Proposal of a Combined PAM and PWM Driving Scheme for Micro-LED Displays

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ABSTRACT

In this paper, a new method for driving an active-matrix microLED display is introduced. This driving scheme is realized by a hardware driver, combined with an FPGA and it is evaluated by spatial luminance measurements. Based on those measurements an algorithm for non-uniformity compensation is proposed.

1 Introduction

The demand of high-quality displays increased over the last few years. Mobile devices tend to have bigger displays and their brightness must fight against the sunlight to improve readability. This effect is also a crucial fact for automotive displays. In addition, a low power consumption and a high contrast ratio is demanded in every use case. Therefore, the usage of OLED displays is dramatically increasing over the last few years. There is only one severe drawback, the aging artifacts of OLED. Regarding these aspects, microLED displays are seen as a gamechanger since they are meant to fulfill all the requirements.

1.1 MicroLED technology

MicroLED is a rising star in display technology. While LC-Displays and OLED-Displays are dominating the market nowadays, microLED displays may replace them in future. They exist of single anorganic LEDs for every individual subpixel. Therefore, they are more durable than OLED displays, while the efficiency is higher compared to LC-Displays. Caused by the fact that each single pixel can be controlled individually, the contrast ratio is equal to OLED technology, but the maximum luminance is higher. This results in good usability for HDR displays, while the power consumption stays low. Actual technologies use different driving – methods which are shortly introduced.

1.2 Standard driving methods

In OLED displays, there exist two main driving techniques. First, analog-driven (PAM) active matrix TFT and digital, PWM driven ones.

While the analog-driving scheme has a constant, but variable current over a whole programming period, the digital-driving scheme has a fixed voltage-level. This voltage is either turned on or off and the duty cycle while programming corresponds to its actual greyvalue. This results in a time-coded greyvalue for digital and an amplitude proportional to the greyvalue for analog driving, as also mentioned in [1].

In analog driving the control signal introduces a current through the emissive device, which results in a color drift at different brightness levels, whereas in digitally driven displays this effect does not occur, because the current is always at a constant level.
Both driving schemes have been evaluated over years in OLED Displays. For microLED displays, a combined approach shall be introduced in this paper to combine low operational voltages, with absence of an ADC, high color depth and a standard pixel circuit. We expect an improvement of image quality, costs and lifetime of the microLED devices.

2 Proposal of a combined PAM and PWM driving scheme for MicroLED Displays

Emissive active-matrix displays are controlled by different pixel circuits. One example is shown in Fig. 2, and it is used by our prototype, provided by Visionox as well.
A standard 2T1C pixelcircuit is amended by an EM switch which is globally controlling for PWM-Dimming mode. This EM switch is a crucial device for our new approach, a combined PAM and PWM driving scheme for microLED displays.

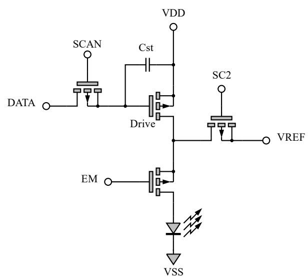

Fig. 2 A Simple Pixel Circuit

2.1 Display

Figure 3 shows the microLED prototype from Visionox.

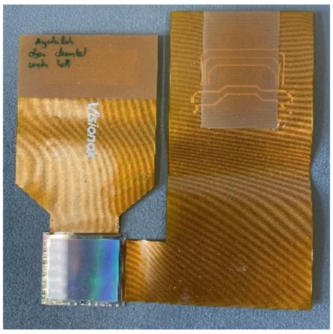

Fig. 3 MicroLED Display

Its size is about 30mmx30mm, and it consists of 64x64 pixel, each of the three subpixel is of blue color, which may be converted to red and green, using converting phospors in a further processing step. All data and scan lines are led out separately via FPC and two 300 Pin connectors. In addition, there are VDD, VSS, EM, VREF and SCAN2 pins connected.

2.2 Approach

Digitally driven microLED displays combine several improvements compared to analog driven ones. They provide a higher color depth while using no ADC. Furthermore, constant currents provide a better predictability of aging, less color drift and a low power consumption. But they also have a drawback. Digital drivers need high gate-source voltages which are hard to be supported by an IC driver. A further reason, the approach of a combined PAM / PWM controlled driving scheme is introduced, it has advantages in terms of lifetime, as [2] shows. The operational voltages are listed in table 1, whereas the drive transistor is operated in saturation as with PAM.

Table 1. Driving Voltages

Voltage	VDD	VSS	SCAN	DATA	EM	SC2	VREF
High	7V	0V	-18V	-12V	-18V	10V	0V
Low	7V	0V	10V	10V	10V	10V	0V

The specific of the new driving scheme is, that a PWM operation for every single pixel is proposed, as in the following.

2.3 Driver Setup

Our prototype is composed out of two different hardware components. A PCB for driving, demultiplexing and voltage conversion and an FPGA, that decomposes the image data for PWM and delivers the serialized control signals to the PCB.

In the FPGA a framebuffer for one frame is used and this frame is to be decomposed into several, so called, subframes. We perform a gamma-correction on the 8bit RGB input data, so that a linear resolution of 13bit is calculated. Every bit is represented by one subframe as shown in Fig. 4 for the 6 MSB of Lena. Since the human eye acts as an integrator, all the subframes are perceived as one single image, as seen in eq. 1 from [2].

$$L_{obs} = \sum_{i=1}^{n} \sigma_i * \frac{t_i}{t_{Frame}} * L_0 \quad (1)$$

With L_{obs} as the perceived luminance, σ_i as the binary for the pixel on/off state, t_i as the width of a subframe, t_{Frame} is the period of a frame and with L_0 the peak luminance for a steady-state operation.

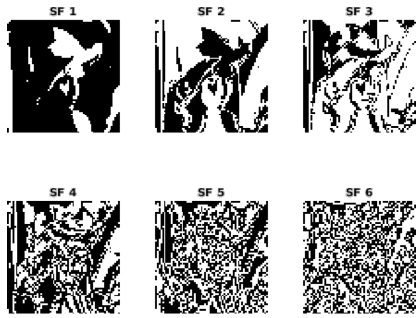

Fig. 4 Image Decomposition

As mentioned, each frame is split into 13 subframes. Every subframe is divided into a programming and a shining period, as seen in Fig. 5. While *programming*, the capacitor Cst of every single pixel is either charged or discharged, so that the Drive transistor is on or off. Then, during the *shining* phase, the EM transistor is turned on for a time, weighted corresponding to its t_i value. During that time, the on-pixels are shining. For the next programming, EM is turned off again and the shining period is terminated.

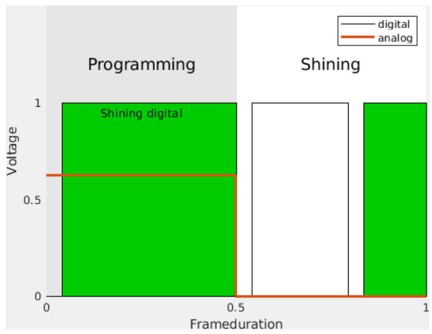

Fig. 5 Analog vs Subframe Based Digital-driving Scheme

Figure 6 shows the control circuit for the new driving scheme. The signals sent to the PCB need to be timed and serialized, so that the used FPGA IOs are minimized. These are generated in the block, called TCON and then sent out as a general LVCMOS33 signal.

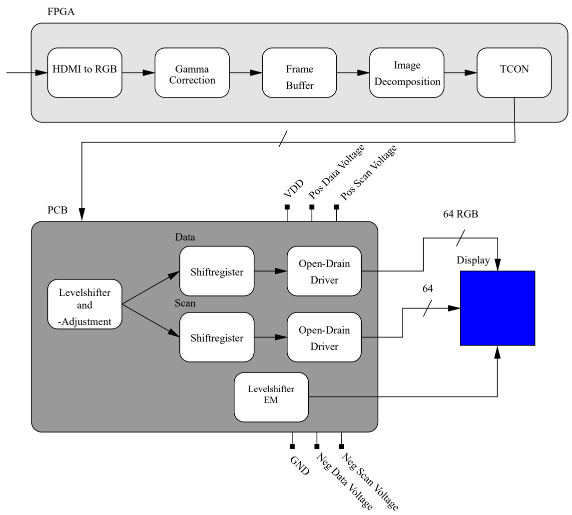

Fig. 6 System Overview

The PCB acts as a driver, realized by demultiplexer and voltage converter. The first stage is a combined logic-level converter and shifter from LVCMOS33 to -VSCAN / -VDATA for low and -VSCAN+5V / -VDATA+5V for high level, realized by a standard SN74ACT08D. Second stage is a HV5632 chip by microchip, which is a combined 32bit shift register and open-drain driver to control the scan and data pins of the active matrix. Furthermore, there is a LM7171 acting as a comparator, that is switching the voltage level of EM transistor.

The proposed method has several improvements compared to a pure analog driving scheme. There is no high-resolution ADC needed to supply the different grey-scale voltages. There is only one constant current flowing which is turned on and off, so that the luminance is proportional to the pulse width, and the color drift is minimized. With this driving scheme the simplest pixel circuit is sufficient, this may yield in a higher active area or better transparency. Of course, there also exist challenges. One is a higher refresh rate, due to the subframes. Another challenge is the accuracy of Vgs since the driving transistor is in saturation mode. In consequence, the voltage levels must be constant for a uniform luminance distribution. Now, this paper discusses proposals to examine and solve some of the mentioned challenges.

3 Challenges

MicroLED displays are manufactured in a transfer process according to state of the art. This affects the uniformity, since different LEDs from various batches may be mounted on a carrier. Therefore, we move on studying the uniformity of microLED displays.

3.1 Measurement of Uniformity

Our measurement setup, as shown in Fig. 7, consists of the microLED display driven by the proposed digital scheme and an ELDIM Umaster imaging colorimeter with a macro lens (TTO-120-23) mounted. This is used to measure the spatial luminance distribution, produced by the tested display. To avoid any noise-luminance, this setup is installed in a dark chamber.

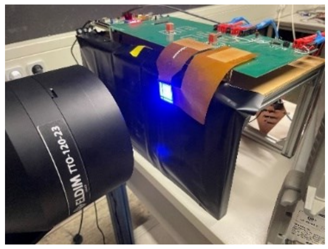

Fig. 7 Photo of Measurement Setup

Another method for an indirect measurement of the nonuniformity of the display could be realized through a current measurement of every single pixel. Either with help from a shunt resistor at every single pixel circuit, or a single shunt at the common ground node and sequentially measuring one pixel after another. This method would also be applicable for an aging compensation, but first we are concerned on luminance measurement, for a calibration process at the beginning of lifetime.

In Figure 8, a full white image is displayed on 3 different microLED panels. All three displays show some dead lines, which are caused by broken flexwires or dead solder points on the connector. Display 1 and 2 have dead pixels which are always on. All displays have some single pixel which are not shining at all. This could occur due to defective LEDs or faults in their pixel circuit. Display 2 and 3 have a brighter lower half. Since display 1 does not, it seems like different batches of LEDs with different current efficiency are mounted on those two displays. A second kind of artifact occurs in display 1. The right half (next to the connectors) is brighter than the left. The brightest spot there is about 8 times higher than the mean value in the middle. In a similar, but not comparable way, this holds true for display 2. Next to the connector the panels show a slightly brighter area. This may be caused by the voltage drop due to the resistance on the signal lines, since both panels are brighter than display 3.

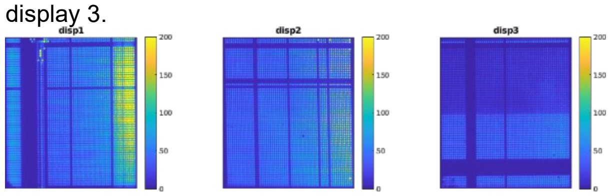

Fig. 8 Comparison of 3 Different Samples

3.2 Compensation Approach

As Figure 8 shows, current microLED displays suffer from a huge spatial nonuniformity in luminance. In the following, the possibilities of compensation shall be shortly discussed. For purely analog driven displays the most straightforward approach is to decrease the current for pixels which are too bright. This implies an algorithm which adapts the control signal of every single pixel based on an optical measurement. Since this paper handles a combined analog/ digital driving scheme, we can deal with benefits of both schemes. PWM easily allows a higher grey scale resolution, while PAM may increase the current amplitude. One effect plays a big role in the compensation strategy. Since we deal with constant voltage levels for every pixel, we cannot apply an individual voltage for a single pixel, which is a basis for an individual current setting. But instead, an individual lighting time for every pixel, according to its electro-optical behavior can be applied. Realizing that implies, that a higher resolution in greyscale enables an accurate compensation of non-uniformity. In addition, the global current amplitude can be increased to meet the luminance objective.

The principle for compensation is written in equation 2. A grey value is adapted by an individual compensation factor of a pixel to meet the required luminance of a specific pixel.

$$GV_{out} = \frac{1}{CF} * GV_{in} \tag{2}$$

$with\ GV = greyvalue, CF = compensation\ factor$

The compensation factor may be extracted from an optical measurement in the testing phase of the production. For the first implementation, the image compensation is executed offline. In future, this method shall be implemented in FPGA, so that a real-time compensation can be performed. All individual CF's are determined based on a spatial luminance measurement. These factors can be stored as a LUT in the FPGA. For the current display resolution there is no need for compression of LUT size. Later a compression for the compensation table like [3] shows, may be introduced.

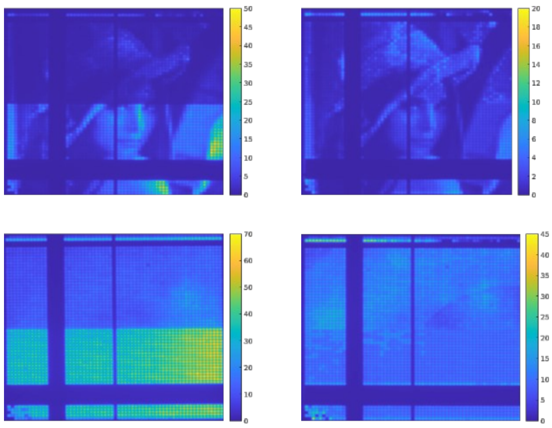

Fig. 9 Uncompensated vs Compensated Image on disp3

Figure 9 shows a comparison of uncompensated images on the left and offline compensated images on the right. The uniformity as well as the visual quality are significantly enhanced. Since the HDMI interface only allows 8bit color depth while offline processing, the possible accuracy is not fully utilized, and some artifacts occur in the compensated images. We expect that these issues will get mitigated when implementing the compensation in FPGA, because in there the compensation can be applied on 13bit. Furthermore, the spatial luminance measurement tends to introduce some errors.

4 Results and Future Work

In this paper, a combined PAM and PWM driving scheme for AM-microLED displays has been introduced. We developed a hardware driving system and an FPGA as TCON and for image-manipulation is used. The driving scheme is based on an image decomposition technique and employs a simple 3T1C pixel circuitry.

Our method increased the color depth and simultaneously, it has less requirements on hardware, like no usage of ADC and simplest pixel circuits. We evaluated the scheme on our prototype device and learned that a uniformity compensation is necessary. It may be realized by this new driving scheme so that the uniformity is substantially improved.

Therefore, we proposed a method for a compensation, and we tested this on the microLED display, again.

In future a current measurement unit shall be introduced to improve uniformity compensation. This also allows measurements on aging and with that in mind, introduce aging compensation can be introduced as a further step. A further topic is the state-dependency of the gate-source voltage of the Drive transistor, in order to more accurately meet the LED current.

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