Jan. 24, 1967 W. F. NIKLAS 3,300,668

IMAGE CONVERTER TUBE

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FIG. 1

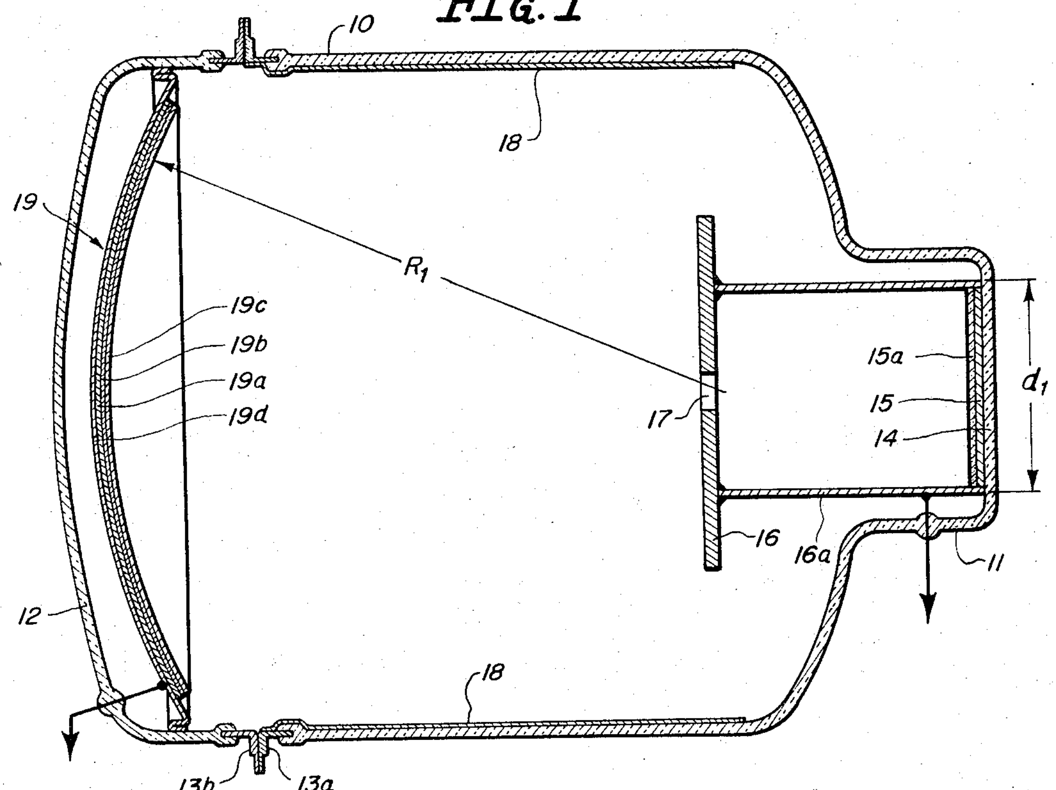

FIG. 2
(PRIOR ART)

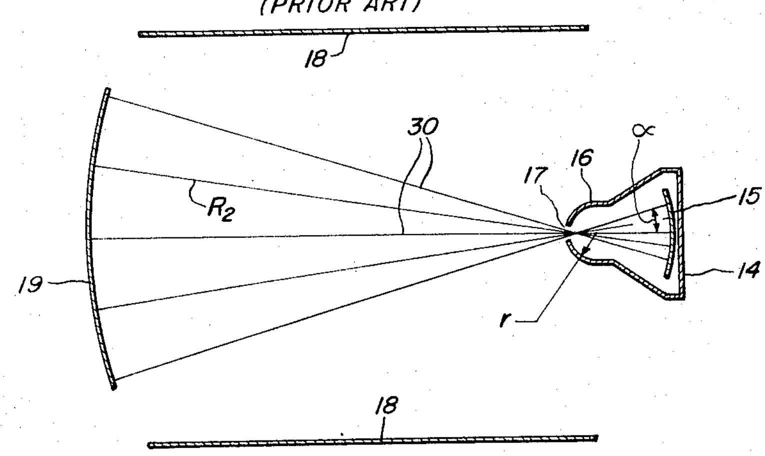

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IMAGE CONVERTER TUBE

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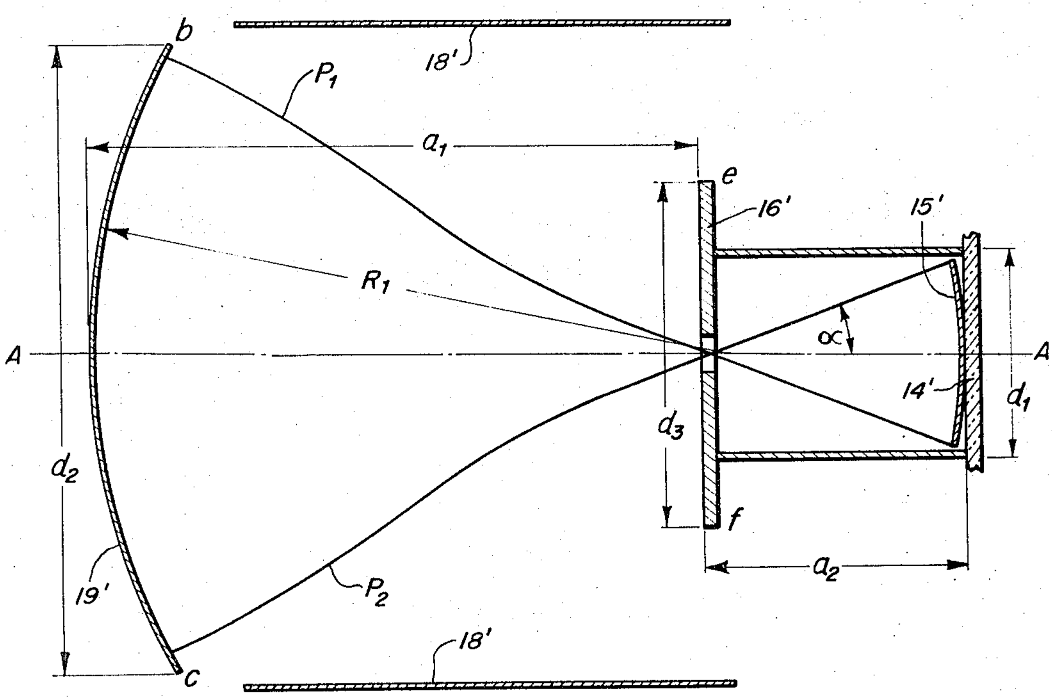

FIG. 3

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IMAGE CONVERTER TUBE

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4 Claims. (Cl. 313—65)

This invention pertains to the construction of image converters and is especially directed to the structure of an image converter which produces visible images of good resolution and larger size than heretofore obtained.

As previously constructed, an image converter comprises a photo-emissive cathode which is responsive to incident radiation to develop an electron image for projection upon a viewing screen. Following the cathode in the direction of the image screen is a cylindrical focussing electrode having a diameter approximately the same as the diameter of the cathode. An anode is provided, spaced from the cathode beyond the focus electrode, and quite small in diameter compared with the cathode. The anode is disposed across the tube axis and has a central aperture through which electrons which have been emitted, accelerated and focussed in the electron-optical system of the converter pass to impact a fluorescent target positioned beyond the anode on the opposite side from the cathode and serving as the viewing screen. The cathode and the leading portion of the anode are formed as concentric spherical sections of generally uniform radius and the focussing field which they establish is also generally uniform in space between cathode and anode.

Experience has shown that only very small images may be obtained with image converters of this construction. Actually, the demagnification is related to the ratio of cathode radius and anode radius and usually is in the range from 7 to 12. Because the image is of small size only relatively low resolution is obtained. In addition, small images require light optical systems for comfortable viewing, which among other disadvantages, generally show a high degree of "directionality" and permit no more than one observer to view the image at any given time.

It is an object of this invention, therefore, to provide a new and improved image converter tube which avoids or minimizes the aforedescribed difficulties of prior devices.

It is a particular object of the invention to provide a novel image converter tube producing a visible image of relatively large size.

Another specific object of the invention is to provide a novel image converter producing an enlarged image with improved resolution.

Still another object of this invention is to provide an image converter tube permitting the observation of the visible image by more than one observer at any one time.

The invention is concerned generally with an image converter tube of the type having an input element, responsive to a received radiation pattern for developing an electron image, and an output element, responsive to the received electron image as propagated from the input to the output element along a reference optical axis of the tube and focused on the output element, for providing a visible image constituting a replica of the radiation pattern and further of the type making use of the known electron optical lens characteristics of concentric spheres and propagating and focusing the electron image thereby inherently requiring a given axial length from input element to output element for a given low-order minification. Specifically, the invention is directed to an improved electron optical system for a tube of the foregoing type and given minification which system requires an axial length from input to output element substantially less than the aforesaid given length. In accordance with the invention, the improved electron optical system consists essentially of a photoemissive cathode constituting the input

element and disposed transversely and coaxially of the reference axis and responsive to the radiation pattern for developing an electron image, the cathode having the configuration of an approximately spherical section of an effective radius R_1. The viewing screen, constituting the output element of the tube, is spaced from the cathode and is disposed transversely and coaxially of the reference axis; the viewing screen has a diameter d_1. A planar anode, disposed transversely and coaxially of the reference axis between the cathode and the viewing screen has a predetermined axial spacing from the cathode of less than $2R_1$ but greater than $.75R_1$. A centrally located aperture in the anode for admitting the electron image has a transverse dimension within the range from d_1 to $2R_1$. The spherical cathode and planar anode together form the primary electron image propagating and focusing arrangement of the tube, the electron focusing action of this arrangement being more strongly convergent in the region of the spherical cathode and less convergent in the vicinity of the planar anode than in the case of a concentric spherical anode-spherical cathode electron optical system of like axial spacing, the net effect of the focusing action of the arrangement being equivalent to a spherical anode-spherical cathode system of an axial spacing substantially greater than the aforesaid predetermined axial spacing. Also included are secondary focus electrode means interposed between the planar anode and the photoemissive cathode and comprising at least one cylindrical electrode, the secondary focus electrode means being electrically separate from the anode and cathode and having a minimum diameter of at least as great as the diameter of the anode.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood, however, by reference to the following description taken in connection with the accompanying drawings in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is a cross-sectional view of an image converter embodying the present invention.

FIGURE 2 is a schematic representation of the electron-optical system of an image converter of the prior art, and

FIGURE 3 is a schematic representation of the electron-optical system of an image converter embodying this invention.

The image converter represented in FIGURE 1 comprises a glass envelope having a substantially cylindrical section **10** terminated in an end portion **11** of smaller diameter and a substantially spherical section **12** of a diameter approximately equal to that of section **10**. Envelope sections **10** and **12** are presealed around their entire perimeters to respective metal flanges **13***a* and **13***b* which, in turn, are sealed together by heliarc welding or the like after the two envelope sections **10** and **12** have been separately processed.

The smaller diameter end section **11** of the tube is closed by a flat glass plate **14** on the inside of which is provided a suitable fluorescent viewing screen **15** of silver activated zinc-cadmium sulfide or the like. This screen has a predetermined diameter d_1 on which a visible image is to be displaced in response to an image of invisible radiations incident on the cathode structure of the tube. As will be explained hereafter, the size of the visible image is decidedly larger than that usually obtained with prior image converters of the same physical size. Screen **15** is preferably aluminized or otherwise provided with a conductive metallic backing layer **15***a* sufficiently thin to be pervious to electrons accelerated to and focussed upon screen **15** by the electron-optical system of the tube.

The electron-optical system includes a photosensitive cathode structure **19** which is generally referred to in the art as a composite multi-layer pick-up screen and serves to develop an electron image in response to incident invisible radiations, such as X-rays. This cathode structure is suitably mounted within envelope section **12** and is generally spherical, in configuration, having a radius R_1. It is positioned transversely of and substantially coaxial of the axis of the tube which corresponds with the axis of the electron-optical path along which electrons emitted from the cathode are projected towards viewing screen **15**. The cathode structure comprises a support or base member **19*d*** which is transparent to the incident invisible radiations to which the image converter is intended to respond. While devices of this type may be constructed selectively to respond to invisible radiations of different wavelengths, the device illustrated will be assumed to be an X-ray image intensifier and therefore the end-portion of envelope section **12** as well as cathode base member **19*d*** will be constructed of material that is transparent to X-rays. The envelope section may of course be of glass and support **19*d*** may be formed of aluminum but its thickness is selected to provide the required rigidity for the structure; otherwise the thickness should be of minimal dimension to increase the sensitivity of the device to incident radiation.

An X-ray sensitive phosphor layer **19*a*** such as silver activated zinc sulfide embedded in a suitable silicone resin is disposed directly upon supporting member **19*d***. A barrier layer **19*b*** which may be of aluminum oxide is superposed over phosphor layer **19*a*** and a photo-emissive layer **19*c*** is placed over barrier layer **19*b***. The photo-emissive layer is generally an antimony-cesium composition and constitutes the electron emitting surface of the cathode structure. This cathode structure may be entirely conventional both as to its composition and method of manufacture.

A conductive layer **18**, which may be a deposit of conductive material such as copper or aluminum on the inner portion of cylindrical section **10**, may be positioned between cathode **19** and an anode **16** of the tube. If employed, it is extended to metal flange **13*a*** to facilitate establishing this electrode at a desired operating potential, preferably ground potential.

The anode **16**, in accordance with the present invention, is a planar structure positioned between cathode **19** and screen **15** to constitute with the cathode the principal electron focussing system of the tube. Structurally, it is a flat disc disposed transversely and substantially coaxially of the tube and electron-optical axis. The anode has a centrally located aperture **17** to provide access for electrons traversing the electron-optical system to an image plane which is approximately coincident with screen **15** and is symmetrical relative to the tube axis. Anode **16** has a maximum axial spacing from cathode **19** equal to $2R_1$ and its dimension transverse to the tube axis is within the range d_1 and $2R_1$. It is supported in position by a conductive cylinder **16*a*** secured within the cylindrical portion of envelope section **11**. The anode is electrically connected to the viewing screen to maintain the screen at the same electrical potential as the anode.

Lead-in connections of conventional construction are relied upon to provide means for establishing between the cathode and anode a potential difference for focussing the electron image originating at the cathode on screen **15** through anode aperture structure **17**. These connections are designated symbolically by the construction lines terminating in arrowheads at the appropriate portions of the image intensifier.

Before considering further details of the electron-optical system, a brief review will be given of the operation of the image intensifier. Normally conductive coating **18** on envelope section **10** is operated at zero potential, cathode structure **19** is operated at a small negative

potential in the order of 200 to 300 volts, while a high positive potential in the range of 25 to 35 kv. is applied to anode **16** and to viewing screen **15**. These elements collectively constitute what is known in the art as an electrostatic triode system.

When an X-ray image is focussed upon end-section **12** of the envelope to impinge upon pick-up screen **19**, it excites phosphor layer **19*a*** which, in response thereto, emits a corresponding light image. The light image traverses the transparent barrier layer **19*b*** and excites photo-emissive layer **19*c***, which in turn emits an electron image which is the counterpart of the X-ray image initially received. The focussing and accelerating effects provided by the action of the electrostatic field between cathode **19** and anode **16** cause the electron image to be projected along the electron-optical system and to be focussed through anode aperture **17** upon viewing screen **15**. At this juncture, the electron image is converted to a visible image which is viewable on screen **15**. The reduction in image size, attributable to the focussing of the image from the cathode surface which is larger than the anode and viewing screen surface, contributes to brightness gain. The brightness gain is, of course, desirable and yet the size of the visible image is greater than that achieved with prior image intensifiers of comparable dimensions. To facilitate an understanding of how the image size is increased, consideration will first be given to the electron optics of the prior art structure.

The electron optical system of that prior structure, as indicated in FIGURE 2, features a spherical cathode **19** of constant radius R_2 while the effective portion of the anode **16** is its spherical cap which may likewise be thought of as a spherical section of constant radius r. In other words, the anode and cathode, which constitute the principal electrodes of the focussing and accelerating system are approximately concentric spherical sections and the application of a potential difference therebetween gives rise to an electrostatic field in the space between the cathode and anode.

The equi-potential planes are likewise spherical in configuration and their effect on electrons emitted from the cathode surface is that of a converging lens, focussing the electrons in the direction of the anode aperture as indicated by construction lines **30**. The image plane of this system is curved oppositely to the curvature of the anode and cathode. The aperture **17** of the anode structure contributes a divergent lens effect which modifies this image plane, tending to reduce its curvature or flatten it to coincide more closely with the plane of image screen **14**.

It will be observed that the cone angle defined by construction lines **30** and representing the overall focussing effect is quite small and for this reason the visible image developed on screen **14** is necessarily of relatively small diameter for any practical spacing of the image screen, from anode aperture **17**, smaller than the distance between the cathode and the anode. As indicated above, this is characterized as a de-magnification and the extent of de-magnification is related to the ratio of cathode to anode radius, usually being in the range of 7 to 12. This inherently results in high brightness gain but also imposes the requirement of a very high inherent resolution on the viewing screen if image detail is to be satisfactory.

FIGURE 3 permits a ready comparison of the electron optics of the structure with that shown in FIGURE 1. The dash-dot line A—A represents both the axis of the tube and that of the electron-optical system. An obvious and significant structural difference is that the spacing between facing surfaces of the cathode and anode is not uniform as occurs when concentric spherical electrodes are employed. The inter-electrode distance is shortest between the edge portions of the anode and cathode and the electric field in this region is strongly convergent but the strength of the converging field decreases as the electrons influenced by that field, travel in the direction of the anode. As the anode is approached, the electric field

References Cited by the Examiner

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2,774,002	12/1956	Carlo	313—65
2,955,219	10/1960	Niklas	313—65
3,225,204	12/1965	Schagen et al.	250—213

OTHER REFERENCES

Zworykin: "The Electron Telescope" in Electronics, January 1936, pp. 10–13 relied upon; see particularly Fig. 13 of the drawing on page 10.

HERMAN KARL SAALBACH, *Primary Examiner.*

S. CHATMON, *Assistant Examiner.*

lines change configuration from that of a strongly convergent field, progressively through weaker converging effects and ultimately to a divergent field close to the surface of the anode.

The convergent action of the field is very strong so that the net-effect of the field will be of convergent type and the cross-over of the construction lines P_1 and P_2 will be shifted along the axis A—A in the direction of the cathode. For the case illustrated the cross-over will be shifted into the anode aperture. The angle α, of the cone encompassing the paths of the electrons is larger than in the case of the prior art structure illustrated in FIGURE 2. As a consequence the diameter d_1 of the image established on screen **15** is materially larger than that obtained with prior structures employing concentric spherical electrodes for the cathode and anode.

By way of example, an intensifier constructed in accordance with FIGURE 1, having essentially the same significant cathode dimensions and the overall length of the tube as the prior structure, resulted in linear demagnification of approximately 3 whereas the prior structure exhibits demagnification in the range of 7 to 12 as previously mentioned. Moreover, it has been discovered that an intensifier embodying the invention has a significantly higher resolution than prior devices, being at least 25% higher in a tube that has been constructed and operated.

In describing the components of the structure of FIGURE 1, a range has been given for tube dimensions which contributes significantly to the operation of the device. Based on present experience, it is preferred that the ratio of cathode radius R_1 to the diameter d_2 of the cathode emitting surface be within the range of 1.1 to 2 and the spacing a_1 of the anode from the cathode be within 0.8 and 1.1 times the cathode surface diameter d_2. The ratio of the anode dimension d_3, transverse to the tube axis, to the cathode surface diameter d_2 should be from 0.2 to 0.8 and the diameter d_1 of the image screen to the cathode surface diameter d_2 is from 0.2 to 0.5. The diameter of the anode aperture is approximately twice the thickness of the anode electrode for optimized performance of the electron optical system.

Further by way of illustration and in no sense restrictive on the dimensions of the device, an image converter having the structure of FIGURE 1 and producing a large visible image of improved resolution employed the following parameters:

	Inches
Cathode radius R_1	8
Cathode surface diameter d_2	9
Anode diameter d_3	4½
Image diameter d_1	3
Anode to cathode spacing a_1	10⅞
Anode and image screen spacing a_3	5⅛
Anode thickness	¼
Diameter of anode aperture	½

A further improvement may be realized by constructing the cathode in the manner described in United States Patent 2,974,244, issued to W. F. Niklas and assigned to the assignee of the present invention. Such a cathode structure is formed of a succession of contiguous sections individually of substantially uniform radius and arranged symmetrically relative to the tube axis with the radius of these sections decreasing with their spacing from the axis of the tube. As explained in the Niklas patent, such a structure has a further flattening effect on the image plane which results in improved focus of the entire screen area.

While particular embodiments have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. In an image converter tube of the type having an input element, responsive to a received radiation pattern for developing an electron image, and an output element, responsive to the received electron image as propagated from said input to said output element along a reference electron optical axis of said tube and focused on said output element, for providing a visible image constituting a replica of said radiation pattern and of the type making use of the known electron optical lens characteristics of concentric spheres in propagating and focusing said electron image thereby requiring a given axial length from input element to output element for a given low-order minification, an improved electron optical system for said tube with said given minification requiring an axial length between said elements substantially less than said given length, said improved electron optical system consisting essentially of:

a photoemissive cathode constituting said input element and disposed transversely and coaxially of said reference axis and responsive to said radiation pattern for developing an electron image, said cathode having the configuration of an approximately spherical section of an effective radius R_1;

a viewing screen constituting said output element disposed transversely and coaxially of said reference axis and having a diameter d_1;

a planar anode, disposed transversely and coaxially of said reference axis between said cathode and said viewing screen, having a predetermined axial spacing from said cathode of less than $2R_1$ but greater than $.75R_1$, having a centrally located aperture for admitting said electron image and having its transverse dimension within the range of d_1 and $2R_1$, said photoemissive cathode and planar anode together forming the primary electron image propagating and focusing arrangement for said tube, the electron focusing action of said arrangement being more strongly convergent in the region of said spherical cathode and less convergent in the vicinity of said planar anode than in the case of a concentric spherical anode-spherical cathode electron optical system of like axial spacing, the net effect of the focusing action of said arrangement being equivalent to a spherical anode-spherical cathode system of an axial spacing substantially greater than said predetermined axial spacing;

and secondary focus electrode means interposed between said planar anode and said photoemissive cathode and comprising at least one cylindrical electrode, said secondary focus electrode means being electrically separate from said planar anode and photoemissive cathode and having a minimum diameter at least as great as the diameter of said cathode.

2. The combination according to claim **1** in which said image converter tube comprises a glass envelope and in which said secondary focus electrode means consists of a conductive coating applied to the interior of said glass envelope.

3. The combination according to claim **1** wherein the ratio of said radius R_1 to the diameter of said photoemissive cathode is between 1.1 and 2, the ratio of said transverse dimension of said anode to said cathode diameter is between .2 and .8, the ratio of the axial spacing of said planar anode from said photoemissive cathode to said cathode diameter is between .8 and 1.1, and the ratio of said viewing screen diameter, d_1, to said cathode diameter is between .2 and .5.

4. The combination according to claim **3** in which the diameter of said centrally located anode aperture is substantially equal to twice the thickness of the transverse portion of said anode.

(References on following page)