

A large, stylized graphic of the letter "V" is positioned on the left side of the slide. It features a vibrant, multi-colored gradient that transitions from blue at the bottom, through green, yellow, orange, and red, to a dark blue at the top. The "V" is thick and has a modern, rounded design.

A Variable Refresh Rate Technology and Driving Scheme

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A Variable Refresh Rate Technology and Driving Scheme

Yuqing Wang*, Ying Shen, Tao Peng, Pei Wu, Jie Lin

- Abstract : *Aiming at OLED VRR flicker caused by non-integer EM cycles and LTPO TFT electron trapping, this paper proposes an EM cycle integerization and duty cycle compensation scheme. Tests show flicker index ≤ 0.09 (33Hz), brightness variation $\leq 3\%$, switching latency $\leq 4ms$, and 18% power reduction vs 60Hz, outperforming existing OLED VRR solutions.*



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Why Existing Solutions Fall Short

Work	Target Display	Key Limitation for OLED VRR
You et al. (2020)	LCD	✗ Brightness variation > 3% on OLED — no OLED-specific luminance calibration
Moon et al. (2023)	LTPO OLED	✗ Extra reset pulses required → ↑ circuit complexity & switching latency (>8 ms)
Lee et al. (2024)	Regional VRR	✗ Cross-region delay > 8 ms — fails full-panel, real-time responsiveness requirements
G-SYNC (Slavenburg et al.)	LCD	✗ Narrow range (2.4:1) — incompatible with OLED' s wide-range need (1–120 Hz)

The Fundamental Gap: No existing solution delivers all of the following for OLED

- ✓ Flicker-free (Index ≤ 0.1)
- ✓ Brightness-stable (Variation $\leq 3\%$)
- ✓ Ultra-low-latency (Switching ≤ 4 ms)
- ✓ Wide-range, full-panel VRR (1–120 Hz)
- ✓ No additional reset circuitry

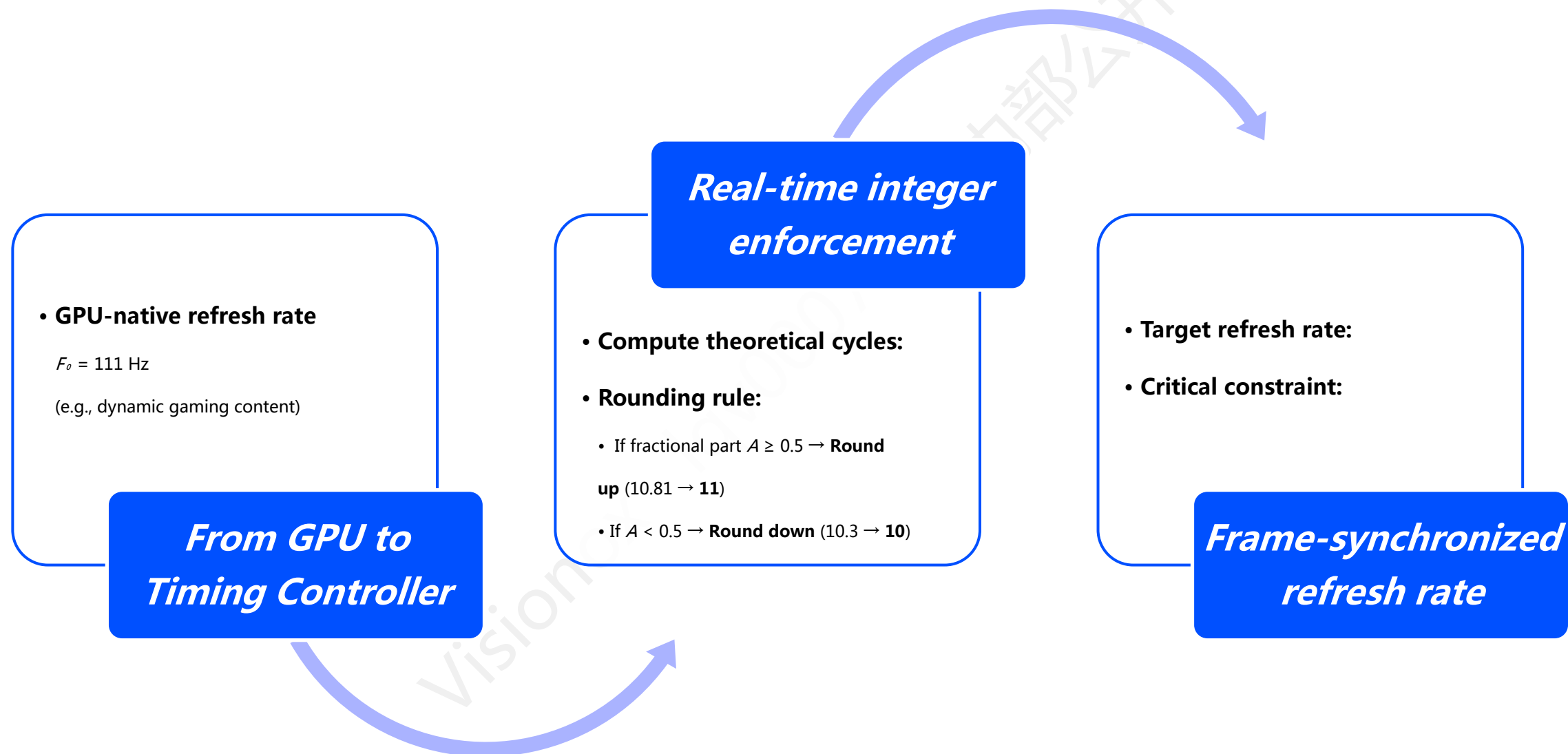
Fundamental Insight Why flicker occurs in OLED VRR

- Non-integer EM cycles per frame
 - Incomplete emission → Brightness Jumps
- LTPO TFT electron trapping
 - Charge accumulation → Brightness Drift
 - These two effects couple and amplify each other

Co-Design Solution How we eliminate it, together

- EM Cycle Integerization
 - Enforces exact integer EM cycles per frame
 - Eliminates jumps by guaranteeing full-cycle emission
- Adaptive Duty Cycle Compensation
 - Dynamically adjusts pulse width (↑↓) or interval (↑↓)
 - Stabilizes drift by counteracting TFT trapping kinetics







Round-Up Scenario

Cause: Longer EM period → Brightness overshoot

Compensation: ↓ Pulse width

Benefit: Precise brightness restoration

✓ Eliminates overshoot-induced flicker

Bonus effect: Full EM cycles → ↓ TFT electron trapping → ↓ long-term brightness drift



Round-Down Scenario

Cause: Shorter EM period → Brightness undershoot

Compensation: ↑ Pulse interval

Benefit: Precise brightness restoration

✓ Prevents undershoot-induced dimming

Bonus effect: Full EM cycles → ↓ charge leakage → ↑ temporal stability

Challenge

- **Frame-to-frame switching**
 - Risk of tearing, latency, or luminance glitch
 - Especially critical for gaming & scrolling

Principle

- **EM-Boundary Alignment**
Equation: $F_1 \cdot n_1 = F_2 \cdot n_2$
 - F_1, F_2 : Target refresh rates (Hz)
 - n_1, n_2 : Integer EM cycles per frame
 - Ensures identical total emission time across transitions

Validation

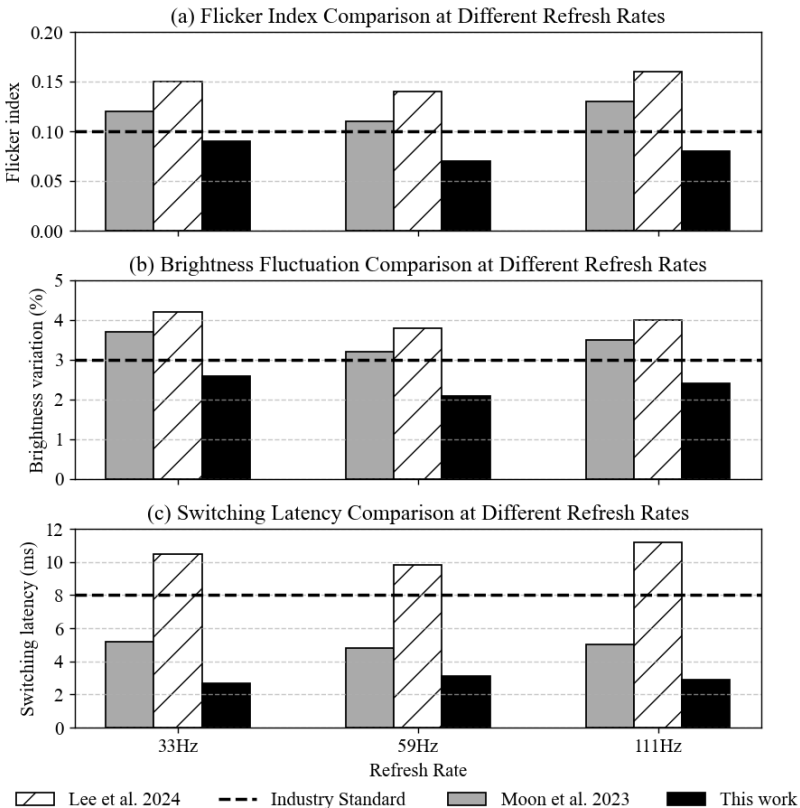
- **Example: 111 → 70 Hz**
 - Rounded to 109.1 Hz ($n_1 = 11$) and 70.6 Hz ($n_2 = 17$)
 - $109.1 \times 11 = 1200.1 \text{ ms}^{-1}$
 - $70.6 \times 17 = 1200.2 \text{ ms}^{-1}$
 - ✓ EM boundaries perfectly aligned

Test Platform: 6" FHD+ LTPO AMOLED | 500 nits | EM period T = 0.833 ms

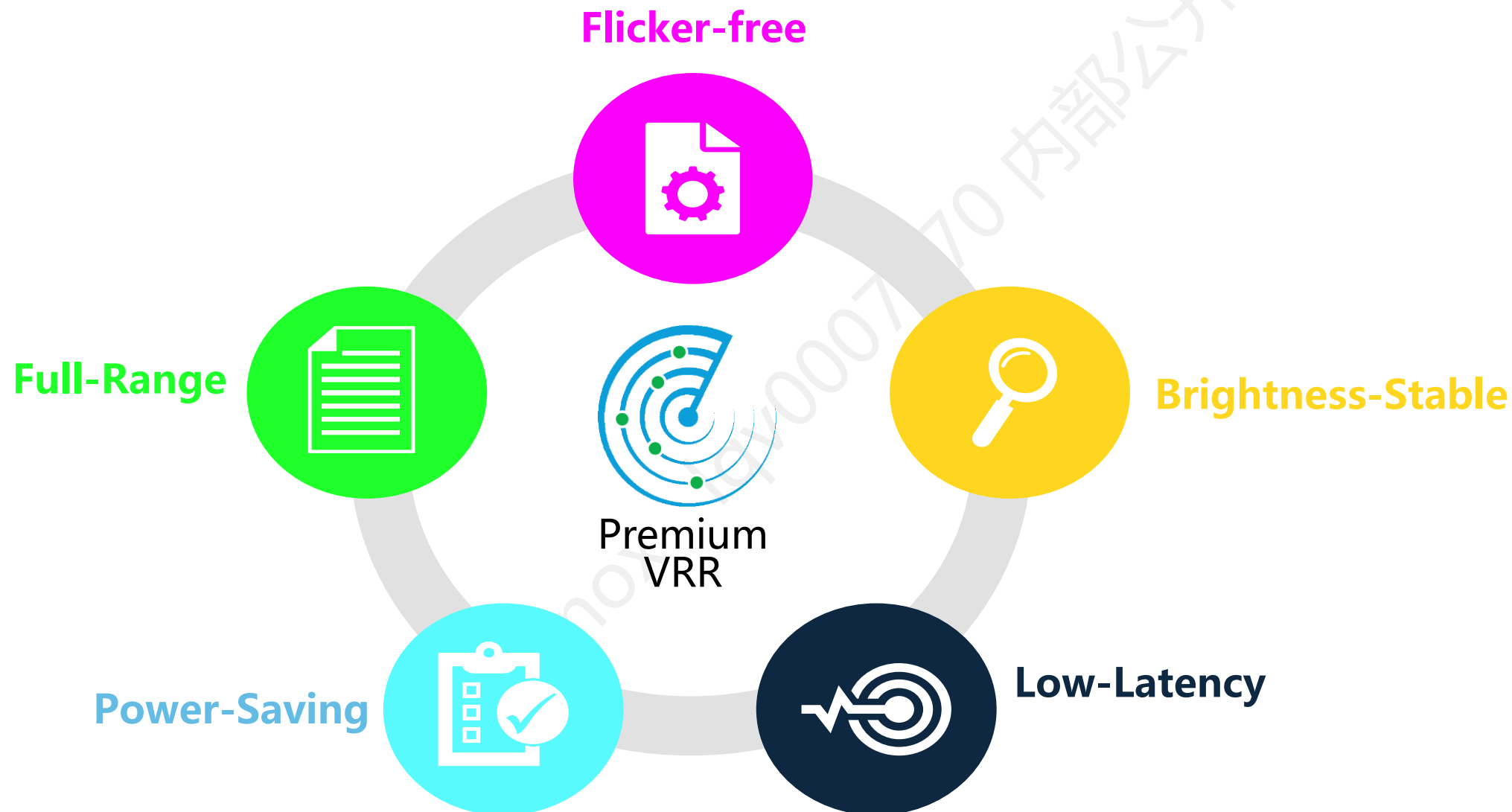
Metric	Our Solution	Industry Standard	Status
Brightness Variation (at 33 Hz)	2.6% ± 0.2%	≤ 3% (IEC TR 62778)	✓ Only solution compliant
Switching Latency (111 Hz → 75 Hz)	2.7 ms ± 0.3 ms	≤ 8 ms (VESA AdaptiveSync)	✓ 2.9× faster than threshold
System-Level Power Reduction (vs. fixed 60 Hz)	18% ± 1.5%	—	✓ Highest reported for full-panel OLED VRR
VRR Range	1–120 Hz, full-panel	Typically 40–120 Hz (LCD), or <10:1 (OLED regional)	✓ Widest validated range to date

Test Setup

- Display: 16.x" FHD+ LTPO AMOLED notebook (500 nits typical)
- Measurement: Konica Minolta CS-2000 spectroradiometer (± 0.1 nits accuracy)
- Conditions: Full grayscale, ambient light controlled (100 lux), all VRR rates (1–120 Hz)



Key Metric	Measured Result	Requirement	Status
Flicker Index (IEC TR 62778)	≤ 0.09 @ 33 Hz	≤ 0.1	✓ Exceeds spec
Brightness Variation	$\leq 3\%$ across all gray levels & all VRR rates	$\leq 3\%$ (VESA DisplayHDR™)	✓ Fully compliant
Switching Latency (111 $\rightarrow$ 75 Hz)	≤ 4 ms (mean)	≤ 8 ms (AdaptiveSync)	✓ 2 $\times$ margin



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