United States Patent

Fisher et al.

[15] **3,668,388**

[45] **June 6, 1972**

[54] **MULTI-CHANNEL PHOTOMULTIPLIER TUBE**

[72] Inventors: **Mahlon B. Fisher**, Skaneateles; **Charles K. Schiller**, Seneca Falls, both of N.Y.; **Ojars J. Ziemelis**, Sunnyvale, Calif.

[73] Assignee: **GTE Sylvania Incorporated**

[22] Filed: **Feb. 24, 1971**

[21] Appl. No.: **118,458**

[52] **U.S. Cl.** **313/95,** 313/96, 313/105

[51] **Int. Cl.** **H01j 31/50**

[58] **Field of Search** 313/94, 95, 96, 105

[56] **References Cited**

UNITED STATES PATENTS

2,130,152 9/1938 Perkins ....313/95 X

2,236,012 3/1941 Shockley ....313/95 X

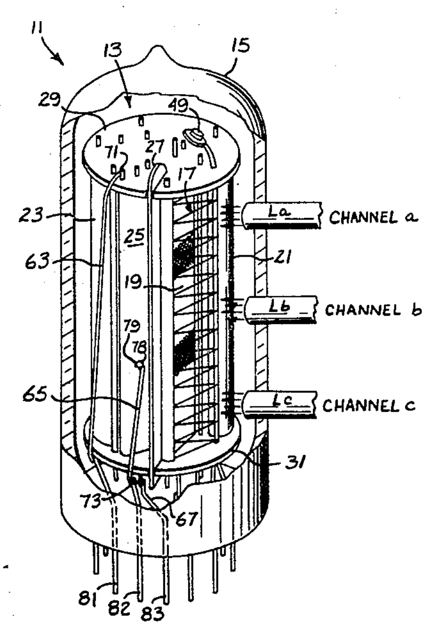
Primary Examiner—Roy Lake

Attorney—Norman J. O'Malley, Donald R. Castle and Frederick H. Rinn

[57] **ABSTRACT**

The improved photomultiplier tube utilizes a multi-channel structure within a common envelope. A photocathode and a plurality of dynode members each have barrier means associated therewith to effect a plurality of related-area elements on each member providing a plurality of separate photomultiplier channel areas thereon. The anode structure has a separate anode element for each individual channel with a separate electrical connection extending therefrom. The photocathode and the separate dynode members each have individual electrical connections which are common to the related channel areas respectively formed thereon.

12 Claims, 5 Drawing Figures



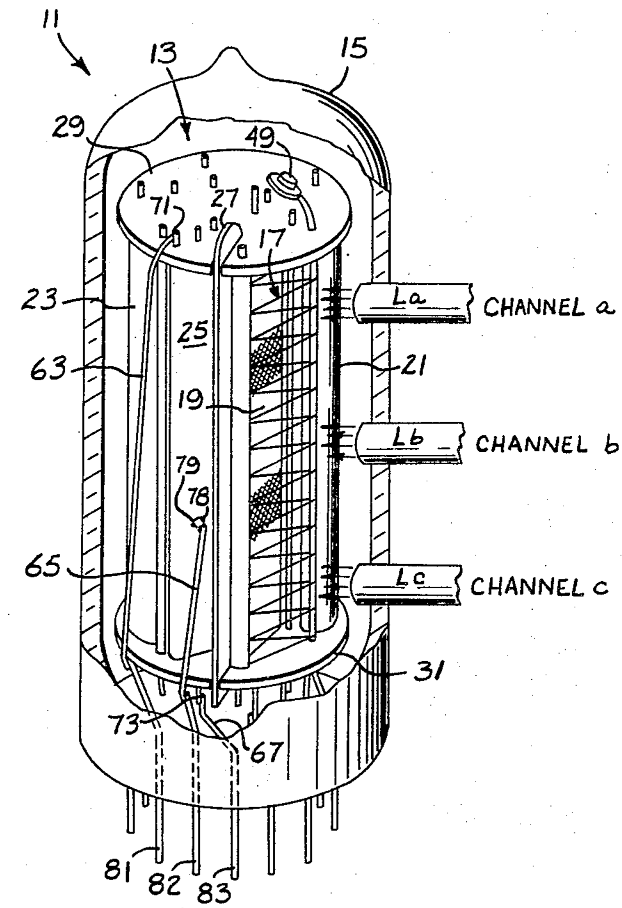


Fig. 1

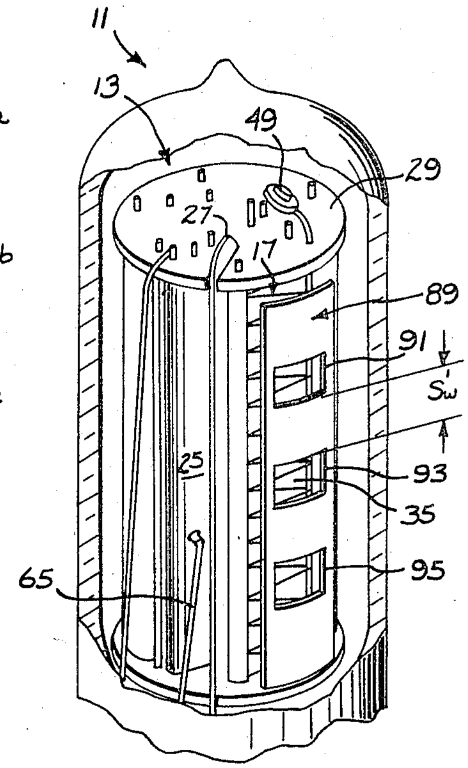


Fig. 2

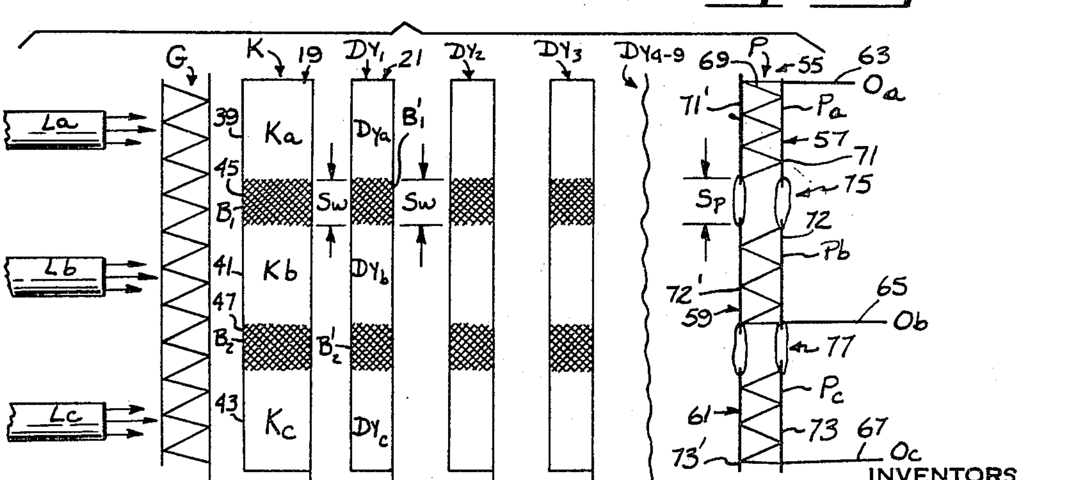


Fig. 3

INVENTORS
MAHLON B. FISHER,
CHARLES K. SCHILLER, &
OJARS J. ZIEMELIS

BY Donald R. Castle
ATTORNEY

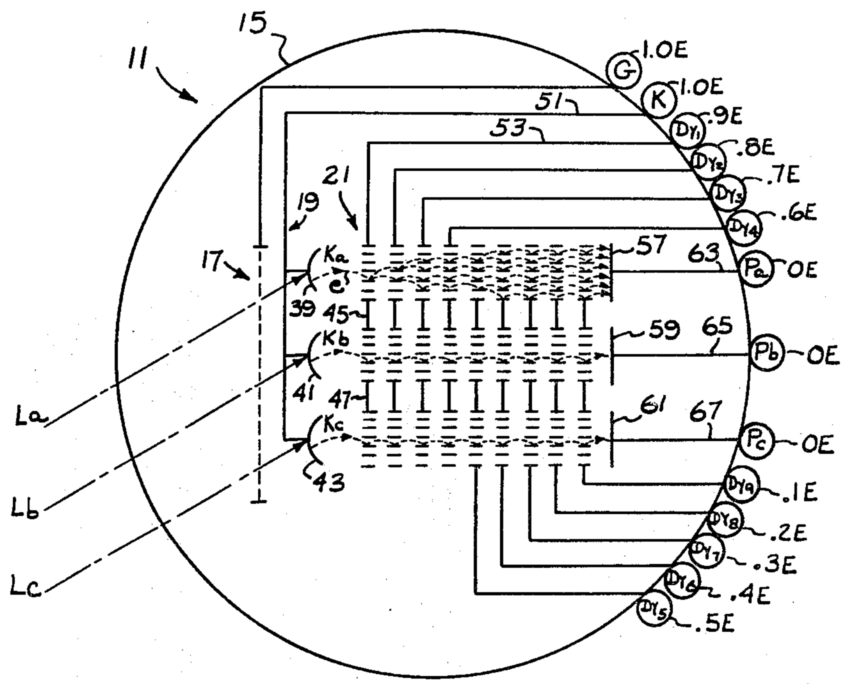


Fig. 4

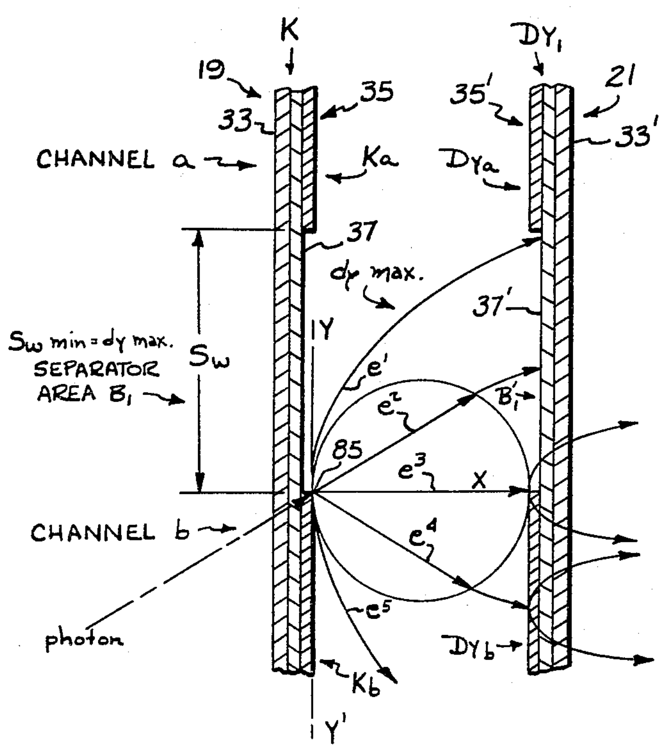


Fig. 5

INVENTORS
MAHLON B. FISHER,
CHARLES K. SCHILLER, &
OJARS J. ZIEMELIS
BY Donald R. Castle
ATTORNEY

MULTI-CHANNEL PHOTOMULTIPLIER TUBE

BACKGROUND OF THE INVENTION

This invention relates to multiplier phototubes and more particularly to multi-channel photomultiplier tube construction contained in a common envelope.

Multiplier phototubes are amplifiers of photon generated current utilizing the principle of cascaded secondary emission. Typical multiplier arrangements employ a photocathode upon which photons of radiant energy are directed. The photoelectrons released therefrom are accelerated and focused to impinge the secondary emissive surface of an adjacent positively charged dynode member or electrode from which a plurality of secondary electrons are emitted. These secondary electrons are, in turn, impelled to bombard the active surface of another adjacent dynode which has a greater positive potential, thereby causing the emission therefrom of a greater number of new secondary electrons. This impact-and-release process is cascaded by additional sequentially positioned dynodes to amplify the initial photocurrent by as much as a factor of 10^5 or more. Thus, for each initial photon of incident light directed to the active surface of the photocathode, a vast number of secondary electrons reach the anode of the tube providing an output response representing a large amplification of the input signal.

Photomultipliers lend themselves to a number of applications relating to the increase of a minute photoemission current to an output response of a desirably greater value. Typical of such usage is the employment of photomultipliers in video electronic applications such as flying spot scanning systems, wherein still or moving film images are converted to video signals for ultimate television viewing. Such systems, when adapted to color imaging, conventionally utilize a plurality of photomultiplier tubes, usually one for each channel which are arranged to handle the additive primary signals, i.e., blue, green and red. For example, in a three separate tube color system employing three separate but related tubes, non-uniform aging between the respective tubes often necessitates periodic gain adjustments of the individual tubes in order to attempt to maintain the proper color balance of the system. It has been found that the sensitivity and the spectral response characteristics of a photomultiplier tube are apt to change under both shelf-life storage and normal operational conditions. Such deviations are primarily due to variations in the residual gas pressure and changes in material compositions within the individual tubes. Usually, each tube has its own characteristic aging which is determined by its previous processing history. Thus, the cooperative usage of a plurality of separate tubes in the same system inherently introduces variables which may, over a period of time, markedly and determinately affect the quality of the overall output of the video system.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to reduce the aforementioned disadvantages by providing an improved photomultiplier tube having a plurality of channels within a common envelope.

Another object is to provide a multi-channel photomultiplier tube that exhibits improved related operational characteristics of the several channels during usage.

A further object is to provide a multi-channel photomultiplier tube that can be expeditiously and economically manufactured.

The foregoing objects are achieved in one aspect of the invention by the provision of a photomultiplier tube that utilizes a multi-channel structure enclosed in a common envelope. As used herein, the definitive term "multi" is intended to mean two or more. The multi-channel structure comprises a photocathode member, a plurality of related dynode members and an anode structure. The photocathode member and each of the dynode members have barrier or separator means associated therewith to effect a plurality of isolated substantially like-area elements on each member to provide a plurality of related but separate photomultiplier channels. The photocathode member and the individual dynode members each have separate externally extending electrical connections which are common to the several related channels thereon. The anode structure has an individually defined and isolated anode element for each of the channels represented on the final of the dynode members. Each of the isolated anode elements has a separate externally extending electrical output connection. The several related channels are exposed to the same processing history and are operated in the same residual gas atmosphere since they are within a common vacuum enclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective partially illustrating the tube structure of the invention;

FIG. 2 is a partial perspective showing an embodiment of the invention;

FIG. 3 is a layout showing related parts of the invention;

FIG. 4 is a schematic of the invention; and

FIG. 5 is an enlarged presentation showing the operational relationship between the photocathode and the first dynode member in the structure.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For a better understanding of the present invention, together with other and further objects, advantages, and capabilities thereof, reference is made to the following specification and appended claims in connection with the aforedescribed drawing.

While the invention relates equally to any photomultiplier tube structure comprising a plurality of channels, the described exemplary embodiment relates to a three channel device.

With reference to the drawings, there is shown in FIG. 1 a perspective view of a three-channel photomultiplier tube 11 whereof part of the structure is identified. The example shown and described is a conventional circular photomultiplier structure, but the invention is not intended to be limited thereto. Since the structure of a circular type photomultiplier is well-known, details of the shapings and orientations of the several electrode members will not be delineated herein. In this instance the internal structure 13 of the tube, which is enclosed in the envelope 15, comprises a grid (G), a photocathode (K), nine dynode members (DY_{1-9}) and an anode structure (P). These cooperating members are oriented relative to one another in the conventional manner, with the relationship being further illustrated in FIGS. 3 and 4. The internal structure 13 as presented in FIG. 1 shows the grid (G) 17, the photocathode member (K) 19, the first dynode member (DY_1)21, the seventh dynode member (DY_7) 23, the ninth dynode member (DY_9) 25, and a metallic shield member 27 all of which are supported by insulative planar members 29 and 31. In FIG. 1, the anode structure (P) is hidden by the ninth dynode member 25.

For the tri-channel embodiment shown, luminous energies in the form of trichromatic beams (L_a), (L_b), and (L_c) representing the separate inputs of channels (*a*), (*b*) and (*c*), are discretely directed to traverse a window area portion of the envelope, pass through the grid (G) 17, and impinge specific active areas (K_a), (K_b) and (K_c) of the photocathode (K) 19.

In greater detail, for the embodiment illustrated in FIGS. 1, 3, and 5, the photocathode (K) 19 is an opaque member formed of a metallic base material 33 such as nickel or nickel alloy. The cathode surface oriented to receive the photons of the respective luminous energies (L_a), (L_b) and (L_c) is treated to provide an active surface of secondary emissive material 35. The cathode surface to be activated is first coated with a uniform layer of nickel oxide 37 which is non-emissive and forms a barrier layer on the base material 33 to prevent the subsequently applied areas of antimony from diffusing thereinto. The antimony is applied to specific separated areas (K_a) 39, (K_b) 41, (K_c) 43 by a conventional vaporization technique comprising a time-temperature relationship to achieve the desired thickness. During the antimony vaporization procedure, two discrete areas **45** and **47** of the cathode **19** are masked to prevent the deposition of antimony thereon, thereby providing two barrier or band-like separator areas (B_1) and (B_2) of non-emissive material **45** and **47** respectively to prevent the cross-modulation of signals. Materials found to be suitable for this usage are those exhibiting low secondary emission characteristics, for example, such being at least one selected from the alphabetical grouping consisting of carbon, gold, silicon, silver, titanium, nickel oxide, and silicon oxide. In this instance, the non-emissive separator material is nickel oxide. The widths (S_w) of the separator bands (B_1) and (B_2) will be discussed later in this application. During subsequent tube processing cesium vapor is released within the envelope, as from a cesium generator **49**. The released cesium vapor reacts with the priorly disposed antimony to form a cesium-antimony compound (Cs_3Sb) which provides a secondary emissive surface **35** in each of three cathode areas **39, 41,** and **43.** The photocathode member (K) **19**, having the three individual secondary emissive areas formed thereon with separator barriers therebetween, defines a plurality of related areas on a common element which has a single electrical connection **51** extending externally therefrom.

Associated with the photocathode (K) are a plurality of shaped dynode members, in this instance nine in number ($DY_{1\text{-}9}$), spatially positioned in parallel relationship with one another to provide unobstructed deflective electron paths sequentially therebetween. Each of the dynodes ($DY_{1\text{-}9}$) is formed of metal base material **33′** such as nickel or nickel alloy, and has an active surface from which secondary electrons are readily emitted. Additionally, each dynode has two band-like electron separator areas (B'_1) and (B'_2) of non-emissive material similarly disposed thereon to effect three isolated substantially like-area dynode elements (DY_a), (DY_b), and (DY_c).

The first dynode member (DY_1) **21** is spatially and parallelly positioned relative to the photocathode **19** to receive secondary electrons emitted therefrom. The formation of the active surface areas of the first dynode **21** is similar to that already described for the photocathode **19**; i.e., a first or barrier layer of nickel oxide **37′** is formed on the base material **33′** upon which the secondary emissive material **35′**, in the form of cesium-antimony (Cs_3Sb) is disposed to provide the three aforementioned separated dynode elements (DY_a), (DY_b), and (DY_c). These respective elements are positionally and collectively related on each dynode member to define the three separate photomultiplier channels (*a*), (*b*) and (*c*) within the structure **13**. Each of the dynode members has an individual externally extending electrical connection, as for example, connection **53** for the first dynode member **21**.

A formed anode structure (P) **55** is parallelly related to the final of the dynode members (DY_9), and comprises an individually defined and isolated anode elements (P_a), (P_b), and (P_c) **57, 59,** and **61** respectively for each of the three channels. Each of the defined anode elements **57, 59** and **61** has a separate externally extending electrical connection **63, 65** and **67** respectively.

In greater detail, each of the anode elements **57, 59** and **61** in the anode structure **55** is formed as a helically wound grid-like framework made up of a plurality of laterals **69** of light wire, such as 3 mil nickel or nickel alloy wire. These separate anode elements are supported between pairs of siderod members **71, 71′, 72; 72′,** and **73; 73′** respectively, which are of, for example, 30-mil nickel or nickel alloy material. The turns-per-inch (T.P.I.) of the laterals in the structure are of a density to facilitate attraction of the secondary electrons without inhibiting deflection thereof from the final dynode. In this instance, a T.P.I. of approximately 25 is found to be an adequate density of lateral wire elements.

The three anode elements **57, 59,** and **61** are formed into the anode structure **55** by utilizing two pairs of separators or insulative spacers **75** and **77**. These spacers are of glass or ceramic material and have insulative lengths (S_p) that substantially equal the widths (S_w) of the described dynode separator areas (B'_1) and (B'_2). The separate output electrical connections **63, 65** and **67** for the respective individual anode elements **57, 59** and **61**, as shown in FIGS. **1** and **3**, are extended from various portions of the anode (P) structure **55**. A first channel output (O_a) such as connection **63** for the anode element (P_a) **57** is attached to the portion of anode siderod **71** protruding from planar member **29**. A second channel output (O_b) such as connection **65** for the anode element (P_b) **59**, being affixed to siderod **72**, encompassed by an insulative ceramic **78** extended through an aperture **79** in the ninth dynode member **25**; the aperture being oriented preferably through a separator barrier area of that dynode. A third channel output (O_c) such as connection **67** for the anode element (P_c) **61** is attached to the portion of anode siderod **73** protruding from the planar member **31**. These respective connections **63, 65,** and **67** extend exteriorly of the tube envelope **15**, as through base pin elements **81, 82** and **83**, to facilitate connection with externally associated circuitry.

Operational aspects are referenced in FIG. **4** wherein related negative DC voltages (E) are supplied in incremental amounts to the plurality of electrodes in the tube **11**, beginning with the photocathode (K) and continuing sequentially through the dynodes ($DY_{1\text{-}9}$) to the respective anodes ($P_{a\text{-}c}$). For example, if a representative voltage value of 1.0 E is applied to the photocathode (K), a more positive voltage such as 0.9 E is applied to the first dynode member (DY_1), and for each succeeding dynode members ($DY_{2\text{-}9}$) there is a one-tenth of E differential with the final anodes being individually at ground or OE. In this manner, interstage secondary emission is sequentially increased with resultant output amplification of the input signal. The build-up of impact-and-release secondary emission trajectories between electrodes as initiated by electron (*e*), are diagrammatically shown for channel (*a*).

It is to be noted that a grid (G) **17** is usually positioned in front of the photocathode (K) **19** and maintained at cathode voltage to initially control the primary emission from the active surfaces of the cathode and prevent the primary electrons from bouncing outwardly toward the luminous source.

It has been found that the widths of the respective band-like non-emissive separator areas (S_w), as formed on the photocathode (K) and on the respective dynode members ($DY_{1\text{-}9}$), are very important to prevent the development of cross-modulation or noise between the channels. A formulation has been developed to establish a minimum band or separator width (S_w min.) whereof electron velocity and direction of travel are taken into consideration. With particular reference to FIGS. **1** and **5**, a photon from, for example, luminous energy source (L_b) impinges the edge of the photocathode active area (K_b) at a point of impact **85** and liberates therefrom a plurality of secondary electrons ($e^{1\text{-}5}$) which, in turn, are directed and attracted to the more positive first dynode member (DY_1) **21**. As shown, exemplary secondary electrons (e^1) and (e^2) impinge on the non-emissive separator area (B'_1). Thus, it is important that the separator barrier area (B'_1) of the first dynode member (DY_1) be of sufficient width to prevent secondary electron (e^1) from bombarding the first channel emissive area (DY_a) **35′**. The velocity of each liberated secondary electron is a vector quantity, comprised of both magnitude and direction. The distribution of the directions of the velocities of these electrons is a cosine function. The distribution of the magnitudes of the velocities thereof is independent of direction, and is found to be "gaussian-like" centered within a comparatively narrow range of electron volts. Therefore, to determine the path of travel of electron (e^1), which is liberated in the Y axis direction, a cosine function is established for the point of electron emission **85**; relative to which the following terminology and relationships are expressed:

S_w min = minimum width of separator are (B'_1) in cm.

dy max = maximum travel of electron (e') in substantially Y direction in cm.

Vy = velocity of electron (e') in substantially the Y direction in cm/sec.

E = energy of electron (e') expressed in ergs.

m = mass of electron (e^1) in grams = 9.108×10^{-28} g.

T_t = transit time per stage in sec.

(1) $S_w \min = dy \max = Vy \times T_t$

whereof

(2) $Vy = \sqrt{2E/m}$

For example, in considering an operational condition wherein there is a 1,000-volt differential between the photocathode (K) and the anode (P) comprising 100-volt incremental steps between the individual stages in the tube, measurement of the transit time (T_t) of signal travel from the photocathode to the anode is found to be substantially 20 nanoseconds. This constitutes a transit time (T_t) of 2 nanoseconds per stage. In considering the velocity of the secondary electron (e^1) in the critical direction Y, the maximum energy (E) of the electron (e^1) is calculated from known data to be substantially 5 electron volts (eV) which is converted to ergs.

$$Vy = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2(5\text{eV})(1.6\times10^{-12}\text{ ergs/eV})}{9.1\times10^{-28}\,g}}$$

$$= 1.14\times10^{8}\text{ cm/sec.}$$

$S_w \min = dy \max = Vy\times T_t = 1.14\times 10^{8}$ cm/sec $(2\times 10^{-9}$ sec.$)=$ 0.23 cm for 5 eV secondaries.

Thus, the width (S_w) of the non-emissive separator areas should be in excess of a minimum of 0.3 cm. Preferably, a safety factor is added to prevent unanticipated generation of deleterious cross-modulation.

With reference to FIG. 2, there is shown another embodiment wherein the barrier means associated with the photocathode member is in the form of a mask **89** of non-emissive opaque material having at least two related apertures therein. In the exemplary three-channel tube **11** of this embodiment there are three discretely formed apertures **91, 93,** and **95** in the mask structure **89**. Positionally, this apertured mask barrier is oriented in spatial relationship to the active surface of the photocathode member (K) to segregate the separate luminous energy inputs L_a, L_b, and L_c on separated areas of the photocathode. When a mask barrier **89** of this type is utilized, the primary emissive surface **35** of the photocathode cK) may be formed as a continuous active layer thereon, the separation of channels being effected by the separator spacing (S'_w) between apertures. Positioning of this mask **89** is adequately accomplished either within the envelope **15** or exteriorly thereof.

Thus, there is provided a multi-channel photomultiplier tube that represents a distinct improvement over the employment of a plurality of separate tubes in a common application. The related operational characteristics of the several channels in a common envelope environment provides marked improvement in the handling of the separate signals and enhances the quality of the output. In the multi-channel tube, the several channels, being within a common envelope, are exposed to the same processing history and are operated in the same residual atmosphere. Therefore, all channels will exhibit similar aging characteristics, and a related color balance will be maintained throughout the life of the tube. The multi-channel tube can be expeditiously and economically manufactured, as the multi-channel structure utilizes far fewer parts than are required to fabricate the needed plurality of single channel tubes. Also manufacturing costs relating to tube sealing, processing, testing, packing, transportation and storage are drastically reduced. Additionally, the compact multi-channel tube represents cost and space saving advantages in the video application and facilitates reduction in the complexity of operational circuitry thereof.

While there have been shown and described what are at present considered the preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the invention as defined by the appended claims.

What is claimed is:

1. A multi-channel photomultiplier structure enclosed in a common envelope having a window area, said structure comprising:

a formed photocathode member having an active surface with a primary emissive material disposed thereon, said photocathode member being positioned in said envelope in a manner that said active surface is oriented to receive incident luminous energy beamed through the related window-area of said envelope, said photocathode having an externally extending electrical connection;

a plurality of formed dynode members spatially positioned in discrete parallel relationship with one another to provide unobstructed deflective electron paths sequentially there-between, the first of said dynode members being spatially and parallelly positioned relative to said photocathode member to receive substantially primary emission therefrom, each dynode member having an individual externally extending electrical connection and an active surface with secondary emissive material disposed thereon, each dynode member having at least one band-like electron separator area of non-emissive material similarly disposed thereon to effect a plurality of isolated substantially like-area dynode elements on each dynode member, said respective dynode elements being positionally and collectively related to define a plurality of separate photomultiplier channels;

a formed anode structure parallelly related to the final of said dynode members, said anode structure having an individually defined and isolated anode element for each of said channels, each of said anode elements having a separate externally extending electrical connection; and

barrier means associated with said photocathode member to provide for the reception of a plurality of discrete areas of input luminous energy.

2. A multi-channel photomultiplier structure according to claim **1** wherein said barrier means associated with said photocathode member is in the form of at least one band-like separator area of non-emissive material disposed on the active surface of said photocathode to effect a plurality of separate primary emissive areas thereon.

3. A multi-channel photomultiplier structure according to claim **2** wherein said non-emissive separator areas are of a material exhibiting low secondary emission characteristics.

4. A multi-channel photomultiplier structure according to claim **3** wherein said non-emissive separator areas are of at least one material selected from the group consisting of carbon, gold, silicon, silver, titanium, nickel oxide and silicon oxide.

5. A multi-channel photomultiplier structure according to claim **1** wherein said band-like non-emissive separator areas are of a width determined by the formula:

(1) S_w min. = dy max. = $Vy \times T_t$

whereof:

(2) $Vy = \sqrt{2E/m}$

S_w min. = minimum width of separator area (B) in cm.

dy max. = maximum travel of electron (e) in substantially the Y direction in cm.

Vy = velocity of electron (e) in substantially the Y direction in cm./sec.

E = energy of electron (e) expressed in ergs.

m = mass of electron (e) in grams.

T_t = transit time per stage in m sec.

6. A multi-channel photomultiplier structure according to claim **1** wherein said barrier means is oriented on the active surface of said photocathode in the form of at least one band-like separator area of non-emissive material to effect a plurality of isolated substantially like-area cathode elements thereon.

7. A multi-channel photomultiplier structure according to claim 1 wherein said barrier means associated with said photocathode member is in the form of a mask of opaque non-emissive material having at least two related apertures therein, said mask being oriented in spatial relationship to the active surface of said photocathode member to segregate at least two separate luminous energy inputs on separated areas of said photocathode surface.

8. A multi-channel photomultiplier structure according to claim 6 wherein said discretely apertured barrier means is oriented within said envelope.

9. A multi-channel photomultiplier structure according to claim 6 wherein said discretely apertured barrier means is oriented exteriorly of said envelope.

10. A multi-channel photomultiplier structure according to claim 1 wherein said photocathode member has a grid member positioned in front of said photocathode in a manner that said luminous energy passes therethrough to impinge on said active photocathode surface, said photocathode and grid members being at a common potential.

11. A multi-channel photomultiplier structure according to claim 1 wherein the individually defined anode elements of said anode structure are separated by insulative spacers, said spacers having lengths substantially equalling the widths of said dynode separator areas.

12. A multi-channel photomultiplier structure according to claim 1 wherein three separate channels are provided to handle the input energies of additive primary hues.

* * * * *