflecting the beam in a direction transverse to the plane of the beam;

an indicating screen;

means for dividing the beam into a plurality of segments;

means for individually intensity modulating each beam segment comprising a pair of parallel rod-shaped modulating electrodes on opposite sides of the path of each beam segment and means for applying an individual modulating voltage to each of said pairs;

the modulation of each beam segment being characterized by a cross-over of the constituent electrons thereof and a subsequent divergence of the beam segment;

and means for preventing overlapping of adjacent beam segments due to such divergence comprising a pair of rod-shaped lens electrodes located between each pair of modulating electrodes and the indicating screen.

8. The cathode-ray tube of claim 7 wherein each pair of modulating electrodes constitutes a first electron lens having a first focal length and each pair of lens electrodes constitutes a second electron lens having a second focal length;

the first focal length being approximately equal to the second focal length and the sum of the first and second focal lengths being approximately equal to the distance between the first electron lens and the second electron lens.

9. A cathode-ray tube comprising:

means for forming and projecting a ribbon electron beam;

a pair of deflecting plates having a center of deflection for deflecting the beam;

an electron collimating lens for focusing the beam;

the distance between the center of deflection and the collimating lens being substantially equal to the focal length of the collimating lens;

an indicating screen;

means for dividing the electron beam into a plurality of segments comprising an electron shield having a plurality of elongated slots located between the collimating lens and the indicating screen;

a plurality of pairs of rod-shaped modulating electrodes for selectively intensity modulating different beam segments;

and a pair of lens electrodes between each pair of modulating electrodes and the indicating screen for focusing each of the different segments of the beam;

each pair of modulating electrodes being characterized by an average focal length and each pair of lens electrodes being characterized by an average focal length;

the sum of the average focal length of each of the modulating electrodes and each of the lens electrodes being substantially equal to the distance between the modulating electrodes and the lens electrodes.

No references cited.