Drive Circuit and Optical Co-Design for High-Performance Under-Display Infrared Recognition

Miao Chang*, Lifang Wang*, Xingxing Yang**,Hongsen Zhang*,Qinggang Liu**

***Hefei Govisionox Technology Co., Ltd.(Visionox's Affiliated Company), Hefei, Anhui, China**
****Visionox Technology Inc., Kunshan, Jiangsu, China**

Abstract

A drive circuit and optical co-design is presented, featuring a full-panel VSS layer with optimized apertures. By shaping opaque regions into circular/octagonal forms and implementing distributed signal routing with controlled spacing (ratio: 0.4–2.5), diffraction is suppressed and IR transmittance is enhanced. The structure achieves ~9% zero-order diffraction efficiency at 940 nm, enabling robust under-display infrared sensing.

Author Keywords

full-panel VSS layer; diffraction; IR transmittance

1. Introduction

The relentless pursuit of larger screen-to-body ratios has propelled under-display (UD) technology to the forefront of display research. While UD cameras for visible light are becoming commercialized, UD infrared (IR) recognition—which is indispensable for secure functionalities like 3D facial authentication and robust gesture sensing—remains a significant challenge. The primary bottleneck lies in the display stack itself, which acts as a hostile optical environment for IR light. The dense pixel matrix, multiple functional layers, and extensive metal interconnects cause severe attenuation and scattering. More critically, the periodic structure of pixels and apertures acts as a diffraction grating, leading to pronounced flare and haze in captured IR images, which drastically degrades the signal-to-noise ratio (SNR) [1, 2]. Previous approaches have primarily focused on material-level optimizations, such as using low-absorption substrates, or on pixel-level adjustments like increasing the aperture ratio at the cost of display resolution [3]. However, a holistic solution that synergistically addresses the electrical requirements of the drive circuit and the optical constraints of light transmission is still lacking [4].

In this work, we propose a co-design methodology that fundamentally rethinks the layout of the drive circuit's metal layer (specifically the VSS layer) to serve a dual purpose: providing stable electrical reference and functioning as a precisely engineered optical element. Our contributions are threefold:

1. We introduce a symmetric aperture shape (circular/octagonal) in the VSS layer to mitigate directional diffraction.
2. We propose a distributed, fine-line routing scheme to replace traditional bulky signal lines, dramatically increasing the open aperture area for IR transmission.
3. We validate the design through simulation and experiment, demonstrating a substantial improvement in both optical efficiency and image quality for UD IR systems.

The pursuit of all-screen devices has accelerated under-display (UD) technology development. While UD cameras are emerging, UD infrared recognition—critical for secure facial recognition and gesture sensing—remains challenging due to significant light attenuation and diffraction through the pixel stack. Conventional display layouts, with rectangular apertures and block metal routing, cause severe haze and flare in IR images. We propose a pixel circuit and metal layer co-design that simultaneously addresses electrical and optical requirements for high-performance UD IR systems.

2. Proposed Structure and Design

2.1 Full-Panel VSS Layer with IR Aperture Array

To ensure electrical stability across the panel, we retained the design of a full-panel, low-resistance metal VSS layer. However, instead of being a solid plane, this layer is patterned with a dense and periodic array of micro scale apertures, and cuts the cathode layer into sub-pixel level segments as illustrated in Fig.1. These apertures are systematically arranged in both the X and Y directions, creating numerous dedicated channels for IR light to pass through. This bidirectional aperture design is a significant departure from traditional layouts where light paths are often restricted by unidirectional routing channels, thereby providing a higher theoretical transmittance ceiling.

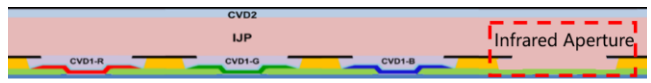


Figure 1. Cross-section of the pixel stack

2.2 Optical Optimization via Symmetric Aperture Shapes

A key insight of our work is that the shape of the opaque region is as critical as the size of the open aperture. Conventional rectangular openings, with their sharp corners and preferential edges, tend to concentrate diffracted light into specific orders and directions, manifesting as strong flare (Fig. 2a). We optimized the shape of these light-shielded areas to be approximately circular or octagonal (Fig. 2b). These shapes possess higher rotational symmetry, which promotes a more uniform distribution of diffracted energy across all angles, effectively scattering the problematic high-intensity diffraction orders and concentrating more energy in the desired zero-order (direct transmission) path.

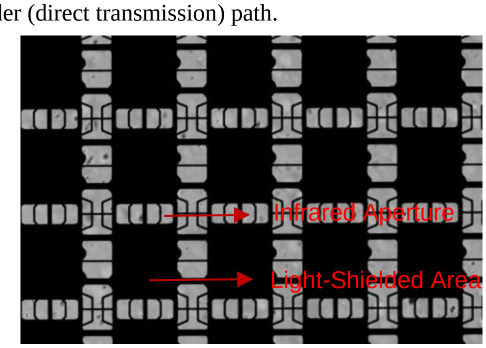


Figure 2a. Schematic of the Aperture Distribution

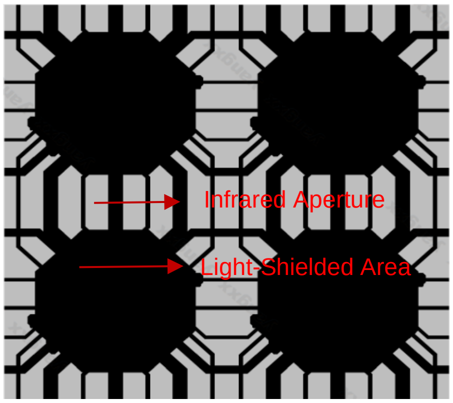


Figure 2b. Schematic of Octagonal Light-transmitting Aperture Distribution

2.3 Distributed Drive Circuit Routing for Maximum Aperture Ratio

The metal traces for drive signals (e.g., scan lines, data lines) traditionally form large, opaque blocks that significantly block light. Our design deconstructs this paradigm. We re-routed these signals using multiple, single-width thin metal lines. These fine lines are then uniformly distributed across the VSS aperture areas, as shown in Fig. 3. This transformation from a "blocked" to a "gridded" opacity dramatically increases the physical open area. To balance the trade-off between increased line resistance and transmittance, we meticulously controlled the spacing-to-line-width ratio to be between 0.4 and 2.5, a range determined through parametric simulation to offer an optimal compromise.

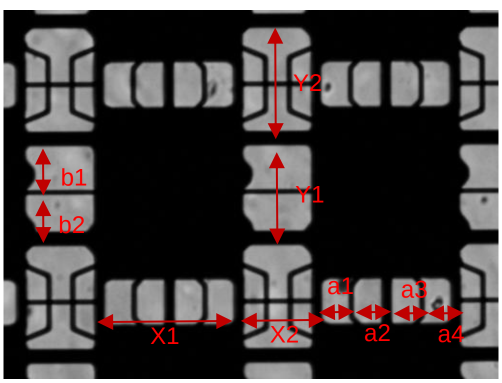


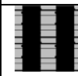
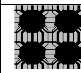
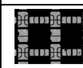
Figure 3. Schematic of the Aperture Dimensions and Distribution(Aperture dimensions $X_1 \approx X_2$ and $Y_1 \approx Y_2$. The key spacing-to-aperture ratios (b_1/Y_1, b_2/Y_1, a_1/X_1, a_2/X_1) are confined to 0.4-2.5.)

3. Simulation and Experimental Results

3.1 Optical Simulation and Analysis

We employed Rigorous Coupled-Wave Analysis (RCWA) to simulate the optical performance of our proposed structure against a conventional baseline. The simulation domain included the complete pixel stack. As shown in Table1, the proposed design with circular apertures shows a marked suppression of higher-order diffraction (orders $|m|>0$, $|n|>0$) compared to the rectangular baseline. The energy is more favorably concentrated in the zero-order (0,0), predicting higher effective transmittance and lower optical noise.

Table 1. Simulation results of transmittance for different design patterns

Case	Design Trans Area	Layout	Simulation Trans	Diffraction 0-level simulation values	Diffraction 0-level simulation net values
1	39%		21.9%	39%	5%
2	35%		21.5%	38.5%	8.5%
3	35%		21%	37.4%	8%

3.2 Experimental Verification

We fabricated a prototype display panel incorporating the proposed co-design on a standard display production line. The optical performance was characterized using a 940nm IR laser emitter and a calibrated photo detector/imaging system, As plotted in Fig. 4,

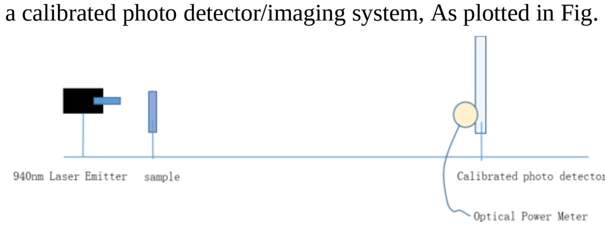
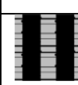
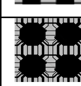
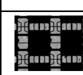


Figure 4. Measurement System

The measured zero-order diffraction efficiency for our design reached ~9% at 940nm, a significant improvement over the ~6.5% measured for the conventional reference design. This ~70% relative improvement is directly attributable to the combined effect of the symmetric apertures and distribute drouting.

Table 2. Test results of transmittance for different design patterns

Case	Design Trans Area	Layout	Simulation Trans	Diffraction 0-level test values	Diffraction 0-level test net values
1	39%		21.9%	26%	6.5%
2	35%		21.5%	30%	10.5%
3	35%		21%	28%	9%

4. Conclusion

We have proposed and validated a holistic drive circuit and optical co-design for high-performance under-display infrared recognition.

By re-engineering the VSS layer into a functional optical element featuring symmetric apertures and a distributed routing grid, we successfully addressed the core issue of diffraction-induced image degradation. The experimental results confirm a substantial boost in zero-order diffraction efficiency to ~9% and a marked improvement in IR image quality. This design provides a practical and manufacturable path forward for integrating advanced IR sensing capabilities beneath the display, without compromising the visual integrity of the all-screen experience.

5. Reference

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