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(54) Method and apparatus for electro-optically convoluting signals.

(57) A method and apparatus for electro-optically convoluting a signal available in image-form with at least one known convolution function. The image of the signal is applied to the entrance window of an electro-optical image-forming device including an integrating screen and deflection means. By controlling the deflection means, the input image is projected onto the integrating screen during time intervals corresponding to the value of the convolution function as associated with the instantaneous deflection and with such an intensity that the convoluted signal in image-form is produced on the screen. The apparatus comprises at least one television camera tube having an image section including deflection means for the input image.

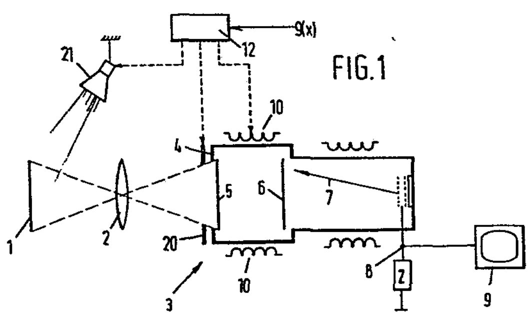

FIG.1

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Title: Method and apparatus for electro-optically convoluting signals.

The invention relates to a method and apparatus for electro-optically convoluting a signal available in image-form with at least one known convolution function. Such a technique can be used, for example, to transform unsharp astronomic images, radar images, X-ray images, air reconnaissance pictures and the like into sharp ones, or to encode or decode images.

It is known, for example from Dutch patent appln. 76,00155 open to public inspection, that the unsharpness of an image can be eliminated by deflecting the unsharp image relative to an optical mask disposed parallel thereto. This mask incorporates a computed or experimentally determined function which defines the transparency of each point of the mask. By determining the light flux on the other side of the mask by means of, for example, a photomultiplier tube and applying the output signal thereof to a monitor, a sharp image of the original unsharp image is produced on the monitor screen. In fact, the achievement of the sharp image is the result of a convolution of the original unsharp image with the (computed or experimentally determined) function incorporated in the mask.

Consequently, this prior technique requires the manufacture, usually by photographic processes, of at least one optical mask but often two masks will be required if the function, which will be called convolution function hereinafter, has positive as well as negative parts.

It is an object of the invention to provide a technique that is simpler than the prior art technique in the sense that it does not require, and hence obviates the manufacture of, such masks.

To achieve this object, in accordance with the invention a method of the above type is characterized in that the image of the signal available in image-form is applied to the entrance window of an electro-optical image-forming device including an integrating screen and deflection means; and that by controlling the deflection means the input image is projected onto the integrating screen during time intervals corresponding to the value of the convolution function as associated with the instantaneous deflection and with such an intensity that the convoluted signal in image-form is produced on the screen.

An apparatus according to the invention is characterized by at least one television camera tube having an image section, which image section includes deflection means for the input image.

The invention will be described in greater detail hereinafter with reference to the accompanying drawings, in which:

Fig. 1 schematically shows an apparatus for performing a method according to the invention;

Fig. 2 illustrates the method according to the invention for a simple form of the convolution function; and

Fig. 3 shows an example of an embodiment of an apparatus according to the invention.

Fig. 1 shows an input image 1, which may be a photographic image or a (stationary or moving) image formed in a different manner. The input image is applied through an object lens system or, in general, an imaging system 2 to the entrance window of an electro-optical device 3.

In Fig. 1 an electro-optical device in the form of a television camera tube comprising an image section, for example an image isocon, is used. The input image is applied via the entrance window 4 of the camera tube to the photocathode 5 located directly behind the entrance window, which photocathode 5 is responsive to incident light to emit electrons in an amount proportional to the amount of incident light. By applying a suitable potential difference between the photocathode and a target 6 disposed opposite to the photocathode, the input image is projected onto the target in the form of a charge image. The target is of known per se structure and is adapted to also allow scanning from behind by means of an electron beam 7 in known per se manner, as a result whereof an image output signal can be obtained at 8 in a manner known in the television art, which image output signal can be visualized on a monitor 9 in a likewise known manner.

In order to allow convolution of the input image with a given function in the desired manner, the section of the camera tube according to the invention between the photocathode and the target, the so-called image section, is provided with horizontal and vertical deflection coils; for the sake of clarity, only a single set of deflection coils 10 is shown in the drawing. In accordance with the invention, the deflection coils are controlled by means of signals derived from the convolution function, so that after the completion of the deflection in accordance with the convolution function, the charge image formed on the target is representation of the input image convoluted with the convolution function. The control device is schematically shown in Fig. 1 at 12.

In this manner no masks need be manufactured and no separate integrating device is required as the target fulfils this function.

For the purpose of elucidation, the method according to the invention will now be described with reference to a simple example.

It is assumed that the input image, designated $f_o(x)$, is one-dimensional and will therefore form a line on the target, the constituent image points of which line each have a brightness corresponding to $f_o(x)$. This line lies in the x-axis. It is further assumed that the input image has to be convoluted with a known, likewise one-dimensional convolution function $g(x)$.

Mathematics teaches that the brightness of each image point x_n of the x-axis of the convoluted image $f_s(x)$ can be computed as follows:

$$f_s(x_n) = \int_{-\infty}^{+\infty} f_o(x_n - x) \cdot g(x) dx$$

This integral is known by the following names: convolution integral, superposition integral, folding integral, Duhamel integral.

It appears from the above that by means of the convolution integral the brightness of each point of the sharp image can be computed if $f_o(x)$ and $g(x)$ are known in mathematical form.

It is an object of the present invention, however, to form the sharp image without the need to first point-wise scan the unsharp image in order to determine $f_o(x)$.

By way of a simple example it is assumed that $g(x)$ and $f_o(x)$ have the following form (see Fig. 2):

$g(x) = 1$ for $x=2$
$g(x) = 1$ for $x=3$
$g(x) = 0$ for $x \neq 2$ en $x \neq 3$
$f_o(x) = 1$ for $x=1$
$f_o(x) = 2$ for $x=2$
$f_o(x) = 3$ for $x=3$
$f_o(x) = \frac{1}{2}$ for $x=4$
$f_o(x) = 0$ for $x \neq 1, 2, 3, 4.$

Using the above computation, the following values for $f_s(x)$ are found:

$f_s(x) = 0$ for $x=0$ en $x < 0$
$f_s(x) = 0$ for $x=1$
$f_s(x) = 0$ for $x=2$
$f_s(x) = 1$ for $x=3$
$f_s(x) = 3$ for $x=4$
$f_s(x) = 5$ for $x=5$
$f_s(x) = 3\frac{1}{2}$ for $x=6$
$f_s(x) = \frac{1}{2}$ for $x=7$
$f_s(x) = 0$ for $x=8$ en $x > 8$

This result can be obtained by first projecting $f_o(x)$ in shifted fashion so that $f_o(o)$ coincides with the point $x = 2$ and subsequently again projecting $f_o(x)$ so that $f_o(o)$ coincides with $x = 3$. In other words, $f_o(x)$ is first shifted two positions to the right and subsequently three positions to the right and the shifted functions are superposed. The duration of each projection of the shifted $f_o(x)$ is determined by the value of $g(x)$. This means that in the present example the two projections have the same duration, so that one and the same intensity of the image is achieved. However, if, for example, $g(3)$ would have the value 2 instead of the value 1, the second projection, i.e. the one with $f_o(x)$ shifted three positions to the right, should have to have a duration twice that of the first projection, assuming that the relationship between duration of the projection and intensity of the image formed on the screen is a linear one.

Consequently, in general $f_s(x)$ can be achieved by shifting $f_o(x)$ along the x-axis until $f_o(o)$ coincides with a point on the x-axis in which $g(x) \neq o$ and by projecting $f_o(x)$ in this point for a duration determined by the associated value of $g(x)$ and by subsequently repeating these steps for all of the other points on the x-axis in which $g(x) \neq o$. This procedure requires $f_o(x)$ to be known in image-form only and not in mathematical form.

Although the example proceeds from very simple one-dimensional functions and only a small number of image points, the same technique may be applied to more complicated two-dimensional functions and a large number of closely spaced image points and even to continuous functions.

In some cases the convolution function $g(x)$ may have negative parts. As a result thereof it may appear necessary to form negative image information as an intermediate step in the convolution procedure. When using a television camera tube as described above, in which a charge image is formed on the target, it is possible indeed to also form negative contributions to the ultimate charge image. As a matter of fact, normally a television camera tube is adjusted so that the charge image on the target is the result of the secondary emission caused by the primary photoelectrons originating from the photocathode. Due to the secondary emission, a positive charge image is produced. It is possible, however, to adjust the tube so that the image is formed directly by slow primary photoelectrons reaching the target. In this manner, negative contributions to the image are formed.

In principle, it is sufficient to change the potential difference between photocathode and target in order to re-adjust the tube. In the event of a relatively high potential difference a positive contribution to the charge image is achieved whereas in the event of a relatively low potential difference a negative contribution thereto is achieved.

Consequently, the control device 12 should control not only the deflection coils but also the adjustment of the tube. However, in general the absolute value of the intensification of the image section for forming positive charge differs from that for forming negative charge. Consequently, this should be taken into account in the control device when re-adjusting the tube.

Should the re-adjustment of the tube be found objectionable, the problem of processing the negative parts of the convolution function may be solved by separating this function into a negative and a positive portion and subseguently convoluting the positive portion with the image to be processed in a first tube and concurrently convoluting the modulus of the negative portion with the image to be processed in a second tube.

The desired output image is achieved by subtracting the output signal of the second tube from that of the first tube. This is schematically shown in Fig. 3. The signal 1 available in image-form is applied through a semi-transparent mirror 30 and an optical system 2a to a device 3a similar to the one designated 3 in Fig. 1 in order to realize convolution with the positive portion $g(x)_{pos}$ of the convolution function $g(x)$, while the image is at the same time reflected by the semi-transparent mirror 30 to a mirror 31 applying the image through an optical system to a device 3b similar to the one designated 3 in Fig. 1 in order to realize convolution with the negative portion $g(x)_{min}$ of the convolution function $g(x)$.

The output signals of the two devices are subtracted from each other in known per se manner in a differential amplifier 33, the output signal of which may be applied to, for example, a monitor 9 in order to visualize the result of the convolution.

By means of the method according to the invention, an unsharp input image can be transformed into a sharp output image in, for example, 20 msec. This high processing rate renders the invention suitable for processing stationary as well as moving images.

There are different manners of realizing that the input image is projected onto the target at locations determined by the convolution function during the period of time determined by this function.

A first possibility is the use of a step-like voltage applied to the deflection means. The level of a certain step determines the location of the projection of the image, while the time interval during which this level is maintained determines the intensity.

If the transition from a first level to a next (i.e. from a first projection location on the target to a next projection location) cannot take place momentaneously, during this transition it can be ensured that no electrons reach the target, for example, by deactivating the accelerating field between photocathode and target. In this manner, the image that might be formed during the transfer between two locations can be suppressed.

Such a temporary suppression of the image integration can also be obtained by means of a fast shutter (designated 20 in Fig. 1) mounted in front of the entrance window, which shutter closes for short periods of time at the desired instants in accordance with the associated values of the convolution function. If necessary, an additional lamp 21 may be used for illuminating the input image.

A further possibility is to apply such a deflection voltage to the deflecting means that the input image is moved with uniform speed to and fro over the target, for example in accordance with a television frame, at any rate over that portion of the target where the convolution function is not permanently nil. The intensity at the successive image positions is determined by a light source modulated in accordance with the convolution function, if necessary in combination with a shutter, or only by controlling the shutter times in accordance with the values of the convolution function.

It is also possible to use a plurality of light sources, if necessary with associated shutters, so that different portions of the image can be processed with different convolution functions.

In all cases, the control of the light sources and/or shutter(s) should be related to the instantaneous location of the projection of the image on the target and hence to the instantaneous value of the deflection voltage(s), as indicated by the broken lines in Fig. 1.

Various modifications of the above embodiments of the method and the apparatus according to the invention will be obvious to the worker in the art. Such modifications are considered to fall within the scope of the invention.

= CLAIMS =

1. A method for electro-optically convoluting a signal available in image-form with at least one known convolution function, characterized in that the image of the signal available in image-form is applied to the entrance window of an electro-optical image-forming device including a screen integrating according to time and further including deflection means; and that by controlling the deflection means the input image is projected onto said integrating screen during time intervals corresponding to the value of the convolution function as associated with the instantaneous deflection and with such an intensity that the convoluted signal in image-form is produced on the screen.

2. A method according to claim 1, characterized in that the intensity of the image formed on the integrating screen, as associated with each deflection position and determined by the convolution function(s), is obtained by illuminating the input image with light of constant intensity and controlling the duration of each projection in accordance with the associated value of the convolution function.

3. A method according to claim 1, characterized in that the intensity of the image formed on the integrating screen, as associated with each deflection position and determined by the convolution function, is obtained by projecting the input image during a constant time interval and controlling the brightness of each projection in accordance with the associated value of the convolution function.

4. A method according to claim 2 or 3, characterized in that in between two successive projections of the input image onto different locations of the integrating screen, the image formation on said screen is prevented.

5. A method according to claim 4, characterized in that the image formation is prevented by applying a suitable potential to the integrating screen.

6. A method according to claim 4, characterized in that the image formation is prevented by means of a shutter disposed in front of the entrance window, which shutter is controlled by a signal derived from the convolution function.

7. A method according to any one of preceding claims 1-5, characterized in that the input image is illuminated by at least one light source, said light source being actuated at instants and for intervals as determined by the convolution function and providing the same light intensity when actuated.

8. A method according to claim 6, characterized in that the input image is illuminated by at least one constant light source.

9. A method according to claim 1 or 3, characterized in that such an electrical signal is applied to the deflection means that the input image is continuously deflected over the integrating screen and that the input signal is illuminated with a light intensity determined by the convolution function(s) only at locations determined by said convolution function(s).

10. A method according to claim 9, characterized in that the illumination is each time realized by means of one or more light sources the intensities of which are controlled by the convolution function(s) and by means of at least one shutter disposed in front of the entrance window and controlled by the convolution function(s).

11. A method according to claim 10, characterized in that a plurality of groups of light sources is used for illuminating the input image, which are each controlled by a separate convolution function.

12. A method according to any one of the preceding claims, characterized in that the image-forming device is a television camera tube having an image section.

13. A method according to any one of the preceding claims, characterized in that a convolution function having positive and negative parts is used and that the convolution function is accordingly divided into a positive portion which is convoluted with the signal available in image-form in a first electro-optical image-forming device producing a first partial image output signal, and a negative portion which is converted into a positive portion by omitting the minus sign and which is convoluted with the signal available in image-form in a second image-forming device producing a second partial image output signal; and that for forming the desired final output image the second partial image output signal is subtracted from the first partial image output signal.

14. A method according to any one of claims 1-12, characterized in that a convolution function having positive and negative parts is used and that the convolution function is divided into a positive portion which is first convoluted with the signal available in image-form to produce a first convoluted partial image signal which is temporarily stored, and a negative portion which is converted into a positive portion by omitting the minus sign and which is subsequently convoluted with the signal available in image-form to produce a second convoluted partial image signal; and that for forming the final convoluted image the second partial image signal is subtracted from the first partial image signal.

15. A method according to any one of claims 1-12, characterized in that a convolution function having positive and negative parts is used; that the electro-optical image-forming device is a television camera tube on the target of which positive as well as negative charge image contributions can be formed by re-adjusting the tube; and that in the event of a positive value of the convolution function the tube is operated in the positive mode and in the event of a negative value of the convolution function the tube is operated in the negative mode.

16. An apparatus for electro-optically convoluting a signal available in image-form with at least one known convolution function, characterized by at least one television camera tube having an image section, which image section includes deflection means for the input image.

17. An apparatus according to claim 16, characterized by a control device applying to the deflection means a signal derived from the convolution function.

18. An apparatus according to claim 17, characterized by a shutter disposed in front of the entrance window, which shutter is controlled by the control device so as to be closed at instants determined by the convolution function.

19. An apparatus according to any one of claims 16-18, characterized by a constant light source illuminating the input image.

20. An apparatus according to claim 16, characterized by a control device applying to the deflection means a periodic electrical signal for regularly deflecting the input image, and applying to the shutter disposed in front of the entrance window a signal derived from the convolution function so as to open and close said shutter at instants determined by the convolution function and for intervals determined by said convolution function.

21. An apparatus according to claim 16 or 20, characterized by a control device applying to said deflecting means a periodic electrical signal for regularly deflecting the input image and controlling one or more light sources by means of a signal derived from the convolution function so as to illuminate the input image at instants determined by the convolution function and for intervals determined by said convolution function.

22. An apparatus according to claim 21, characterized by a plurality of lamps for illuminating the input image, the light sources being divided into groups each receiving from the control device a control signal derived from an associated convolution function.

23. An apparatus according to any one of claims 16-22, characterized in that the image section of the television camera tube is re-adjustable so that in a first range of potential differences between the photocathode and the target of the image section a positive charge image contribution can be formed on the target while in a second range of potential differences between the photocathode and the target of the image section a negative charge image contribution can be formed on the target; and that means are provided for re-adjusting the image section in response to each change in polarity of the convolution function.

24. An apparatus according to any one of claims 16-23, characterized by two television camera tubes each having an image section including deflection means, means being provided for applying the signal available in image-form to the entrance windows of the two tubes, and switching means being provided for switching on one tube and switching off the other in response to each change in polarity of the convolution function, the image formation in one tube being realized under the influence of the positive portion of the convolution function and the image formation in the other tube being realized under the influence of the modulus of the negative portion of the convolution function; and by a device subtracting the output signals of the two tubes from each other.

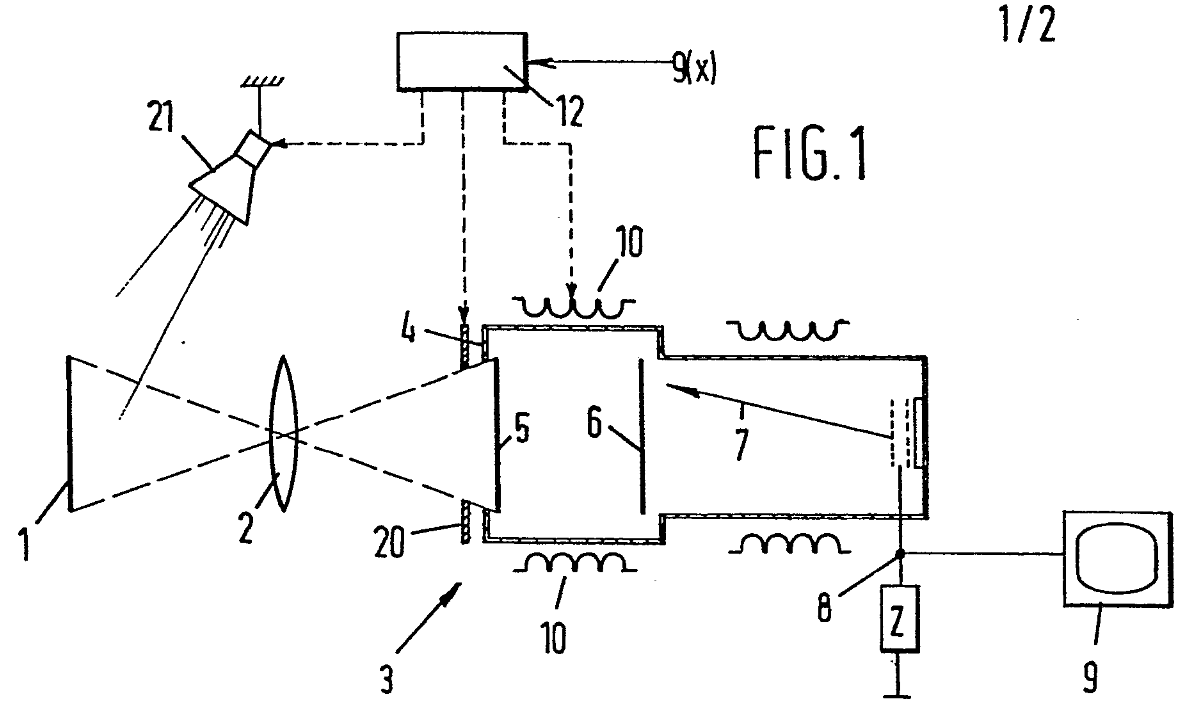


FIG.1

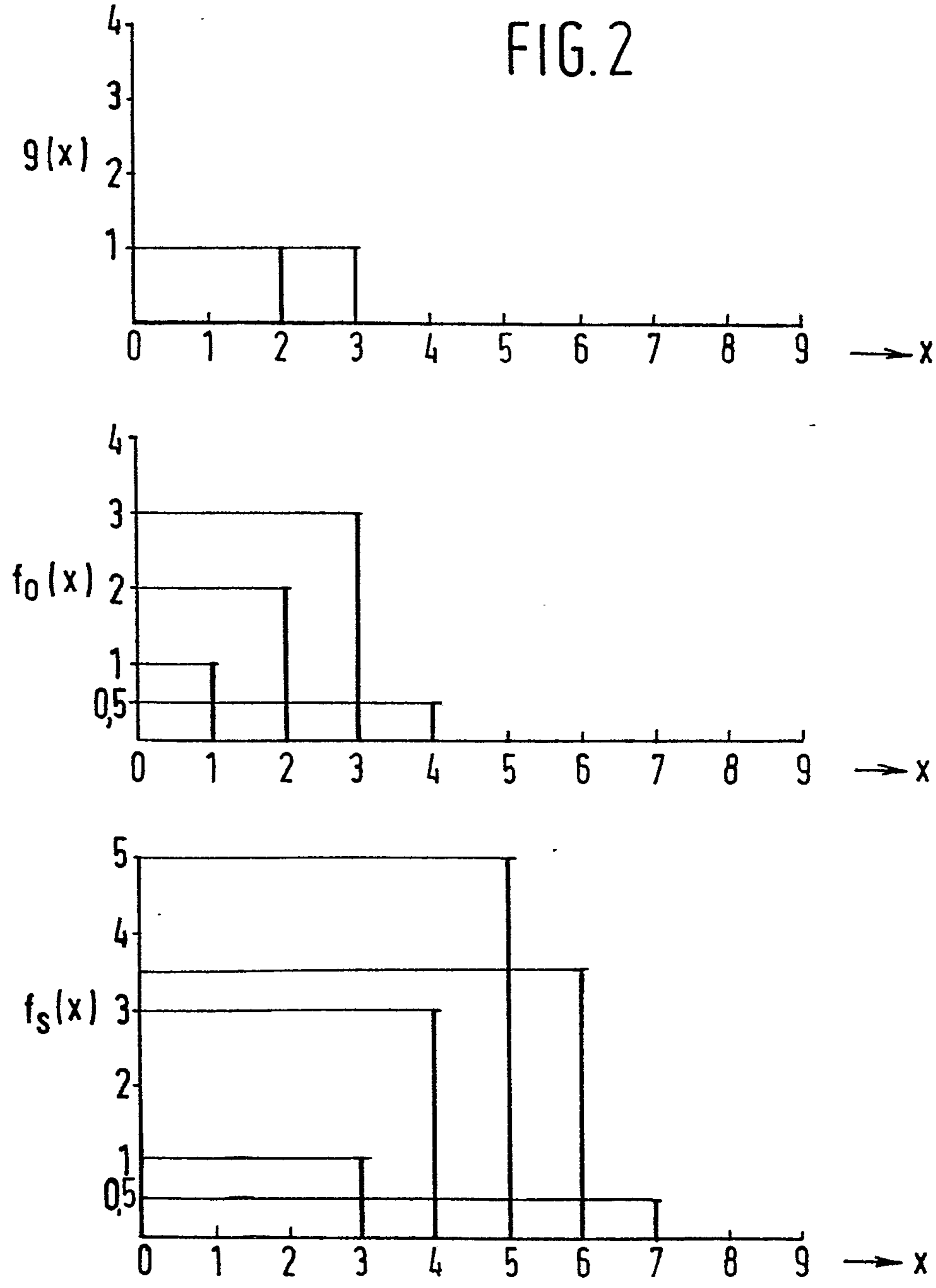
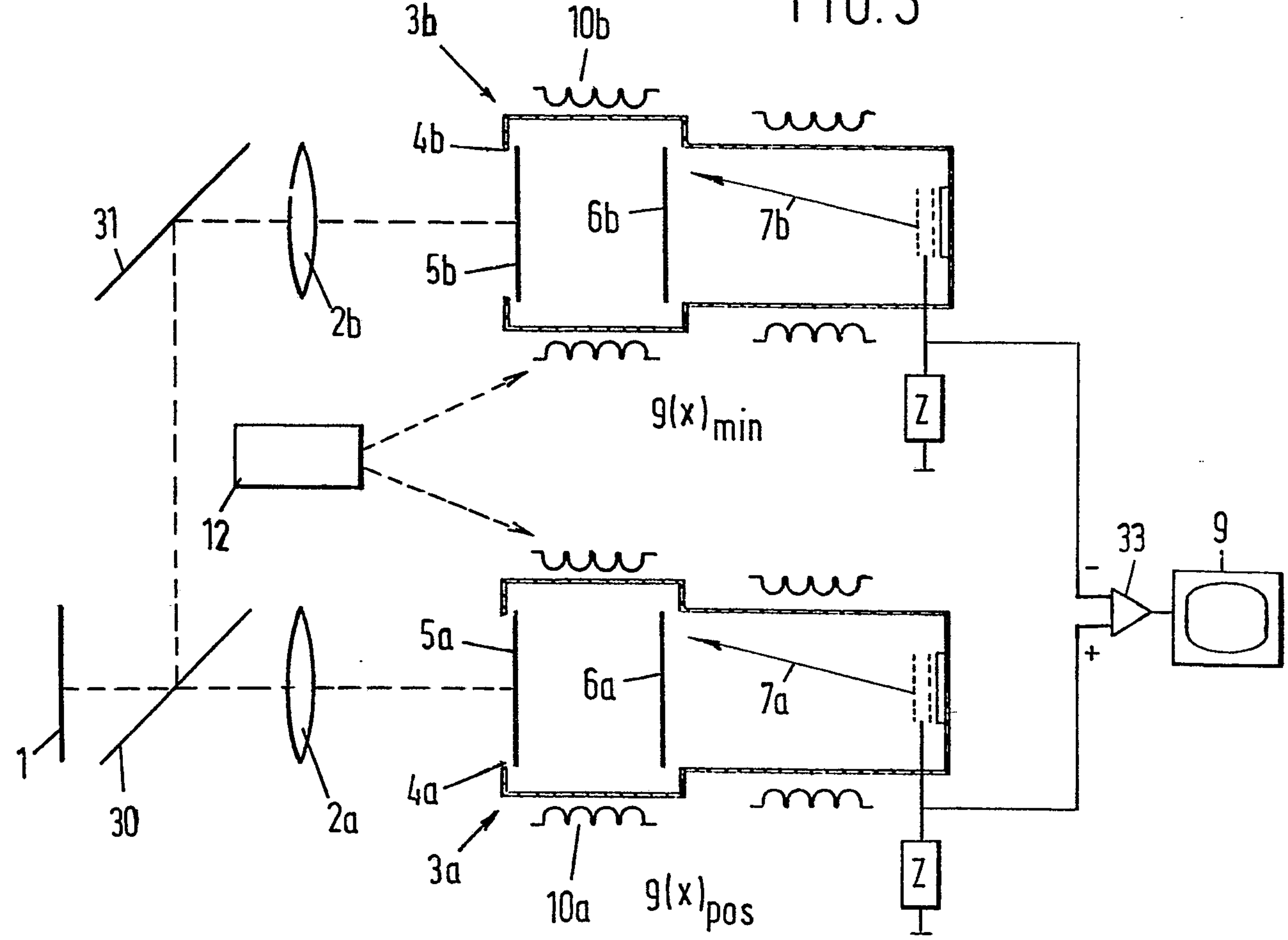


FIG.2

FIG. 3


3b
10b
4b
31
6b
7b
5b
2b
g(x)min
Z
12
33
9
-
+
5a
6a
7a
1
30
2a
4a
3a
10a
g(x)pos
Z

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EUROPEAN SEARCH REPORT

Application number

EP 81 20 1229

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
Y	US - A - 4 139 897 (USA SECRETARY OF NAVY)	
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	* Column 7, lines 27-45 *	1,3-6, 9,10, 13-16, 23,24
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CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)

G 06 G 9/00

TECHNICAL FIELDS SEARCHED (Int.Cl. 3)

G 06 G 9/00
G 02 B 27/38

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	02-02-1982	THOMAES

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EUROPEAN SEARCH REPORT

Application number
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DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
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A	US - A - 4 039 815 (DE OUDE DELFT) * Column 2, lines 12-54; column 3, lines 1-14 * -----	1,13,24	
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