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Liquid Crystal Displays for Automotive Instrument Panels

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Electronic displays are becoming more important for automotive instrument panels because of the need to save space and energy. Liquid crystal displays (LCDs) provide many advantages, such as the capacity to produce thin panels, no wash out in bright ambient light and flexibility of pattern design. The recent improvement of LCDs resulted in a wide operating temperature range of −30°C to +85°C, a good response time of less than 1 s at −30°C and a long life of more than 10 years.

Since the first practical application of LCDs which was introduced in car-clocks in 1980, we have seen some applications in other automobile parts. In 1982, LCDs were introduced in instrument panels. The twisted nematic liquid crystal display (TN-LCD) is a suitable display technology for automotive applications because of its high contrast, short response time, and high reliability. Because of this good visibility and reliability, they will be used more in automobiles in the near future.

1. INTRODUCTION

The needs to improve fuel economy, to meet government emission standards, and to save dashboard space are resulting in the use of electronic displays which interface easily with control electronics, and are more versatile than conventional mechanical and electromechanical displays.

Today, millions of LCDs are used in wrist watches, clocks, pocket calculators, and measuring instruments. LCDs have many advantages in their application to automotive instrument panels: low voltage and low power requirements, excellent visibility in high ambient light, color capability, flexibility of pattern design, and compatibility with the low power CMOS integrated circuit.

For actual automotive application, however, LCDs had some drawbacks: narrow operating temperature range, long response time at low temperatures, limited viewing angle, and low reliability. Twisted nematic liquid crystal displays (TN-LCDs) and guest-host liquid crystal displays

(GH-LCDs) will be suitable displays for automotive instrument panels. TN-LCDs had several shortcomings, such as a restricted viewing angle and limited stability due to the polarizers. The White-Taylor type GH-LCD and double layered GH-LCD are constructed without polarizers and have no restrictions in the viewing angle, but they have less contrast and a longer response time than TN-LCD. The GH-LCD is in the improvement stage for practical application. Recently, the above problems in the TN-LCD have been solved by using improved polarizers and liquid crystal materials. TN-LCDs are now being applied to automobiles.

Now LCDs have the potential to replace not only mechanical and electromechanical instrument panels but also active electronic displays such as vacuum fluorescent displays, light-emitting diodes, and plasma displays. This paper reviews advances made in TN-LCDs for automotive applications.

2. DESIGN AND OPERATING CONSIDERATIONS OF LCDs

For automotive application, the minimum acceptability for electronic displays are as follow:

(1) Operating temperature range: $-30°C \sim +85°C$
(2) Contrast ratio: 5:1
(3) Response time: 500 ms at $-30°C$
(4) Viewing angle: $\pm 45°$
(5) Brightness: Visible when flood with 60,000 Lux and when in dark
(6) Colors: Red, Blue, Green
(7) Power supply: 5 V
(8) Life: 100,000 h
(9) Display size: 100 mm $\times$ 200 mm

To fulfill these requirements and to make LCDs fully useful for automotive instrument panels, the following problems have to be solved:

(1) Production of large area LCD panels.
(2) Improvement of the readability of the LCDs.
(3) Improvement of the operating temperature range and the response time of the LCDs.
(4) Improvement of electrical connection reliability.
(5) Improvement of the climatic stability of the LCDs.

Early LCDs had many problems, but they have been solved by using improved packaging techniques, stable LC molecule alignment techniques, and chemically stable LC molecules.

2.1 Panel construction

The replacement of the present electromechanical instrument panel requires a size of more than 100 mm × 200 mm for an LCD panel.

In order to avoid undesirable coloring in the TN-LCD, the tolerance of the thickness of the LC layer must not exceed ±0.5 μm. To solve this problem, fine glass particles or point seal is inserted in the gap between the front and back glass planes.

Another problem to solve with large area LCDs was to find the appropriate orientation technology. It could be solved by using a rubbing method and an organic seal. This method is well suited for mass production of large-area LCD panels.

2.2 LC material

The response time of TN-LCDs is given by the following equations:

$$t_r = \eta d^2 (\varepsilon_0 \, \Delta\varepsilon \, V^2 - \pi^2 k)^{\frac{1}{2}}$$

$$t_d = \eta d^2 (\pi^2 k)^{\frac{1}{2}}$$

where, t_r: rise time, t_d: decay time, η: viscosity, d: thickness of LC layer, $\Delta\varepsilon$: dielectric anisotropy, V: applied voltage, k: elastic constant. From the above equations, a lower viscosity and a thinner LC layer are required to shorten the response time.

The viewing angle depends on the anisotropy of the refractive index Δn, and a small Δn gives a wide viewing angle. However, a small value $\Delta n \cdot d$ causes a low contrast ratio and undesirable coloring. Therefore, we can not make the value of Δn and d too small.

The first reliable and stable LC materials useful for automotive applications were biphenyl materials. Biphenyls provide a high positive dielectric anisotropy which are useful for TN-LCDs; however, the response time and viewing angle need some improvements.

Recently, the study of LC materials has developed rapidly and many new families have been developed.[1] One of the new LC materials is phenylcyclohexanes (PCH),[2,3] and the mixtures of PCH have many advantages: wide operating temperature range (−30°C ~ +85°C), very low viscosities (around 20 cp at 25°C) and small Δn (around 0.1). The electro-optical characteristics of PCH mixtures are shown in Figures 1 and 2. They show that the operating voltage is only 3.6 V (rms) at −30°C and the response time is about 600 ms at −30°C.

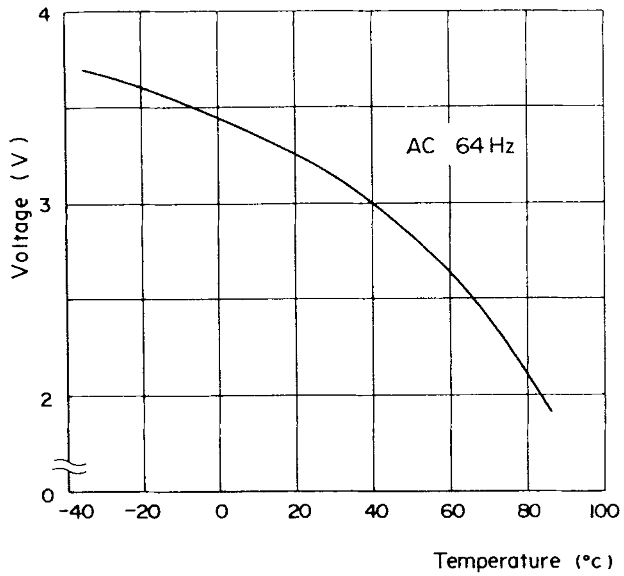

FIGURE 1 Temperature dependence of operating voltage.

In order to extend the operating temperature range and to shorten the response time, a simple heater system can be employed. By attaching a flat panel heater to the rear of the LCD panel, warm-up from −40°C to +10°C was achieved in about one minute.[4]

2.3 Contrast

Since LCDs are passive display, they do not wash out in high ambient lighting conditions and require some illumination at night, as shown in Table I.

The legible contrast of LCDs depends on the ambient illumination and the display method.

Transmissive mode LCDs using back illumination have good visibility in low ambient lighting conditions, but the contrast ratio may decrease in direct sunlight. Reflective mode LCDs with an integral reflector give an excellent contrast ratio in high ambient lighting conditions, but have poor visibility in low ambient lighting conditions.

Transflective mode LCDs with a transflector and a back illuminator have good visibility over the complete range of ambient conditions. The construction of transflective mode LCDs is shown in Figure 3. These LCDs

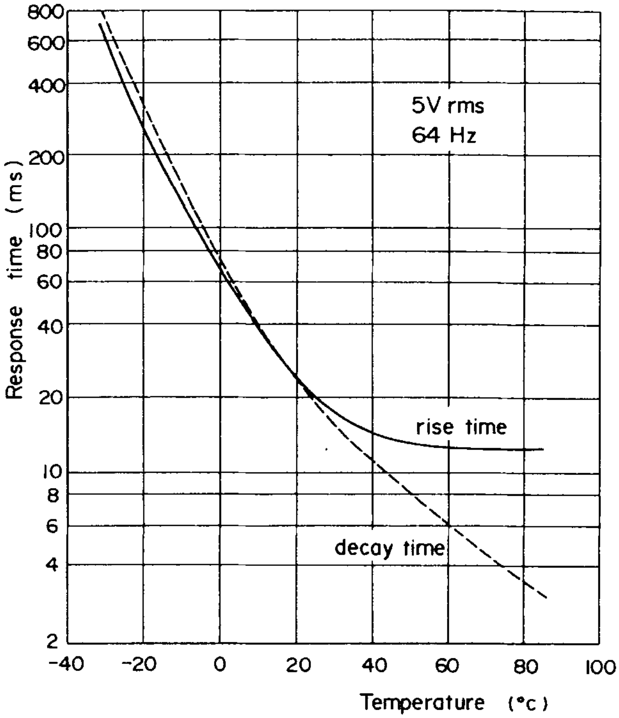

FIGURE 2 Temperature dependence of response time.

usually operate in the reflective mode, however, at night they operate in the transmissive mode. In automotive applications, negative displays of transflective mode LCDs should be used.

Polarizers are also important for contrast and brightness. Long-time performance was a serious problem in the past, but today high quality polarizers are available which meet outdoor specifications and give a contrast ratio of more than 5:1.

TABLE I

Illuminator for LCD

Illuminator	Brightness	Thickness	Voltage	Life
Electroluminescent	Low	Thin	High	Middle
Incandescent lamp	Low	Middle	Low	Short
Fluorescent lamp	High	Thick	High	Middle

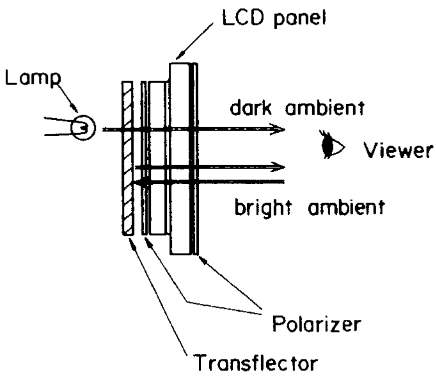

FIGURE 3 Construction of transflective LCD.

2.4 Color

Colored filters or colored polarizers are employed in automotive instrument panels. Current standards require the use of at least red, blue, and green. Using colored filters gives colored patterns in black backgrounds or black patterns in colored backgrounds. Using colored polarizers gives colored patterns in bright backgrounds. Colored polarizers have some limitations of variety of colors and hue.

2.5 Connection

For large area LCDs, three connection techniques can be considered.

(1) Elastomer connection (Zebra connection) with holder material.
(2) Soldered pin connection.
(3) Direct connection to flexible printed circuit board.

The Zebra connection is very commonly used but requires sufficient space for the holder material. The pin connection as used for vacuum fluorescent displays has a cost problem. Either the Zebra connection or the pin connection should be selected for now, because the direct connection method, though simple, is still under development.[5]

3. PRACTICAL APPLICATION IN AUTOMOBILES

Applications of LCDs in automobiles have been discussed and evaluated since 1970. Toyota Motor Co. introduced a car-clock using TN-LCD in its

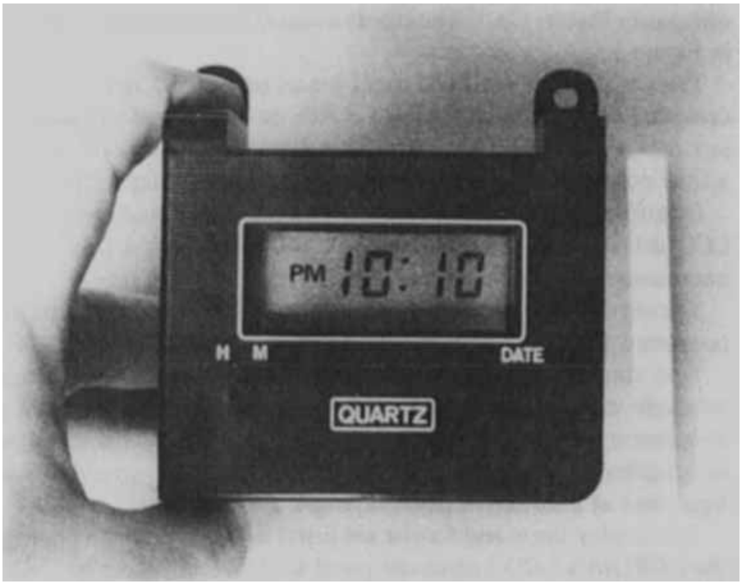

FIGURE 4 LCD car-clock.

CRESTA model in 1980. That was the first practical application of LCDs in automobiles. This car-clock is shown in Figure 4. After that, small-size LCDs became widely applied in car-clocks and car-radios.

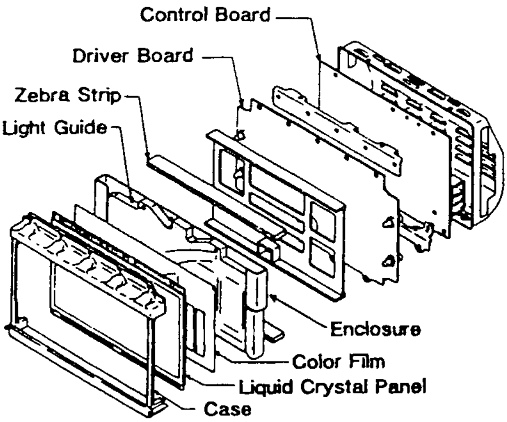

FIGURE 5 Construction of the LCD instrument panel (CORDIA).

The first LCD instrument panel was introduced in the CORDIA by Mitsubishi Motors Co.[6,7] The construction of the instrument panel is shown in Figure 5.

The transflective TN-LCD panel has an area of 105 mm × 160 mm, an operating temperature range from −30°C to +85°C and a response time of less than 400 ms at −20°C. It is assembled in a plastic case together with a light guide panel, a color film, and two printed circuit boards.

One of the printed circuit boards is an LCD driver board with two CMOS LCD drivers, and the other is a control board with a single chip 8-bit microcomputer.

The driver board has lead-out terminals on both sides, and they are connected with LCD terminals by zebra connectors.

Four small incandescent bulbs located on the driver board are inserted into light inducing holes on the light guide panel. The light guide panel is transparent, and its front side is printed in white. As a result of these techniques, the light guide panel works as a flat light source in dark ambient light, and as a reflective panel in bright ambient light.

The display items and format are listed in Table II, and a photograph of the CORDIA's LCD instrument panel is shown in Figure 6.

Recently, another LCD instrument panel was introduced in the GLORIA by Nissan Motor Co. The construction is shown in Figure 7. Figure 7.

It has four TN-LCD panels which display the speedometer, tachometer, gauges and indicators. A panel heater is attached to the rear of the speedometer LCD panel to shorten its response times. Two fluorescent lamps are placed behind the LCD panels. The driver board is connected with the LCD panels by soldered-pins attached to the LCD panels.

The displays items and format are listed in Table III, and a photograph is shown in Figure 8.

FIGURE 6 Instrument panel of the CORDIA model.

TABLE II

Display Item and Format (Cordia)

Display item	Format	Color
Speedometer	Digital (2½ digits)	Amber
Tachometer	Bargraph (75 segments)	Amber, Red
Fuel gauge	Bargraph (15 segments)	Green
Temperature gauge	Bargraph (10 segments)	Green

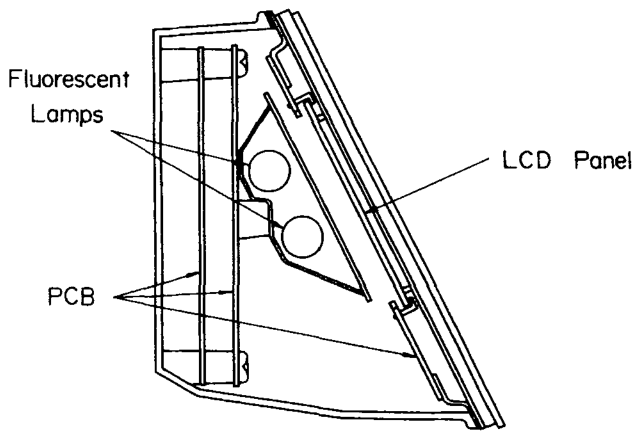

FIGURE 7 Construction of instrument panel (GLORIA).

TABLE III

Display Item and Format (Gloria)

Display item	Format	Color
Speedometer	Digital (2½ digits)	White
Tachometer	Bargraph (40 segments)	White, Red
Fuel gauge	Bargraph (12 segments)	White
Temperature gauge	Bargraph (12 segments)	White
Warning and monitoring indicators	Pictographs and characters	White, Red Yellow, Blue

FIGURE 8 Instrument panel of the GLORIA model.

4. CONCLUSIONS

As automobiles get smaller and on-board electronic control systems become more prevalent, electronic displays become more important to the automotive instrument panels. LCDs have many advantages: low voltage and low power requirements, excellent visibility in high ambient light, color capability, flexibility of pattern design, and compatibility with the integrated circuit. With the improvement of the operating temperature range, of the response time at low temperatures, and of the reliability, the major problems preventing the introduction of LCDs in automotive instrument panels have been solved. The LCDs will be used more in automobiles in the near future.

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