Sept. 26, 1961 L. E. WALKUP 3,001,849

APPARATUS FOR ELECTROSTATIC RECORDING

Filed July 15, 1958 3 Sheets-Sheet 1

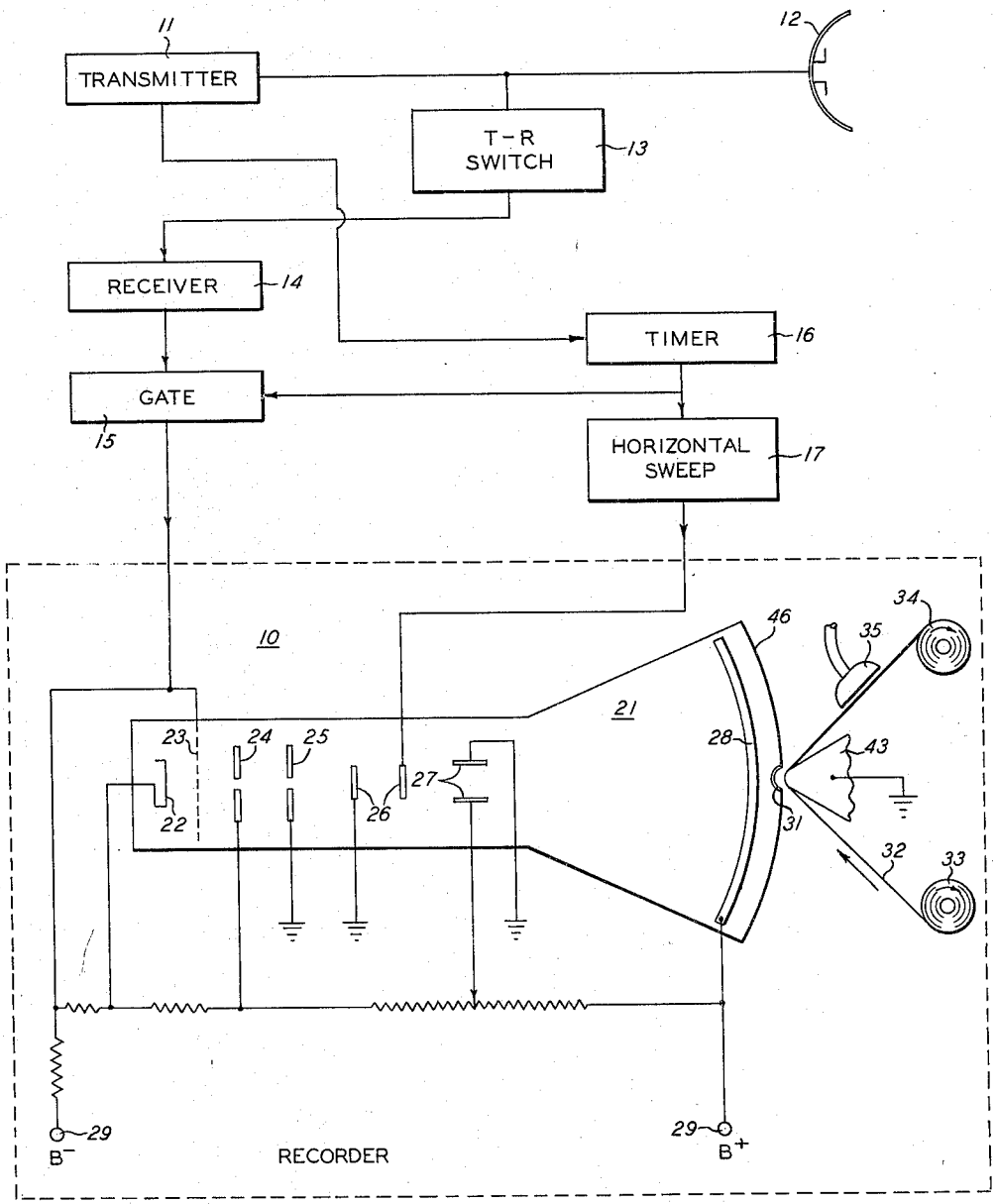


FIG. 1

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APPARATUS FOR ELECTROSTATIC RECORDING

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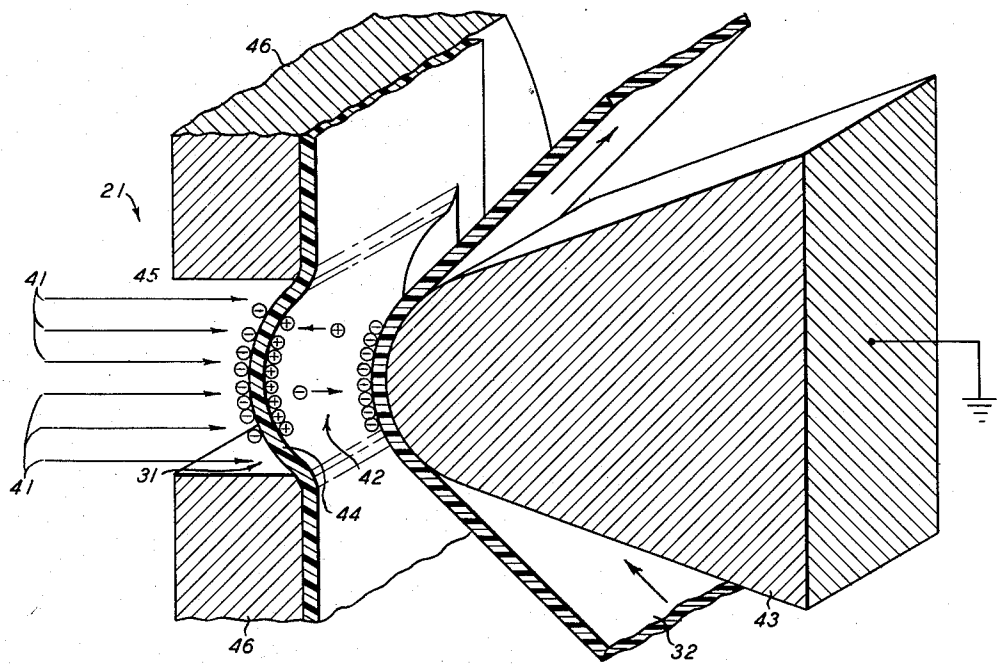


FIG. 2

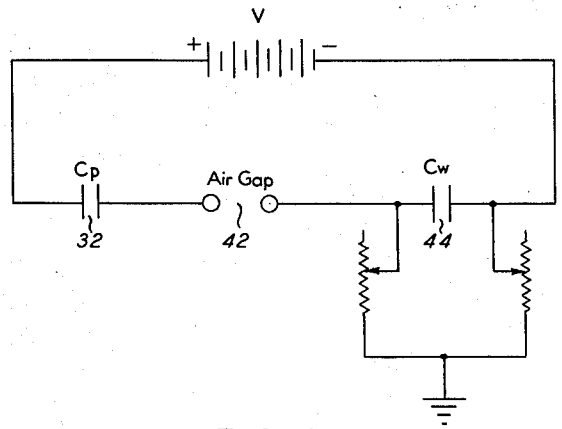


FIG. 3

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APPARATUS FOR ELECTROSTATIC RECORDING

Filed July 15, 1958 3 Sheets-Sheet 3

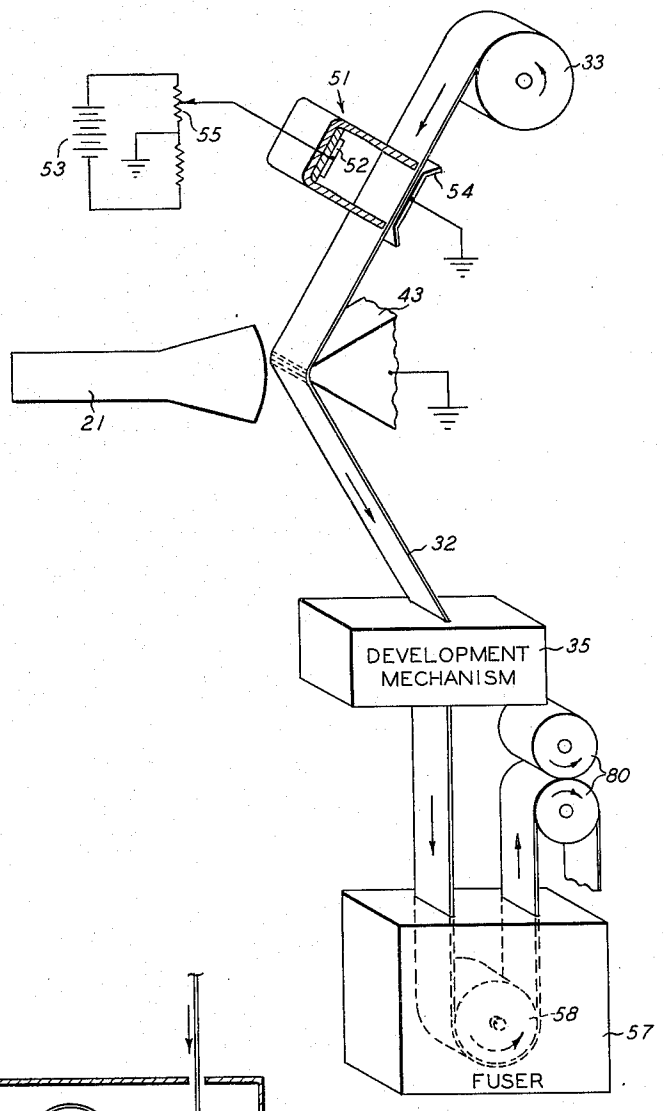


FIG. 4

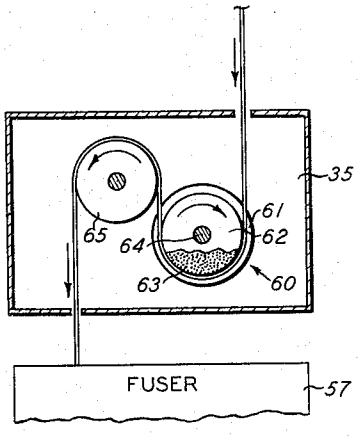


FIG. 5

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3,001,849

APPARATUS FOR ELECTROSTATIC RECORDING

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Filed July 15, 1958, Ser. No. 748,739
4 Claims. (Cl. 346—74)

The present invention relates to the art of recording intelligence, and more particularly to a method and apparatus for recording such intelligence by means of a cathode ray or electron beam.

In the high speed recording of intelligence, particularly facsimile or image recordings, in many environments the image intelligence is conveyed to a recording station by electrical transmission wherein the image intelligence is carried in the form of varying characteristics of electrical transmission denotative of the intelligence. At the recording station suitable means are provided for transducing the electrical transmission into a visual form and reducing the same to record, permanent or transitory as the needs dictate. In many environments the sensing of the intelligence to be transmitted and the transmission thereof, particularly when sensed electronically or optically, may be effected with extreme rapidity. However, the transducing and reduction of the intelligence to visual and record form frequently imposes serious time limitations on the overall system due to the inability of the recording station to accept the information at the rate capabilities of the sensing and transmission systems.

Electron beam or cathode ray tubes with phosphor screens, due to their ability to respond essentially instantaneously to electrical intelligence applied thereto, have therefore commonly been resorted to as a means for transducing the electrically transmitted intelligence into visual form. However, the image on the phosphor screens of such tubes is transitory, and does not of itself afford a suitable means for displaying a large amount of intelligence simultaneously, or a memory of intelligence for any significant period of time, particularly if the nature of the transmitted intelligence is continuously varying. Numerous efforts have been directed to recording permanently the transitory images from cathode ray tubes by various optical photographic methods. For many purposes such optical photographic recording is not well adapted, because of the time delay between exposure and developing of the record, the need for wet developing techniques and equipment, and the sensitivity of optical film to cosmic, nuclear, and other radiation. The foregoing drawbacks of optical photographic recording systems is particularly apparent in the environment of military radar, where the equipment may be installed in high altitude reconnaissance craft, and where the need for providing rapid permanent recording of the radar intelligence is important.

The present invention is directed to recording of intelligence, particularly facsimile or image intelligence, wherein the intelligence is transmitted or presented to the recorder in electrical form. The present invention utilizes a cathode ray or electron beam as the means for transducing the electrical intelligence to record form, thereby taking advantage of the substantially instantaneous response characteristics of such beam. However, rather than utilizing a phosphor screen to convert the intelligence to visual form with the foregoing attendant limitations thereof and disadvantages in the ensuing optical photographic recording of the phosphor image, in accordance with the present invention, the beam is utilized to create an electrostatic image on a moving web, and by xerographic techniques, the electrostatic image may be immediately and continuously developed into a visual image, and, if desired, formed into a permanent record.

More particularly, in accordance with the present invention, an electron beam is caused to repetitively traverse a single line of scan at a desired repetition rate. The target scanned by this beam is chosen from a material which is highly resistive electrically, and is substantially opaque to (i.e., essentially non-transmissive of) the impinging electron beam. With each traverse of the target, the beam deposits an electron charge on the impinged surface. The quantity of charge deposited along the line of scan on the target may be caused to vary in accordance with variations in the beam current during the traverse, as effected by electrical intelligence signals fed to the recording station. While one side of the target is thus repetitively traversed by the electron beam, a web of dielectric sheet material is fed past and in close proximity to the opposite side of the target. By maintaining the remote side of the web grounded or at a suitable potential difference from the target, the air dielectric between the target and web is disrupted and ionized, resulting in the positive ions traveling to the target, and the negative ions traveling to the web and establishing a corresponding charge thereon. If the web is properly positioned relative to the target, the resultant charge thus induced on the web will constitute a line of charge, and quantity of charge along the length of the line will correspond to the quantity of charge and variations thereof created on the target by the electron beam. Thus, for each traverse of the target, a line of electrostatic charge is induced on the web corresponding to the intelligence fed to the recording station. The rate of movement of the web past the target, and the rate of scan of the target by the electron beam are appropriately correlated to provide on the web a succession of lines of electrostatic charge, which taken together denote the image or facsimile intelligence fed to the recording station. This electrostatic image may be immediately and continuously developed by xerographic means to provide a visual image of the intelligence, and this image may, if desired, be fixed to provide a permanent record.

It is accordingly one object of the present invention to provide for the recording of intelligence presented in electrical form.

Another object of the present invention is to provide for the recording of facsimile or image intelligence.

A further object of the present invention is to provide for the recording of intelligence presented in electrical form and transduced to record form by use of an electron beam.

A still further object of the present invention is to provide for the reduction of intelligence carried as a modulation of an electron beam in record form.

An additional object of the present invention is to provide for the reduction of intelligence carried as a modulation of an electron beam into record form by xerographic means and methods.

Other objects and advantages of the present invention will become apparent to those skilled in the art from a consideration of the following detailed description of one exemplary specific embodiment of the present invention had in conjunction with the accompanying drawings, wherein:

FIG. 1 is an exemplary presentation of one embodiment of the present invention, showing a radar system in functional block diagram cooperating with an electron beam recorder, illustrated schematically;

FIG. 2 is an enlarged detailed view, partially in section, of the electron beam target used in FIG. 1 and the adjecent image receiving web;

FIG. 3 is an equivalent circuit diagram of the electron beam target and web of FIG. 2; and

FIGS. 4 and 5 are schematic showings of a typical xerographic developing system used in conjunction with the electron beam recorder of the present invention.

As previously indicated, one environment in which it is contemplated that the present invention will find important utility is that of recording intelligence derived from a radar scanning system. So far as the present invention is concerned, the particular radar system, or the particular mode of radar scan, is not material. However, in FIG. 1 there is presented schematically an exemplary embodiment of a recorder embodying the principles of the present invention, in conjunction with a functional block diagram of a generalized radar system.

In FIG. 1, the recorder **10** is shown within a dashed line box being fed intelligence from a radar system. The radar system comprises a transmitter **11**, feeding an antenna **12**. The reflected energy is transmitted by the antenna through the T-R switch **13** to receiver **14**, whose detected output is fed to the recorder **10** through a gating circuit **15**. Timer **16** keyed by the radar transmissions triggers a horizontal sweep circuit **17** for the recorder and the gating circuit **15** to program and synchronize the horizontal sweep sequence of the recorder with the application of the received radar intelligence.

The radar received intelligence and horizontal sweep circuit output are applied from circuits **15** and **17** to the recorder. The recorder comprises a cathode ray tube **21**, whose electron gun and beam control circuits are of conventional design. These include a cathode **22**, control grid **23**, first and second anodes **24** and **25**, electrostatic horizontal deflection plates **26**, electrostatic vertical deflection plates **27**, and intensifying ring **28**, all operated in a conventional manner from a suitable power supply generally indicated as **29**. The output of the radar receiver **14** as passed by the gating circuit **15** is applied to the control grid of the electron gun, and thus controls the electron beam current. The output of the horizontal sweep circuit **17** is applied across the horizontal beam deflection plates **26**, and thus controls the electron beam scan pattern and sequence across the target of the cathode ray tube. It may be mentioned at this time that the vertical beam deflection plates **27** are adjustably set to a selected bias value. The reason for this is, as will become apparent subsequently, that the present recorder operates on only one horizontal line or vertical position for the electron beam.

Considering the general operation of the apparatus thus far described, for each scan cycle of the radar system, the reflected energy denoting that scan cycle is passed by the gate **15** and applied to the control grid **23** of the electron gun in tube **21**. Simultaneously and in timed relation thereto, the electron beam is caused to effect one scan across the tube target, generally denoted by numeral **31**, the vertical deflection plates of the tube being biased to this vertical angle. The intelligence contained in the reflected radar energy, which may for example be in the time of receiving the reflected energy or in the intensity thereof, or both, is utilized to modulate the current in the electron beam of tube **21** through operation of the control grid **23**. Thus, as determined by the radar intelligence, a varying quantity of charge, or a varying charge pattern, is established along the horizontal scan line on the target **31** for each scan cycle of the electron beam. As will be more fully explained subsequently, from this charge pattern applied to the target **31**, a corresponding line of charge pattern is induced on that portion of the web **32** immediately adjacent the target. Thus, as each successive line of intelligence, so to speak, is obtained from the radar system, it is accordingly transduced onto successive lines of the web **32** as the latter is advanced past the target from supply roll **33** to take-up roll **34**. At **35** the electrostatic charge pattern thus induced on web **32** is developed by xerographic means into a visual image, thereby providing a visual facsimile presentation and record of the radar intelligence information, such as the topography scanned by the radar system.

Considering in detail the feature of the present invention whereby the lines of charge pattern are induced onto the web **32**, reference is had primarily to FIG. 2 which is an enlarged detailed view of the cathode ray tube target **31** and the immediately adjacent area of web **32**. The face **46** of the tube **21** is provided with a horizontal narrow slit **45**, preferably not much wider than the electron beam designated by arrows **41**. The electron beam target is formed by covering the slit **45** with a film of high electrical resistance material such as polyethylene terephthalate. The window thus formed should be essentially impervious to the electrons impinging thereon from beam **41**. As illustrated in FIG. 2, electrons from the beam **41** are collected on the inside surface of film or membrane **44**. Immediately opposite and exterior of the window slit **45** and membrane **44** there is positioned a mandrel **43** of electrical conducting material which may be grounded as shown, or have a positive potential applied thereto. A negative potential may also be used in which case the bias acts as a "gate" recording on web **32** only those signals greater than a controlled and predetermined level. Web **32** of dielectric material, such as polyethylene terephthalate aluminized on the surface contacting the mandrel **43**, is passed over the tip of the mandrel **43** in intimate electrical contact therewith. In order to provide uniform spacing between the window film **44** and the web **32** over the extent of the window, the window is formed concave with respect to the outside of the tube **21**, and the tip of mandrel **43** is formed convex with a matching radius of curvature.

The electron charge accumulated on the inner surface of window film **44** sets up an electrostatic field between said inner surface and the mandrel **43**, and when the potential thereof is of a sufficient magnitude, the air in the space **42** between film **44** and web **32** is ionized. The positive ions are attracted to the outside surface of window film **44**, while the negative ions are attracted to web **32**. The resultant electrostatic charge thus induced on any spot on web **32** is a function of the charge present on that portion of the inside surface of window film **44** immediately opposite the spot on web **32** under consideration. Since the charge developed on any particular portion of window film **44** is a function of the electron beam current impinged thereon, and this in turn is a function of the radar intelligence obtained from the radar system, it is apparent that for each cycle of scan along target **31** by beam **41**, a line of intelligence is induced across the web, with the variations of intelligence within that line being denoted by the variations in charge induced thereon.

An equivalent circuit diagram of the foregoing window and pickup web is presented in FIG. 3. V denotes the potential difference between the inside surface of target **31** and the mandrel **43**. C_p is the capacitance of web **32**, the air gap is the spacing **42** between film **44** and web **32**, and C_w is the capacitance of window film **44**. Since the charges accumulated on either surface of the target or window sheet must, for good reproduction of the applied intelligence, be removed before the scanning electron beam returns for its next sweep, each side of C_w (the target) is provided with a high resistance path to ground, which represents the resistance of the window film **44** and the charge dissipation paths for the electrons and ions collected on the surfaces of the window film. When the potential V is high enough, the air in the gap **42** becomes ionized with the consequent formation of equal amounts of positive and negative charge. The charge, Q, either the total negative or the total positive charge produced in this ionization can be expressed as:

$$Q = C_t(V - V_{ab}) = \frac{C_p C_w}{C_p + C_w}(V - V_{ab}) \qquad (1)$$

wherein V_{ab} is the potential required for electrical break-

down of the air gap, C_p is the capacitance of the pickup web **32**, C_w is the capacitance of the window sheet, and C_t is the total capacitance of the system with the air gap **42** broken down electrically.

Considering further the electrical characteristics of the present invention, the potential of charge deposited on the inner surface of the target window **31** may be expressed as

$$E=\frac{Q}{C}=\frac{1}{C}\int idt \qquad (2)$$

where

E is the potential of accumulated charge in volts,
Q is the accumulated charge in coulombs,
C is the capacitance of charge area of target window to ground in farads,
i is the electron beam current in amperes, and
t is the charging time of area involved in seconds.

Also,

$$i=i_o-f(t)i_o \qquad (3)$$

where

i_o is the initial charging current in amperes, and
$f(t)$ is some function of time.

Substituting Equation 3 into Equation 2,

$$E=\frac{i_o}{C}\int[1-f(t)]dt \qquad (4)$$

The function $f(t)$ was determined experimentally for a type 5UP electron gun operated at an acceleration potential of 2400 volts, and found to be

$$f(t)+\frac{2E}{E_{bb}} \qquad (5)$$

where E_{bb} is the acceleration potential in volts. Equation 4 then becomes

$$E=\frac{i_o}{C}\int\left[1-\frac{2E}{E_{bb}}\right]dt \qquad (6)$$

which becomes

$$E=\frac{E_{bb}}{2}\left(1-e-\frac{2i_o t}{CE_{bb}}\right) \qquad (7)$$

when 200 v.$<E<$2000 v.

The capacitance of a 1 mm. diameter charged target window area of a 125μ thick polyethylene terephthalate window spaced 38μ from a 125μ thick polyethylene terephthalate pickup web is about 2×10^{-14} farad. Substituting this value for C in Equation 7, for an acceleration potential of 2400 volts, an initial current of 45μ amperes, and an exposure time of 1μ second gives a window potential of slightly more than 1000 volts. Since about 700 volts are required to break down this air gap, there would result an electrostatic image potential of about 150 volts, which is sufficient for xerographic development.

We have found that in order to obtain a disruption of the air gap and resultant induction of the charge onto the pickup web, for a cylindrically shaped target window and pickup mandrel of the nature herein described, the air gap **42** between the window and pickup web should be in the range of from about 25μ to about 125μ. Therefore, defining the general operational parameters of the present invention, from Equations 3 and 4, the components in the expression

$$\frac{i_o}{C}\int[1-f(t)]dt$$

where

$$f(t)=\frac{i_o-i}{i_o} \qquad \text{(Eq. 3)}$$

must be of such value that the expression shall equal a value greater than approximately 700 volts, and preferably about 1000 volts, when the value of C includes an air gap in the range of from about 25μ to about 125μ.

It was previously mentioned that the cylindrical curvature of the target window and mandrel facilitated close positioning of the pickup web to the target window with good electrical contact between the web and the mandrel. In addition, this configuration enhances the line resolution on the pickup web, because it results in concentrating the charge induced on the web. However, there are practical limitations on making the radius of curvature too small, because a circular electron beam intercepts the cylindrical target surface over an elliptical area in which the charge density at the ends of the major axis of the ellipse are accordingly diminished. Preferably, the radius of curvature of the target window and mandrel should be chosen so that the charge density at the ends of the major axis is not substantially less than 95% of that at the center. This limit to the value of the radius of curvature of the target and mandrel is, of course, a function of the chosen electron beam diameter.

With reference to FIGS. 4 and 5, there is presented the principles of, and an exemplary mechanism for, transducing into visual form the electrostatic image of intelligence induced on web **32** by operation of the electron beam. The thin electrically insulating web **32** drawn from supply roll **33** may be a plastic film, such as polyethylene terephthalate, polystyrene, celluose acetate, ethyl cellulose, or like sheet material of good insulating properties, and preferably of the order of one or two mils thick; or it may be of paper coated on the working surface with one of these plastics, or with a wax; or in some instances thoroughly dry paper or cellophane can be used. As the web **132** is drawn from its roll **33**, it first passes through a preliminary charging device **51**, where the web is brought to a uniform state of electrostatic charge. From the preliminary charger, the web is then passed between the electron beam target of tube **21** adjacent one surface of the web, and the ground mandrel **43** adjacent the opposite surface, where an electrostatic charge pattern depicting the intelligence is induced on the web. The web then enters a development mechanism **35**, where the electrostatic charge pattern on the web is rendered visible by the selective application of a finely divided material, such as electroscopic powder, or a liquid ink, or like material. As the web emerges from the developer, the intelligence carried thereon is visually intelligible. Where a permanent record of the intelligence is desired, the web is then passed to fuser **57**, where the powder is permanently fused to the web, or the ink is dried. As is apparent, if only a transistory presentation of the intelligence is desired, the fuser may be omitted, and instead of a fresh web supply roll, the web may be in the form of an endless belt, with means interposed between the developer **35** and the preliminary charger **51**, on the return side, to clean the intelligence off the web.

The purpose of preliminary charger **51** is to establish over the web a uniform electrostatic charge preparatory to receiving the intelligence charge pattern. Charger **51** comprises a housing within which is located an electrode **52** coated with a radioactive source of ionizing particles, such as a polonium layer, which faces one surface of the web. The opposite surface of the web **15** is contacted by a ground plate **54**, while voltage source **53** as tapped by a potentiometer **55** is connected to the electrode **52**. The potentiometer **55** is center-tapped to ground, and the battery of voltage source **53** is preferably one hundred to several hundred volts. By varying the potentiometer setting, one can thus establish a field of either polarity and of adjustable intensity between electrode **52** and web **32**.

The alpha or other ionizing particles emitted by the radioactive layer on electrode **52** produce ionization of the air in the chamber **51** into negative and positive ions, and these ions migrate in opposite directions, depending on their polarity, under the influence of the electrostatic field existing between electrode **52** and plate **54**. As ions

of one polarity deposit their charge on web 32, the field becomes altered by the charge on the web until a state of equilibrium is reached, in which the potential of the web surface is equal to the potential applied to electrode 52 by the potentiometer. Whether a small positive potential or negative potential is applied to the web, as controlled by the setting of the potentiometer tap, depends on factors subsequently considered. In some instances the electrode 52 may be held at ground potential, in which case the device merely serves to remove incidentally acquired electrostatic charges from the web in preparation for receiving the electrostatic intelligence charge pattern. Instead of a radioactive source of ionizing particles, the electrostatic charges may be supplied by corona emission as disclosed, for example, in U.S. 2,777,957 to L. E. Walkup. With the web 32 thus prepared, it is passed between the electron beam target of the tube 21 and mandrel 43 to receive the intelligence charge pattern, as aforedescribed.

The web 32 carrying the intelligence in electrostatic charge form, passes from intelligence transducing station into the developer 35, shown schematically in FIG. 5. This device comprises a pair of rollers 60 and 65. Roller 60 includes a central bearing shaft 64 carrying a pair of axially spaced disks 62 over which the web edge peripheries pass. Flanges 61 confine the web in place on disks 62. The web and disks 62 thus form a hopper in which a supply of electroscopic powder 63 is contained. It is preferable, although not necessary, that the powder 63 be charged by triboelectric or other means to carry the electrostatic charge opposite from that induced on the web at the transducing station. The powder adheres in the charged areas to produce a visible presentation of the intelligence carried by the web. As the powder 63 is tumbled over the web 32, if the initial preliminary charging of the web at 51 were of a polarity opposite from that at the tube 21, then this background charge on the web would be of the same polarity as the charged powder, and would assist in repelling the developer powder from this background area. After being developed, the web passes from roller 60 up over roller 65, and down into fuser 57. In fuser 57 the web passes about roller 58 where it is heated to a temperature sufficient to fuse the developer powder to the web, or, if ink were used as the developer, to dry the ink thereon, thus forming a permanent visual and directly readable record of the intelligence transduced at tube 21. The web may then pass between suitable drive rolls such as 80.

The described method of rendering the pattern of electrostatic charges visible, i.e., developing the image, is known as "loop" development. This system is disclosed in U.S. 2,761,416 to C. F. Carlson. The method of development is not critical in the instant invention and other methods for contacting electrostatically charged marking particles with the electrostatic image may be used. Thus a spray of electrostatically charged liquid droplets or dry powder particles, as disclosed in U.S. 2,784,109 to L. E. Walkup may be used for magnetic brush development described in U.S. 2,791,949 to Simmons and Saul are all operable. A powder cloud development apparatus particularly suited for use as developer 35 in the present system is the device known as a slot development apparatus more particularly described in U.S. 2,815,734 to C. F. Carlson. Devices such as that described in said U.S. 2,815,734 have been made wherein the development system is limited to ¼ inch, thereby making possible almost instantaneous viewing of the developed image. The choice of a particular developing process or apparatus would obviously be dependent on the combination and design limitations imposed in assembling the machine for a particular operation.

Similarly, the means of permanently affixing the powder image to the backing material is not critical in the instant invention. Thus, if no permanent image is desired, after examination of the roll, the loosely adhering powder image may be wiped off as by swabbing with cotton or a rapidly rotating fur brush and the roll reused. If a permanent record is desired, the powder particles may be rendered adherent to the backing material by heating, as previously disclosed herein, or by contacting the powder-bearing sheet with the vapors of a solvent for the marking particles or for a resin coating on the image receiving member as disclosed for example in U.S. 2,776,907 to C. F. Carlson. Where liquid droplets are used, absorption of the liquid into the capillaries of the backing member or an evaporation of the liquid would serve to affix the image to the image receiving sheet. Other means of affixing the powder image, as by the use of pressure, by spraying with a fixative lacquer, etc., also may be used if desired. If desired the powder image may be transferred as from dielectric web 32 to an image support member as paper and affixed thereto with web 32 being cleaned and recycled in the image-forming process.

Several means have been suggested in the prior art for direct recording with an electron beam. In general these processes used a "pin" tube or a Lenard window. Apparatus according to the instant invention offers enhanced simplicity of construction as compared to the complex pin matrix of the "pin" tube and the continuous pumping of the cathode ray tube inherent in the Lenard window. (In the Lenard window the membrane is thin enough so that the electron beam passes through the "window." "Windows" which are pervious to electron beams are also pervious to air.) In addition the Lenard window entails very high accelerating voltages in the cathode ray tube and generally has poor resolution due to scattering of the electron beam by the "window." Furthermore, the prior art has not recognized the various parameters whose control is essential for dependable operation with high resolution. Thus, in the instant invention for the first time there are disclosed means whereby the electrostatic image forming process may be accurately controlled for dependable operation with high resolution to thereby directly record intelligence with an electron beam.

From the foregoing detailed exemplary description of the present invention, it will be appreciated that there is presented a method and means for recording electrically transmitted intelligence, utilizing an electron beam as the means of transducing the electrical form of intelligence onto record form, in such manner as the record may be rendered visual and permanent, if desired, by usual xerographic techniques. Although the present recording technique has been illustrated in conjunction with a radar system for sensing and presenting the intelligence to be recorded, such is presented only as exemplary of one field of use for the present invention. As will be apparent to those skilled in the art, the present invention may be utilized generally in the field of recording, and it is not intended that the foregoing description shall be interpreted as limiting the scope of the present invention to radar. Also, other variations, modifications and adaptations of the present invention will be apparent to those skilled in the art, and such as come within the spirit and scope of the appended claims are considered to be embraced by the present invention.

I claim:

1. An electron beam recorder comprising a sealed and evacuated cathode ray tube having an electron gun for generating an electron beam and an electron beam target area, said target area having a narrow elongated slit therein, a thin air impervious membrane covering said slit, said membrane being of uniform and continuous electrical properties and being of high electrical resistance and substantially impervious to electrons from said beam, and an electrically conducting mandrel adjacent said membrane but spaced therefrom and adapted to support a web of insulating material in spaced relation to said membrane, said mandrel, being in electrical circuit with

said gun, whereby said web and mandrel are in capacitive relation to said membrane, and a charge established on said membrane by scanning thereof by said beam will disrupt the air between said membrane and web and thereby induce a line of electrostatic charge on said web in accordance with the electron charge carried by said membrane.

2. An electron beam recorder as set forth in claim 1, wherein said membrane is concave from the exterior of said tube, and said mandrel is convex with a radius of curvature substantially equal to that of said membrane.

3. An electron beam recorder as set forth in claim 2, wherein the spacing between said mandrel and membrane is chosen to provide an air gap between said web and

window of from approximately 25 to approximately 125 microns.

4. An electron beam recorder as set forth in claim 3, wherein the width of said slit is approximately equal to the diameter of the electron beam.

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