Optimization of Environmental Integrated Surface Display

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Abstract

Environmental integrated surface display technology blends into its surroundings when not in use, but becomes operational and visible when powered on. However, this also leads to the decrease of module's transmittance and display brightness. Light passing through the surface film encounters irregular obstruction and reflection from ink particles within the film, resulting in reduced display uniformity, bright spots, severe color shifts, and brightness decay at wide viewing angles. This paper addresses the aforementioned issues arising from the development of environmental integrated surface display technology and provided theoretical simulations to improve and optimize problems such as brightness loss, poor uniformity, bright spots, and color shifts.

Author Keywords

Environmental Integrated Display; Display Brightness Loss；Display Uniformity; AMOLED

1. Introduction

The existing environmental integrated display technology has been primarily applied in the home appliances and automotive interior. Early Application Stage: Surface display technology is mainly used in ambient translucent surfaces such as floors, door trims, and dashboards. These applications mainly showcase the technology's decorative and ambient lighting capabilities. Through translucent surface technology, floors can present unique visual effects, while door trim panels and dashboards can create distinctive ambient lighting.

Advanced Application Stage: When the market shows a favor of new techs, surface display technology expands its application to functional indications such as central control instruments, steering wheels, and seat adjustments. On automobile console, surface display technology enables seamless information display and touch operations, enabling both natural texture visual effects and instant info delivery. On steering wheels, buttons and displays can be realized through surface display technology, improving aesthetics and functional intuitiveness.

In terms of seat adjustments, drivers can adjust seat parameters through touchscreens or gestures, enabling personalized settings and memory functions.

The environmental integrated surface display technology discussed in this article features a modular layered structure consisting of a protective layer (surface substrate), as shown in figure 1, a surface ink layer (which may include a light-blocking layer), and an AMOLED display panel. This structure combines the advantages of surface film materials and AMOLED displays, creating a synergetic effect of tactile and visual enjoyment. The light transmittance of the surface film material is less than 50%, leading to a brightness loss of over 70% (including the polarizing film), a brightness uniformity of less than 80%, a reflectivity of 10% to 15%, and severe chroma noise issues to the display module. Additionally, the module is thicker, with brightness decay exceeding 20% at large viewing angles, and the critical technical challenge lies in the ink of the surface film material blocking the light emission of the AMOLED display, exacerbating the chroma noise problem.

2. Experimental Background

When the environmental integration surface display module is off, ambient light is reflected by the surface film material and enters human eye, with the reflected light playing a dominant role, allowing the observer to see the texture effect of the environmental integration surface. When the display screen of the environmental integration surface display module is on, the light from the AMOLED display module takes precedence, passing through materials such as the surface film and entering the human eye, enabling the observer to see the images displayed by the AMOLED display module.

The strong charge transport ability, resulting in increase of the transverse charge transport and decrease of vertical, and the OLED radiation recombination luminescence decrease.

Figure 1. Environmental integrated display activation/deactivation mode

The ink printing layer on the surface of environmentally integrated surface film material forms the surface color depth through the size and density of chroma noise. The colors involved include Cyan (C), Magenta (M), Yellow (Y), and Key (Black, K), with CMYK color mixing proportions creating the surface color gamut. CMYK is a color model used in the printing industry that relies on reflected light. It works by sunlight or artificial light hitting the printed material and then reflecting into our eyes to reveal the content.

In Figure 2, the CMYK color ink particles are opaque and distributed irregularly in terms of both regions and heights within the ink printing layer on the surface film material. When the environmental integrated display AMOLED module is lit on, the RGB subpixels of the AMOLED display emit light that enters the ink printing layer. The ink particles randomly block and reflect the emitted light, resulting in chroma noise and color shifts as shown in figure 2 that could be seen by human eyes.

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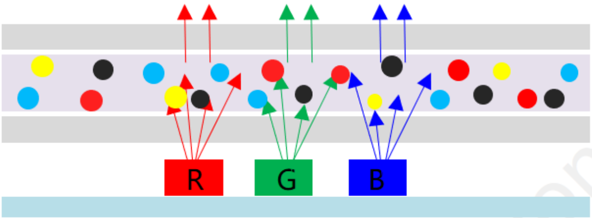


Figure 2. Analysis of chroma noise and Color Deviation Issues on Environmentally Integrated Surface Displays

3. Experimental Process

For the mass production of environmental integrated AMOLED display, mechanical performance is essential. we compared the regular cover layer of flexible AMOLED and three different surface film material and the result shows as the following table. Table 1 presents the pencil hardness test data, while Table 2 shows the scratch resistance test data and water droplet angle test data. The conclusion of the mechanical performance tests are as follows: Among the pencil hardness test data, the hardness of the black wood grain surface material reached a maximum of 3H, while the yellow wood grain and leather materials did not reach 10B. In terms of scratch resistance, the black wood grain and yellow wood grain materials failed (NG) after 50 cycles, and the leather material failed after 10 cycles. The mechanical performance of the individual surface material is weaker compared to the flexible cover plate.

Table 1. Pencil Hardness Test Data

Module Material	Pencil Hardness	0 hr	24hr
Flexible Cover	4 H	OK	OK
Dark Wood Grain Surface Film Material	B	OK	OK
	H	OK	OK
	2H	OK	OK
	3H	OK	OK
	4H	NG	NG
Yellow Wood Grain Surface Film Material	10B	NG	NG
	9B	NG	NG
Black Leather Surface Film Material	10B	NG	NG
	9B	NG	NG

Table 2. Scratch Resistance Test Data & Water Contact Angle Data

Module Material	Steel Wool	Eraser
Flexible Cover	2500	2500
Dark Wood Grain Surface Film Material	50	500
Yellow Wood Grain Surface Film Material	50	500
Black Leather Surface Film Material	10	500

We also tested the optical properties of the surface material. Figure 3 presents the transmittance test data for the individual surface module, while Figure 4 shows the reflectivity test data. The conclusions of the material optical property tests are as follows: The transmittance is 90% and gradually increases below 420nm. Above 420nm, the transmittance for leather is approximately 33%, for black wood grain it is around 16.8%, and for yellow wood grain it is 68%. The reflectivity is 6%, with leather having a reflectivity of approximately 5.5%, black wood grain around 7.4%, and yellow wood grain showing significant fluctuations, with reflectivity being around 12% below 550nm and rapidly rising to 20% above 550nm. The optical properties of the individual surface material are inferior to regular flexible cover layer.

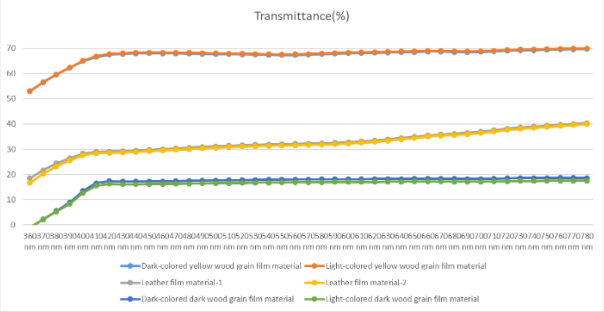


Figure 3. Transmittance Test Data for Surface Monomer

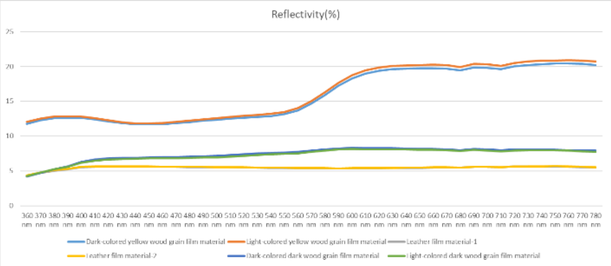


Figure 4. Reflectance Test Data for Surface Module Monomer

Figure 5. Diagram of epidermal sample

Table 3 presents the simulated data for transmittance and reflectivity of various surface display modules. The conclusions of the simulations for transmittance and reflectivity of the surface display modules are as follows: The leather display module has a transmittance of 30% and a reflectivity ranging from 7.5% to 9.6%; the yellow wood grain display module has a transmittance of 70% and a reflectivity ranging from 22.1% to 25.6%. Our target for the surface display module is a transmittance of 70% and a reflectivity of 7%.

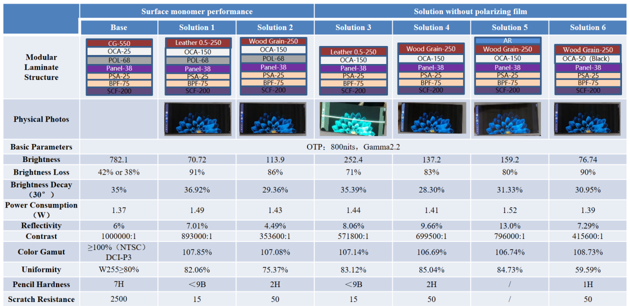
Table 3. Simulated data for transmittance and reflectance of multiple surface display modules

Surface monomer performance	Module transmittance （%）	Module reflectivity （%）	Single surface material transmittance/reflectivity （%）
Leather	30	9.6	30% / 5%

Leather	30	7.5	30% / 5% + BM
Yellow wooden grain	70	25.6	70% / 16% + BM
Yellow wooden grain	70	22.1	70% / 16% + BM + AR
Our target	70	7	

Table 4 presents the parameter test data for the stacking configurations of various surface display modules. After attaching the surface film material, the brightness of the display module significantly decreases. The leather display module, without a polarizer, achieves an optimal brightness of 232.4 nits. Removing the polarizer increases the reflectivity, with the wood grain and BOCA schemes achieving an optimal reflectivity of 7.29%. The leather scheme experiences faster brightness decay at large viewing angles, with a brightness decay of 35.39%. When the screen is lit, the surface reduces the brightness of the display panel, necessitating an increase in the transmittance of the surface film material to at least above 50%. Reducing the thickness of the surface film material from 250μm to 80μm enhances the brightness of the display module to 600 nits. Poor brightness uniformity requires calibration and adjustment. When the screen is off, for the surface texture to be clear and achieve an integrated effect, the reflectivity of both the surface and the display screen needs to be reduced to less than 7%.

Table 4. Parameter test data for overlaying schemes of multiple surface display modules



	Surface monomer performance			Solution without polarizing film			
	Base	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Modular Laminate Structure	CG-550 OCA-25 POL-68 Panel-38 PSA-25 BPF-75 SCF-200	Leather 0.5-250 OCA-150 POL-68 Panel-38 PSA-25 BPF-75 SCF-200	Wood Grain-250 OCA-150 POL-68 Panel-38 PSA-25 BPF-75 SCF-200	Leather 0.5-250 OCA-150 Panel-38 PSA-25 BPF-75 SCF-200	Wood Grain-250 OCA-150 Panel-38 PSA-25 BPF-75 SCF-200	AR Wood Grain-250 OCA-150 Panel-38 PSA-25 BPF-75 SCF-200	Wood Grain-250 OCA-50 (Black) Panel-38 PSA-25 BPF-75 SCF-200
Physical Photos							
Basic Parameters	OTP：800nits，Gamma2.2						
Brightness	782.1	70.72	113.9	252.4	137.2	159.2	76.74
Brightness Loss	42% or 38%	91%	86%	71%	83%	80%	90%
Brightness Decay （30° ）	35%	36.92%	29.36%	35.39%	28.30%	31.33%	30.95%
Power Consumption （W）	1.37	1.49	1.43	1.44	1.41	1.52	1.39
Reflectivity	6%	7.01%	4.49%	8.06%	9.66%	13.0%	7.29%
Contrast	1000000:1	893000:1	353600:1	571800:1	699500:1	796000:1	415600:1
Color Gamut	≥100%（NTSC） DCI-P3	107.85%	107.08%	107.14%	106.69%	106.74%	108.73%
Uniformity	W255≥80%	82.06%	75.37%	83.12%	85.04%	84.73%	59.59%
Pencil Hardness	7H	＜9B	2H	＜9B	2H	/	1H
Scratch Resistance	2500	15	50	15	50	/	50

Figure 6 shows a comparison of the difference with and without a polarizer for a white display image on the wood grain surface display module. Figure 6 presents a similar comparison for a color striped display image on the same module. Figure 7, on the other hand, demonstrates the difference with and without a polarizer for a leather surface display module. Based on the actual images, the conclusions drawn from the comparisons are as follows:

In terms of reflectivity, the ranking is as follows: 1. leather surface with polarizer, 2. wood grain surface with polarizer, 3. wood grain surface with black OCA, 4. leather surface without polarizer, 5. wood grain surface without polarizer, 6. wood grain surface without polarizer but with surface treatment.

For brightness, the ranking is as follows: 1. leather surface without polarizer, 2. wood grain surface without polarizer but with surface treatment, 3. wood grain surface without polarizer, 4. leather surface with polarizer, 5. wood grain surface with black OCA, 6. wood grain surface display module with polarizer.

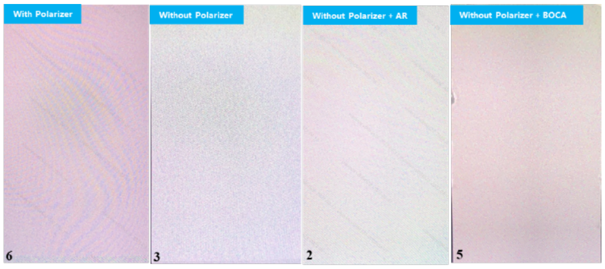


Figure 6. Difference Chart of Wood Grain Surface Display Module with and without Polarizer for White Images

Figure 7. Difference Chart of Wood Grain Surface Display Module with and without Polarizer for Color Striped Images

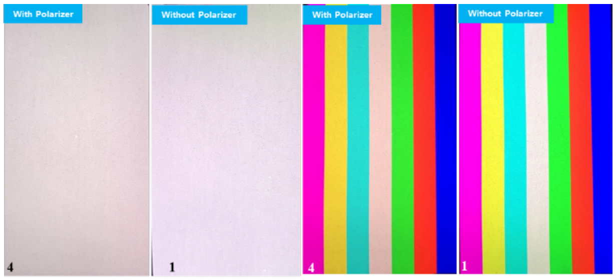


Figure 8. Comparison of Leather Surface Display Module with and without Polarizer

The calibration and adjustment for the environmental integrated display module involve the following steps: First, we set the module is in a darkroom. Secondly, we used the CCD for alignment and focusing. In the darkroom environment, the CCD captures grayscale display data and transmit to a data processing computer. Then the computer generates calibration data, which is subsequently written into the DDIC through data transmission. The whole process is demonstrated in figure 9.

A unique aspect of the calibration model for the environmental integrated display module is that, prior to entering the data processing stage for calibration, it is necessary to capture the appearance image information of the module under an indoor illuminance of 100 to 300 nits using the CCD. This information serves as an important image data set. During the data processing phase for calibration, the texture and appearance information of the integrated display module is combined with the grayscale display data captured in the darkroom for calibration.

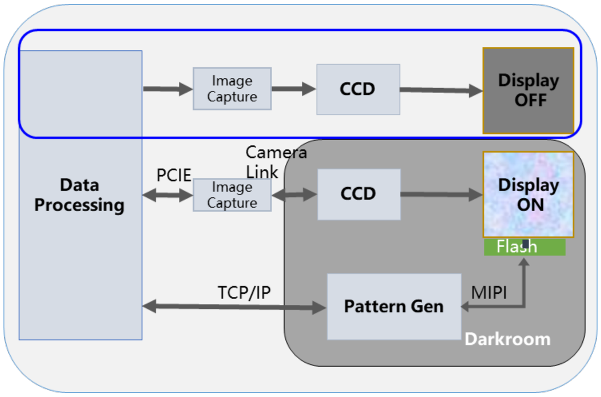


Figure 9. Schematic Diagram of Image Data Calibration Process

4. Conclusions

This paper conducts detailed research and testing on the issues of reduced display uniformity, bright spots, and color shift at large viewing angles in the environmentally integrated surface display, which is based on a laminated structure comprising a protective layer surface substrate, surface ink layer, and AMOLED display module. Additionally, it introduces some solutions to address the issues of screen uniformity and bright spots. This paper provides a reference for the problems of large viewing angle color shift caused by the display spacing between the surface film material and AMOLED display, establishes a practical solution for the technical development of environmentally integrated surface display.

Our subsequent work plan, as one of the display integration technologies, environmentally integrated surface display technology encompasses the optimization of surface materials, enhancement of display transmittance, reduction of display reflectance, improvement of display moiré patterns and chroma noise, and an increase in reliability.

The technology roadmap for environmentally integrated surface display technology includes two directions. Direction 1 is a pixel-level punching and overlaying solution for surface film materials, combined with high-precision module bonding for displays. Direction 2 is a solution for preparing pixel-level ink surface on AMOLED display modules.

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