

PATENT SPECIFICATION (11)

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(54) LIQUID CRYSTAL DISPLAY DEVICE

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese Company, of 3-4, 4-chome, Ginza, Chuo-ku, Tokyo, Japan, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:

This invention relates to liquid crystal display devices and in particular to liquid crystal display devices for compact portable instruments such as timepieces, e.g. wrist-watches.

Compared with conventional electric display devices such as, for example, nixie tubes, light emitting diodes, Braun tubes, fluorescent display tubes etc., liquid crystal display devices have, inter alia, the following advantages:

1. they have an extremely small power consumption,
2. they may be relatively thin and of small size

3. since liquid crystal display devices are passive, a display having good contrast can be obtained in good ambient light conditions.

According to one aspect of the present invention there is provided a liquid crystal display device comprising a liquid crystal display cell consisting of a liquid crystal material disposed between electrode structures arranged to enable an electric field to be applied to the liquid crystal material, and at least one polarizing plate of the absorbing type for causing linearly polarized light to be incident on the liquid crystal display cell, the or at least one of the polarizing plates having a transmittance (as herein defined) in the range between 38% and 45%.

The term "transmittance" is defined as

$$\frac{\text{white light per unit area which passes through a polarizing plate (polarized light)}}{\text{white light per unit area which is normally incident upon the polarizing plate (unpolarized light)}} \times 100$$

Preferably the liquid crystal display cell is disposed between a pair of polarizing plates arranged with their planes of polarization at right angles to one another.

According to a further aspect of the present invention there is provided a calculator or timepiece, e.g. a wristwatch, having a liquid crystal display device as recited above.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a cross-section of a liquid crystal display device according to the present invention;

Figure 2 shows graphically and for the purposes of illustration, the relationship between the visual brightness of a white background viewed through two polarizing plates having their planes of polarization parallel to one another and the transmittance (as herein defined) of the polarizing plates;

Figure 3 shows graphically and for the purposes of illustration, the relationship between the visual brightness of a white background viewed through two polarizing plates having their planes of polarization at right angles to one another and the transmittance (as herein defined) of the polarizing plates; and

Figure 4 shows graphically the relationship between the contrast of the display of the liquid crystal display device of Figure 1 and the transmittance (as herein defined) of the polarizing plates thereof.

Referring to Figure 1 there is shown in cross-section a liquid crystal display device according to the present invention. The liquid crystal display device comprises a liquid crystal display cell consisting of a pair of spaced apart parallel transparent glass plates 1, 1', the opposed surfaces of which are each provided with a respective transparent conductive film 2, 2'. The glass plate 1 together with its conductive film 2 forms a first electrode structure or electrode plate 8 and the glass plate 1' together with its conductive film 2' forms a

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second electrode structure or electrode plate 8'. The electrode plates 8, 8' are maintained spaced apart by spacers 3, 3' which also seal a liquid crystal material 4 between the electrode plates.

5 The spaces 3, 3' may be constituted by polyester films. The electrode plates 8, 8' are treated in the conventional manner to make the liquid crystal material optically active so that the plane of polarization of linearly polarized
10 light passing through the liquid crystal material is rotated through 90°.

The liquid crystal display cell is disposed between a pair of polarizing plates 5, 5' of the absorbing type whose planes of polarization are at right angles to one another. The polarizing
15 plate 5 is bonded by means of a bonding agent to the electrode plate 8 and the polarizing plate 5' is bonded by means of a bonding agent to the electrode plate 8'. The polarizing plates 5, 5' are made, for example, of plastics material. A
20 white light scattering plate 6 is mounted on the polarizing plate 5'. Lead terminals 7, 7' enable driving signals to be applied to the electrode plates 8, 8' respectively.

25 In Figure 1 an electric field cannot be applied across the liquid crystal material 4 in a portion 9 because the conductive film 2 is absent from this portion. Therefore, light which is incident on the polarizing plate 5 is linearly
30 polarized and the linearly polarized light passes through the liquid crystal material which rotates the plane of polarization of the linearly polarized light through 90°. The light therefore passes through the polarizing plate 5' and is
35 scattered and reflected by the light scattering plate 6 so that a white display is provided. Thus the optical activity of the liquid crystal material has the effect that it is as if the light scattering plate 6 were viewed through two polarizing
40 plates whose planes of polarization are parallel to one another.

On the other hand, an electric field can be applied across the liquid crystal material 4 in a portion 10 of the liquid crystal display device.
45 When no electric field is applied to the liquid crystal material in this portion it functions in the same manner as the portion 9. However, when an electric field is applied across the liquid crystal material in the portion 10 its
50 optical activity is destroyed and so the linearly polarized light passing through the polarizing plate 5 does not have its plane of polarization rotated by the liquid crystal material and is consequently absorbed by the polarizing plate
55 5'. Thus the lack of optical activity of the liquid crystal material has the effect that it is as if the light scattering plate 6 were viewed directly through the two polarizing plates whose planes of polarization are at right angles
60 to one another.

The contrast of the display of the above described liquid crystal display device is, in effect, the same as the contrast between viewing the light scattering plate 6 through two
65 polarizing plates whose planes of polarization

are parallel to one another and viewing the light scattering plate 6 through two polarizing plates whose planes of polarization are at right angles to one another. Since the transmittance (as herein defined) of a conventional polarizing plate of the absorbing type is approximately 30% the transmittance (as herein defined) of two polarizing plates is approximately 20% when their planes of polarization are parallel to one another. Therefore, as compared with the contrast of viewing directly a black character on a white background, the contrast of viewing the same black character on a white background through two polarizing plates whose planes of polarization are parallel to one another is only 1/5th. Such a relatively poor contrast is a distinct disadvantage and, in fact, limits the practical application of conventional liquid crystal display device. The liquid crystal display device according to the present invention and described above avoids this disadvantage by using polarizing plates of the absorbing type with a transmittance (as herein defined) in the range between 38% and 45% for the reasons to be given hereinafter.

Figure 2 shows graphically the relationship between the visual brightness of a white background viewed through two polarizing plates having their planes of polarization parallel to one another, and the transmittance (as herein defined) of the polarizing plates: Figure 2 is based upon experimental data. If the transmittance (as herein defined) is 1, the brightness is a function of $\ln I$. As will be seen from Figure 2, the brightness increases rapidly up to a transmittance (as herein defined) of 50% but thereafter the increase in brightness tails off.

Figure 3 shows graphically the relationship between the visual brightness of a white background viewed through two polarizing plates having their planes of polarization at right angles to one another, and the transmittance (as herein defined) of the polarizing plates: Figure 3 is also based upon experimental data. It will be seen that the brightness increases rapidly when the transmittance (as herein defined) reaches approximately 45%.

Figure 4 shows graphically the relationship between the contrast of the liquid crystal display device of Figure 1 and the transmittance (as herein defined) of the polarizing plates 5, 5'. It will be appreciated that the contrast is the difference in visual brightness of the portion 9 where the optical activity of the liquid crystal material is such that the polarizing plates act as if their planes of polarization are parallel to one another so that the relationship between visual brightness and transmittance (as herein defined) is as indicated in Figure 2, and the visual brightness of the portion 10 when an electric field is applied across the liquid crystal material so that the relationship between visual brightness and transmittance (as herein defined) is as indicated

in Figure 3. From Figure 4 it will be seen that the contrast of the display of the liquid crystal display device of Figure 1 is a maximum when the transmittance (as herein defined) of the polarizing plates is between 38% and 45%.

5 The liquid crystal display device of Figure 1 can, therefore, be used to advantage in electronic timepieces, e.g. wristwatches and other compact portable instruments where, even in locations having a relatively low ambient light condition, the display produced is clearly visible.

WHAT WE CLAIM IS:-

- 10 1. A liquid crystal display device comprising a liquid crystal display cell consisting of a liquid crystal material disposed between electrode structures arranged to enable an electric field to be applied to the liquid crystal material, and at least one polarizing plate of the absorbing type for causing linearly polarized light to be incident on the liquid crystal display

cell, the or at least one of the polarizing plates having a transmittance (as herein defined) in the range between 38% and 45%.

2. A liquid crystal display device as claimed in claim 1 in which the liquid crystal display cell is disposed between a pair of polarizing plates arranged with their planes of polarization at right angles to one another.

3. A liquid crystal display device substantially as herein described with reference to and as shown in the accompanying drawings.

4. A calculator or timepiece, e.g. a wrist-watch, having a liquid crystal display device as claimed in any preceding claim.

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