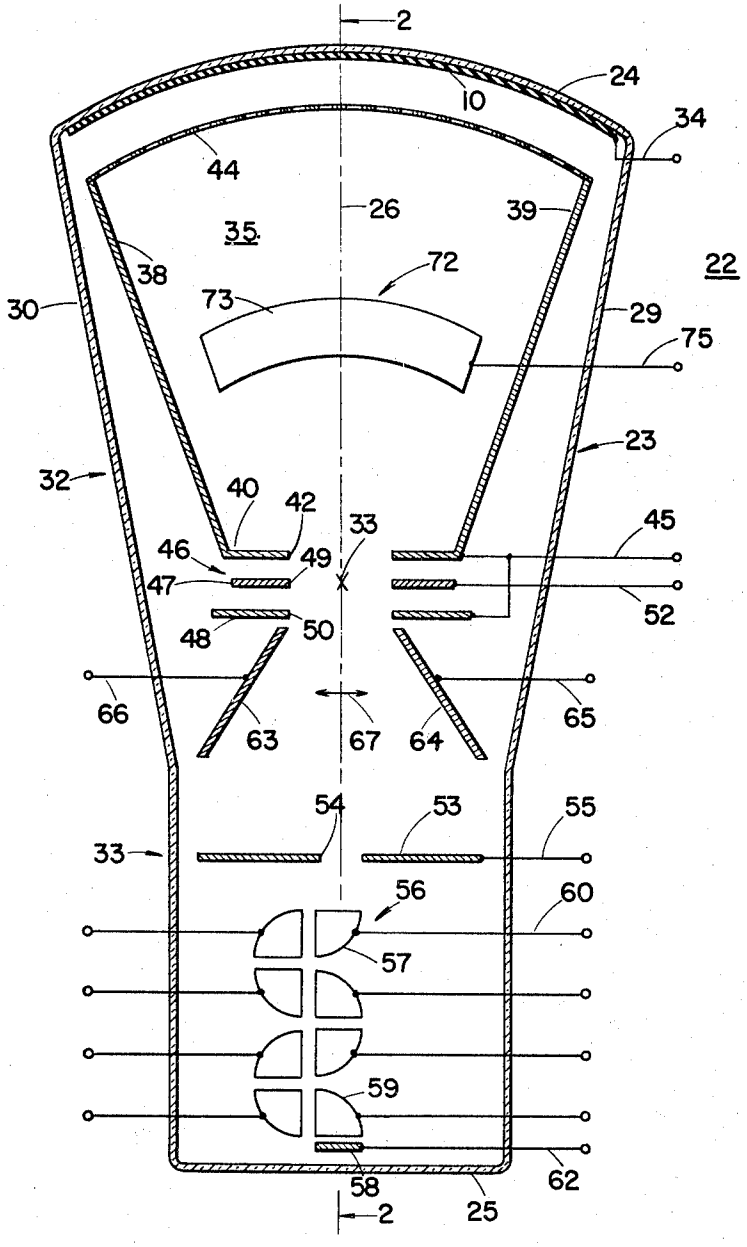
July 2, 1968 R. H. CLAYTON 3,391,295

ELECTRON SYSTEM FOR CONVERGENCE OF ELECTRONS FROM PHOTOCATHODE HAVING CURVATURE IN A SINGLE PLANE

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FIG. 1



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FIG. 2

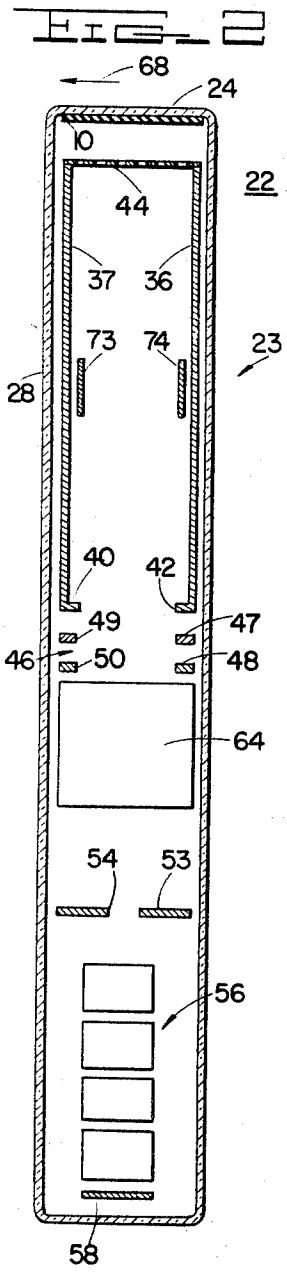


FIG. 3

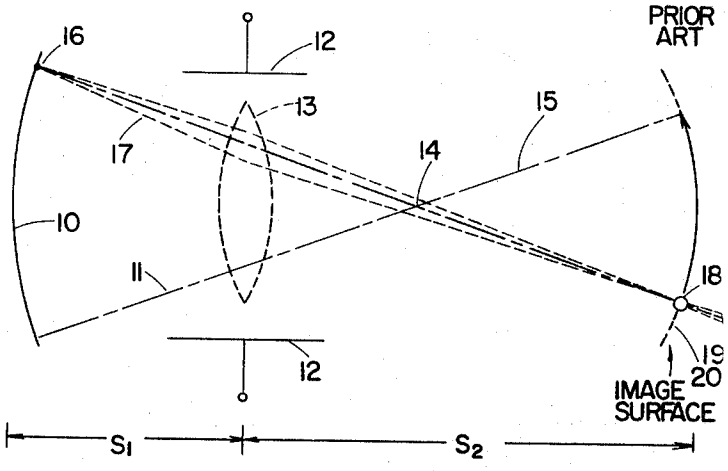


FIG. 4

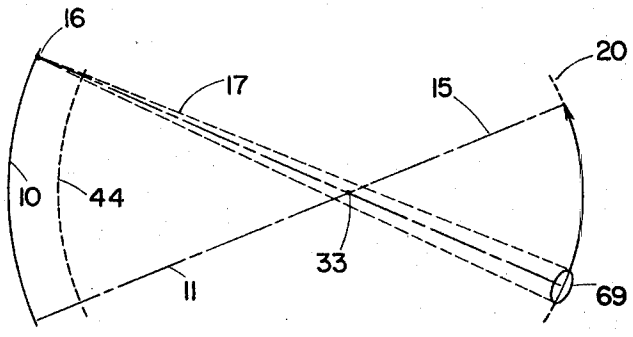
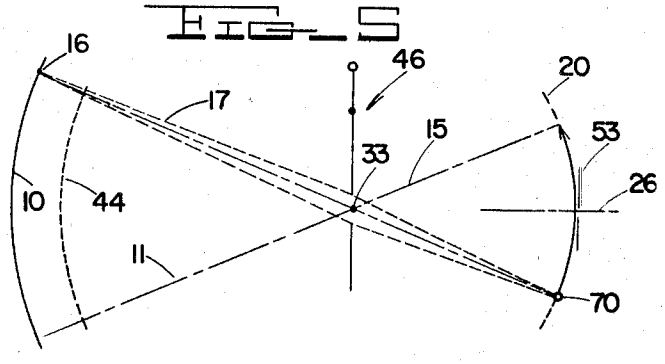


FIG. 5



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ELECTRON SYSTEM FOR CONVERGENCE OF ELECTRONS FROM PHOTOCATHODE HAVING CURVATURE IN A SINGLE PLANE

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ABSTRACT OF THE DISCLOSURE

An image tube is provided with an electron lens at the cross-over point of the total electron beam so that incremental electron rays are converged and focused for optimum spot resolution without affecting the magnification of the total beam. A photocathode and accelerating mesh and a flat longitudinal drift electrode enclosing the beam provide convergence of the total beam. Deflection plates, a scanning aperture and an electron multiplier are employed in an image dissector configuration.

This invention relates generally to phototubes and more particularly to an image dissector tube.

A conventional image dissector tube comprises a photocathode for emitting an electron beam in response to incident radiation, the beam being area-modulated to provide an electron image in response to an incident radiation image. In all electrostatic versions, the beam is accelerated by an accelerating electrostatic field and electrostatically focused, and is deflected over a defining aperture. The electrons which pass through the aperture being received by target electrode means, typically an electron multiplier, thereby providing a time-based video output signal. In such conventional image dissector tubes, a distributed electrostatic lens is provided which causes the beam to converge to a cross-over point and thereafter diverge. The initial electron emission from the surface of the photocathode includes tangential components and in conventional electrostatically focused tubes, the distributed focusing field provides convergence of these tangential components over the entire trajectory of the beam.

The electrons emitted from an incremental spot on the surface of the photocathode can be considered to be a ray or bundle of electrons and thus in conventional electrostatically focused tubes, both the entire beam and the individual incremental rays or budles forming the beam are focused by the distributed electrostatic lens system. In such tubes, however, the condition of optimum focus of the electron image is established by the location of the minimum circle of confusion of the reconverged incremental rays or bundles of electrons, i.e., the minimum sized spot provided on the image surface in response to emission from an incremental spot on the photocathode surface. In the reconvergence of the incremental rays or electron bundles, the distributed electrostatic lens system has its principal plane somewhere between the cathode and anode, generally approximately midway therebetween. Thus, in order to obtain the minimum circle of confusion of the reconverged incremental rays or electron bundles at the image surface, i.e., optimum spot resolution, an image distance is provided which is large compared with the object distance, which in turn results in relatively large magnification and poor resolution. In most optical systems, reduction in the magnification ratio results in improvement in resolution. However, in such conventional tubes, the distributed electrostatic lens system provides convergence of the incremental rays or electron bundles at a minimum circle of confusion point spaced from the point of convergence and divergence of the total beam,

i.e., the cross-over, and thus an effort to reduce the magnification results also in increasing the spot size of the incremental rays or electron bundles thus deteriorating the resolution.

It will thus be observed that in conventional electrostatically focused image tubes, there have been two conflicting requirements, i.e., magnification of the total image and spot resolution, optimum spot resolution, however, determining overall magnification. It is therefore desirable to provide a phototube, i.e., a multiplier phototube, image dissector or image converter, in which magnification of the image is determined independently of spot resolution.

In addition to the foregoing, there are applications for a camera tube which scans in only one direction, relative motion in the other direction between the camera tube and the optical image being viewed providing frame scanning. It is also at times desirable to provide such a camera tube which will accommodate an extended image in the scanning direction, i.e., a relatively long line. It may further be desirable in applications for such tubes to employ a reflection optical system, i.e. folded optics by reason of the greater light gathering power and reduced weight of such systems with respect to reflective optical systems of comparable performance. In the case of such folded optical systems, it is further desirable to limit the volume of the camera tube and especially the head-on cross-sectional area. In a simple folded optical system, the camera tube obstructs a part of the incident light, and thus a tube having a smaller head-on cross-sectional area, in a plane perpendicular to its axis, increases the effective aperture of the optical system. While double folded optical systems, such as the Cassegrainian system can overcome obstruction by the camera tube, in many applications where a wide field of view is desired in the optical system, the focal length is too short in such a double folded system. It is therefore desirable to provide a flattened camera tube which will accordingly receive more light from a simple folded optical system.

It is further desirable in camera tube applications of the type discussed above to employ a multiplier-type tube, such tubes having a dynamic range exceeding other types of camera tubes, i.e., its signal output is linear over a more extended range as a function of the incident light intensity. Of all presently existing camera tubes, the image dissector with photomultiplier output is the only one in which the detectivity is limited only by the photoelectron statistics; the capability of an image dissector to detect emitted electrons terminates only when the number of electrons emitted per band width increment becomes statistically indistinct. Furthermore, an image dissector is not an integrating device such as the image orthicon and vidicon tubes, and thus the absence of integration permits changing of the scanning rate at will.

It is therefore desirable to provide an image dissector tube of the photomultiplier type adapted for line scanning and having a flat configuration to provide minimum head-on cross-sectional area, and it is further desirable that such a tube be capable of minimum magnification with optimum resolution, the spot resolution being independent of the magnification is aforesaid.

It is accordingly an object of the invention to provide an improved phototube.

Another object of the invention is to provide an improved phototube in which spot resolution is independent of magnification.

A further object of the invention is to provide a line scanning image dissector tube.

Yet another object of the invention is to provide a line-scanning image dissector tube having minimum head-on cross-sectional area and spot resolution independent of magnification.

In accordance with the broader aspects of the invention, a phototube is provided comprising photocathode means for emitting an electron beam in response to incident radiation. First electrode means is provided spaced from the photocathode means for accelerating the electrons of the beam and second electrode means is provided cooperating with the first electrode means for providing a field-free electron drift space. In accordance with the invention, the photocathode means and the accelerating electrode means are cooperatively arranged to provide a field for converging the beam to a cross-over point spaced from the drift space, the beam thereafter diverging from the cross-over point. Electron lens means is provided adjacent the cross-over point for reconverging the electrons of the beam having initial velocities tangential to the surface of the photocathode means. The electron lens means adjacent the cross-over point of the total or gross beam thus focuses the incremental electron rays or bundles to provide optimum spot resolution independently of magnification of the total beam.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic cross-sectional view of a line scan image dissector tube incorporating the invention;

FIG. 2 is a schematic cross-sectional view of the tube of FIG. 1 taken along the line 2—2 thereof;

FIG. 3 is a diagram showing beam focusing in conventional prior image tubes and useful in explaining the invention; and

FIGS. 4 and 5 are diagrams showing the focusing system of the present invention and useful in explaining the same.

Referring now briefly to FIG. 3, a photocathode **10** is shown emitting an electron beam **11** in response to incident radiation, the beam **11** being accelerated by conventional accelerating electrodes, shown schematically at **12** as being a single electrode, but commonly comprising several electrodes coupled to different potentials, provide a distributed electrostatic focusing field which can be said to form an electrostatic lens shown in dashed lines **13**, which converges the total or gross electron beam **11** to a cross-over point **14**, the total beam thereafter diverging as at **15**. Considering now a single incremental illuminated spot **16** on the surface of the photocathode **10**, the electrons emitted from the spot **16** can be considered to be a ray or bundle of electrons **17**, these rays or bundles of electrons forming the total electron beam **11**. Electrons are emitted from the spot **16** on the photocathode **10** in something approaching a cosine squared density distribution, and thus there are electrons which are emitted tangentially from the spot **16**. The distributed electrostatic lens system **12** of the conventional tube reconverges these tangential electrons of each incremental ray, thus converging the incremental ray or bundle of electrons **17** to a circle of minimum confusion **18** after which the ray diverges again, as at **19**. It is thus seen that the cross-over point or point of minimum circle of confusion **18** of the incremental ray or bundle of electrons **17**, which establishes the condition of optimum focus and thus the image surface **20**, is not the same as the cross-over point **14** of the total or gross beam **11**. It is further seen that, under this condition, the image distance S_2 is relatively great compared with the object distance S_1, the magnification ratio being proportional to S_2/S_1.

It will now be seen that merely moving the image surface **20** toward the photocathode **10**, while reducing the magnification, will result in deterioration of the spot focus of the incremental ray **17** since the circle of confusion **18** will become larger. Finally, it will be seen that the magnification and spot resolutions are interdependent, any adjustment of the electrostatic focusing system affecting both the magnification and the spot resolution.

Referring now to FIGS. 1 and 2 of the drawing, there is shown the flat line scan image dissector tube of the invention, generally indicated at **22**, comprising an enclosing envelope **23** having opposite ends **24**, **25** and a major axis **26**. Envelope **23** is formed of suitable insulating material, such as glass, and end **24** is the faceplate of the tube and is transparent to the incident radiation of the wavelength which the tube is intended to detect. Envelope **23** has flat parallel top and bottom walls **27**, **28** and side walls **29**, **30** which define a funnel portion **32** and a neck portion **33**, the faceplate **24** thus being wider than the end **25**. In accordance with the invention, faceplate **24** is formed as a section of a cylinder having its radius of curvature extending from axis or center of curvature **33** which is on the longitudinal axis **26** of the envelope **23** normal to the top and bottom walls **27**, **28**. Photocathode **10** is deposited in any conventional manner on the inner surface of the faceplate **24** and may, in accordance with conventional practice, have a transparent conductive coating deposited thereon to which an external lead **34** is coupled.

A tunnel electrode assembly **35** is provided comprising spaced, parallel, flat top and bottom walls **36**, **37** respectively parallel with the top and bottom envelope walls **27**, **28**, and contained within side walls **38**, **39** which respectively converge toward envelope end **25**. Tunnel electrode **35** has a rear end wall **40** with a central aperture **42** therein symmetrically disposed on the major axis **26** of the envelope **23**. A fine mesh conductive screen **44** extends across the front end of the tunnel electrode **35** being connected to the top and bottom walls **36**, **37**, and the side walls **38** and **39**, mesh **44** likewise forming a section of a cylinder having its radius of curvature extending from axis **33**. Mesh **44** is thus uniformly equally spaced from faceplate **24** and the photocathode **10**. Tunnel electrode **5** has external lead **45** connected thereto, and thus when appropriate potentials are applied to the photocathode lead **34** and the tunnel electrode lead **45**, an accelerating field is provided by the mesh **44** to accelerate the electrons emitted by the photocathode **10** in response to incident radiation toward end **25** of envelope **23**.

Mesh **44** top and bottom walls **36**, **37**, side walls **38**, **39** and end wall **40** of tunnel electrode **35**, all being connected to external lead **45** and thus to the same source of potential, provide a field-free drift space for the electrons emitted by photocathode **10** and initially accelerated by the accelerating field provided between the mesh **44** and the photocathode **10**. It will now be seen that by reason of the curvature of photocathode **10** and mesh **44** about axis **33**, the total or gross electron beam **11** emitted by the photocathode **10** will be converged to axis **33** as the cross-over point, the beam diverging again beyond axis **33** as shown in FIG. 4 at **15**. It will further be seen that by reason of the forming of the photocathode **10** and mesh **44** as segments of concentric cylinders, the electron beam **11** is emitted in planes parallel to the top and bottom walls **27**, **28** and converged in those parallel planes.

An einzel lens **46** is provided at the axis **33**, einzel lens **46** comprising plates **40**, **47** and **48** having apertures **42**, **49** and **50** therein symmetrical about the major axis **26** of the envelope **23**, and the end wall **40** of the tunnel electrode **35**. The central apertured plate **47** of the einzel lens **46** is connected to external lead **52** while plates **40**, **48** are connected to external lead **45**.

Plate electrode **53** is provided having a beam-defining aperture **54** therein symmetrically disposed on axis **26** of the envelope **23**, plate **53** being connected to external lead **55**. A conventional photomultiplier **56** is provided between the apertured plate **53** and the end wall **25** of envelope **23**, photomultiplier **56** having its initial stage **57** facing aperture **54** and having target electrode **58** asso-

ciated with the final multiplier stage **59**. The successive stages of the photomultiplier **56** are coupled to leads **60** which are adapted to be connected to progressively higher voltages by an internal or external voltage divider in accordance with conventional practice. The target or output electrode **58** is connected to external lead **62**, which in turn is adapted to be connected to a video signal output circuit in accordance with conventional practice.

A pair of line deflecting electrodes **63**, **64** are positioned between the einzel lens **46** and the apertured plate member **53** and are respectively connected to external leads **65**, **66** which are adapted to be connected to a suitable source of deflection voltage in accordance with conventional practice. Line deflection electrodes **63**, **64** deflect the divergent beam **15** in planes parallel with the top and bottom wall **27**, **28** of envelope **23** across the aperture **54** in the plate member **53** with the electron beam passing through the aperture **54** being multiplied by the photomultiplier **56** and generating a time-based video signal, as is well known to those skilled in the art. Line deflection plates **63**, **64**, thus provide line scanning in the direction shown by the arrows **67** in FIG. 1 and it will be understood that frame scanning is provided by relative motion of the light image across the tube **22** in a direction at right angles to the direction **67** of line scanning, as shown by the arrow **68** in FIG. 2.

Referring now again to FIG. 4, while the arcuate electrostatic field provided between mesh **44** and photocathode **10** converges the total or gross electron beam **11** to form a cross-over at axis **33**, which is the coincident center of curvature of photocathode **10** and mesh **44**, this field does not reconverge electrons with initial velocities tangential to the surface of photocathode **10**. Thus, even though the main beam **11** is converged at axis **33**, the incremental rays or bundles of electrons **17** emitted from incremental illuminated spot **16** on the surface of the photocathode **10** continue to diverge, as shown in FIG. 4. Thus, unless means are provided for reconverging the incremental rays or bundles of electrons forming the main beam **11**, **15**, the resulting spot **69** on any chosen image surface **20** would inherently be larger than the spot **16** on the photocathode **10**, thus providing inherently poor resolution.

Referring now to FIG. 5, since the incremental rays or bundles of electrons **17** have not been converged by the field established by the mesh **44** and photocathode **10**, it becomes possible to locate an electrostatic lens **46** at the cross-over point **33** of the main beam **11** for focusing the incremental rays **17**. Lens **46**, being at the cross-over point **33** of the main beam **11** thus does not affect the convergence and divergence of the main beam **11**, **15** but does reconverge the incremental rays **17** through a minimum circle of confusion spot **70** on the image surface **20**. It will be seen that the reconvergent field provided by the electrostatic lens **46** may be suitably adjusted to determine the location of the minimum circle of confusion spot **70** substantially independently of the magnification provided by a field established by mesh **44** and photocathode **10**. Thus, if the magnification provided at the point of optimum spot resolution **70** is too great or too small, the magnification can be adjusted to the desired ratio by adjustment of the field provided by mesh **44** and photocathode **10**, or, alternatively, if with the desired magnification ratio the spot resolution is not optimum, it can be optimized by adjustment of the focusing field provided by lens **46**.

It will be readily seen that other types of electrostatic lenses well known to those skilled in the art may be employed for the ray reconverging lens **46**, such as a bipotential lens or a magnetic short lens. It will be readily seen that, in the case of an image dissector, the apertured plate **53** is preferably positioned immediately adjacent intersection of the image surface **20** with the major axis **26** of the envelope **23**.

It will now be seen that the geometry of the mesh **44** and photocathode **10** in conjunction with the location of the image surface **20**, i.e., aperture plate **53**, determines the image focus or divergence, i.e., the magnification, while spot resolution of the incremental rays **17** is provided by the central lens **46** which brings the incremental rays or electron bundles **17** into optimum focus at the image surface **20**.

It will be observed, by reference to FIG. 2, that the photocathode **10** is flat along any radius extending from axis **33**, whereas it is curved in any plane parallel to the top and bottom walls **27**, **28** of the envelope **23**. Thus, an inherent astigmatic condition is provided since the initial divergence due to the tangential electron velocities is reduced to a greater extent by the electron field provided by photocathode **10** and mesh **44** in the planes including the curvature than in planes which do not include the curvature. This condition can be corrected by an astigmatism correcting lens or by providing the center lens **46** with one or more of the elements having an elliptical or rectangular aperture. In the embodiment illustrated in FIGS. 1 and 2, an astigmatism lens **72** is provided comprising electrodes **73**, **74** located within the tunnel electrode **35** and respectively parallel to the top and bottom walls **36**, **37** thereof, electrodes **73**, **74** being respectively arcuate with radii of curvature extending from the axis **33**. Astigmatism correction electrodes **73**, **74** are respectively connected to external leads **75**. When connected to appropriate potentials, the electrodes **73**, **74** form an astigmatism lens which tends to converge both the main beam **11** and the incremental bundles **17** therein in planes normal to the top and bottom walls **27**, **28** of the envelope **23** in the manner of a conventional electrostatic lens.

It will be readily apparent that the invention is not restricted to electrostatic deflection, and that a conventional magnetic deflection yoke may be substituted for the deflection plates **63**, **64**. It will further be seen that the electrostatic focusing system of the invention is not restricted to an image dissector tube, but also may be employed in a multiplier phototube or image converter tube.

While there have been described above the principles of this invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of this invention.

What is claimed is:

1. A phototube comprising: photocathode means at one end of said tube for emitting an electron beam in response to incident radiation; first electrode means spaced from and parallel to said photocathode means for accelerating the electrons of said beam; second electrode means cooperating with said first electrode means and extending axially along and around said beam for providing a field-free electron drift space; said photocathode means and said first electrode means being cooperatively curved to provide a field for converging said beam in one plane to a cross-over point spaced from said drift space, said beam thereafter diverging from said cross-over point; electron lens means positioned at said cross-over point for reconverging and focusing incremental electron rays of said beam onto an image area toward the other end of said tube without affecting the total electron beam and means for converging said beam and incremental rays in a plane normal to said one plane.

2. The tube of claim **1** wherein said first electrode means comprises a conductive screen electrode and said second electrode means comprises a conductive tunnel electrode having parallel top and bottom walls and side walls converging from said photocathode end toward said cross-over point, said screen being connected to the end of said tunnel electrode adjacent said photocathode and closing the same.

3. The tube of claim **1** wherein said photocathode means and first electrode means are respectively curved

with radii of curvature extending from said cross-over point.

4. The tube of claim 1 wherein said lens is an einzel lens.

5. The tube of claim 1 further comprising apertured scanning electrode means adjacent said image area target electrode means adjacent said apertured electrode means, and beam deflection means between said lens means and apertured electrode means for deflecting the beam over the aperture in said apertured electrode means thereby providing an image dissector tube.

6. The tube of claim 1 further comprising an evacuated enclosing envelope having opposite ends, one of said ends being a faceplate transparent to said radiation; said photocathode means being deposited on the inner surface of said faceplate; said first electrode means comprising a conductive screen spaced from said faceplate toward the other end of said envelope; said second electrode means comprising a conductive tunnel electrode having opposite ends with one end connected to and closed by said screen; said tunnel electrode extending toward said other envelope end and having parallel top and bottom walls and side walls converging from said photocathode end toward said cross-over point; said faceplate and screen being curved about radii of curvature extending from said cross-over point; said cross-over point being spaced from the other end of said tunnel electrode toward said other envelope end; said beam and incremental rays being converged in a plane normal to said top and bottom walls onto said image area; an apertured electrode adjacent said image area; electron multiplier means on the side of the aperture in said apertured member toward said other envelope end; and beam deflection means between said lens means and apertured electrode for deflecting the beam over said aperture thereby providing an image dissector tube.

7. The tube of claim 1 wherein said photocathode means and first electrode means respectively are formed as segments of concentric cylinders having radii of curvature extending from said cross-over point; said cross-over point being the axis of said cylinders whereby said convergence and divergence of said beam is essentially in planes normal to said axis.

8. The tube of claim 1 wherein said means for converging said beam and incremental rays in a plane normal to said one plane comprises electrode means in said drift space parallel with said one plane.

9. The tube of claim 1 further comprising an evacuated enclosing envelope having a longitudinal axis, opposite ends and generally flat parallel top and bottom walls, one of said ends being a faceplate transparent to said radiation; said photocathode being deposited on the inner surface of said faceplate; said first electrode means comprising a conductive screen spaced from said faceplate; said faceplate and screen being respectively formed as segments of concentric cylinders having radii of curvature extending from said cross-over point; said cross-over point being the axis of said cylinders whereby said convergence and divergence of said beam is in planes essentially normal to said cylinder axis; said cylinder axis being normal to said top and bottom sides and on said envelope axis; said second electrode means comprising a tunnel electrode having opposite ends and generally flat top and bottom walls respectively parallel with said envelope top and bottom walls; said screen being connected to and closing one of said tunnel electrode ends; said tunnel electrode extending toward said other envelope end and having an apertured end wall at its other end, the aperture in said end wall being on said envelope axis; said cross-over point being spaced from said apertured end wall toward said other envelope end; said tunnel electrode having side walls converging from said one end to said apertured end wall; an apertured scanning plate adjacent said image area in a plane normal to said envelope axis and to said top and bottom walls; the aperture in said plate being on said envelope axis; electron multiplier means on the side of said last-named aperture toward said other envelope end; and beam deflection means between said lens means and said apertured plate for deflecting said diverging beam in directions at right angles to said cylinder axis over said last-named aperture thereby providing an image dissector tube with scanning in one direction.

10. The tube of claim 9 wherein siad lens means is an einzel lens.

11. The tube of claim 9 wherein said means for converging said beam and incremental rays comprises a pair of electrodes in said tunnel electrode respectively parallel with said top and bottom walls thereof; said pair of electrodes being respectively arcuate with radii of curavture extending from said cylinder axis.

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