July 7, 1964 R. D. KETCHPEL 3,140,415

THREE-DIMENSIONAL DISPLAY CATHODE RAY TUBE

Filed June 16, 1960 4 Sheets-Sheet 1

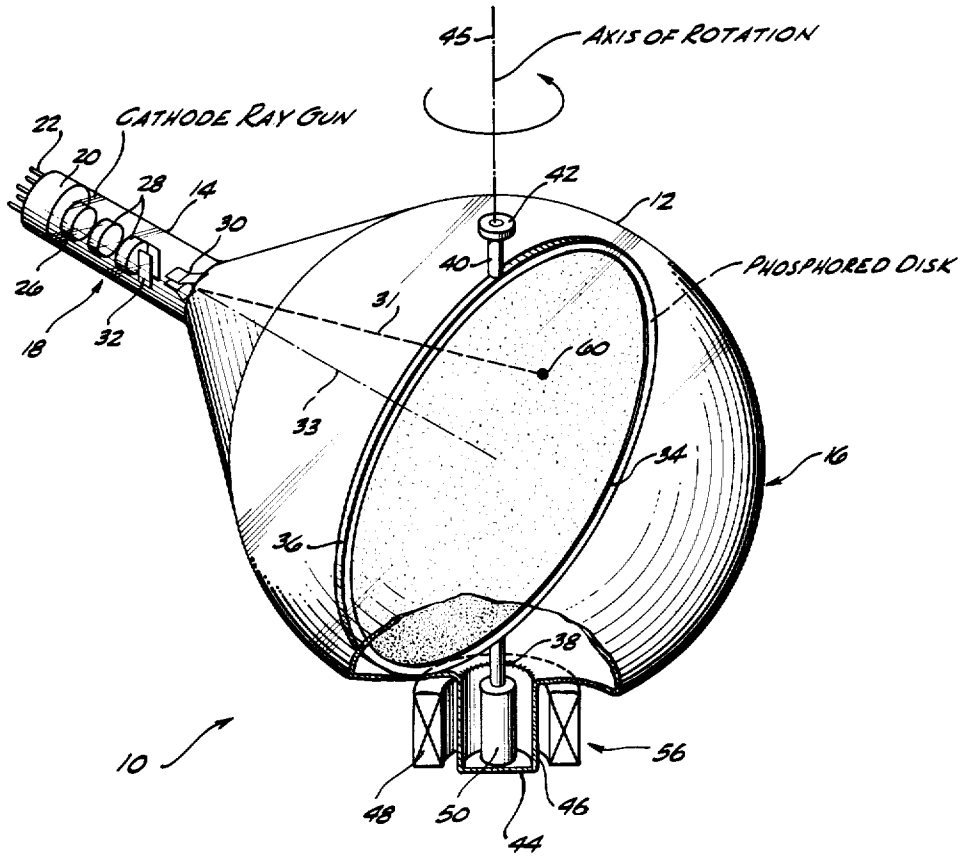


FIG. 1.

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Filed June 16, 1960 4 Sheets-Sheet 2

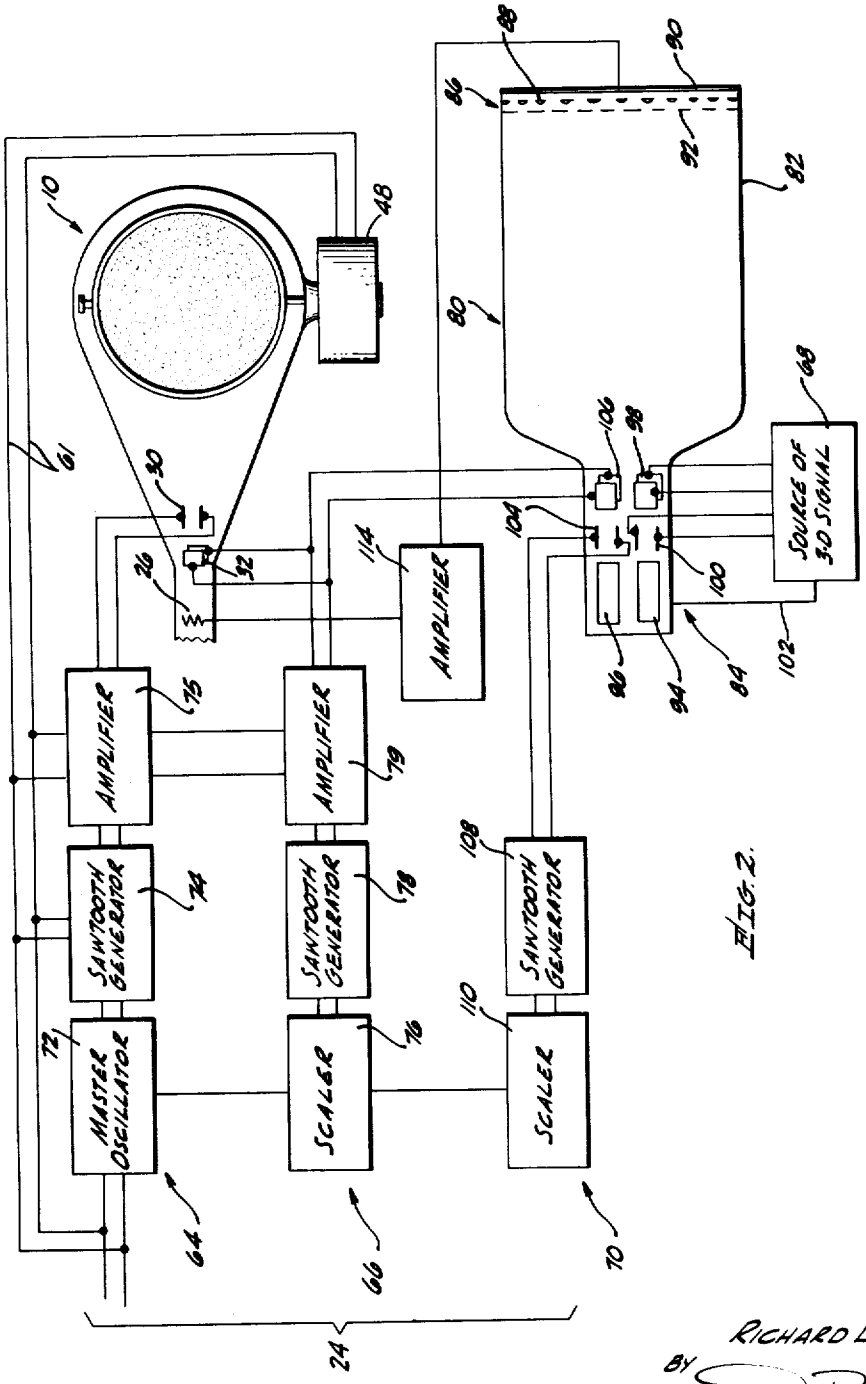


FIG. 2.

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THREE-DIMENSIONAL DISPLAY CATHODE RAY TUBE

Filed June 16, 1960 4 Sheets-Sheet 3

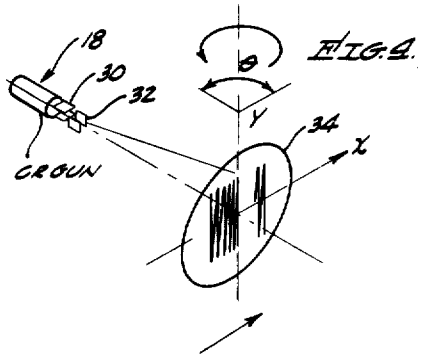


FIG. 4.

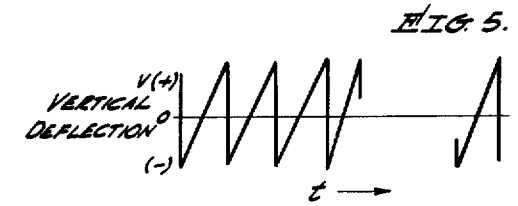


FIG. 5.

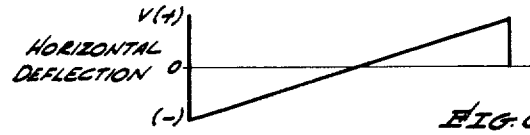


FIG. 6.

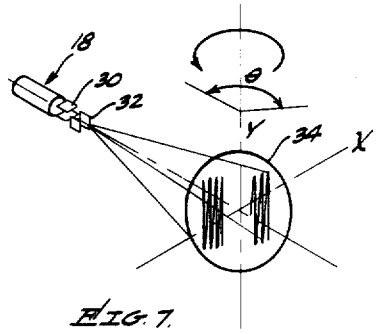


FIG. 7.

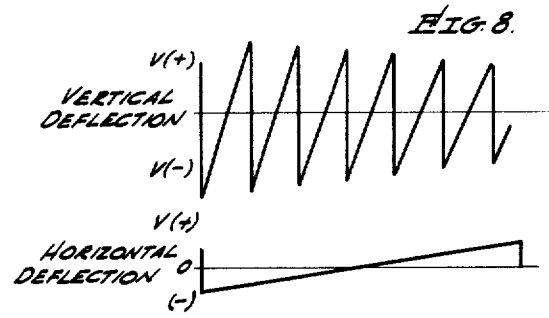


FIG. 8.

FIG. 9.

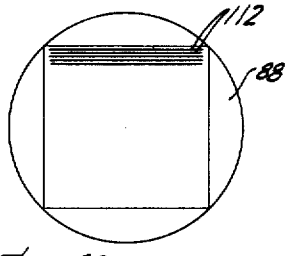


FIG. 10.

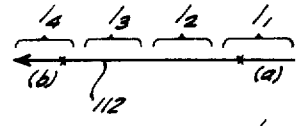


FIG. 11.

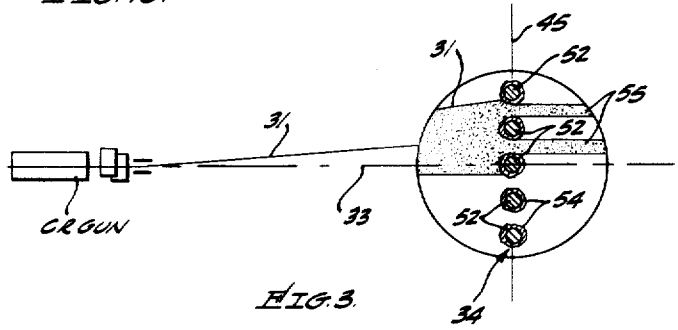


FIG. 3.

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THREE-DIMENSIONAL DISPLAY CATHODE RAY TUBE

Filed June 16, 1960 4 Sheets-Sheet 4

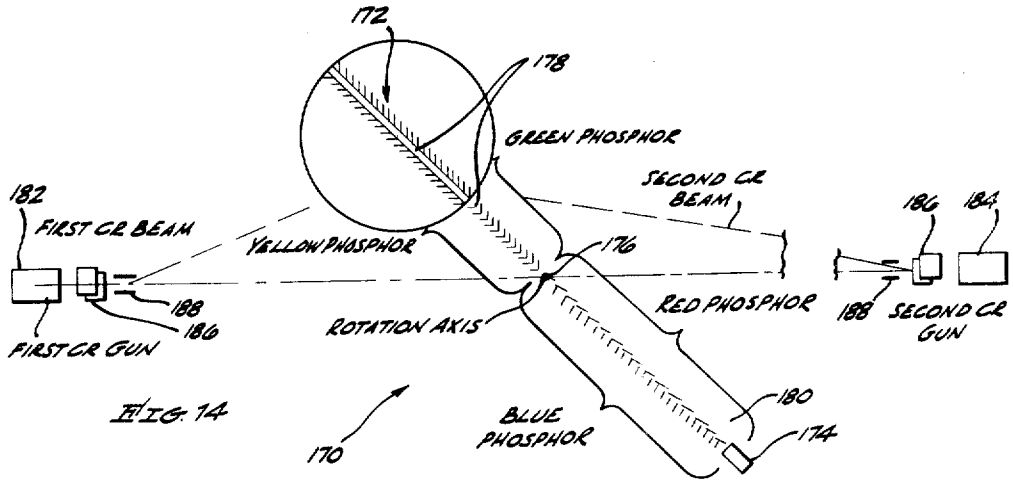


FIG. 14

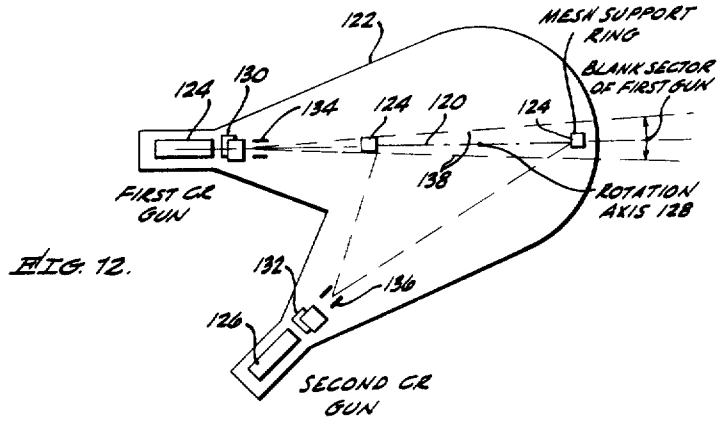


FIG. 12.

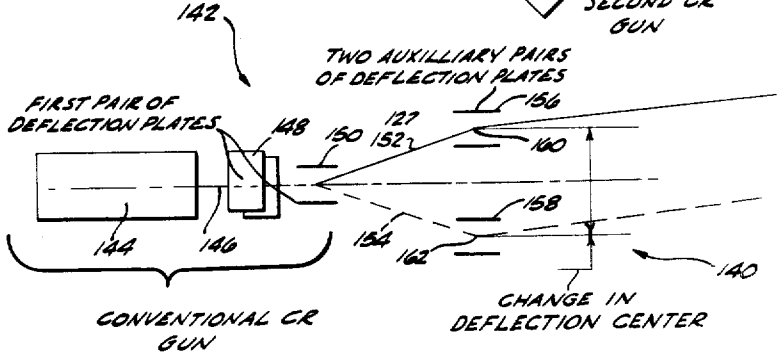


FIG. 13.

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United States Patent Office 3,140,415 Patented July 7, 1964

3,140,415

THREE-DIMENSIONAL DISPLAY CATHODE RAY TUBE

Richard D. Ketchpel, Malibu, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Filed June 16, 1960, Ser. No. 36,525
25 Claims. (Cl. 313—146)

The present invention relates to display means and more particularly to means for providing a three-dimensional visual display that occupies a volume.

In the past, numerous attempts have been made to provide a visual display having three dimensions so that an observer can perceive the intelligence presented thereby. Although such attempts have resulted in several means capable of accurately displaying such intelligence, they are all subject to several objections. In some systems no effort is made to create a three-dimensional display. Instead, in one type of system a single planar display is presented to the operator with the dimension in a direction normal to the plane being perceived by the color of the display, the size of the display, etc. In another type of system a plurality of planar displays are produced with each of these planes representing a different plane in space. To utilize such a display the operator endeavors to correlate the intelligence in each of the planes and to then simultaneously perceive all three dimensions. Although the foregoing systems are capable of providing an observer with the desired intelligence, their accuracy is dependent upon a high degree of skill in the observer. As a consequence, the use of such systems is limited to special applications such as a three-dimensional radar system where a skilled operator is available. It will be noted that in the foregoing types of systems a three-dimensional display is not created, although the display contains adequate information for the observer to perceive all of the intelligence.

Another means of visually displaying intelligence having three dimensions is to create an illusion of a three-dimensional display. One means of creating such an illusion is to employ a stereoptic presentation wherein the observer's eyes simultaneously view two different planar displays. The observer is then able to perceive the three dimensions by physiologically combining the two pictures. Unfortunately, such methods require an accurate depth perception on the part of the observer. They also necessitate the use of special viewing glasses and/or restrictive viewing positions. Accordingly, such systems cause substantial amounts of fatigue in the observer and therefore have not found wide acceptance.

More recently, it has been proposed to provide means for producing a visual display that actually possesses three dimensions, i.e., the visual display actually occupies a volume or space. For example, it has been proposed to provide a volume in which localized portions of the gas in the volume can be selectively ionized. The ionized portion of the gas will then luminesce with visible light which is properly arranged into a correct pattern will create the desired display. Unfortunately, in order to create a display of this nature having an acceptable amount of resolution the ionized portions of the gas must be very small and extremely numerous. In order to control the ionization in this manner it is necessary to employ substantial quantities of equipment within the display volume. Since such equipment absorbs light, the resultant light losses make the display volume substantially opaque to visible light. As a result, adequate quantities of the light from the display cannot escape so as to be visible to the operator.

It has also been proposed to create a three-dimensional display by providing a phosphorescent screen in a vacuum and reciprocating the screen in translation through a predetermined space, i.e., the display volume. During such movement, an electron gun disposed in the vacuum on a line substantially normal to the plane of the screen directs a stream of electrons onto the screen so as to cause phosphors thereon to luminesce with visible light. By scanning the electron stream through the display volume and coordinating such scanning with the movement of the reciprocating screen it has been possible to produce a visible display that actually occupies the space swept by the reciprocating screen. Unfortunately, the reciprocating of the screen in translation through the vacuum presents several mechanical problems that impose severe physical limitations on the size of the display that can be produced. For example, if a large size screen is to be employed and a large volume is to be swept, in order to obtain an acceptable resolution the screen must move at a high rate of speed. As a result, extremely large acceleration forces will be created on the screen structure. In addition, since the display is created on a plane surface that is moving in translation, and since it is impossible for an observer to see anything in a plane containing his eyes, the viewing area will be limited primarily to a line normal to the surface of the screen. As the observer moves from such a position the quality of the display will progressively decrease until it becomes virtually invisible as he approaches the plane of the screen.

It is now proposed to overcome the foregoing difficulties by providing display means wherein a display of three-dimensional intelligence can be created that will actually occupy a predetermined display volume and which may be viewed by an observer from virtually any position without the necessity of using any form of special viewing apparatus. More particularly, this is to be accomplished by providing an oscilloscope tube which has a display volume in which a luminescent visible display can be created. A screen having at least one surface upon which a display can be created, is disposed in the display volume and rotated about an axis. The surface of the screen will thus be swept through the entire display volume. By causing the various portions of the screen to luminesce with visible light in timed sequence with the angular position thereof, a visible display can be created in all portions of the display volume so that the display actually possesses three dimensions and occupies a volume. The resultant display may be viewed from virtually any direction.

More particularly it is proposed to provide a screen that is rotatably mounted in a vacuum and has one or more surfaces that are adapted to have preselected portions excited so as to luminesce with visible light. In the present instance the surface has a phosphorescent material that will produce visible light when bombarded with electrons. It may thus be seen that if an electron gun is also disposed in the vacuum so as to project a stream of electrons into the display volume, by coordinating the motion and intensity of the beam with the angular position of the screen, a visible display may be produced. This display will be created on the moving surface whereby the visible display will possess three dimensions and occupy the display volume. Accordingly, the resultant display will be an accurate visual representation of the three-dimensional intelligence supplied thereto and it may be viewed from virtually any location without the necessity of using any special viewing apparatus.

In the four sheets of drawings:

FIGURE 1 is a perspective view with portions thereof broken away of an oscilloscope tube embodying the present invention;

FIG. 2 is a block diagram of control means suitable for use with the tube of FIG. 1;

FIG. 3 is a fragmentary view of a portion of the oscilloscope in FIG. 1 with the screen portion thereof being on an enlarged scale;

FIG. 4 is a fragmentary view of the oscilloscope of FIG. 1 with the screen therefor being disposed in one operating position;

FIGS. 5 and 6 are views of waveforms of signals in various portions of the oscilloscope when the screen is in the operating position of FIG. 4;

FIG. 7 is a fragmentary view similar to FIG. 4 but showing the screen in a different operating position;

FIGS. 8 and 9 are views similar to those in FIGS. 5 and 6 of waveforms of signals occurring when the screen is in the position of FIG. 7;

FIG. 10 is a fragmentary view of a storage tube suitable for use in the control means of FIG. 2;

FIG. 11 is a view on an enlarged scale of a storage line in the storage tube of FIG. 10;

FIG. 12 is a view of another embodiment of the present invention;

FIG. 13 is a view of an additional embodiment of the present invention; and

FIG. 14 is a view of a still further embodiment of the present invention.

Referring to the drawings in more detail, and particularly to FIGS. 1 through 11 thereof, the present invention is embodied in an oscilloscope tube **10** adapted to create a three-dimensional display. The oscilloscope tube **10** includes an outer envelope **12** capable of retaining a vacuum therein of sufficient magnitude to permit the free passage of electrons therethrough. The envelope **12** includes a display portion **16** and a gun portion **14** that is disposed on the opposite side of the envelope **12** from the display portion **16**. Since the display that will be created will be of the visual type, the display portion **16** should be made of a transparent material such as glass to permit viewing of the display from outside of the envelope **12** with a minimum amount of distortion. The display portion **16** of the envelope **12** preferably has a surface of revolution such as a cylindrical or spherical shape to conform generally to the shape of the display volume in which the display is to be created.

In order to create the display, a screen **34** that may have preselected portions thereof made to luminesce and means for controlling such luminescence are provided. Any suitable form of so-called electroluminescence wherein predetermined limited areas of the screen are excited so as to produce visible light, may be employed. However, in the present instance, the screen which is provided in the display portion **16** of the envelope **12** includes a phosphorescent surface that will luminesce with visible light when bombarded with electrons. In addition, an electron gun **18** is disposed in the gun portion **14** for projecting electrons onto the screen **34**. The electron gun **18** which may be of conventional design is mounted on a base **20** sealed in the gun portion **14**. The base **20** includes a plurality of prongs **22** that project outwardly for insertion into a suitable receptacle. The receptacle may in turn be electrically connected into a control circuit **24**, such as shown in FIG. 2. The inner ends of the prongs **22** are electrically connected to the various elements of the electron gun **18** such as a cathode, a control grid **26**, beam forming elements **28**, and suitable deflection means.

Although the deflection means may be of the electromagnetic variety, in the present instance, electrostatic means are employed. This means includes a pair of parallel vertical deflection plates **30** and a pair of parallel horizontal deflection plates **32** that are orthogonally disposed relative to each other. During operation of the electron gun **18**, the electrons radiated from the cathode will be confined into a small beam **31** by the beam forming elements **28** and will have an intensity determined by

the potential on the grid **26**. The beam will then travel between the horizontal and vertical deflection plates **30**, **32** and into the display volume. The amount and direction of vertical deflection of the beam **31** from the axis **33** of the gun **18** as the electrons travel into the display volume will be determined by the amount and polarity of the voltage differential across the vertical plates **30**. Similarly, the amount and direction of horizontal deflection of the beam **31** in the horizontal direction will be determined by the amount and polarity of the voltage differential across the horizontal plates **32**. Thus, by applying appropriate voltages and currents to the prongs **22**, the various elements in the gun **18** will cause a well defined beam **31** of the desired intensity to be projected into the display volume. In addition, by applying the proper signals to the deflection plates **30**, **32** the beam **31** can be rapidly scanned throughout the display volume so as to impinge on any portion of the screen **34**.

The screen **34** which is to be supported in the display volume includes a rigid frame or ring **36** that has a pair of short shafts **38**, **40** that project diametrically outwardly from the opposite sides thereof. The ends of the shafts **38**, **40** are adapted to be mounted on suitable bearings **42**, **44** disposed on the envelope **12** at the opposite sides of the display volume. Preferably the axis **45** of revolution and the axis of the electron gun are disposed substantially normal to each other with the gun being aimed substantially at the center frame. It will thus be seen that the frame **36** will be free to rotate about the axis **45** of the shafts **38**, **40**. The frame **36** may be a circle, a rectangle or any other desired shape so that as it rotates the frame **36** will sweep throughout the dis play volume and generate a volume of revolution.

A mesh of fine wires **52**, for example a 250-pitch stainless steel wire mesh, is stretched over the frame **36** and secured thereto. The mesh will thus form a plane that will rotate with the frame **36**. The mesh is sprayed on one or both sides with a suitable phosphorescent material **54** so that the individual wires **52** are substantially entirely coated by the material. The phosphorescent material may be of any suitable variety such as P–11 (ZnS:Ag) which will luminesce with visible light when struck by electrons but will have a very short persistence.

In this embodiment it is desirable for the mesh to be transparent to the electron beam **31** and also to visible light. Thus, if a beam **31** of electrons is directed toward the screen **34**, at least a portion of the electrons **55** will be able to pass through the spaces between the wires. Thus the phosphors on the front side of the wires and at least a portion thereof on the back side will luminesce with visible light. As a result, visible light will be radiated in all directions and will be visible to an observer irrespective of which side of the screen **34** he is on. The electrons **55** that pass through the spaces between the wires and those that collect on the screen may be carried away by a conductive surface on the face of the envelope.

In order to rotatably drive the screen **34** about the axis **45** of the shafts **38**, **40**, a synchronous electric motor **56** is provided. In the present instance, the motor **56** includes an armature **50** provided on one of the shafts **38** so as to be located inside of the envelope **12** and a coil **48** outside of the envelope **12**. To facilitate such an arrangement a pocket **46** projects from one side of the envelope **12** for housing the armature **50**. The coil **48** is then provided on the exterior of the pocket **46** so as to create a rotating magnetic field therein that will act on the armature **50** and thereby synchronously drive the screen **34**. For reasons that will become more apparent subsequently, this is preferably a synchronous motor **56** which will cause the screen **34** to rotate at a fixed speed determined by the frequency of the current in the lines **61** supplying power to the motor **56**.

When the coil **48** is excited the motor **56** will cause the screen **34** to rotate about the axis **45** of the shafts **38**, **40** at some fixed speed. Although this speed is not

critical, it has been found that at approximately 900 revolutions per minute or 15 revolutions per second a display can be created that will have adequate resolution and will have no apparent flicker to the human eye.

Although other means may be employed for driving the screen **34** the present arrangement has numerous advantages. For example, since the bearings **42**, **44** and the rotating shafts **38**, **40** are disposed entirely inside of the envelope **12**, all of the moving parts are inside of the vacuum and no moving parts must extend through a side wall of the envelope **12**. As a result, the envelope **12** may be permanently hermetically sealed. In addition, the coil **48** which drives the screen **34** is disposed outside of the envelope **12** in the open atmosphere. As a result, heat generated by the coil **48** may be readily dissipated into the air rather than into the interior of the tube **10**. Consequently, the motor **56** and the tube **10** will remain cooler.

It may be seen that as the coil **48** synchronously drives the armature **50**, the shafts **38**, **40** will rotate on the bearings **42**, **44** and cause the screen **34** and the phosphorescent surface thereon to rotate on the axis **45** at a fixed rate determined by the line frequency. The phosphorescent surface will thus sweep the display volume and thereby effectively create a phosphorescent volume of revolution. Simultaneously with such motion the electron gun **18** may project a beam **31** of electrons into the display volume so as to impinge upon the phosphorescent surface and cause at least portions thereof to luminesce with visible light.

If the grid **26** is biased beyond cutoff, then no electrons will ever enter the display volume and the entire screen **34** will remain dark. However, if the grid **26** is momentarily biased above cutoff, the electron beam **31** will be gated and the electrons in the beam **31** will impinge upon a small area of the screen **34** and cause a luminescent point **60**. If the beam is gated "on" every time the screen **34** is in a given angular position, the point **60** of light will appear fixed in space and the position thereof will be dependent upon the deflection of the beam **31** and the angular position of the screen **34** at the instant of time the beam **31** is gated "on." Accordingly, by varying the amount of deflection produced by the horizontal and vertical deflection plates **32**, **30** and also the instant of time the beam is gated "on," the point of light can be created anywhere within the display volume swept by the screen **34**. If the beam is gated "on" for a very short time the luminescent area will appear as a spot. However, if the beam is "on" for a sufficient period to permit the screen to rotate through a perceptible distance the luminescent area will acquire the appearance of a line. Moreover, by creating a large number of these points and/or lines a visible display can be created that actually occupies the volume swept by the screen **34**.

In order to control the electron gun **18** and cause the electron beam **31** to create such a display, the control circuit **24** disclosed in FIG. 2 may be employed. The control circuit **24** includes a vertical deflection circuit **64**, a horizontal deflection circuit **66**, a source **68** of signals having three-dimensional information, and means **70** for electrically interconnecting said source **68** to the oscilloscope **10**.

The vertical deflection circuit **64** includes a master oscillator **72** and a sawtooth generator **74**. The input of the master oscillator **72** is interconnected with the same power lines **61** that supply current to the coil **48**. These lines **61** not only supply power to the oscillator **72** but also supply a synchronizing signal that will cause the output signal from the oscillator **72** to have a frequency that is some predetermined multiple of the power line frequency and which will always have some predetermined time relation thereto. The output of the oscillator **72** is electrically interconnected with the input to the sawtooth generator **74** which may be of conventional design. The output of the generator **74** is connected to the vertical deflection plates **30** so as to apply a voltage signal thereto. This signal has an instantaneous voltage that progressively increases from a minimum to a maximum and then instantly returns to the original minimum value in synchronism with the input signal from the oscillator **72**.

It has been found desirable for the output from the vertical generator **74** to be interconnected with the vertical deflection plates **30** by means of a vertical variable gain amplifier **75**. The amplifier **75** is connected to the power line **61** or to the horizontal deflection **66** circuit so as to derive a synchronizing signal therefrom that will be effective to control the gain thereof. The amplifier **75** will thus be effective to cause the amplitude of the scan signal fed to the deflection plates to periodically vary. Thus, the electron beam **31** will be vertically scanned across the screen **34** at a uniform velocity and then instantly returned to its original position for a repeated scan, and the amplitude of the scan will be determined by the gain of the amplifier **75**.

The horizontal deflection circuit **66** includes a so-called scaler **76** and a horizontal sawtooth generator **78**. The input of the scaler **76** is connected to an output from the master oscillator **72**. The output signal from the scaler **76** will have a frequency that is some predetermined fraction of the frequency of the signal supplied to the input of the scaler **76** by the oscillator **72**, for example 128 times less. In addition, the output signal will have a predetermined time relation thereto. The output signal from the scaler **76** is in turn fed into the input of a horizontal sawtooth generator **78**. The output of the generator **78** is coupled to the horizontal deflection plates **32** and will supply a sawtooth voltage signal thereto. This interconnection is preferably accomplished by means of a horizontal variable gain amplifier **79**. This amplifier is interconnected with the power line **61** or another suitable source of a synchronizing signal that will control the gain of the amplifier. Thus the amplitude of the horizontal deflection will vary periodically. This signal on the horizontal deflection plates **32** will cause the beam **31** to be horizontally swept across the display volume at a rate that is slower than the vertical scan by an amount corresponding to the decrease in frequency occurring in the scaler **76**.

It should be noted that since the output of the horizontal sawtooth generator **78** will be synchronized with the current in the coil **48**, the horizontal scanning of the beam **31** will be synchronized with the angular position of the screen **34**. When the screen is in the position of FIG. 4, i.e., $\theta=90°$, the surface of the screen will be substantially equally spaced from the electron gun. Accordingly, if the gain of the amplifier **75** is constant the amplitude of each of the vertical deflections will be substantially equal. As a result, the top and bottom edges of the raster will be parallel and equally spaced. When the screen **34** has turned to the position of FIG. 7, i.e., $\theta=135°$, the surface of the screen will have one edge considerably closer to the electron gun **18** than the other edge. Under these circumstances if the gain of the vertical amplifier **75** varies as seen in FIG. 8 the vertical deflection of the beam **31** will be greatest when it is directed toward the closest edge of the screen **34** and the least when it is directed toward the more remote edge. As a result, the amount of deflection of the beam **31** at the point of incidence on the screen **34** will be standardized. Thus, the top and bottom edges of the raster will remain parallel and uniformly spaced irrespective of the angular position of the screen. This will insure a raster of uniform height at all times.

The horizontal amplifier **79** may also be of the variable gain variety and have its gain controlled from the power line **61**. It will thus operate in a manner similar to the vertical deflection means in that the amount of horizontal deflection may vary in a manner similar to that in FIGURES 6 and 9. Thus, irrespective of the angular posi-

tion of the screen, a raster of substantially uniform width may be obtained.

If the screen **34** is a plane surface, scanning the beam **31** horizontally across the display volume approximately 128 times every time the screen **34** rotates 180°, the entire area of the screen **34** will be scanned every time the angle θ changes slightly more than one degree. This will result in the electron beam electronically scanning the display volume approximately 256 times every time the screen mechanically sweeps the display volume. It may be seen that by scanning the screen **34** in this manner while the screen is rotating at 900 r.p.m. or 15 revolutions per second, the display volume will be completely scanned 30 times per second. Due to the persistence of the human eye the resultant light appears as a continuous bright spot. If it is desirable to reduce the bandwidth, the screen may be rotated at a slower speed without producing excessive flicker. It should be noted that since the various portions of the display are created at different times, the scanning rate may be reduced to a very slow rate before a perceptible flicker will appear in the display.

As previously pointed out, the output signal from the vertical sawtooth generator **74** will be approximately 128 times higher than the output signal from the horizontal sawtooth generator **78**. As a result of this ratio the electron beam will be scanned vertically approximately 128 times for each horizotnal scan. Also, as the screen **34** rotates about its axis **45**, the beam **31** of electrons will be swept horizontally through the display volume in synchronism with the rotation of the screen **34** at a rate of approximately 256 times for each revolution. It may thus be seen that the electron beam **31** will be effective to create a raster in the display volume.

The signal source **68** may be of any suitable variety capable of producing signals having three-dimensional information such as might be obtained from a television system or a radar system.

The means **70** for interconnecting the signal source **68** with the oscilloscope **10** may include a storage tube **80** of conventional design and the associated scanning circuits therefor. The present storage tube **80** employs an envelope **82** that has a vacuum therein and includes a gun portion **84** and a storage portion **86** at the opposite ends thereof. The storage portion **86** includes storage grid **88**, a conductive output plate **90** behind the grid **88**, and a collector grid **92** in front of the storage grid **88**. The storage grid **88** is a dielectric structure that will permit localized charges to be accumulated thereon without the charges leaking off.

If an electron having the proper velocity collides wtih the storage grid **88**, it will cause secondary emission of electrons from the grid **88**. If the secondary electrons are attracted to the collector grid **92** and prevented from returning to the storage grid **88**, a positive charge will be created. Thus, by directing a stream of electrons onto an area on the grid **88** the secondary emission will cause a deficiency of electrons or a positive charge to be built up on that portion of the grid **88**.

If the electrons of the proper energy level approach the grid **88**, they will be able to penetrate through those areas of the storage grid **88** which do not have an excessive negative charge thereon. Such electrons will be incapable of causing secondary emission from the grid **88** but they will travel onto the conductive plate **90** and produce a currnet therein. In the event such electrons approach the grid **88** at a point having a negative charge, the charge will repel the electrons and prevent the beam from passing therethrough.

The gun portion **84** of the storage tube **80** includes a write gun **94** and a read gun **96** that are adapted to independently direct two separate beams of electrons into the storage area **86** of the tube **80**. The write gun **94** includes suitable beam forming means and horizontal and vertical deflection plates **98**, **100** for controlling the direction of the beam. The electrons in this beam have

the proper energy level to cause secondary emission from the storage grid **88** when they strike the surface thereof. Thus, by connecting the deflection plates **98**, **100** and the control grid **102** in the write gun **94** to the signal source **68** the beam can scan across the surface of the storage grid and write a charge pattern on the grid **88** that will represent the information present in the signals from the three-dimensional source **68**.

The read gun **96** also includes beam forming elements, vertical deflection plates **104** and horizontal deflection plates **106**. The horizontal deflection plates **104** are interconnected with the horizontal deflection plates **32** of the oscilloscope **10** so that the electron beam from the read gun **96** will scan horizontally across the storage grid **88** simultaneously with the horizontal scanning in the oscilloscope **10**. The vertical deflection plates **104** are interconnected with a storage tube sawtooth generator **108** triggered by a storage tube scaler **110**. The scaler is effective to reduce the frequency from the horizontal scaler **76** by an amount corresponding to the number of times the horizontal deflection plates **32** in the oscillosocpe **10** cause the beam **31** to scan the display volume for each half revolution of the screen **34**. It may thus be seen that as shown in FIGS. 10 and 11 the information will be stored on the surface of the grid **88** in the form of a large number of horizontal lines **112**. Each of these lines **112** will comprise a large number of increments 1_1, 1_2, 1_3, etc., shown in an enlarged scale in FIG. 11. Each increment includes the information for each vertical line in the display produced on the screen.

Since the electrons in the read beam have the proper amount of energy to pass through the storage grid **88**, if there is not an excessive negative charge on the grid at the point of incidence, as the beam scans along a horizontal line it will strike the conductive output plate **90** with varying intensity dependnig on the storage pattern. As the electrons strike the plate **90** they will cause a current signal therein which will be fed through the storage tube amplifier **114**. The signal will then be amplified and fed to the grid **26** of the oscilloscope **10** to thereby control the intensity of the beam **31**.

In order to utilize the present invention the cathodes of the electron guns **94**, **96** are activated so as to be capable of radiating electron beams, and the synchronous motor **56** is started so as to cause the screen to be rotated in synchronism with the line frequency. In addition, the various other portions of the control means are also activated including the source of three-dimensional signals **68**.

The write gun **94** in the storage tube **80** will then proceed to scan across the storage grid **88**. As the signal source **68** causes the write beam to vary in intensity, it will cause varying amounts of secondary emission from the storage grid **88** to occur. This in turn will cause a charge pattern to be created on the storage grid **88** that will contain positively and negatively charged areas corresponding to the information in the three-dimensional signal. Each of the horizontal lines **112** across the storage grid **88** will contain all of the information for a complete scanning of the screen **34** for some predetermined θ plane for the screen. The electron beams from the read gun **96** in the storage tube **80** and the electron gun **18** in the oscilloscope **10** are then simultaneously scanned across the storage grid **88** and the display volume respectively in synchronism with each other. As the read beam traverses horizontally across the storage grid **88**, varying amounts thereof will penetrate through the grid **88** and strike the output plate **90**. The amount of the electrons arriving at the plate **90** and the amplitude of the resultant signal at the plate **90** will correspond to the charge placed on the grid **88** by the write gun **94**. This signal will be increased in strength by the storage amplifier **114** and fed to the grid **26** of the oscilloscope **10** to thereby control the intensity of the

beam **31**. At the same time the beam **31** is being slowly scanned across the display volume it will be rapidly scanned vertically across the display volume. The electrons in this beam **31** will strike the screen **34** and cause luminescence on the screen in accordance with the information stored on the grid **88**. It should be noted that if variable gain amplfiers **75, 79** are employed, the amount of the deflection for the scanning will be varied so that the raster on the screen will be of uniform height and width. Thus a "plane" having an angle of θ will be created. It should be noted that during the scanning, the screen will have rotated a small amount so that the "plane" will actually have a slight curvature.

When the beam **31** has completed a single horizontal scan it will return to its original position and commence a succeeding scan. At the same time the read beam in storage tube **80** will scan across the succeeding lines of the storage grid **88**. During this process the screen will rotate and the screen will be scanned entirely to thereby create a new θ "plane" in the display. As a consequence, as each succeeding θ "plane" is scanned and the various portions of the screen luminesce with light a visible display will be created. It should be noted that since the entire surface of the screen is scanned, when the screen has completed one-half revolution the two halves of the screen will have swept the entire display volume and a complete display will have been created.

Since the screen **34** is made up of a mesh of fine wires **52** that will permit the passage of electrons therebetween, a sufficient amount of phosphorescent material on both sides of the screen will become luminescent when an electron beam is directed thereat to cause visible light to radiate in all directions from both sides of the screen. Thus, the light created will be visible to an observer irrespective of the side of the screen he is located on. It will thus be seen that a display may be created that actually possesses three dimensions and occupies the display volume. Moreover, the display may be readily seen by an observer in virtually any position from which he can see the sceren **34**. Moreover, it has been found that if the screen rotates at 900 r.p.m. and the entire screen is scanned twice each revolution each part of the display will luminesce at approximately 30 times per second. Since this is a higher rate than the human eye can perceive there will be no apparent flicker and the display will appear to have a steady luminescence. It has also been found that if the display volume is scanned 128 times per half revolution the θ "planes" will be spaced apart by approximately one degree. This will produce an acceptable amount of resolution for a display of adequate size. If a greater amount of angular resolution is required the display volume may be scanned at a higher rate. However, if the increased bandwidth would be objectionable, the display volume may be scanned at the same rate but a greater number of θ planes may be created by means of interlacing of the succeeding scannings.

It should be noted that although the display may be viewed from virtually any position, when the screen and the observer's eyes are all in the same plane the observer cannot see the surface of the screen. In addition, the ring **36** will tend to form a shadow that will obscure at least a portion of the display. This tends to produce a discontinuity which appears as a dark plane that divides the display volume into two equal parts. However, as a practical matter it has been found that with a vertical axis **45** of rotation and a ring thickness of .100 inch or less, as a result of the spacing between the observer's eyes there will not be any discontinuity of the foregoing variety apparent in the display.

It will also be apparent that when a single electron gun **18** is employed, whenever the gun axis **33** and the screen **34** are coplanar the beam **31** of electrons will be unable to scan the surface of the screen **34**. Moreover, any errors present in the position of the electron beam **31** or the timing thereof will become very exaggerated when the screen **34** is approaching the edge-on position to the electron gun **18**. This may appear as a plane of discontinuity through the center of the display and/or as distortions in and around such a plane. In addition, due to the thickness thereof, the ring **36** will tend to cast an electron shadow across the surface of the screen **34** whenever it is edged onto the electron gun **18**. Fortunately, when the frame has a thicknes of .100 inch the effects of the shadow are virtually imperceptible.

One means of overcoming the foregoing difficulties is to employ an embodiment such as disclosed in FIGS. 12 or 13. In the embodiment of FIG. 12 the screen **120** is rotatably mounted in an evacuated envelope **122** similar to the foregoing embodiment. The screen **120** includes a rigid ring **124** that has a wire mesh stretched over it to form a plane surface. The opposite sides of the mesh are coated with a phosphorescent material that will luminesce with visible light when excited by an electron beam. Thus the screen **120** may be scanned by electrons to luminesce with visible light and create a three-dimensional visual display in the same manner as in the first embodiment.

The means for scanning the phosphorescent surface of the screen with electrons includes electron gun means disposed in the gun portion of the envelope **122**. The gun means comprises a pair of electron guns **124, 126** that have their axes oblique to each other but in a plane substantially normal to the axis **128** of rotation. Each of these guns **124, 126** is of conventional design having vertical deflection plates **130, 132** and horizontal deflection plates **134, 136**. It will thus be seen that the ring **124** will cast an electron shadow delineated by the dashed lines **138** when the electron beam from the gun **124** is employed. Accordingly, the gun **124** will be incapable of projecting electrons onto the surface of the screen **120** when the screen is in the position of FIG. 12. However, the gun **126** which is angularly disposed to gun **124** will be clearly visible from all portions of the screen. Therefore, the gun **126** will be able to scan the entire surface of the screen **120** during the intervals the gun **124** is unable to do so. Similarly, when the screen is turned so as to be in line with the gun **126** the gun **124** will be able to scan the screen **120**. As a result, it will be seen that even though the angular position of the screen **120** is such that it is disposed in a plane where it is impossible for one of the guns **124** or **126** to scan the screen **120**, the other gun **126** or **124**, respectively, will always be capable of exciting all portions of the screen **120**. It will thus be seen that there will never be any discontinuities formed in the display.

As an alternative, the embodiment **140** shown in FIGURE 13 may be employed for accomplishing the same objective. In this embodiment the screen is substantially identical to a screen in one of the foregoing embodiments in construction and the manner in which it is rotated about its axis and accordingly it is not included in the view. The electron gun means **142** for scanning electrons across the surface of the screen is adapted to be mounted in the oscilloscope tube in a plane substantially normal to the axis of rotation. The gun means includes means **144** such as a hot cathode for generating free electrons and for forming the free electrons into a beam **146**. In addition, a pair of deflection plates **148** for scanning the electron beam **146** in directions parallel to the axis of rotation are provided. For scanning in the other direction a compound set of deflection means are provided. This includes a first set of plates **150** that will cause the beam to alternatively follow a first path **152** or a second path **154**. There is also a second set of deflection plates **156, 158** through which the first or second paths **152, 154** pass respectively. Thus, by varying the voltage on the plates **150** the beam **146** will follow the path **152** between the plates **156** or path **154** between the plates **158**. When the beam **146** is following the path **152** between the plates **156**, it may be scanned across the

surface of the screen from the vantage of the point **160**. When the screen is in an angular position which approaches this point **160**, a voltage may be applied to the plates **150** to cause the beam to follow the path **154** and pass between the plates **158**. The beam will then be scanned across the screen from the vantage of point **162**. This point **162** is substantially outside the plane of the screen. Consequently, the beam may be scanned across the screen at all times from either the plates **156** or the plates **158**.

In the foregoing embodiments the entire surfaces on both sides of the wire mesh are coated with the same phosphorescent material. As a result the display will be made up of black portions, luminescent portions of one color, and the half tones between these extremes. If it is desirable to produce a display that will luminesce with two or more colors the embodiment **170** of FIG. 14 may be employed.

This embodiment **170** is similar to the first embodiments in that it employs an envelope having a display portion and at least one gun portion. A screen **172** which is disposed in the display portion may include a rigid frame **174** and material that is stretched thereover to form a plane surface. The supporting frame **174** may be mounted on a suitable bearing means whereby the screen **172** will rotate about an axis **176** that is disposed in the plane of the material and divides the plane surface into two substantially identical portions **178**, **180**. If the frame **174** is a circle, the screen **172** will thus be divided into two semicircular portions **178**, **180**. The plane surface is preferably formed by a material which will form a boundary that is opaque to an electron beam. However, at the same time the boundary is optically transparent so that light visible to the human eye may pass therethrough. By way of an example, it has been found that a film of 10,000 angstroms of Al_2O_3 possesses the desired characteristics.

The surfaces on the various sides of different portions of the screen **172** may be coated with phosphors which will luminesce with visible light of predetermined colors. Since light of any color can be created by combining the primary colors, it has been found desirable to produce light of one of the primary colors such as blue by the phosphors on the first side of the semicircle **180**. The surface on the opposite side of the semicircle **180** may be coated with a phosphor which will luminesce with another primary color such as red. The semicircle portion **178** on the opposite side of the axis **176** of rotation may have the first side thereof coated with a phosphor which will produce visible light of the remaining primary color, namely yellow. Since these three primary colors may be blended to produce light of any desired color, the remaining surface on the semicircle **178** of the screen may be coated with phosphors that will produce light of any desired color, for example green. However, it has been found that the phosphors producing one of the primary colors, such as red, is generally less efficient than the phosphors producing the other primary colors. Accordingly, the second side of the semicircle may be coated with phosphors for producing red light. It will thus be seen that the entire surface on one side of the screen **172** will be coated with a phosphor for producing red light, while the surface on the other side will be divided into equal portions for producing the other primary colors.

The electron gun means may include two cathode ray guns **182**, **184** that are disposed on diametrically opposite sides of the display volume for projecting streams of electrons into said volume. Each of the guns **182**, **184** includes vertical deflection plates **186** and horizontal deflection plates **188** for scanning the beams throughout the display volume independently of each other. Thus, each of the beams will be capable of scanning all portions of the screen **172**.

During operation of the oscilloscope **170** as the screen **172** rotates on its axis **176** the surface having the blue phosphors thereon will sweep throughout the display volume. In addition, irrespective of the angular position of the screen either the electrons gun **182** or the gun **184** will be able to direct electrons onto any portion of the blue surface. Thus to create a point of blue light at any location in the display volume the gun **182** or gun **184** will direct a stream of electrons onto the blue portion of the screen when it is located in a θ plane including the point. Since the electrons cannot pass through the screen **172**, the phosphors on the opposite side which produce red light, in the present instance, will not luminesce with light. Thus the point of light will consist of only blue light, and since the light may pass through the film it will be visible from all sides. Similarly, a red spot or a green spot may be created.

It may therefore be seen that by a proper timing of the emission of electrons from one or both of the electron guns, a bright spot can be created that consists of one of the primary colors in any portion of the display volume. Also, by "blending" two or more such bright spots a sngle bright spot of any desired color can be created, and moreover, by creating a large number of such spots in a predetermined pattern a three-dimensional display can be created that will occupy the display volume and luminesce with any desired variety of colors.

If a display having only two colors or a combination of two colors is acceptable, a single electron gun may be employed with a screen similar to the screen **34** in the first embodiment. However, both sides of a semi-circle on one side of the axis of rotation have the same phosphors thereon. Both sides of the other semicircle have phosphors that produce light of another color. Thus, by scanning one or the other of the semicircles as they alternatively pass through a given position, one or the other colors will be created.

What is claimed is:

1. In a device of the class described, the combination of a display screen, means for rotating said screen about an axis in the plane of said screen whereby the surface of said screen will sweep throughout a predetermined volume and stationary means for exciting preselected portions of said screen in synchronism with the position thereof.

2. Display means comprising the combination of a screen having a phosphorescent surface adapted to be bombarded by electrons to thereby luminesce with visible light, means for rotating said screen about an axis in the plane of said screen whereby said phosphorescent surface will sweep through a predetermined display volume, stationary means for projecting a beam of electrons into said display volume whereby the phosphors on said screen will luminesce with visible light, and stationary means for scanning said beam of electrons throughout said display volume in synchronism with the angular position of said screen.

3. In an oscilloscope the combination of an optically transparent screen having a phosphorescent surface adapted to luminesce when bombarded by electrons, means for rotating said screen about an axis in the plane of said screen whereby said surface will sweep throughout a predetermined volume, and stationary means for generating and directing a beam of electrons onto said screen for exciting at least a selected portion of said phosphorescent surface.

4. In an oscilloscope the combination of a screen having a phosphorescent surface adapted to luminesce when bombarded by electrons, means for rotating said screen about an axis in the plane of said screen whereby said surface will sweep throughout a predetermined display volume, a stationary electron gun for directing a beam of electrons into said display volume, and stationary deflection means for scanning said beam throughout said volume in synchronism with the angular position of said screen.

5. In an oscilloscope, the combination of a screen mounted for rotation about an axis in the plane of said screen, said screen having a phosphorescent surface thereon adapted to luminesce with visible light when bombarded by electrons, drive means connected to said screen for rotatably driving said screen about said axis whereby said surface will sweep throughout a predetermined display volume, stationary means for radiating a beam of electrons into said display volume whereby said electrons will strike portions of said surface and cause said portions of said screen to luminesce with visible light, and stationary electron beam deflection means electrically synchronized with said drive means for scanning said beam throughout said display volume in synchronism with the angular position of said screen.

6. An oscilloscope comprising, the combination of an evacuated envelope having a transparent portion, a screen disposed in said envelope and having a shaft thereon in the plane of said screen and rotatably mounted within said envelope said screen being visible through said transparent portion of said envelope, said screen having a phosphorescent surface thereon adapted to luminesce with visible light when bombarded with electrons, drive means including a synchronous armature on said shaft disposed inside of said envelope, synchronous coil means disposed on the exterior of said envelope for producing a rotating magnetic field whereby said armature will rotatably drive said screen about the axis of said shaft and cause said surface to sweep through a predetermined display volume, stationary means for projecting a beam of electrons into said display volume whereby said electrons will strike portions of said surface and cause said portions of said screen to luminesce with visible light, and stationary deflection and beam intensity modulation means electrically synchronized with said drive means for scanning said beam throughout said display volume in synchronism with the angular position of said screen.

7. In an oscilloscope, the combination of a screen mounted for rotation about a fixed axis in the plane of said screen, said screen having a phosphorescent surface thereon adapted to luminesce when bombarded by electrons, drive means connected to said screen for rotatably driving said screen about said axis whereby said surface will sweep throughout a predetermined display volume, a stationary electron gun having the axis thereof disposed substantially normal to said axis of rotation and effective to direct a beam of electrons into said display volume for striking selected portions of said phosphorescent surface and causing said portions of said screen to luminesce with visible light, said electron gun including electron beam control means for controlling the intensity and direction of said beam and electrical circuit means connected with said electron beam control means and with said drive means for synchronizing the movement and intensity of said beam with the angular position of said screen.

8. In an oscilloscope, the combination of a screen having a phosphorescent surface adapted to luminesce with visible light when bombarded by electrons, means for rotating said screen about an axis in the plane of said screen whereby said surface will sweep through a predetermined display volume, stationary electron gun and deflection means for generating and projecting a plurality of electron beams into said display volume, and means for synchronizing the movements of said beams with the position of said screen.

9. In an oscilloscope, the combination of a screen having a phosphorescent surface adapted to luminesce with visible light when bombarded by electrons, means for rotating said screen about an axis in the plane of said screen whereby said surface will sweep throughout a predetermined volume, a pair of stationary electron guns for radiating a pair of angularly disposed beams of electrons into said volume, separate stationary deflection means for each of said electron guns for sweeping said beams

throughout said volume, said deflection means being adapted to control the movements of said beams in synchronism with the position of said screen.

10. In an oscilloscope, the combination of a screen mounted for rotation about a fixed axis in the plane of said screen, said screen having a phosphorescent surface adapted to luminesce with visible light when bombarded by electrons, drive means connected to said screen for rotatably driving said screen about said axis whereby said surface will sweep throughout a predetermined volume, stationary cathode ray means for generating and projecting a plurality of electron beams into said volume along oblique axes disposed substantially normal to said axis of rotation, said cathode ray means including deflection means adapted to be operatively interconnected with said drive means for scanning said beams throughout said display volume in synchronism with the angular position of said screen.

11. In an oscilloscope, the combination of a screen mounted for rotation about a fixed axis in the plane of said screen, said screen having a phosphorescent surface adapted to luminesce when bombarded by electrons, drive means connected to said screen for rotatably driving said screen about said axis whereby said surface will sweep throughout a predetermined display volume, a stationary electron gun for radiating a stream of electrons toward said display volume, stationary means for splitting said stream into a pair of electron beams, stationary deflection means for independently scanning each of said beams throughout said display volume, and means for synchronizing the movements and intensities of said beams with the position of said screen.

12. In an oscilloscope having an envelope with a display portion, the combination of a plurality of stationary electron guns and associated deflection means disposed in said envelope on the opposite sides of said display portion for projecting a plurality of electron beams into said display portion, a display screen rotatably disposed in said display portion between said electron guns whereby said beams may simultaneously impinge upon the opposite sides of said screen, said screen consisting of a material electronically opaque to said beams but optically transparent to visible light, a layer of phosphorescent material on each of said sides of said screen, each of said layers being adapted to luminesce with a visible light having a color which is different than the color from the other of said layers.

13. In an oscilloscope having an envelope with a display portion therein, the combination of a display screen rotatably mounted in said display portion, said screen having a plurality of phosphorescent portions thereon being adapted to luminesce with visible light having a color different than the light from the other of said portions, means for rotating said screen about an axis in the plane of said screen whereby said phosphorescent portions will periodically move through said display portion and thereby generate a display volume, stationary electron gun and deflection means for scanning an electron beam throughout said display volume in synchronism with the movement of said screen.

14. In an oscilloscope having an envelope with a display portion therein, the combination of a display screen mounted in said display portion for rotation about an axis dividing said screen into two substantially equal portions, the surface on at least one side of each portion having a phosphorescent material thereon adapted to luminesce with visible light having a color different than the color from another of said surfaces, means for rotating said screen about said axis whereby each of said phosphorescent surfaces will periodically move through said display portion and thereby generate a display volume, stationary electron gun and deflection means for scanning an electron beam throughout said display volume in synchronism with the movement of said screen.

15. In an oscilloscope having an envelope with a dis-

play portion therein, the combination of a display screen disposed in said display portion, means for supporting said screen for rotation about an axis dividing said screen into two substantially equal portions, the surface on at least one side of each portion having a phosphorescent material thereon adapted to luminesce with visible light having a color differing from the color of another of said surfaces, means for rotating said screen about said axis whereby each of said phosphorescent surfaces will periodically move through said display portion and thereby generate a display volume, stationary electron gun and deflection means for scanning an electron beam throughout said display volume in synchronism with the movement of said screen.

16. A display screen for for use in an oscilloscope having a stationary cathode ray gun for projecting a beam of electrons into a predetermined volume and stationary means for scanning said beam throughout said volume, said screen comprising a surface having a phosphorescent material thereon adapted to luminesce when bombarded by said electrons to thereby produce visible light and means for supporting said screen for rotation about a fixed axis in the plane of said screen whereby said surface will sweep through said predetermined volume scanned by said electron beam.

17. A display screen for use in an oscilloscope having a stationary cathode ray gun including deflection means for projecting a beam of electrons into a predetermined display volume, said screen including a member optically and electronically transparent whereby visible light and said electron beam may pass through said member, at least one side of said member having a plane phosphorescent surface adapted to luminesce with visible light, means for supporting said member for rotation about a fixed axis that is contained in said plane surface whereby said surface will sweep through said display volume.

18. A display screen for use in an oscilloscope having a stationary cathode ray gun including deflection means for projecting a beam of electrons into a predetermined display volume, said screen including a rigid frame, a mesh of wire stretched over said frame to form a plane surface, said wire mesh being optically and electronically transparent whereby visible light and said electron beam may pass therethrough, both sides of said wire mesh having a phosphorescent material thereon adapted to luminesce when struck by said electrons, means on said frame for rotatably supporting said frame whereby said surface may rotate about an axis disposed in said plane of said mesh and said surface will sweep through said display volume.

19. A display screen for use in an oscilloscope having a stationary cathode ray gun including deflection means for projecting a beam of electrons into a predetermined display volume, said screen including a planar member, means for supporting said member for rotation about a fixed axis that is contained in the plane of said member and divides said member into two substantially identical portions, each of said portions having a phosphorescent surface on at least one side thereof that is adapted to luminesce with visible light having a color differing from the other portion.

20. A display screen for use in an oscilloscope having a stationary cathode ray gun including deflection means for projecting a beam of electrons into a predetermined display volume, said screen including a planar member that is optically and electronically transparent whereby visible light and said electron beam may pass therethrough, means for suporting said member for rotation about a fixed axis that is contained in the plane of said member whereby said axis will divide said member into two substantially identical portions, each of said portions having a phosphorescent surface that is adapted to luminesce with a visible light having a color that is different than the light from the other portion.

21. A display screen for use in an oscilloscope having a stationary cathode ray gun means for projecting at least one beam of electrons into a predetermined volume and stationary means for scanning said beam throughout said volume, said screen comprising a planar member that is opaque to said stream of electrons but is optically transparent to visible light, means for supporting said member for rotation about an axis disposed in the plane of said member and dividing said member into two separate portions, the surfaces on the opposite sides of each of said portions having phosphors thereon adapted to luminesce with a visible light having a color different than the color from another of said surfaces.

22. A display screen for use in an oscilloscope having a stationary cathode ray gun means for projecting at least one beam of electrons into a predetermined volume and stationary means for scanning said beam throughout said volume, said screen comprising a member which is electronically opaque to said beam of electrons but is optically transparent to visible light, a layer of phosphorous material on each side of said member, the phosphors in each of said layers being adapted to luminesce with a visible light having a color which is different than the color from said other layer.

23. A three-dimensional display system comprising a display screen having a phosphorescent surface; means for rotating said screen about an axis in the plane of said surface whereby said phosphorescent surface will sweep through a predetermined display volume; and stationary projection and scanning means for projecting charged particles onto successive elemental preselected areas of said surface in synchronism with the angular position of said screen.

24. A cathode ray tube, comprising: a sealed substantially evacuated envelope having a transparent portion; a phosphorescent screen rotatably mounted in said envelope on an axis in the plane of said screen and visible through said transparent portion of said envelope and at least one stationary electron gun assembly disposed in said envelope and directed toward said screen.

25. A cathode ray tube, comprising: a sealed substantially evacuated envelope having a transparent portion and having a projecting section of electrical insulating material defining a cavity communicating internally of said envelope; a phosphorescent screen; shaft means mounting said screen in the plane of said screen and rotatably journaled in said envelope with one end projecting into said cavity; and an electric motor having a rotor mounted on said shaft within said cavity and a stator disposed externally of said projecting section in flux linkage with said rotor.

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