

# Development of Contrast Improvement Technology for Automotive Display

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**Abstract**

We investigated the new liquid crystal material that is specialized in improving the contrast ratio while suppressing the decrease in transmittance and ensuring the response performance specific to automotive applications. By reducing the scattering factor of the liquid crystal optical condition, the black transmittance is reduced, and the frontal contrast ratio of 2000 is expected to be achieved. It might be reached 2500 by optimizing the LCD module optical conditions.

**Author Keywords**

Automotive LCDs; Contrast ratio; Viewing angle; FFS mode; Liquid crystal mixture

**1. Objective and Background**

The overall automotive display market is expected to grow at a CAGR of 6.3% and exceed \$15 billion by 2028. Rapidly growing in popularity, automotive display panels are responsible for the multifunctionality of automobiles, providing information such as speed, fuel level, navigation guidance, and entertainment. They also contribute to driving assistance and safety by displaying warnings and alerts for problems such as low tire pressure and engine malfunctions. Besides, various functions can be set, such as air conditioning and audio.

Moreover, automotive displays are becoming higher quality. The first reason is that the image quality of home LCD TVs is improving year by year, and as luxury car owners enjoy watching such TVs, there is a demand for higher image quality automotive displays as well. Secondly, contrast is an important factor in high image quality, and by increasing contrast, the "black" of the display does not leak light at night, and blends beautifully with the surrounding interior. Further as CID and cluster displays, which account for the majority of the market, become larger and hoodless, there is growing user demand for preventing reflections on the windshield, improving CR, and improving visibility by reducing reflections.

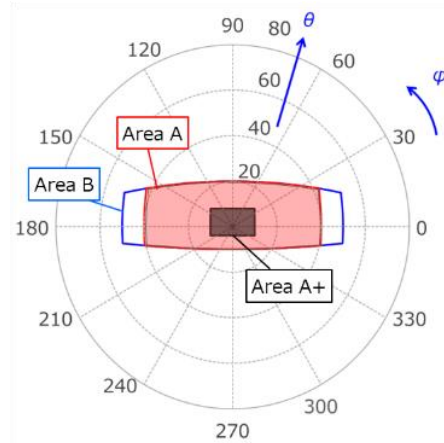
The characteristic value of contrast is the "brightness of white" divided by the "brightness of black. In other words, making the black display as close to black as possible means making the contrast value as high as possible. In addition to contrast, viewing angle is also an important factor in improving image quality.

The viewing angle of automotive displays is limited by the seating arrangement. The vertical viewing angle of automotive displays is narrower than the viewing angles of common monitors, televisions, mobile devices, and other display applications. Furthermore, automotive displays require a relatively wide horizontal viewing angle to provide a clear image for everyone (driver and passengers).

Specific viewing angle conditions, referred to as automotive viewing angle areas, as specified by the German OEM (Automotive Display Specification V5.1) are shown in Figure 1. Each of the A+, A, and B area is defined by the horizontal (H) and vertical (V) angles of the viewing angle coordinate. Curved

boundaries are transformed from linear boundaries in (H, V) coordinates. Contrast values are quantitatively managed within each viewing angle area of the boundaries. Thus, along with high contrast, a wide viewing angle range is another factor contributing to high image quality.

GOEM also specifies response times for displays under the conditions specified in Table 1 below. For example, to prevent blurring when displaying images from a rear-view camera or a speedometer, the liquid crystal material used must have a wide temperature characteristic range.



	Horizontal	Vertical
Normal	±0°	±0°
Area A+	±10°	+8°/ -4°
Area A	±40°	+20°/-10°
Area B	±50°	+20°/-10°

**Figure 1.** Automotive viewing angle areas specifications

Ambient Temperature	Value
Temperature on Panel Surface (Center of Display) +25°C	Max (TG2G) ≤ 22 msec
Temperature on Panel Surface (Center of Display) -20°C	Max (TG2G) ≤ 180 msec
Temperature on Panel Surface (Center of Display) -30°C	Max (TG2G) ≤ 400 msec

**Table 1.** Switching time specifications

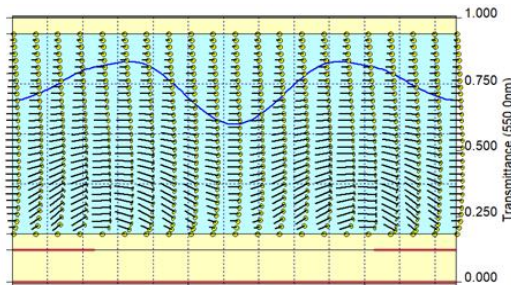
Liquid crystal materials for automobiles generally have a crystallization temperature of -40°C or lower. However, as the viscosity of liquid crystal rises rapidly as it approaches its crystallization temperature, we first tried to reduce the viscosity of the liquid crystal material itself. We also considered further narrowing the panel's cell gap (the gap between the two pieces of glass filled with liquid crystal material). Narrowing the cell gap has a significant effect on the response speed, but it also reduces

the panel transmittance, and managing production with a narrow cell gap also affects the yield.

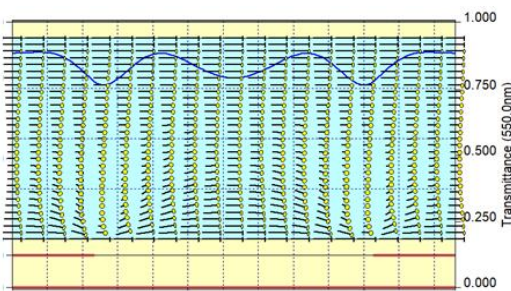
## 2. Simulation study of characteristics

**2.1. LC alignment working mechanism :** In FFS mode, by changing the initial orientation, both positive and negative dielectric anisotropy can be used. The advantages and disadvantages of the optical properties of each liquid crystal are explained. The advantage of negative liquid crystal is that the transmittance is 10 to 20% higher than that of positive liquid crystal.

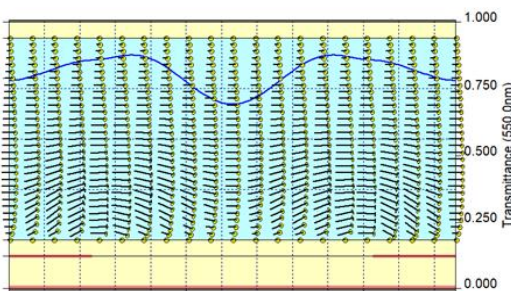
(a) Positive LC



(b) Negative LC



(c) Negative adding to positive LC



**Figure 2.** Simulated Liquid crystal director and transmittance cross section of liquid crystal cell.

In positive liquid crystal, as shown in Figure 2(a), the fringe electric field causes the liquid crystal director (nail shape) to tilt upward perpendicularly to the substrate near the electrode (the red lines) on the electrode substrate side, and the director distribution parallel to the polarizer transmission axis increases in the center

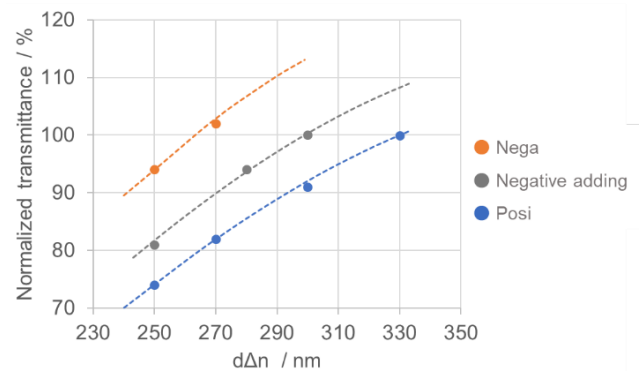
of the gap (slit) between the electrodes. Therefore, the cross-sectional profile of the transmittance (the blue line) has low transmission efficiency at the center of the slit, and a minimum point, or so-called dark line, occurs. In other words, the modal transmittance is low. On the other hand, in the negative type shown in Figure 2(b), the liquid crystal director is not tilted relative to the substrate on the electrode and throughout the slit, but is distributed horizontally, and the director component parallel to the polarizer transmission axis increases, resulting in high transmittance.

Generally speaking, negative addition to positive LC means adding several to several tens of percent of LC components with negative dielectric anisotropy to a positive LC mixture. Basically, by keeping the dielectric anisotropy positive, as shown in Figure 2(c), the cross-sectional profile of the transmittance of the electro-optical properties behaves similarly to that of the positive LC in Figure 2(a). By adding negative LC, the average values of  $\epsilon_{\parallel}$  and  $\epsilon_{\perp}$  become larger than in positive LC, and the ratio of  $\epsilon_{\perp}$  to  $\Delta\epsilon$  becomes larger, therefore, the white transmittance increases compared to positive LC due to the negative component in which the liquid crystal director is distributed horizontally to the substrate. However, the increase in transmittance does not reach that of negative LC.

However, the disadvantage of negative LC is that due to the polar group structure of the negative liquid crystal molecules, impurity ions are easily adsorbed into the negative liquid crystal material, making it less reliable than positive LC. For the above reasons, positive LCs are now widely used to meet the environmental resistance required for automotive applications. Another feature of this negative adding to positive is that it has the same reliability as positive liquid crystal materials.

**2.2. Transmittance :** As is well known, liquid crystal mixtures are broadly classified into those with positive dielectric anisotropy and those with negative dielectric anisotropy. In general, the white transmitted light intensity  $I$  in FFS (IPS) mode [1-2] is expressed by the following equation. Here,  $\theta$  is the angle between the molecular orientation direction and the transmission axis of the polarizer.

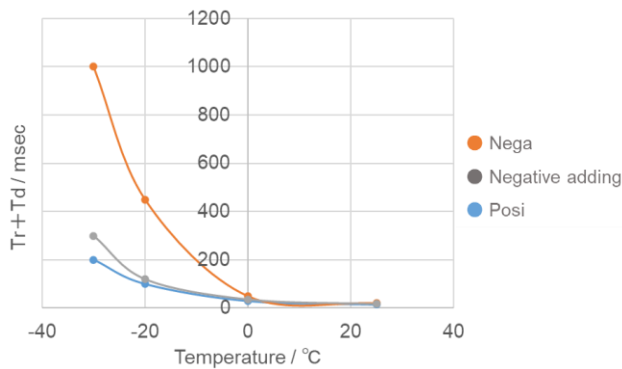
$$I = I_o \sin^2 2\theta \sin^2 \frac{\pi d \Delta n}{\lambda} \quad (1)$$



**Figure 3.** Relationship between transmittance and  $d\Delta n$

As shown in Figure 3, if  $d$  is the cell gap and  $\Delta n$  is the birefringence of the liquid crystal, the white transmittance changes according to the curve relationship of  $d\Delta n$ . This relationship is the same for positive, negative liquid crystal materials. For each liquid crystal material, the smaller the  $d\Delta n$ , the lower the transmittance.

**2.3. Switching time :** Figure 4 shows that the temperature dependence of the response  $Tr + Td$  (the sum of rise and decay of liquid crystal response time) for the positive, negative, and negative adding to positive evaluated in test cells. At room temperature near  $0^\circ\text{C}$ , positive and negative LC have approximately the same response level. On the other hand, at  $-30^\circ\text{C}$ , negative LC is extremely slow, experimentally found to be about 3 to 4 times slower than positive LC. From a safety standpoint, such response performance is not suitable for automotive applications like speed meters and back monitor. With negative amount added, the composition must be adjusted to meet response specifications, as high negative additions result in poor response at low temperatures. In principle, due to the constraints of molecular structure, negative liquid crystals cannot have an absolute  $\Delta\epsilon$  value as large as positive liquid crystals, which means that the driving voltage is higher, and the viscosity reducing components cannot be increased as much as in positive liquid crystals, so negative liquid crystals have a slower response than positive liquid crystals.



**Figure 4.** Temperature dependence of response  $Tr + Td$  for each LC material

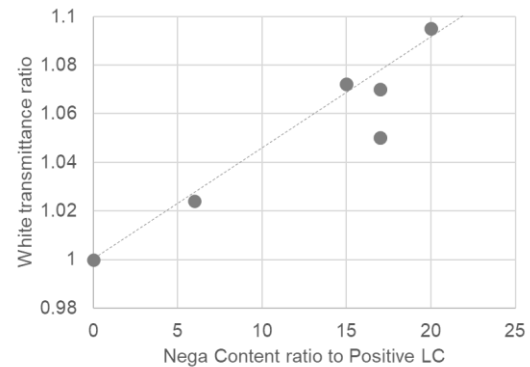
**2.4. New-LC mixture investigation :** When  $d\Delta n$  was kept constant and the relative white transmittance ratio was investigated versus the negative component content, as shown in the figure 5, the white transmittance monotonously increased in proportion to the increase in the negative component content.

However, as shown in Figure 6, it was experimentally found that when  $d\Delta n$  was fixed constant, the  $25^\circ\text{C}$  response slowed down as expected with increasing negative component content.

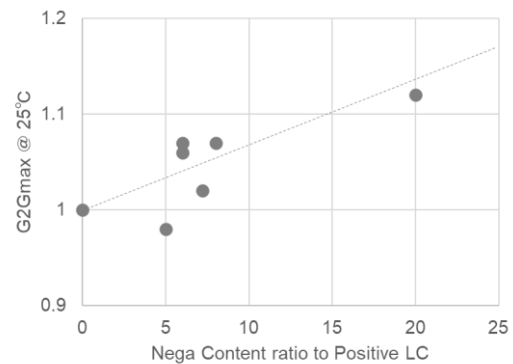
In other words, negative adding, allows for the downward tuning of  $d\Delta n$  while suppressing the transmittance decrease relative to positive LC mixtures (see Figure 3).

The New-LC in this paper can be designed to reduce the delay in response characteristics to a level acceptable for automotive applications by adjusting the amount of negative component

added and narrowing the cell gap. After confirming the low-temperature stability of the liquid crystal composition, we plan to evaluate the response at the extremely low temperature of  $-30^\circ\text{C}$ .



**Figure 5.** Relationship between negative LC content ratio and white transmittance ratio



**Figure 6.** Relationship between Negative LC content positive ratio and  $G2G_{\text{max}}$  switching time

**2.5. Contrast ratio:** On the other hand, one of the factors that determine the black transmittance in the FFS mode is the light leakage due to light scattering caused by liquid crystal fluctuations, and its coefficient, the scattering factor (SF), is proportional to the following equation (2). This is common to both positive and negative liquid crystals, as it affects the black transmittance in the initial alignment state of the liquid crystal molecules when no voltage is applied [3].

$$SF = \frac{(\Delta n(ne+no))^2 \cdot d}{K_{ave}} \quad (2)$$

In general, contrast is improved by lowering the SF value in equation (2). However, reducing  $\Delta n$  to lower the SF value results in a decrease in transmittance, as shown in equation (1). Therefore, as shown in Figure 3, when  $d\Delta n$  is constant, the negative additive LC has a higher transmittance than the positive

LC, so we considered converting the effect of this increase in transmittance into an increase in contrast in order to suppress the decrease in the transmittance level of the positive LC.

### 3. Simulation of Optical properties

The new liquid crystal material is suitable for designing to meet the specific specifications (contrast, response) of automotive displays. The calculation of the response parameter is expressed in equation (3).

$$RP = \frac{\gamma_1 \cdot d^2}{K_{22}} \quad (3)$$

The high CR liquid crystal investigated this time optimizes the composition and physical properties of the LC mixture by adding negative LC to positive LC, suppressing the decrease in relative transmittance of the positive LC, and is expected to achieve CR2000 while ensuring the GOEM specification of 25°C response (22 msec) (see Figure 7).

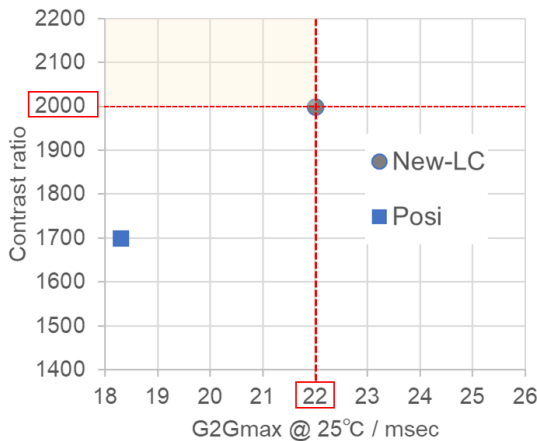


Figure 7. Response time and frontal contrast ratio

		Posi LC Conventional	New-LC Simulation
Contrast Ratio	Frontal	1700	2000
	Area A+ min	1430	1800
	Area A min	650	750
	Area B min	500	650

Table 2. Comparison of liquid crystal materials

In addition to improving the frontal contrast, we expect improvements in viewing angle CR, as shown in Table 2. We plan to verify these characteristics using an actual device.

### 4. Impact

As connected cars equipped with ICT terminal functions, and automobiles with driving support functions, expand and the amount of information displayed to the driver increases, the need for displays that provide a comfortable and enjoyable drive by conveying the necessary information to the driver exactly when needed will continue to grow. Those required display technologies are the elements of high image quality improved contrast and viewing angle.

To meet these needs, we have added negative LC to the positive LC that is generally considered to improve panel transmittance, suppressing the decrease in transmittance, ensuring the response characteristics of the GOEM specification, and making progress in developing the first liquid crystal material that achieves a contrast ratio of 2000. The improvement in frontal contrast also improves viewing angle contrast. Furthermore, LCD panels are expected to reduce color change due to viewing angle. Moreover, by optimizing the optical conditions of the LCD module by using a polarizer with higher polarization and a backlight with improved light collimation, the contrast was found to increase by another 25%, reaching 2500 [4].

Additionally, the combination of an LCD with higher panel contrast and backlight local dimming technology improves the effectiveness of safety assurance and meets the need for clear images like those seen on LCD TVs.

Due to the operating environment and conditions, automotive applications have unique requirements, reliability, and quality standards that are not found in other applications, and we have developed and commercialized products to meet these requirements [5]. As an indispensable display technology for automobiles, we will continue to develop LCDs for automotive use, pursuing improved quality and reliability as well as enhanced visibility.

### 5. Acknowledgements

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### 6. References

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