Driver Technology for 8K Ultra High Definition TV

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ABSTRACT

Driver technology for large 8K UHD 120Hz 10bit color display is presented in 0.13-μm high-voltage CMOS process for column driver IC, and 14nm CMOS process for TCON. The proposed auto-optimized equalizer could compensate -21.4dB channel loss for 4Gbps receiver per lane for 82-inches 8K UHD panel. The proposed line-overdrive technique could compensate insufficient charging time for each line using variable LUT.

1 INTRODUCTION

8K Ultra High Definition (UHD) TV recently made its debut in consumer market and is ready to become a mainstream within a few years. Comparing to 4K UHD TV, the average screen size of 8K TV will become larger because a visible difference between 4K and 8K resolutions will be more apparent to viewers with increasing display size. However, there are several technical limitations to implement large 8K UHD TV with related to driver technology. Lack of electrical charging time within a single line time is one of major obstacles to driving performance. Because large display panel has huge amount of load capacitance from electrical routing between pixels and column driver, the farthest pixel from column driver requires more time to be fully charged whereas the nearest pixel has enough time [1]. Another limitation is high insertion loss due to long signal line for large panel size. A 4Gbps intra-panel interface per lane is required to implement 8K 120Hz 10bit color display, but channel insertion loss may result in a completely closed eye at the input of the farthest IC due to inter-symbol interference [2].

In this paper, new driver technologies were proposed to overcome limitations of large 8K UHD display. With line-overdrive technology, lack of charging time could be compensated, and color distortion could be minimized on 82-inch 8K UHD display panel. Also, the proposed equalization technique based on bit error rate (BER) performance can effectively optimize boosting gain of equalizer at transmitter and receiver.

2 Proposed driver technology

2.1 Auto-optimized Equalization Technique

As shown in Figure 1, 82-inch 8K UHD display panel consists of TCON board, 10cm flexible flat cables (FFC) and 48 column driver ICs which are attached on source PCBs (S-PCB)

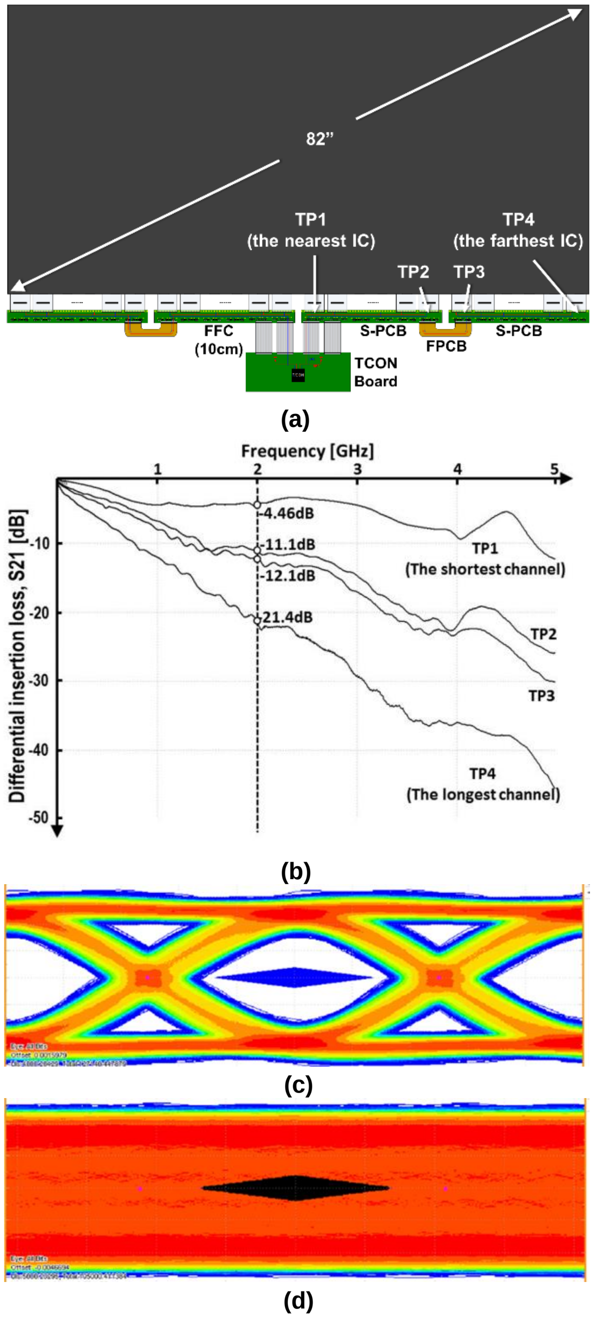


Fig. 1 (a) 82-inch 8K UHD panel configuration, (b) measured insertion losses, (c) eye diagram at TP1, the nearest IC and (d) eye diagram at TP4, the farthest IC

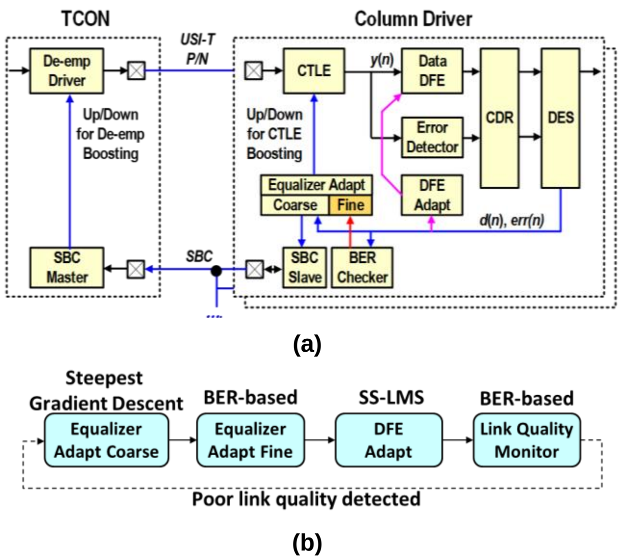


Fig. 2 (a) The proposed equalizers with auto-optimized equalization technique and (b) equalization procedure

and flexible PCB (FPCB) to connect S-PCBs. The measured insertion loss indicates that the farthest column driver IC experiences 21.4dB of insertion loss while the nearest IC has only 4.46dB of loss as depicted in Fig.1(b). In Fig.1(c) and (d), the measured eye diagram at TP4, the input of the farthest IC, was completely closed while it was widely open at TP1, the nearest IC. Since ISI should be compensated by collaboration of de-emphasis function at transmitter and continuous-time linear equalizer (CTLE) at receiver, there could be a lot of equalizer combination settings to find and optimize for each 48 column driver ICs across process, supply voltage, and temperature variation. Moreover, optimization settings should be re-checked if one of the components are just switched to other components of different specification.

Figure 2 describes the proposed equalization method to present multiple combinations of equalizers, their automatic calibration algorithms and fail-safe functions in order to reset and recalibrate equalizers. The proposed technique has three steps. First, Tx de-emphasis and Rx CTLE are tuned by coarse adaptation step. Direction to increase or decrease equalizers are decided by ISI error, err(n) and recovered data, d(n) based on steepest gradient descent algorithm. Boosting gain, $Boost_{tx}$ and $Boost_{rx}$ are respectively defined by

$$err(n) = target(n) - y(n) \quad (1)$$

$$Boost_{tx}(n+1) = Boost_{tx}(n) + \mu_{tx} \cdot err(n) \cdot d(n) \quad (2)$$

$$Boost_{rx}(n+1) = Boost_{rx}(n) + \mu_{rx} \cdot err(n) \cdot d(n) \quad (3)$$

where *target*(*n*) is the target amplitude for CTLE output, μ_{tx} and μ_{rx} is the minimum step to update equalizers. From (2), $Boost_{tx}$ are accumulated for the pre-defined period, and thus Up/Down, a direction to increase or decrease boosting gain is decided at the end of accumulation period. Up or Down signal for de-emphasis is sent to the transmitter by single line of shared bidirectional channel (SBC) which is shared by column driver ICs. SBC is

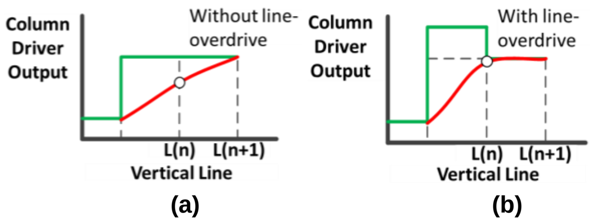


Fig. 3 Basic concept of the line-overdrive technique, column driver output (a) without line-overdrive and (b) with line-overdrive technique

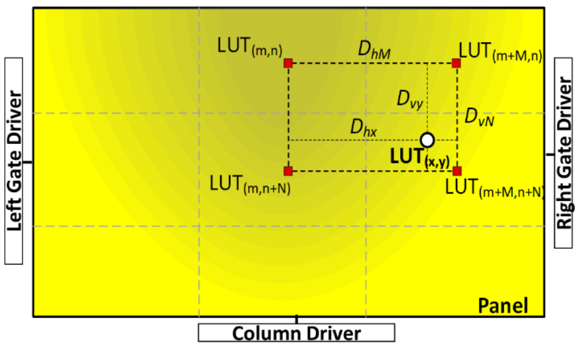


Fig.4 The proposed line-overdrive technique using configurable look-up tables

used for bidirectional data channel between TCON and multiple column driver ICs, and time-shared among multiple column drivers. Then, optimum CTLE values are tuned and decided by accumulated $Boost_{rx}$ as described in (3). Second, auto optimization process moves on to the fine adaptation step. BER checker calculates BER performance, and as a result, CTLE boosting gain is fine-tuned to find optimum equalizer value. Last, decision feedback equalizer (DFE) is adapted by sign-sign least mean square (SS-LMS) algorithm [2], which finishes all auto optimization steps, and Tx/Rx start to transmit normal display while link quality is monitored whether Rx fails to receive video data. If poor link quality is detected due to ESD shock or some fail cases, Tx/Rx enters fail-safe mode; equalizers are reset and optimization process restarts at coarse adaptation step.

2.2 Line-overdrive Technique

Fig. 3 shows the basic concept of line-overdrive technique to overcome lack of charging time for driving each horizontal line. Column driver should finish single video line within 1.7us, single line time of 8K UHD 120Hz 1G1D panel [3]. However, it is very hard to meet this requirement because of insufficient charging time due to large resistive and capacitive load, and thus display should suffer from color shift and non-uniform luminance. Line-overdrive technique can compensate charging time by overdriving for every pixel line by line as described in Fig.3(b). However, overdriving values are different from pixel by pixel at each position from the column driver. Since gate drivers and column drivers are

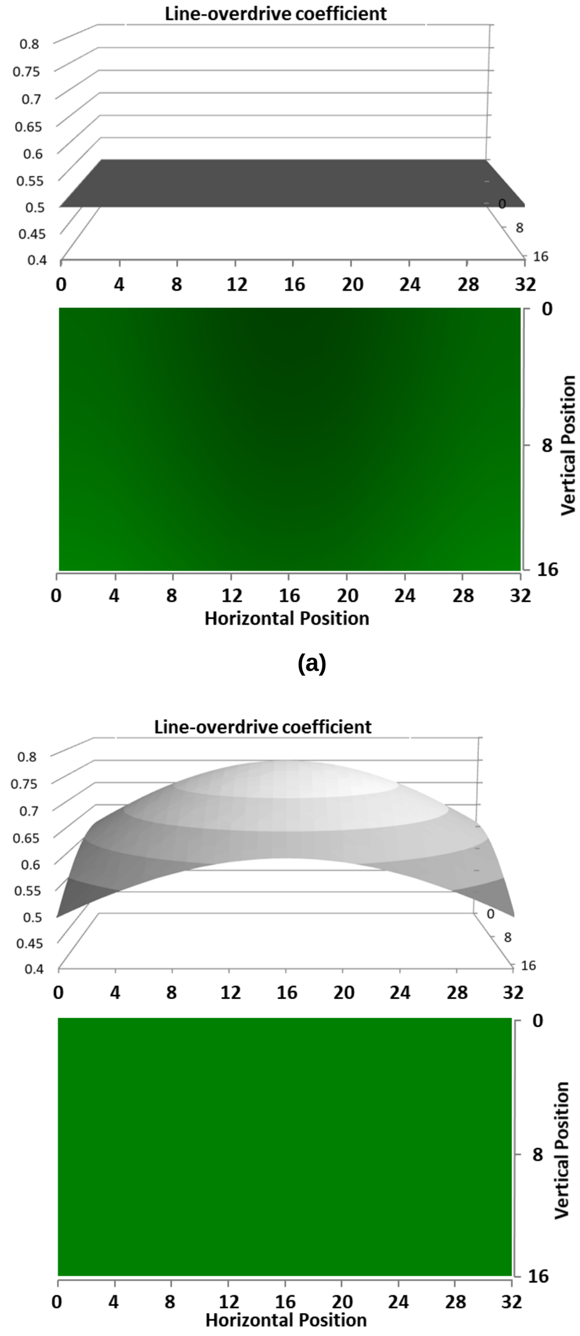


Fig. 5 Simulated coefficient and luminance uniformity with (a) line-overdrive OFF, (b) ON

placed on edge sides of panel, some area at the far distance from drivers show poor luminance and poor color uniformity as shown in Fig. 4. Although each pixel may show different non-uniformity quality depending on each pixel's position, TCON cannot implement all look-up tables (LUT) for every position of pixels to compensate charging time because of increased hardware cost, memory size and power consumption. Therefore, line-overdrive compensation technique using variable and configurable LUT is proposed to compensate non-

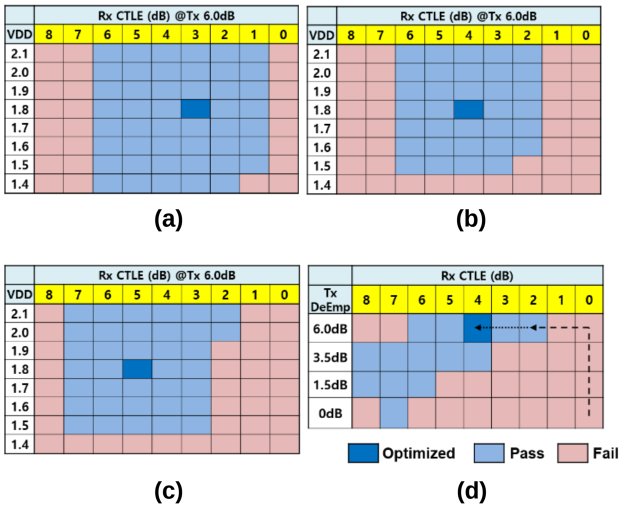


Fig. 6 Measurement results of auto-optimized equalization for (a) -20°C, (b) 25°C, (c) 90°C and (d) optimized boosting step for Tx de-emphasis and Rx equalizer

uniformity performance for specific local area while minimizing hardware cost.

Basically, four neighbor LUTs are used to generate LUT at specific position as described in Figure 4. $LUT_{(m,n)}$, $LUT_{(m+M,n)}$, $LUT_{(m,n+N)}$, $LUT_{(m+M,n+N)}$ are used to interpolate and generate $LUT_{(x,y)}$. Two horizontal overdrive LUTs, LUT_n, LUT_{n+M} are generated as shown in (4), (5),

$$LUT_n = (1 - w_h) * LUT_{(m,n)} + w_h * LUT_{(m+M,n)} \quad (4)$$

$$LUT_{n+M} = (1 - w_h) * LUT_{(m,n+N)} + w_h * LUT_{(m+M,n+N)} \quad (5)$$

and thus $LUT_{(x,y)}$ is generated by

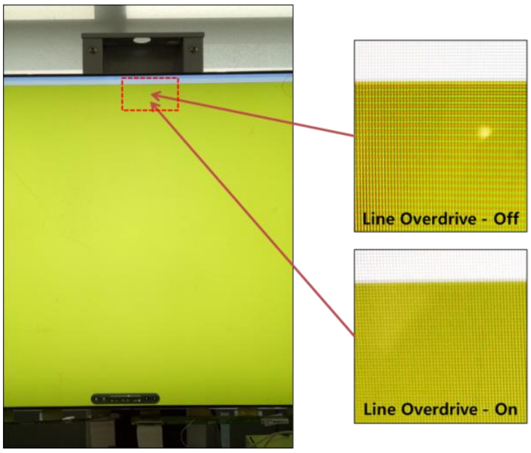
$$LUT_{(x,y)} = (1 - w_v) * LUT_n + w_v * LUT_{n+M} \quad (6)$$

where w_h is D_{hx}/D_{hM}. and w_v is D_{vy}/D_{vN}.

In Figure 5, normalized overdrive coefficient and uniformity of luminance are simulated and compared before and after enabling the proposed line overdrive function at horizontal and vertical position of display. All pixels are evenly divided into 32 horizontal and 16 vertical LUT blocks, and interpolated over-drive LUT values for every pixels are calculated and applied. The simulated results show that the region far from source driver and gate driver requires larger overdrive coefficients to compensate insufficient charging time.

3 Measurement Results

Fig. 6 shows the measurement results of auto-optimization of Tx and Rx equalizers. Optimized Tx de-emphasis code was 6dB, and Rx CTLE was automatically calibrated to 3dB, 4dB, 5dB at temperature variation from -20℃ to 90℃. This optimization codes had enough margin for supply voltage VDD and CTLE codes when display pass/fail was checked to



(a)

(b)

Fig. 7 Measurement results before and after enabling line-overdrive technique with (a) yellow pattern, and (b) animation

sweep all Tx and Rx equalizer codes as shown in Fig. 6(a), (b) and (c). In Fig. 6(d), Tx de-emphasis and Rx CTLE were optimized sequentially in a coarse optimization process. First, boosting gain of Tx de-emphasis was increased while Rx CTLE kept minimum boosting, and when Tx boosting reached to maximum, 6dB, Rx boosting gain started to increase to find the condition where Rx was not under-equalized. Lastly, Rx code was fine-tuned using BER based metric. Checking the margin of optimized Tx and Rx codes, the test results showed enough system margin to quality of display performance.

Fig. 7 shows that measurement results of display before and after the proposed line-overdrive technique. Fig. 7 (a) shows display artifact of color changing at even and odd line with yellow image due to insufficient charging time. Tested with green color image, 9.11cd/m2 at the farthest position from column driver IC were compensated to 10.46cd/m2. In Fig. 7(b), yellow color was restored comparing yellow color in a movie clip before and after compensation.

4 Conclusion

In the paper, driver technology for large 8K UHD 120Hz display has been presented. The proposed auto-optimized equalizers at TCON and column driver IC showed well optimized equalizer performance. The measurement results showed enough margin at wider operating range of power supply with various temperature range. Also, the proposed line-overdrive technique could compensate insufficient charging time due to short line time which was appropriate for 8K 120Hz display.

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