

PATENT SPECIFICATION

(11) 1 500 662

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- (21) Application No. 7692/76 (22) Filed 26 Feb. 1976
 (31) Convention Application No. 50/028 460
 (32) Filed 7 March 1975 in
 (33) Japan (JP)
 (44) Complete Specification published 8 Feb. 1978
 (51) INT CL² G04C 17/00//C09K 3/34; H03H 9/20
 (52) Index at acceptance
 G3T 101 102 301 LA QA RA
 C4X 12
 H1E 1



(54) ELECTRONIC WRISTWATCH

(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 electronic wristwatches.

According to the present invention there is provided an electronic wristwatch including: a piezoelectric vibrator as a time standard; C—MOS electronic circuitry arranged to be driven by the vibrator; a liquid crystal display device comprising a nematic liquid crystal material disposed between a pair of electrode plates which are such as to give the nematic liquid crystal material a spiral or twisted structure, and two polarisers between which the electrode plates and liquid crystal material are disposed; and a single cell or battery acting as a power source, the arrangement being such that the electronic circuitry and display device are driven by a voltage equal to the output voltage of the cell or battery.

Preferably the display device and the cell or battery are disposed side-by-side. The nematic liquid crystal material may be any one of the compositions specified in the following Table 4.

The piezoelectric vibrator may be a tuning fork type flexural vibrator. The vibrator may be formed of quartz crystal material.

In the preferred embodiment the electronic circuitry is a C—MOS IC.

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

Figure 1 is a block diagram of a conventional electronic wristwatch;

Figure 2 illustrates plan and side views of an electronic wristwatch according to the present invention;

Figure 3 illustrates schematically a liquid crystal display device of the wristwatch of Figure 2;

Figure 4 illustrates graphically the voltage-contrast characteristic of one type of liquid crystal compound;

Figure 5 illustrates graphically the voltage-contrast characteristic of a P-cyanophenyl-P'-alkylbenzoate compound;

Figure 6 illustrates graphically the voltage-contrast characteristics of a liquid crystal material suitable for use in an electronic wristwatch according to the present invention;

Figure 7 is a perspective view of a tuning fork type flexural quartz crystal vibrator for use in the wristwatch of Figure 2; and

Figure 8 illustrates the arrangement of electrodes on the vibrator of Figure 7.

Referring to Figure 1 there is shown a conventional electronic wristwatch comprising a piezoelectric vibrator 1 as a time standard, an oscillating circuit 2, a divider circuit 3, a distributing and driving circuit 4, a liquid crystal display device 5, a battery 6 and a boosting circuit 7.

Because the liquid crystal display device cannot be driven directly by the output voltage of the battery 6, whose output voltage is typically 1.5V, but requires a higher driving voltage, the boosting circuit 7 is provided. However, the provision of a boosting circuit, which may include a coil and capacitor, is not conducive to miniaturisation of the wristwatch.

In an electronic wristwatch according to the present invention, the liquid crystal display device can be driven directly by the output voltage, e.g. 1.5V, of a single battery so that a boosting circuit, such as the boosting circuit 7 of Figure 1 is unnecessary; consequently the wristwatch can be made relatively small and thin. Moreover, because the electric power consumed in C—MOS IC circuitry is proportional to the square of the driving voltage, it is advantageous to make the electronic circuitry of a wristwatch according to the present invention of C—MOS IC and to drive the electronic circuitry directly from the battery so that the power consumption can be reduced. When the liquid crystal display device and electronic circuitry are driven at 1.5V, a current of about 3 μ A is consumed and this current is about half the current which is consumed when the driving voltage is between 3 and 6V. When the driving voltage is not the same for all parts of the electronic circuitry it is necessary to give some consideration to the design of the IC in view of its breakdown voltage characteristics, but if the whole of the electronic circuitry can be driven by a voltage of 1.5V, no such consideration needs to be paid.

Figure 2 shows plan and side views of an electronic wristwatch according to the present invention. A liquid crystal display device 11 is driven by a voltage of 1.5V from a battery 12, the display device and the battery lying side-by-side and being secured on a base plate 13 and housed in a casing 14. C—MOS IC electronic circuitry drives the wristwatch using a quartz crystal vibrator 16 as a time standard. By disposing the liquid crystal display device and the battery side-by-side and using a single battery which has a diameter of 7.7 mm, a thickness of 3.4 mm and a capacity of 35 mA·H, it is possible to make the wristwatch with a thickness of less than 5 mm. No boosting circuit is required so enabling the electronic circuitry to be made smaller and increasing the flexibility of design. Because the power consumption of the wristwatch is reduced, it is possible for it to run for a year or more using a small-sized button battery.

Figure 3 illustrates schematically the liquid crystal display device of the wristwatch shown in Figure 2. Liquid crystal material 26 is sealed by a spacer 25 between electrode plates consisting of transparent electrodes 23, 24 made of, for example, tin oxide (SnO_2) or indium oxide (In_2O_3), coated on respective transparent glass base plates 21, 22. The electrode 23, which is divided into seven segments, and the common electrode 24 are so designed to enable the liquid crystal display device to display the numerals 0 to 9 if the segments are suitably energised. The surface of the glass base plate 21 is rubbed with a cotton cloth in a given direction parallel to its length or breadth. The surface of the glass plate 22 is rubbed in a direction at right angles to the direction of rubbing of the glass base plate 21. Because the molecules of the liquid crystal material 26 orientate with the directions of rubbing adjacent the surface of the respective electrode plate, the molecules of the liquid crystal material have a twisted or spiral structure between the electrode plate. The liquid crystal material has an ability to rotate the plane of polarisation of polarised light passing therethrough through 90° and when it is sandwiched between two polarizing filters 27, 28, whose planes of polarisation are at right angles, it appears light. If the planes of polarisation of the polarizing filter 27, 28 are parallel then the liquid crystal display device appears dark. When an electric field, above some given voltage depending upon the composition of the liquid crystal material 26, is applied between the electrodes 23, 24, the molecules of the liquid crystal material, if they have positive dielectric anisotropy, orientate with their molecular axes parallel to the electric field and the light or dark appearance of the liquid crystal display device is reversed. If the electric field is removed, the liquid crystal material 26 returns to its original state, i.e. with a twisted or spiral structure. It is possible to provide a reflection type liquid crystal display device by arranging a diffusing reflecting material (not shown) at the rear of the polarising filters.

The voltage needed to drive the liquid crystal display device is determined by the composition of the liquid crystal material and by the value of the dielectric anisotropy $\Delta\epsilon$ thereof, where

$$\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp}$$

$\epsilon_{\parallel}$ is the dielectric constant in a parallel direction to the molecular macro axis, and $\epsilon_{\perp}$ is the dielectric constant in a direction at right angles to the molecular macro axis.

The threshold voltage V_{th} of the liquid crystal material is given by the formula:

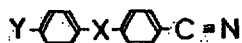
$$V_{th} = \pi \sqrt{\frac{k}{\Delta\epsilon}}$$

where k is a constant.

Thus the larger the dielectric anisotropy the smaller the threshold voltage and thus the smaller the driving voltage required for a liquid crystal display device.

A liquid crystal component having a structural formula:

5



where the nitrile radical is at the end of the benzene ring, has a large dielectric anisotropy. Some compounds having the above structure formula and their temperature characteristics are exemplified in Table 1.

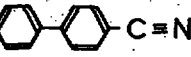
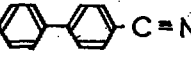
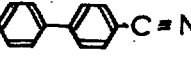
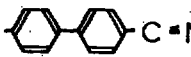
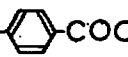
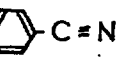
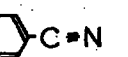
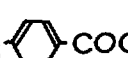
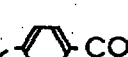
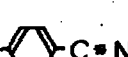
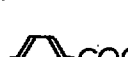
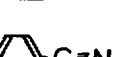
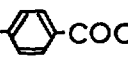
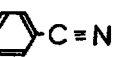
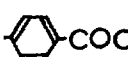
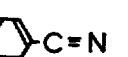
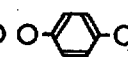
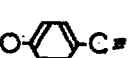
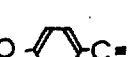
TABLE 1

1. P-alkylbenzylidene-P'-cyanoaniline	temperature characteristic (°C)
$\text{H}_5\text{C}_2-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.I; 76, N.I; 63
$\text{H}_7\text{C}_3-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 65, N.I; 77
$\text{H}_9\text{C}_4-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 38.5, N.I; 62
$\text{H}_{11}\text{C}_5-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 46, N.I; 75
$\text{H}_{13}\text{C}_6-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 33, N.I; 64
$\text{H}_{15}\text{C}_7-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 32.5, N.I; 72
$\text{H}_{17}\text{C}_8-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 32.5, N.I; 69
2. P-alkoxybenzylidene-P'-cyanoaniline	
$\text{H}_3\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 106, N.I; 120
$\text{H}_5\text{C}_2\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 105, N.I; 127
$\text{H}_7\text{C}_3\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 63, N.I; 127
$\text{H}_9\text{C}_4\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 63, N.I; 106
$\text{H}_{11}\text{C}_5\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 62, N.I; 93
$\text{H}_{13}\text{C}_6\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 56, N.I; 96
$\text{H}_{15}\text{C}_7\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 78, N.I; 92
$\text{H}_{17}\text{C}_8\text{O}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 66, N.I; 95

TABLE 1 (Continued)

3. P-acyloxybenzylidene-P'-cyanoaniline	temperature characteristic (°C)
$\text{H}_5\text{C}_2\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 111, N.I; 125
$\text{H}_7\text{C}_3\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 53.7, N.I; 97.6
$\text{H}_{11}\text{C}_5\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 66, N.I; 98
$\text{H}_{13}\text{C}_6\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 54, N.I; 94
$\text{H}_{15}\text{C}_7\text{CO}-\text{C}_6\text{H}_4-\text{CH}=\text{N}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 54, N.I; 99
4. P-cyanobenzylidene-P'-alkylaniline	
$\text{H}_7\text{C}_3-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 68, N.I; 78
$\text{H}_9\text{C}_4-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	N.I; 82.5
$\text{H}_{11}\text{C}_5-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 75, N.I; 78
$\text{H}_{13}\text{C}_6-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 63, N.I; 75
$\text{H}_{17}\text{C}_8-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 66, N.I; 73
5. P-cyanobenzylidene-P'-alkoxyaniline	
$\text{H}_5\text{C}_2\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 105, N.I; 130
$\text{H}_7\text{C}_3\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 113, N.I; 115
$\text{H}_9\text{C}_4\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 63, N.I; 110.5
$\text{H}_{11}\text{C}_5\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 62.5, N.I; 100
$\text{H}_{13}\text{C}_6\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 54.5, N.I; 103
$\text{H}_{15}\text{C}_7\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 50, N.I; 85
$\text{H}_{17}\text{C}_8\text{O}-\text{C}_6\text{H}_4-\text{N}=\text{CH}-\text{C}_6\text{H}_4-\text{C}\equiv\text{N}$	C.N; 79, N.I; 94.5

TABLE 1 (Continued)

6. P-alkyl-P'-cyanobiphenyl	temperature characteristic (°C)
$H_{11}C_5$ -  -C≡N	C.N; 22.5, N.I; 35
$H_{13}C_5$ -  -C≡N	C.N; 13.5; N.I; 29
$H_{15}C_7$ -  -C≡N	C.N; 28.5, N.I; 42
7. P-alkoxy-P'-cyanobiphenyl	
$H_{13}C_6O$ -  -C≡N	C.N; 58, N.I; 76.5
8. P-cyanophenyl-P'-alkylbenzoate	
H_7C_3 -  -COO-  -C≡N	C.I; 99, I.N; 53.5
H_9C_4 -  -COO-  -C≡N	C.I; 66, I.N; 42
$H_{11}C_5$ -  -COO-  -C≡N	C.I; 63, I.N; 56.5
$H_{13}C_6$ -  -COO-  -C≡N	C.N; 44, N.I; 48
$H_{15}C_7$ -  -COO-  -C≡N	C.N; 44, N.I; 56.5
$H_{17}C_8$ -  -COO-  -C≡N	C.N; 45, N.I; 54
9. P-cyanophenyl-P'-acyloxybenzoate	
$H_{11}C_5COO$ -  -COO-  -C≡N	C.N; 68, N.I; 86.5
$H_{13}C_6COO$ -  -COO-  -C≡N	C.N; 85.5, I.N; 54
10. P-cyanophenyl-P'-alkylcarbonate benzoate	
$H_{11}C_5O CO O$ -  -COO-  -C≡N	C.N; 74, I.N; 61
$H_{13}C_6O CO O$ -  -COO-  -C≡N	C.N; 48, N.I; 77.5
$H_{17}C_8O CO O$ -  -COO-  -C≡N	C.N; 72.5, N.I; 77

In Table 1, C-N is the crystal/nematic phase change point and N-I is the nematic/isotropy liquid phase change point.

5 The compounds of sections 1 to 5 in Table 1 have an anil radical ($-\text{CH}=\text{N}-$) in the centre of their molecules. The compounds of Section 1 have a relatively wide liquid crystal phase so that a liquid crystal material having a liquid crystal phase between 0°C and 60°C can be made by mixing compounds of section 1. However, the anil radical is easily affected by moisture. Figure 4 shows graphically the voltage-contrast characteristic of a typical compound of section 1. It will be seen that insufficient contrast is obtained when a driving voltage of 1.5V is used, so that a boosting circuit is required to drive a liquid crystal display device employing a compound or compounds of section 1 if the battery has only an output voltage of 1.5V.

10 Compounds of sections 6 and 7 of Table 1 are stable, and especially have a low crystal/nematic phase change point so that it is possible to make a liquid crystal material which is in the liquid crystal phase at a temperature below 0°C by mixing compounds of sections 6 and 7. However, the compounds of section 6 have a relatively low nematic/isotropy liquid phase change point so that it is very difficult to make a liquid crystal material with a liquid crystal phase between 0°C and 50°C .

15 Compounds of sections 8 to 10 have an ester bond ($-\text{COO}-$) in the centre of their molecules, and these compounds are more stable than compounds having an anil radical e.g. the compounds of section 1. The compounds of section 8 are P-cyanophenyl-P'-alkylbenzoate compound which have a relatively low crystal/nematic phase change point. The dielectric anisotropy of such compounds is

$$\Delta\epsilon \sim 15$$

20 which is larger than that of other compounds of Table 1.

A P-cyanophenyl-P'-alkylbenzoate compound has the general formula:



and its voltage-contrast characteristic is shown graphically in Figure 5.

30 Table 2 shows the temperature characteristics of various liquid crystal materials consisting of a number of P-cyanophenyl-P'-alkylbenzoate compounds in admixture.



TABLE 2

Liquid Crystal Material	temperature characteristic (°C)
1. P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; and P-cyanophenyl-P'-n-heptylbenzoate, in admixture in the ratio of 26:45:29 by weight.	C.N; 18 ~ 20 N.I; 47
2. P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; and P-cyanophenyl-P'-n-octylbenzoate, in admixture in the ratio of 33.3:33.4:33.3 by weight.	C.N; 20 ~ 21 N.I; 52
3. P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; and P-cyanophenyl-P'-n-octylbenzoate, in admixture in the ratio of 10.2:29.9: 30.0:29.9 by weight.	C.N; 12 ~ 15 N.I; 51
4. P-cyanophenyl-P'-n-propylbenzoate; P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-pentylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; and P-cyanophenyl-P'-n-octylbenzoate, in admixture in the ratio of 4.2:12.0:13.8: 23.4:23.4:23.2 by weight.	C.N; 11 ~ 12 N.I; 51

As seen in Table 2, the liquid crystal materials composed solely of P-cyanophenyl-P'-alkylbenzoate compounds have a relatively high crystal/nematic phase change point so that they are unsuitable for use in wristwatches where it is desirable that the liquid crystal material has a liquid crystal phase between 0°C and 50°C. Therefore, to give the liquid crystal material the desired liquid crystal phase it is necessary to add a liquid crystal material having a small positive or negative dielectric anisotropy to liquid crystal material composed solely of P-cyanophenyl-P'-alkylbenzoate compounds, if the resulting liquid crystal material is to be used in a liquid crystal display device driven by a driving voltage of 1.5V. Table 3 exemplifies liquid crystal compounds that may be added to such liquid crystal material to produce a liquid crystal material having a relatively low crystal/nematic phase change point and a nematic/isotropy liquid phase change point above 50°C.

TABLE 3

Liquid Crystal Compound	temperature characteristic (°C)
P-n-hexyloxyphenyl-P'-n-butylbenzoate	C.N; 29, N.I; 50
P-n-hexyloxyphenyl-P'-n-amylbenzoate	C.N; 40, N.I; 59
P-n-heptyloxyphenyl-P'-n-amylbenzoate	C.N; 41, N.I; 56
P-n-amylphenyl-P'-n-heptyloxybenzoate	C.N; 45, N.I; 61
P-n-hexyloxy-P'-n-heptanoyloxybenzoate	C.N; 43, N.I; 81
P-n-amylloxy-P'-n-hexylcarbonatebenzoate	C.N; 41, N.I; 89

Besides adding liquid crystal compounds having a small positive or negative dielectric anisotropy as exemplified in Table 3, it is possible to add homologues and mixtures thereof. It is also possible to add compounds having other radicals, for example, MBBA (P-methoxybenzylidene-P'-n-butylaniline), EBBA (P-ethoxybenzylidene-P'-n-butylaniline), and P-methoxy-P'-n-butylazoxybenzene.

Table 4 shows liquid crystal materials consisting of a compound having small positive or negative dielectric anisotropy together with P-cyanophenyl-P'-alkylbenzoate compounds. These liquid crystal materials are suitable for use with electronic wristwatches according to the present invention.

(13)

TABLE 4

Liquid Crystal Material	temperature characteristic (°C)
1. P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; P-cyanophenyl-P'-n-octylbenzoate; and P-n-hexyloxyphenyl-P'-n-butylbenzoate. In admixture in the ratio of 8.2:23.9:24.0:23.9:20.0 by weight.	C.N; 9, N.I; 50
2. P-cyanophenyl-P'-n-propylbenzoate; P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-pentylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; P-cyanophenyl-P'-n-octylbenzoate; and P-n-hexyloxyphenyl-P'-n-butylbenzoate. In admixture in the ratio of 3.4:9.6:11.0:18.7:18.7:18.6:20.0 by weight.	C.N; 0 ~ 2 N.I; 50
3. Composition composed of P-cyanophenyl-P'-n-propylbenzoate; P-cyanophenyl-P'-n-butylbenzoate; P-cyanophenyl-P'-n-pentylbenzoate; P-cyanophenyl-P'-n-hexylbenzoate; P-cyanophenyl-P'-n-heptylbenzoate; P-cyanophenyl-P'-n-octylbenzoate; and P-n-hexyloxyphenyl-P'-n-butylbenzoate. In admixture in the ratio of 2.9:8.4:9.7:16.4:16.4:16.2:30.0 by weight.	C.N; 2, N.I; 50

All the liquid crystal materials exemplified in Table 4 are responsive to a driving voltage of 1.5V. The characteristic of composition 2 of Table 4 is shown in Figure 6.

Generally speaking, the voltage-contrast characteristic is shifted towards the high voltage side as the temperature is lowered. The threshold voltage V_{th} , i.e. the voltage at which the contrast is 90% of the saturation value, is shifted by between 0.1V and 0.2V as the temperature is reduced from room temperature (about 25°C) to 0°C. In practice, however, a contrast of 90% of the saturation value proves to be sufficient. Accordingly, the saturation voltage V_{sa} must be below 1.5V at a temperature of 0°C in order to obtain sufficient contrast with an applied electric field of 1.5V.

The voltage characteristics are also dependent upon the thickness of the layer of liquid crystal material and the thinner the layer of liquid crystal material the lower the threshold voltage V_{th} and the saturation voltage V_{sa} . Accordingly, it is desired to make the layer of liquid crystal material as thin as possible. However, if the layer of liquid crystal material is less than 5 μ thick, slight unevenness in thickness causes interference colours. Taking all the considerations into account it has been found to be advantageous to make the layer of liquid crystal material substantially 5 μ to 10 μ thick.

It will be seen from Figure 6 that the liquid crystal composition 2 has an excellent voltage-contrast characteristic which is better than that shown in Figure 5, there being contrast greater than 90% of the saturation value at 0°C at 1.5V.

Figure 7 illustrates a tuning fork type flexural quartz crystal vibrator 31 for use in the wristwatch of Figure 2 and Figure 8 shows the arrangement of electrodes on the vibrator of Figure 7. For ease of explanation in Figure 8 the thickness of the vibrator has been exaggerated relative to the width and the angle α in Figure 7 has been made 0°.

The vibrator 31 is produced from NT-cut quartz crystal material and has an upper surface inner electrode 32, a lower surface outer electrode 32', an upper surface outer electrode 33 and a lower surface inner electrode 33'. The upper surface inner electrode 32 and the lower surface outer electrode 32' are electrically connected and the upper surface outer electrode 33 and the lower surface inner electrode 33' are electrically connected. The X, Y, Z axes are the electrical, mechanical and optical axes of the vibrator, respectively. The vibrator is cut from a quartz crystal plate which is an X-plate rotated through α° about the X-axis and further rotated by β° about the Y'-axis generated by the Y-axis upon being rotated through α° . The angle α may be between 0° and 10° and the angle β may be between 50° and 70° or between -50° and -70°.

When a positive voltage is applied to the electrodes 32, 32' and a negative voltage is applied to the electrodes 33, 33', the electric fields 34, 35 (Figure 8) are set up within the quartz crystal material. Components 36, 37 of electric fields 34, 35, respectively along the X-axis cause distortion of the quartz crystal material. In each tine of the tuning fork components 36, 37 are in opposite directions relative to the centre line of the tine so that the quartz crystal vibrator has an expanding distortion to one side and a contracting distortion to the other. Therefore, when an alternating current is applied to the electrodes, a symmetrical flexural vibration is caused.

This kind of vibrator is formed from very thin quartz crystal plate, so that the tuning fork shape and the electrode shape can be made by a chemical process, e.g. a photo-etching process, to produce a small and, especially, a super-thin vibrator. The vibrator may, therefore, have a thickness which is about 0.1 mm, a width of about 1 mm and a length of about 4.5 mm and may be housed in a very small casing.

Because the fork type vibrators widely used up to now are produced from a quartz crystal plate by a mechanical process, e.g. by means of a diamond cutter, much time and cost is expended, and they have to be at least 0.5 mm thick (for example one conventional tuning fork type vibrator has a thickness of about 0.6 mm), have a width of about 1.5 mm and a length of about 6 mm. Consequently, conventional tuning fork type vibrators are not suitable for miniaturisation.

The embodiment of the present invention described above uses a C-MOS IC driven by a driving voltage of 1.5V. The embodiment has the following important features:

1. A boosting circuit is unnecessary and the construction is simplified because the liquid crystal display device and the electronic circuitry is driven by a driving voltage of 1.5V supplied directly by the battery.

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2. A small-sized and low-cost wristwatch is produced, because the quartz crystal vibrator used as the time standard is small-sized and thin, a boosting circuit not being required so that a small battery is sufficient to power the wristwatch for a relatively long time.

3. The wristwatch may be made relatively thin and of flexible design because the liquid crystal display device and the battery do not lie upon one another but rather side-by-side.

In the embodiment described above the electronic circuitry and the liquid crystal display device are driven by a voltage of 1.5V directly from a single cell or battery in order to reduce power consumption. The voltage of 1.5V is selected because this is the typical voltage produced by batteries which are currently available. However, the electronic circuitry of the liquid crystal display device could be driven directly by a single battery producing an output voltage of 2V or 3V.

It will be appreciated that it is not essential to use a quartz crystal vibrator as a time standard but one composed of lithium tantalate, for example, may be used: indeed any piezo-electric vibrator may be used as the time standard.

WHAT WE CLAIM IS:—

1. An electronic wristwatch including: a piezoelectric vibrator as a time standard; C—MOS electronic circuitry arranged to be driven by the vibrator; a liquid crystal display device comprising a nematic liquid crystal material disposed between a pair of electrode plates which are such as to give the nematic liquid crystal material a spiral or twisted structure, and two polarisers between which the electrode plates and liquid crystal material are disposed; and a single cell or battery acting as a power source, the arrangement being such that the electronic circuitry and display device are driven by a voltage equal to the output voltage of the cell or battery.

2. A wristwatch as claimed in claim 1 in which the display device and the cell or battery are disposed side-by-side.

3. A wristwatch as claimed in claim 1 or 2 in which the nematic liquid crystal material is any one of the compositions specified in Table 4.

4. A wristwatch as claimed in any preceding claim in which the piezoelectric vibrator is a tuning fork type flexural vibrator.

5. A wristwatch as claimed in claim 4 in which the vibrator is formed of quartz crystal material.

6. A wristwatch as claimed in any preceding claim in which the electronic circuitry is a C—MOS IC.

7. A wristwatch substantially as herein described with reference to and as shown in the Figures 2, 3, 6, 7 and 8 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1978.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

