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EUROPEAN PATENT APPLICATION

⑳ Application number : **91305513.3**

㉑ Int. Cl.⁵ : **G09G 3/20**

㉒ Date of filing : **18.06.91**

㉓ Priority : **22.06.90 GB 9013914**

㉔ Date of publication of application :
02.01.92 Bulletin 92/01

㉕ Designated Contracting States :
DE FR GB IT NL

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㉙ **Visual display.**

㉚ A visual display has a flicker frequency which is higher than a critical flicker fusion frequency for central vision so that, when viewed directly, no flicker is discernable. The flicker frequency is less than a critical flicker fusion frequency for peripheral vision so that flicker is at least subliminally apparent in the peripheral vision in order to attract attention to the display. A suitable flicker frequency for many purposes is 75 Hz.

The present invention relates to a visual display.

It is known that human peripheral vision is more sensitive to and aware of flicker and movement than central vision. Although this sensitivity and awareness is dependent on the level of illumination, there is a substantially constant difference of about 15 Hz between the perception thresholds of flicker for central and peripheral vision for substantially any given level of illumination. This difference occurs between subtended viewing angles of approximately 10° and approximately 30°, with very little change in perception taking place between subtended viewing angles of 30° and 70°.

Liquid crystal displays have been used in personal computers and television sets and have also been used as a modulating element in television projectors. In order to form the display, a liquid crystal display panel is normally illuminated from behind by a steady source of light, generally referred to as a back light. All development has been directed to producing a displayed image which is steady and does not flicker.

In the case of cathode ray tube displays, it is well known that, for relatively low refresh or frame rates such as 25 Hz, a short persistence phosphor CRT exhibits more flicker than a phosphor of long persistence. However, long persistence phosphors cannot be used to reduce flicker in television displays because the long decay period of the phosphor "smudges" a moving picture to an unacceptable degree.

Cathode ray tubes having phosphors of short persistence produce a pulsatile light output whose effect on the retina of the eye is to enhance the received light energy by a factor of approximately two compared with a liquid crystal display which is back lit with a "chopped" light source having a duty factor in the region of 50%. For both central and peripheral vision, this apparent doubling of energy received by the retina is equivalent to raising the threshold frequency at which flicker fusion occurs by about 10 Hz.

At present there are two standards for television picture "refresh" rates, namely the European system which uses a 50 Hz field rate and the North American system which uses a 60 Hz field rate. At high levels of illuminance, both systems (and especially the 50 Hz system) are perceived to exhibit flicker.

Recent developments in television towards the production of higher definition images propose that field rates should be doubled i.e. to 100 or 120 Hz. Such refresh rates ensure that, even for very high levels of illuminance, there is no discernible flicker in the central or peripheral vision. However, steady pictures produced by such television systems can tend to remove some of the interest from the images.

According to the invention, there is provided a visual display having a flicker frequency for at least a portion of the display which is between a critical flicker

fusion frequency for central vision and a critical flicker fusion frequency for peripheral vision.

The term "critical flicker fusion frequency" as used herein means the threshold frequency for the prevailing illumination above which flicker is not discernible in the relevant portion of vision. As noted above, the critical flicker fusion frequency for peripheral vision is greater than that for central vision by approximately 15 Hz throughout most of the range of illumination produced by visual displays. The portion corresponding to central vision or "foveal" vision is that part of an image which subtends at the eye of a viewer an angle of less than or equal to approximately 10°. The portion for peripheral vision is that part of an image which lies outside a subtended angle of approximately 30°.

By choosing a display flicker frequency which is greater than the critical flicker fusion frequency for central vision, the viewer sees a steady display image which is substantially free from flicker. However, when the visual display falls within the peripheral vision of the viewer, the viewer is aware, at least subliminally, of flicker in the display image. This perceived flicker is similar to movement in the peripheral vision in that the viewer's attention is immediately drawn to the displayed image because the critical flicker fusion frequency for peripheral vision is greater than the flicker frequency. The effect is to make the displayed image more interesting or attractive and to draw attention to it while avoiding any substantial trace of flicker once the viewer is concentrating on the image.

In the case of a sequentially refreshed display, such as a cathode ray tube displaying a television signal, the refresh rate is preferably made equal to the flicker frequency. In the case of interlaced television pictures, the field rate is made equal to the flicker frequency whereas, in the case of non-interlaced pictures, the frame rate is made equal to the flicker frequency.

The display may comprise a plurality of picture elements whose light transmissive properties are controllable and rear illumination means whose output is amplitude modulated at the flicker frequency. Thus, even if the actual refresh rate of the picture is higher than the critical flicker fusion frequency for peripheral vision, modulating or "chopping" the rear illumination means at the flicker frequency ensures that the peripheral vision of the viewer perceives flickering in the displayed images. Preferably, the mark/space ratio is adjustable so as to allow adjustment of the critical flicker fusion frequencies for central and peripheral vision. As noted above, pulsatile light emission has the effect of raising the critical flicker fusion frequencies and it has been found that alternating the mark/space ratio permits adjustment of these frequencies such that they lie on either side of, for instance, a predetermined refresh rate. The peak light

output of the rear illumination means may be adjustable in order to compensate for variations in perceived brightness caused by varying the mark/space ratio.

The picture elements may, for instance, be provided by a liquid crystal display.

As a possible alternative to controlling the rear illumination means, the picture elements themselves may be controlled by superimposing an amplitude modulation on the picture element control signals.

In the case of a display comprising a plurality of light emitting picture elements, means may be provided for amplitude modulating the light outputs of the picture elements at the flicker frequency.

Means may be provided for varying the flicker frequency in accordance with the level of illumination. For instance, the flicker frequency may be varied so as to ensure that it lies between the critical flicker fusion frequencies for central and peripheral vision for the whole of the display or only part thereof. Also, the flicker frequency may be adjusted in accordance with the content of the displayed image, for instance to compensate for different illumination levels corresponding to different images. Also, means may be provided for selectively varying the flicker frequency to be above the critical flicker fusion frequency for peripheral vision for predetermined times. During such times, a viewer does not perceive flicker in his peripheral vision and this may be used to limit the effect or to increase the impact of the attraction at certain times, for instance in accordance with program content of the image. Also, any tendency to habituation i.e. for the peripheral vision flicker attraction to lose its effect can be reduced or avoided by making use of the effect occasionally and/or for relatively short periods.

The flicker frequency is preferably at the arithmetic, or possibly geometric, mean of the critical flicker fusion frequencies for central and peripheral vision. This allows for variations in illumination of the display while ensuring that flicker-free direct viewing and peripheral vision flicker perception are maximised for most or all of the normal ranges of illuminations present in, for instance, the image displayed by a television set in normal levels of ambient illumination.

It has been found that a flicker frequency of 75 Hz can be used with a wide variety of displays in a wide variety of applications and, in many ways, represents an optimum frequency. For instance, it bears a simple relationship to the field frequencies of the standard television systems mentioned above and thus facilitates conversion between television standards. In combination with 720 active i.e. image carrying picture lines, conversion between television standards is facilitated, so that a new standard for high definition television of 720 active lines per frame by 75 frames per second has many advantages.

The invention will be further described, by way of

example, with reference to the accompanying drawings, in which:

Figure 1 is a graph of retinal illuminance against screen refresh frequency illustrating critical flicker fusion frequencies for different screen illuminance, types of display, and viewing angles;

Figure 2 shows part of Figure 1 to a greatly enlarged scale and illustrating the effect of varying the duty factor a liquid crystal display light output;

Figure 3 is a graph of flicker fusion frequency against screen illumination for peripheral and central vision and for different types of display; Figures 4 to 7 are graphs corresponding to Figure 3 and illustrating operation of different types of display;

Figure 8 is a diagrammatic illustration of a visual display constituting an embodiment of the invention;

Figure 9 is a front view of part of the display of Figure 8; and

Figure 10 is a block schematic diagram of a visual display constituting another embodiment of the invention.

In Figures 1 to 7 of the accompanying drawings, retinal illuminance is shown in Trolands, screen illuminance is shown in Candella per square metre, and screen refresh frequency and flicker fusion frequency are shown in Hertz (Hz). The steady or direct component in Trolands is equal to the product of the net screen luminance and the area of the pupil, with the pupil area measured in square millimetres and the screen luminance measured in Candella per square metre (cdm^{-2}).

In Figures 1 to 7, frequency axes are linear whereas illuminance axes are logarithmic.

Figure 1 illustrates critical flicker fusion frequencies for viewing angles of 10°, 30°, 50° and 70° at different levels of screen luminance for cathode ray tube displays and for liquid crystal displays of the back lit type having pulsed back-illumination with a duty factor of approximately 50%. Throughout most of the region of interest, in particular above screen luminance levels of approximately 100 cdm^{-2} , the differences in critical flicker fusion frequencies for viewing angles of 30°, 50°, and 70° are relatively small so that the value for 30° may be chosen to represent the critical flicker fusion frequency for peripheral vision.

Figure 1 illustrates the phenomenon that the difference between critical flicker fusion frequencies for central and peripheral vision is substantially constant, at least to a fair approximation, at all light levels and for different types of display, this difference amounting to approximately 15 Hz. The differences in critical flicker fusion frequencies for cathode ray tube displays and liquid crystal displays for the same screen illuminance results from the fact that a cathode ray tube provides a relatively lightly pulsatile or pulsed

display whereas the pulsed back lit liquid crystal display is illuminated with a duty factor of approximately 50%. The critical flicker fusion frequencies for central and peripheral vision for a cathode ray tube display are therefore greater than for such a liquid crystal display for the same level of screen illuminance.

Figure 2 illustrates this in more detail for a particular value of screen luminance and illustrates equal illuminance in the form of a "template" bounded by a parallelogram 10. The template 10 encloses horizontal lines representing a short or medium persistence phosphor CRT (11), a liquid crystal display with pulsed back lighting having a 50% duty factor (12), and liquid crystal displays with pulsed back lighting having duty factors of less than 50% (13 to 17). The back lighting of the LCD is pulsed with a mark/space ratio such that the duty factor progressively increases from the line 13 to the line 17 and to a maximum value of 50% at the line 12, the peak light output of the pulsed back lighting increasing, for instance approximately inversely, with decreasing duty factor to maintain constant screen luminance. As can be seen from Figure 2, as the duty factor decreases the critical flicker fusion frequencies for central and peripheral vision increase towards, that for the CRT display. Duty factor could be increased beyond 50% if desired to lower the critical flicker fusion frequencies below those for the line 12. This provides a ready means for varying the critical flicker fusion frequencies for a liquid crystal display.

Figure 3 illustrates the range of screen illuminance for a typical video signal, the actual levels of illuminance being typical for projection television. The screen illuminance varies from about 1000 cdm⁻² for black level to about 3000 cdm⁻² for peak white level. Typical illuminance values for a domestic television set would be about an order of magnitude smaller.

Figure 4 shows a cathode ray tube template in the form of a parallelogram 20 superimposed on the graph of Figure 3 to allow selection of a suitable display flicker frequency between the critical flicker fusion frequencies for central and peripheral vision. For the range of levels of screen illuminance corresponding to the video signal shown, a refresh frequency for the display of, for instance, 85 Hz ensures that flicker will be perceived in the peripheral vision throughout the range of screen illuminance whereas central vision will not be sensitive to flicker. In other words, a refresh rate of 85 Hz lies below the critical flicker fusion frequency for peripheral vision throughout the range of screen illuminance but above the range of critical flicker fusion frequencies for central vision. A refresh rate of 75 Hz would be more suitable for a domestic television set.

Figure 5 illustrates a steady liquid crystal display template 30 corresponding to a liquid crystal display with back lighting of 50% duty factor. A refresh rate of 75 Hz lies between the critical flicker fusion fre-

quencies for central and peripheral vision for illuminance levels associated with projection television whereas a refresh rate of 65 Hz would be appropriate for a domestic television set.

Figure 6 shows a plurality of templates for pulsatile liquid crystal displays with back lighting having different duty factors and illustrates that the critical flicker fusion frequencies for central and peripheral vision may be adjusted, for instance so as to permit a predetermined refresh rate to lie between the critical flicker fusion frequencies for the range of screen illuminance require for a given application. For instance, if a refresh rate of 75 Hz is chosen as a television standard, a liquid crystal display may be used both in domestic television sets and in projection televisions, whereas Figure 3 indicates that a cathode ray tube display could be used for the range of illuminance associated with domestic television sets but not for ranges associated with projection televisions, because the critical flicker fusion frequencies for central and peripheral vision at the light outputs required for projection television would be greater than the refresh frequency.

Figure 7 illustrates a dynamic template 40 which may be achieved by varying the duty factor of a liquid crystal display in accordance with the illuminance level represented by a video signal. For instance, by increasing the duty factor as the screen illuminance increases (and by varying the peak level of back lighting approximately inversely to compensate), the variation in critical flicker fusion frequencies for central and peripheral vision over the range of screen illuminance can be substantially reduced. Thus, a refresh rate of 75 Hz falls well below the lowest critical flicker fusion frequency for peripheral vision and well above the highest critical flicker fusion frequency for central vision over a wide range of illuminance levels. Such an arrangement may be used, for instance, for displaying a series of images exhibiting a very large variation in screen illuminance or for images which present very high contrast.

Figure 8 illustrates a visual display comprising a liquid crystal display screen 50 behind which is located a back light comprising a constant output light source 51 and a rotary shutter 52. The liquid crystal display screen 50 is viewed from the front (as shown at 53) and comprises a plurality of picture elements, for instance addressed in a raster-scan sequence or simultaneously at a picture refresh frequency determined by a television system controlling the display. The rotary shutter 52 comprises a wheel of opaque material with radially extending regions having different light-transmissive properties, as shown in Figure 9. The wheel 52 rotates about its axis and interrupts light from the light source 51 to the screen 50 at the flicker frequency, which is preferably 75 Hz.

As shown in Figure 9, the wheel 9 is movable perpendicular to its axis so that different concentric rings

alternately pass and interrupt light from the constant light source 51 to the screen 50. The innermost ring 60 does not interrupt the light but provides the greatest neutral density attenuation of light. The next ring comprises portions 61 interspersed with opaque sectors. The portions 61 are neutral density filters but provide less attenuation than the ring 60. Correspondingly, the outermost ring comprises portions 62 which provide relatively little light attenuation and which are likewise interposed with the opaque sectors.

By moving the shutter 52 perpendicular to its axis during rotation, it is possible to vary the mark/space ratio, and hence the duty factor, of illumination of the screen 50. In order to compensate for the changing duty factor, the peak light output supplied to the screen varies approximately inversely with the duty factor. The critical flicker fusion frequencies may therefore be adjusted, for instance in accordance with screen illuminance, so as to ensure that the display flicker of 75 Hz always falls between the critical frequencies for central and peripheral vision.

In alternative embodiments, the function of the "mechanical" rotary shutter may be performed by electronic means. For instance, the back light may be of the type which is capable of providing a variable mark/space light output and variable peak power so as to maintain constant average light output and hence screen illuminance. Alternatively, the back light may provide constant light output and the liquid crystal display screen may be controlled so as to block periodically the transmission of light to act as a shutter. Again, it is preferable that the intensity of the back light can be increased to compensate for changes in the mark/space ratio of the "electronic shutter" so as to maintain constant screen illuminance.

In another embodiment, the display may comprise a plurality of light emitting means, such as an array of lamps or the like. In this case, the light emitting elements may be modulated so as to provide a flicker frequency between the critical flicker fusion frequencies for central and peripheral vision.

Displays of this type may be used in various applications. For instance, the display may be arranged to optimise the curiosity of potential viewers so as to attract them to view the display. The "mechanical" or "electronic" shutter may be adjusted so that, for any chosen average screen illuminance, the critical flicker fusion frequencies for central and peripheral vision are set either side of the screen refresh frequency or flicker frequency. Such adjustment may be made dependent on any changes to a "brightness" control of the display.

The display may be used to provide program enhancement by dynamically changing the critical frequencies so as to emphasise, possibly subliminally, changes in mood of a television programme. In the case of a liquid crystal display, for instance, the duty

factor or mark/space ratio may be increased so as to lower the critical flicker fusion frequencies when pastoral scenes are portrayed. However, the duty factor may be temporarily reduced so as to raise the critical frequencies and increase peripheral curiosity for more dramatic moments. Such changes may be updated periodically, for instance approximately every ten seconds. The duty factor may be changed so as to avoid habituation. It is also possible to alter the critical frequencies to such an extent that the viewer perceives flicker in the central or foveal vision in order to produce a more dramatic effect.

Another possible application is to provide dynamic control of curiosity and watchability of the display. Whereas bright scenes may have been adjusted such that the critical frequencies are on either side of the screen refresh frequency, dimly lit scenes may allow the critical flicker fusion frequency for peripheral vision to fall below the refresh frequency, thus inadvertently eliminating the peripheral vision curiosity effect. This can be avoided by increasing the pulsatility of the display in mid and dark grey areas of the scene. For dark areas of the picture, the peripheral curiosity effect may be maintained by reducing the mark/space ratio of a pulsed display instead of reducing the instantaneous light intensity.

The embodiment shown in Figure 10 comprises a raster-scan display of the type used in televisions. A composite video signal is supplied to an input 70 and is processed by an intensity/colour processing circuit 71. The output of the circuit 71 is connected to a cathode ray tube 72 so as to control the or each electron beam within the tube 72. The input signal is also supplied to a sync generator 73, which extracts vertical and horizontal sync pulses from the composite input signal and supplies these to a vertical time base 74 and a horizontal time base 75, respectively. The vertical time base 75 operates at 75 Hz in order to define the field or frame rate, depending on whether the input signal represents an interlaced or non-interlaced display. As described above, the 75 Hz field or frame repetition rate corresponds to a flicker frequency between the critical fusion flicker frequencies for central and peripheral vision. The horizontal time base 75 generates horizontal scanning signals so as to define 720 lines per frame.

Claims

1. A visual display characterised in that a flicker frequency for at least a portion of the display is between a critical flicker fusion frequency for central vision and a critical flicker fusion frequency for peripheral vision.
2. A display as claimed in Claim 1 of the sequentially refreshed type, characterised in that the refresh

rate is equal to the flicker frequency.

3. A display as claimed in Claim 2 of the interlaced raster-scan type, characterised in that the field rate is equal to the flicker frequency. 5
4. A display as claimed in Claim 2 of the non-interlaced raster-scan type, characterised in that the frame rate is equal to the flicker frequency. 10
5. A display as claimed in Claim 1, characterised by a plurality of picture elements (50) whose light transmissive properties are controllable and rear illumination means (51, 52) whose output is amplitude modulated at the flicker frequency. 15
6. A display as claimed in Claim 5, characterised by means (52) for amplitude modulating the rear illumination means with a rectangular waveform of controllable mask/space ratio. 20
7. A display as claimed in Claim 5 or 6, characterised in that the plurality of picture elements are constituted by a liquid crystal display (50). 25
8. A display as claimed in Claim 1, characterised by a plurality of picture elements whose light output properties are controllable and means for superimposing on picture element control signals an amplitude modulation at the flicker frequency. 30
9. A display as claimed in any one of the preceding claims, characterised by means for varying the flicker frequency in accordance with the level of illumination. 35
10. A display as claimed in any one of the preceding claims, characterised by means for selectively varying the flicker frequency above the critical flicker fusion frequency for peripheral vision for predetermined times. 40
11. A display as claimed in any one of the preceding claims, characterised in that the flicker frequency is the arithmetic or geometric means of the critical flicker fusion frequencies for central and peripheral vision. 45
12. A display as claimed in any one of the preceding claims, characterised in that the flicker frequency is 75 HZ. 50
13. A display as claimed in Claim 12 of the raster-scan type, characterised by 720 active picture lines. 55

SCREEN LUMINANCE
and
TYPE OF DISPLAY

RETINAL
ILLUMINANCE
(TROLANDS)

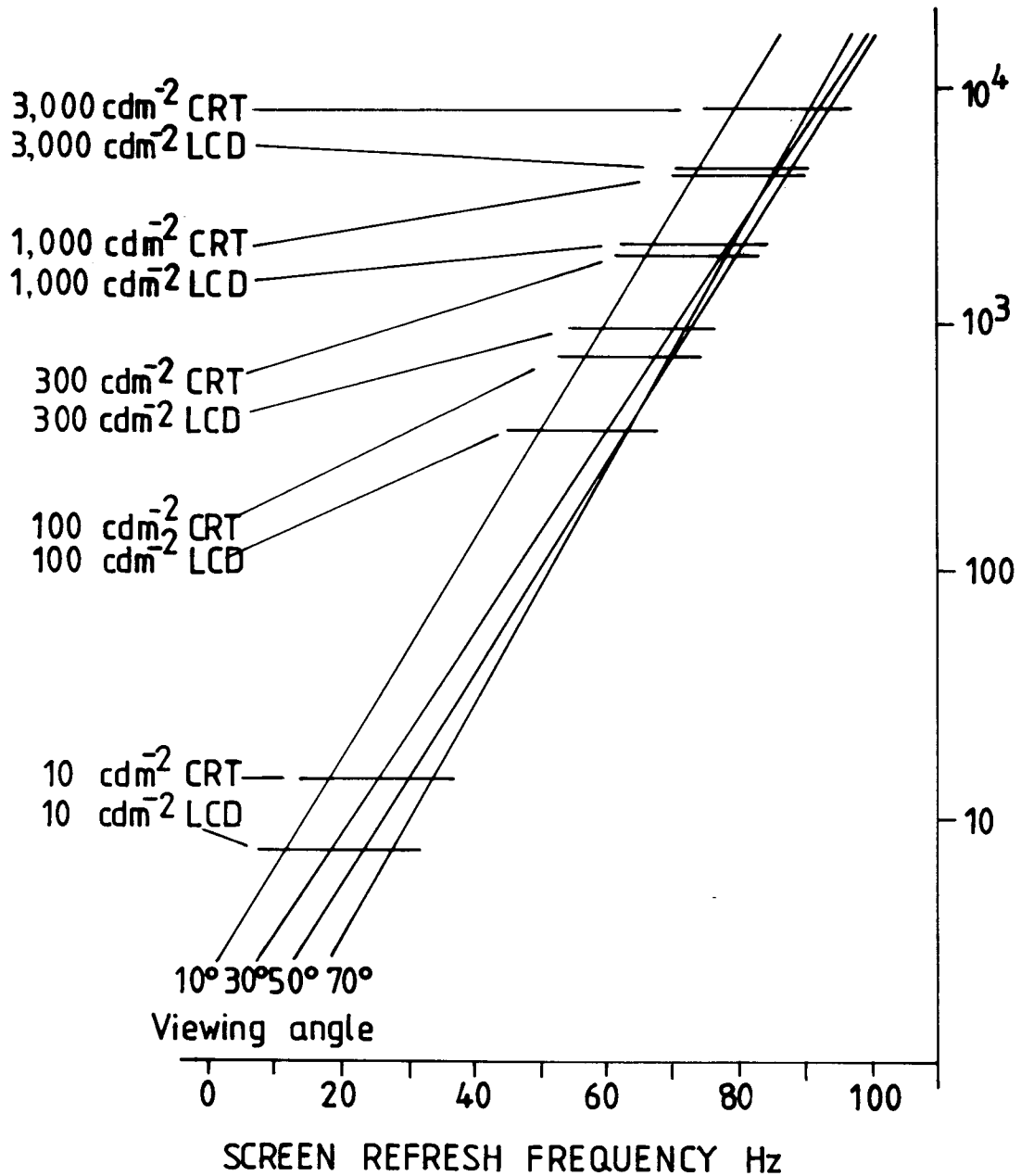
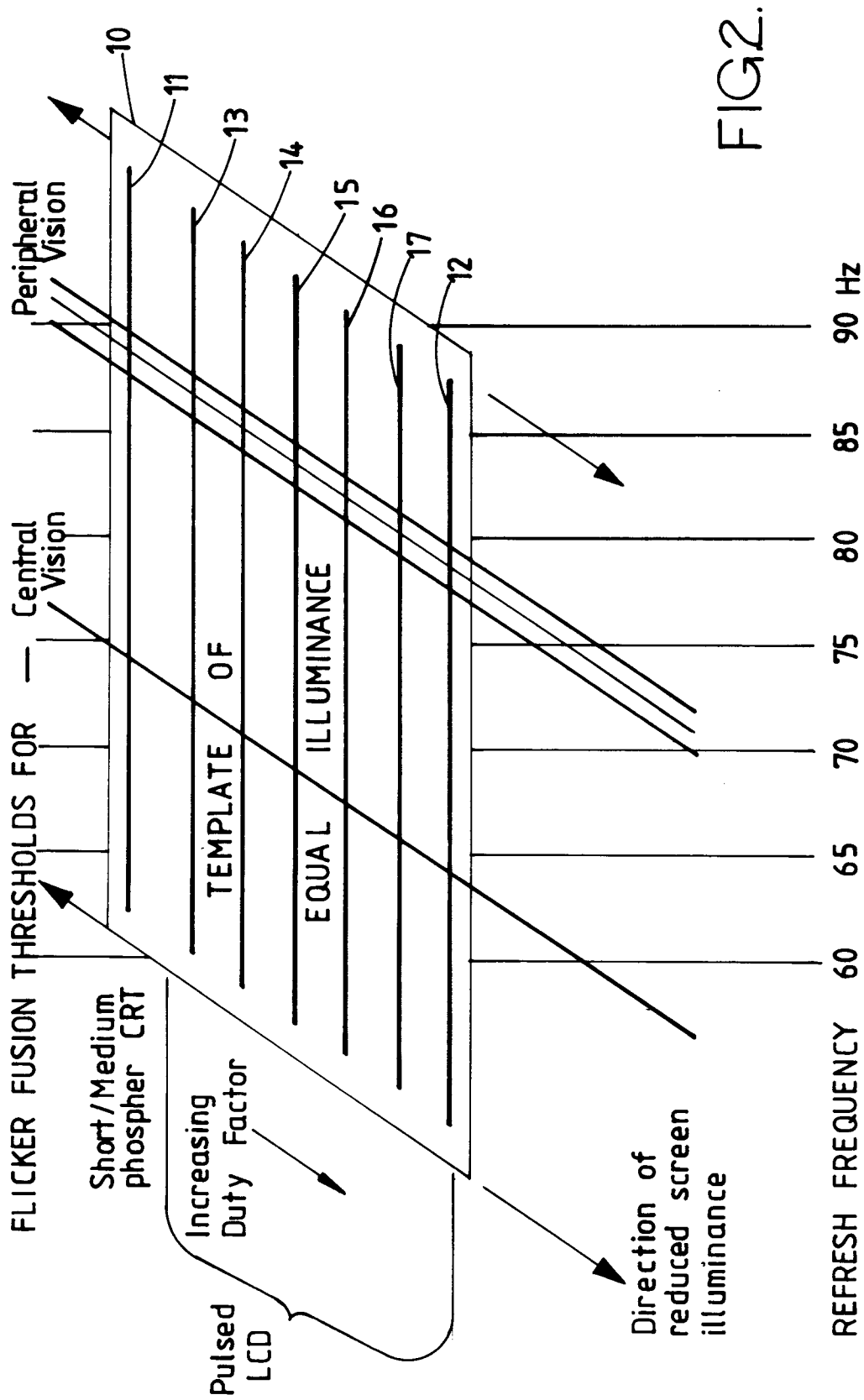


FIG.1.



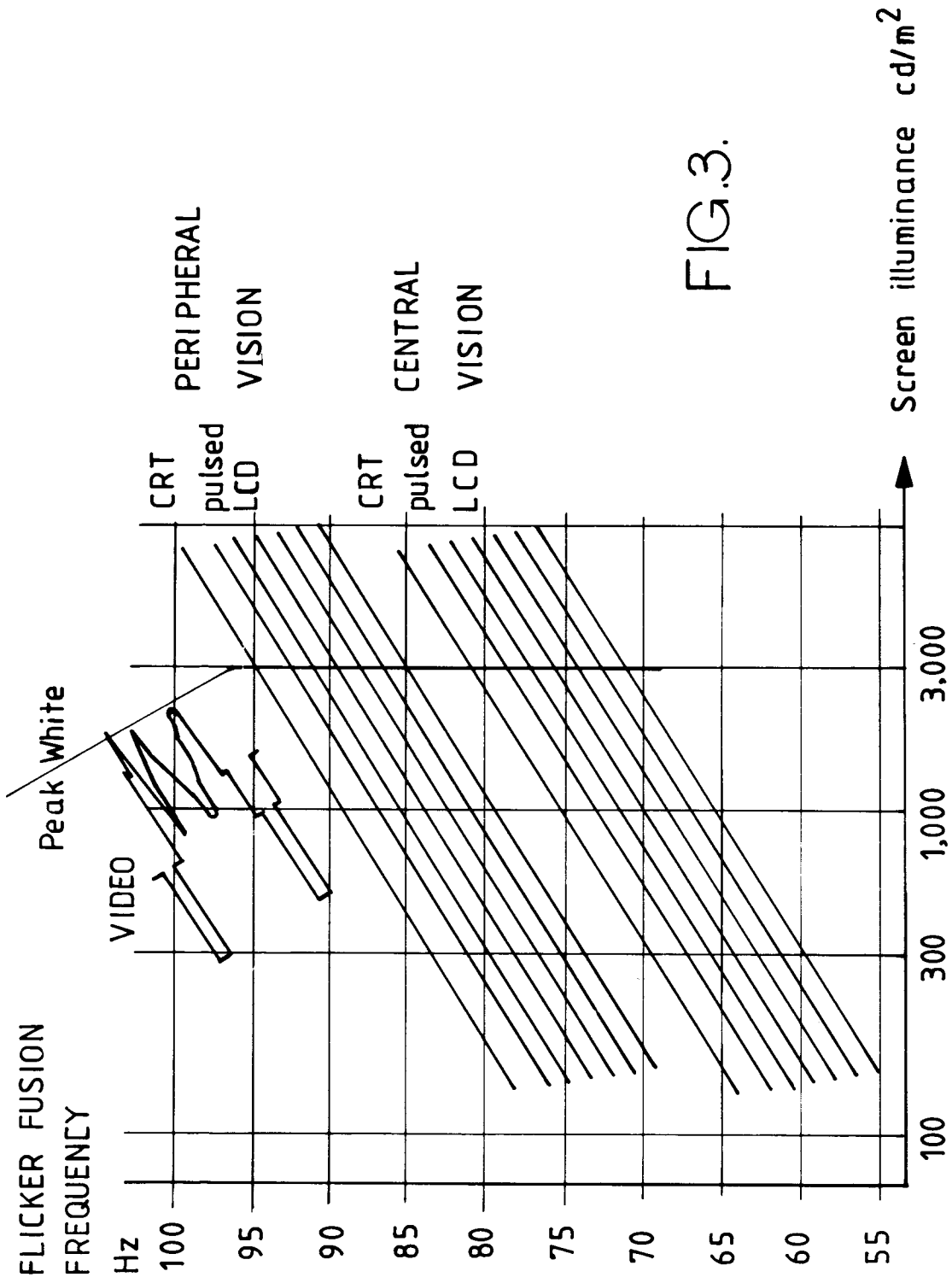


FIG.3.

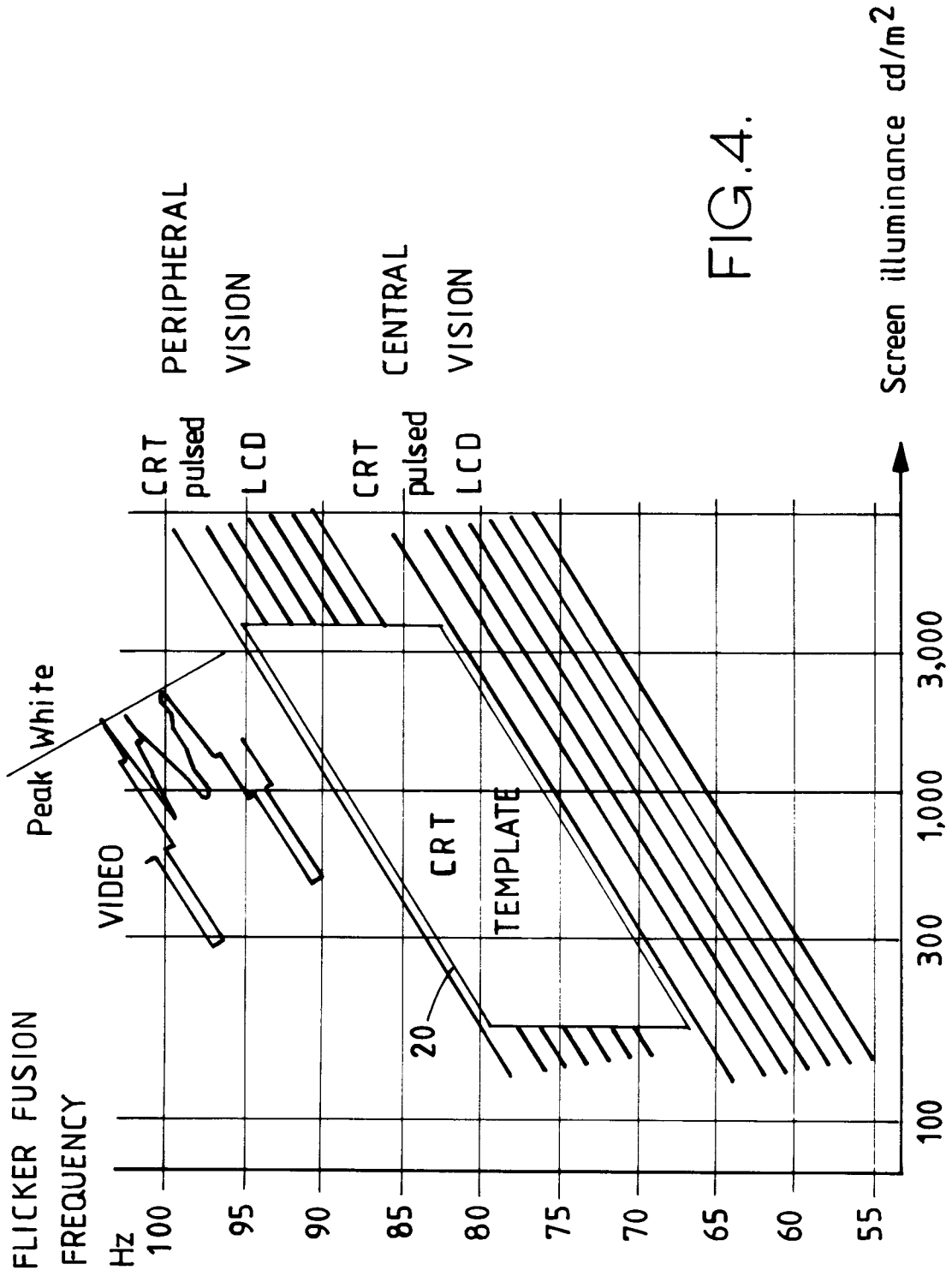


FIG.4.

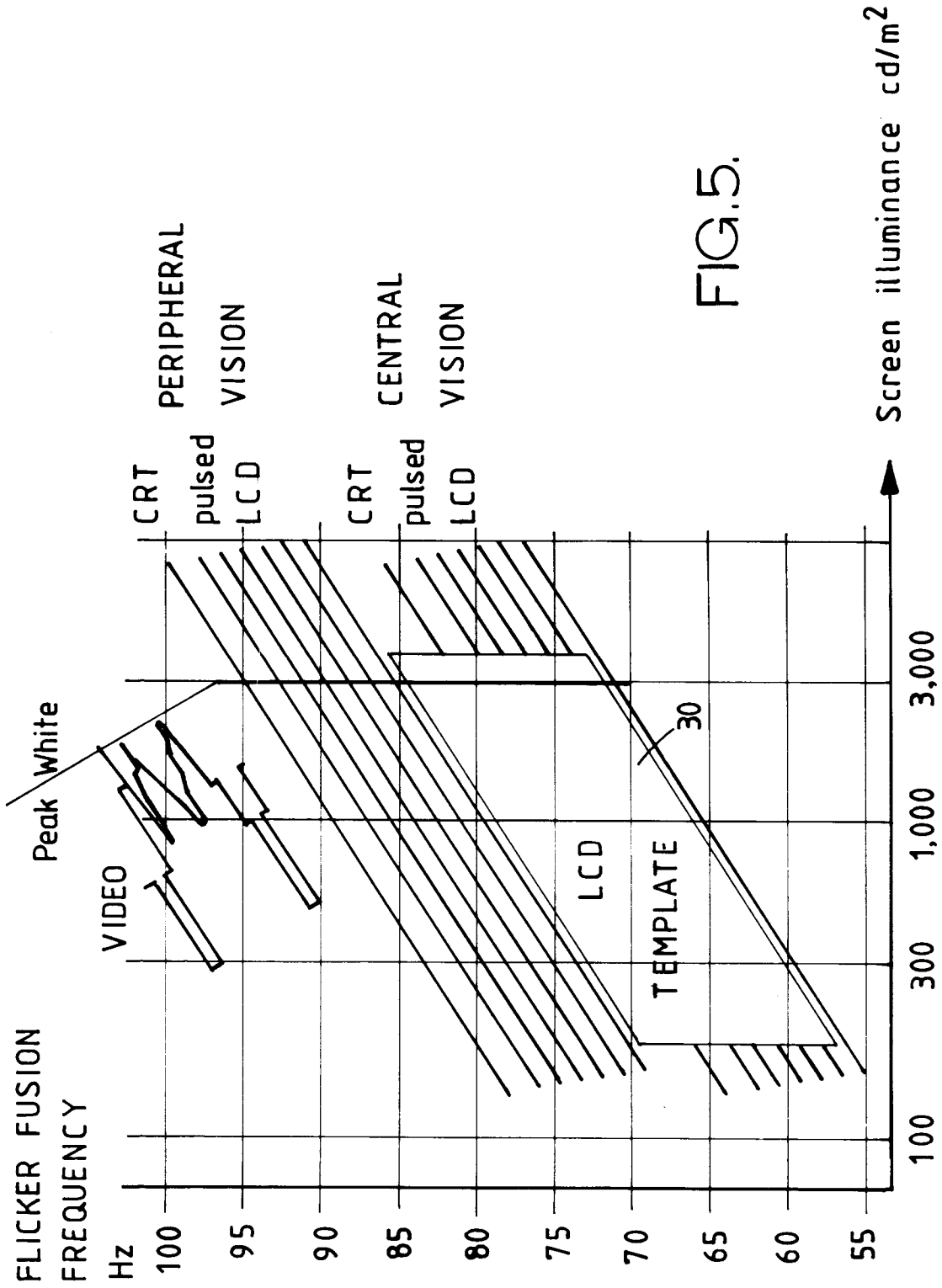
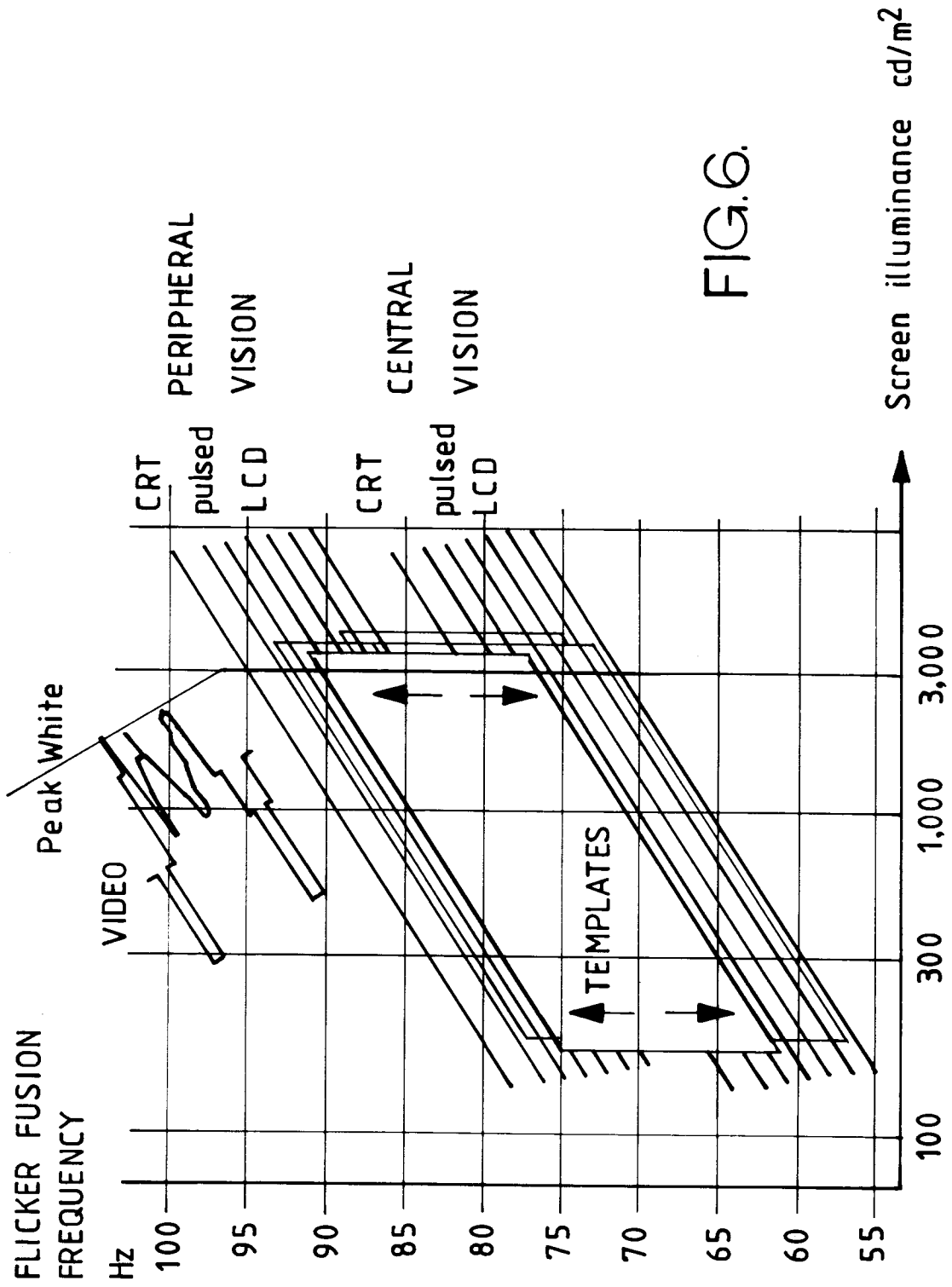


FIG.5.



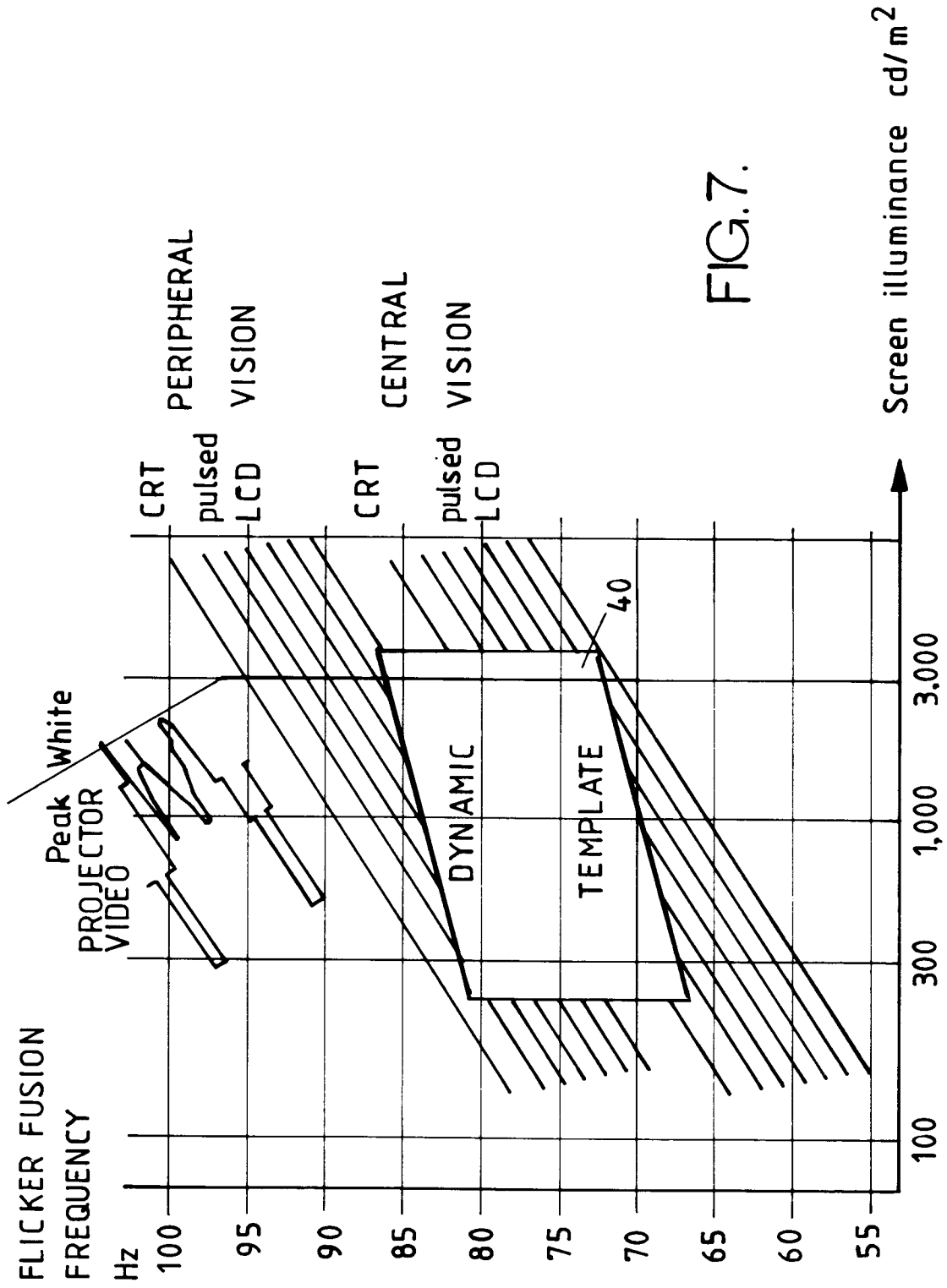
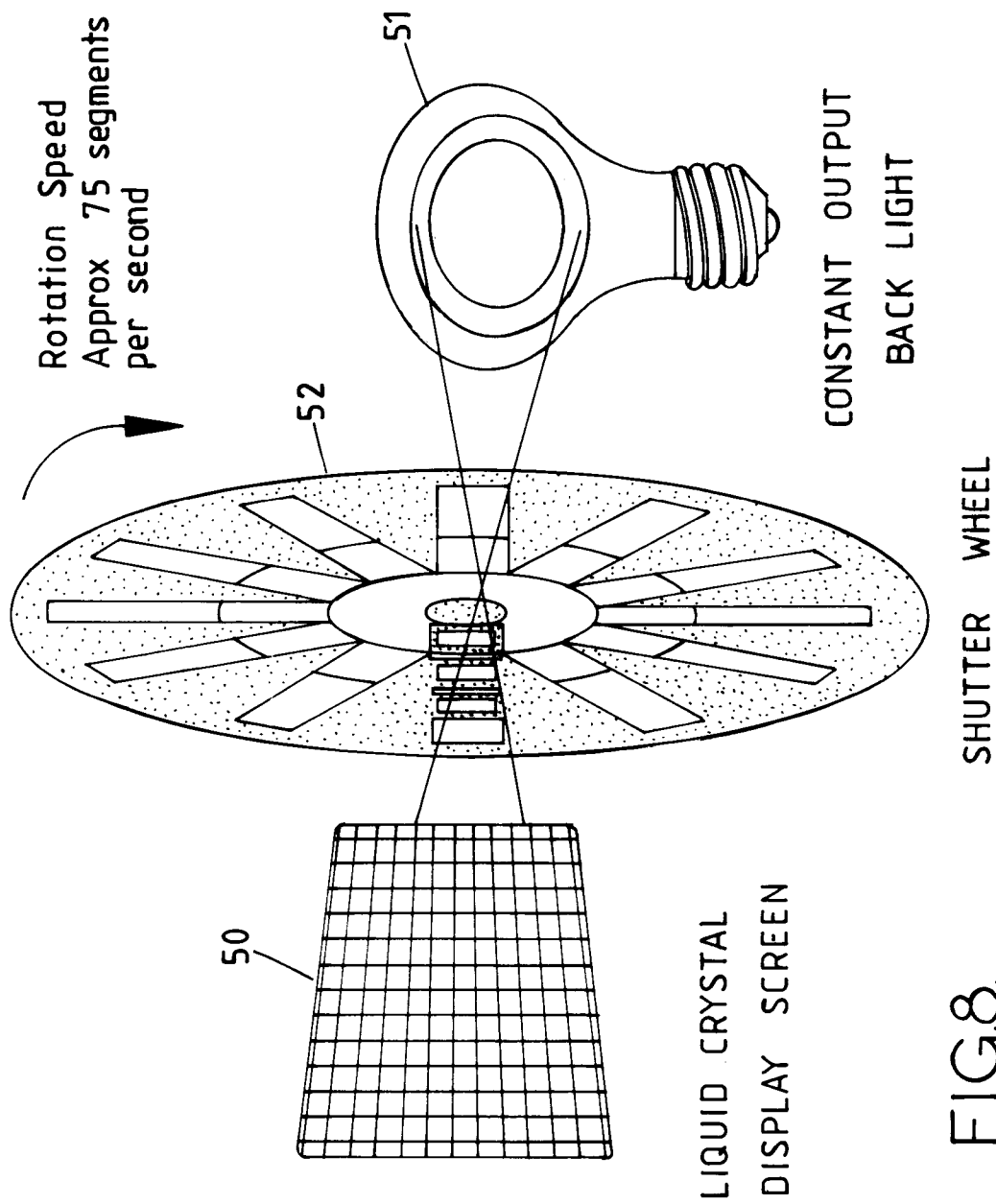
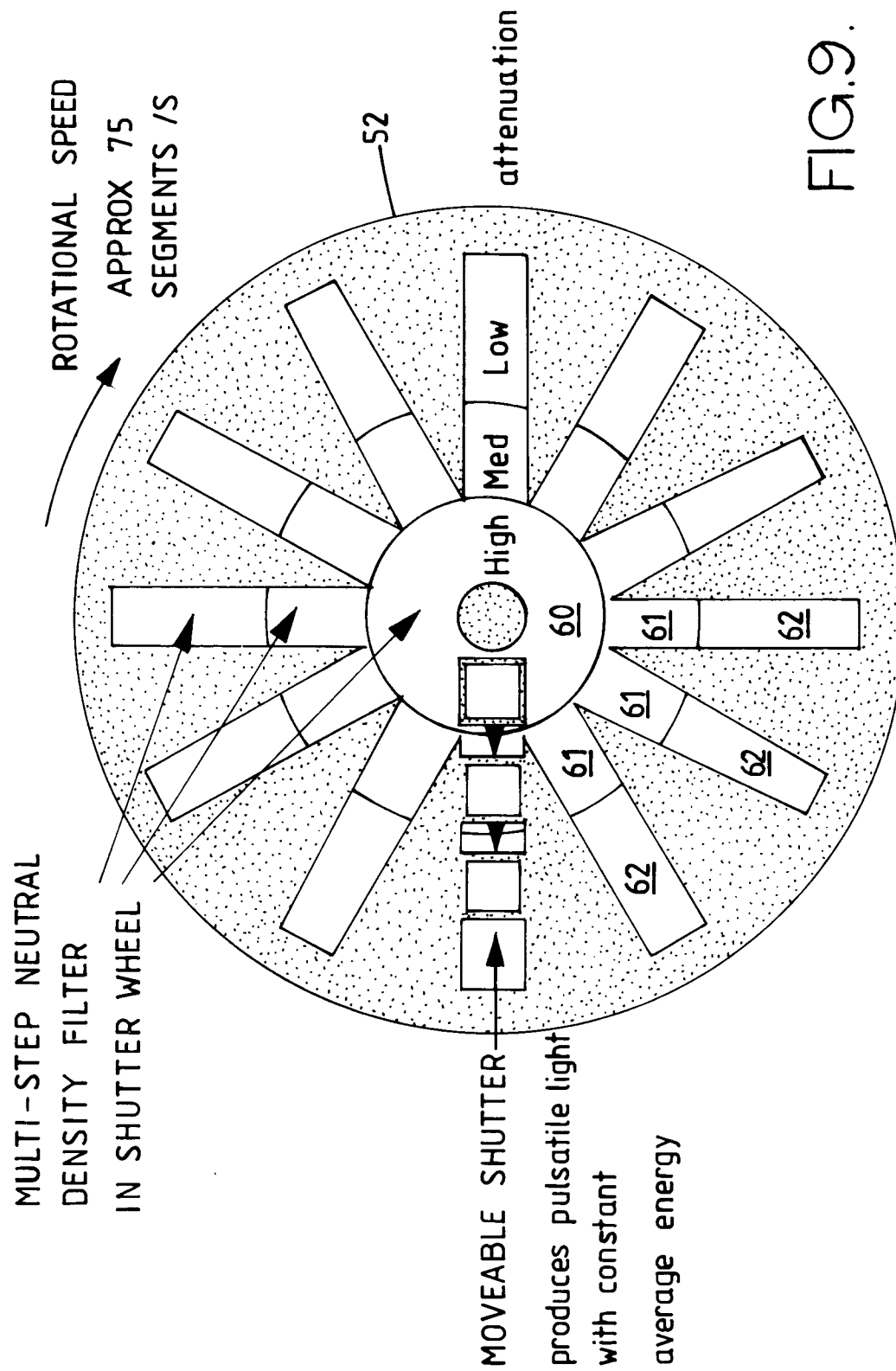


FIG.7.





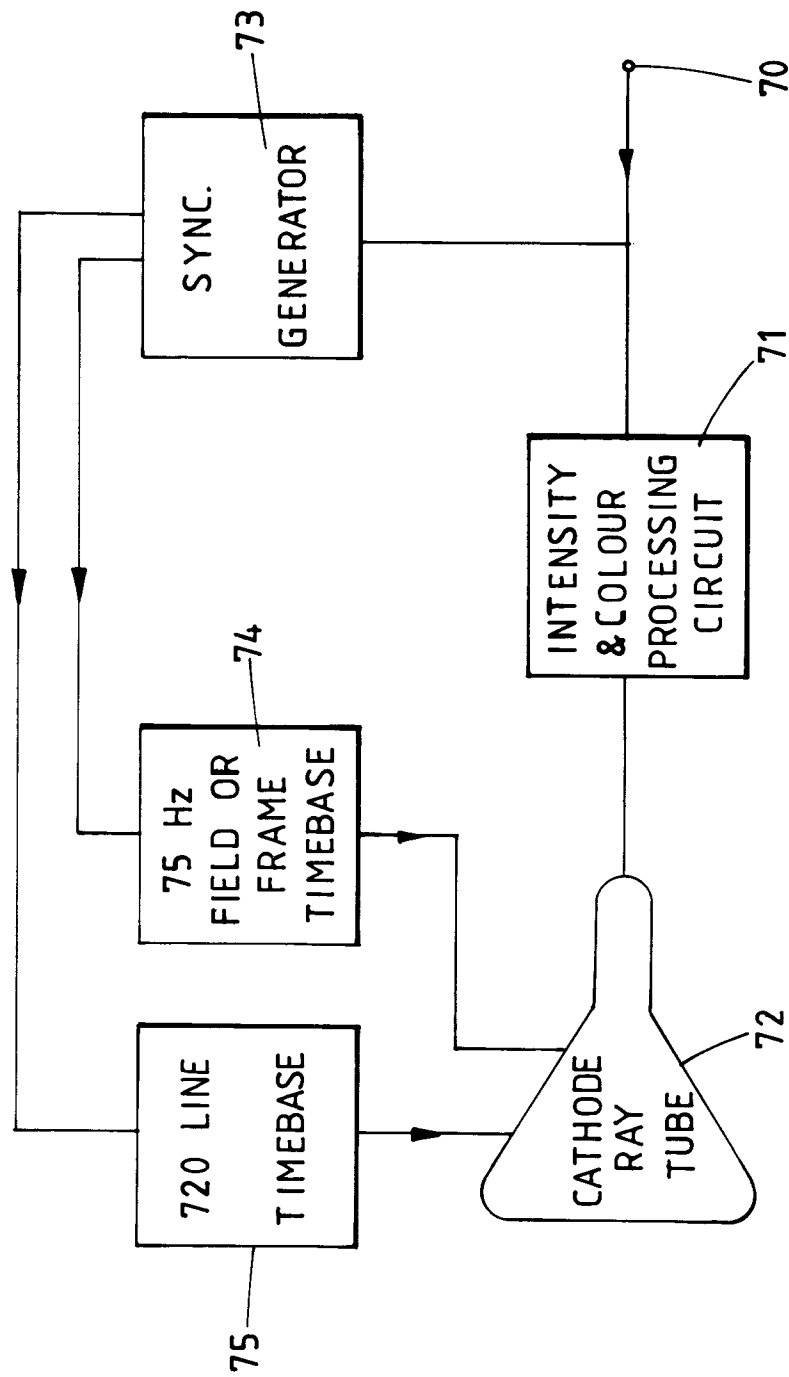


FIG.10.