



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

A compact and efficient method of RGB to RGBW data conversion for OLED microdisplays

Citation for published version:

Can, C & Underwood, I 2011, 'A compact and efficient method of RGB to RGBW data conversion for OLED microdisplays', Paper presented at International Display Research Conference (IDRC 31) EuroDisplay 2011, Bordeaux-Arcachon, France, 19/09/11 - 22/09/11 pp. 59-62.

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



A Compact and Efficient Method of RGB to RGBW Data Conversion for OLED Microdisplays

Chi Can, Ian Underwood

Scottish Microelectronics Centre, University of Edinburgh, West Mains Road, Edinburgh, United Kingdom, EH9 3JF

Abstract

A compact and efficient method is introduced for RGB-to-RGBW conversion in an OLED microdisplay. The method is capable of being integrated on the CMOS active matrix backplane. Optical analysis of the conversion algorithm shows good preservation of colour saturation in the image.

1. Introduction

Reducing power consumption and increasing battery life are key aims of portable electronic systems. In the case of electronic information displays (EIDs) this means maximising the efficiency of the display. Microdisplays exhibit lower power consumption than equivalent direct-view panels [1] thus enabling microdisplay-based personal display systems (μ PDs) such as electronic viewfinders and video glasses to exhibit increased battery life. Organic Light Emitting Diode (OLED) microdisplays exhibit lower power consumption than Liquid Crystal on Silicon (LCOS) microdisplays [2].

An “ideal” OLED display would use direct emission of red, green and blue light from RGB sub-pixels but the necessary technology for RGB OLED microdisplays is currently at the research stage [3] and some years away from commercial use. In the meantime, the three sub-pixels in each pixel of an OLED microdisplay emit White light through red, green and blue Colour Filters (W+CFs) respectively.

The addition of a fourth, white sub-pixel (WSP), to form an RGBW pixel improves luminance and/or efficiency for any colour EID that uses white emission through colour filters. The novel use of four sub-pixels including WSP per pixel has been reported as advantageous in many circumstances[4,5].

One key to acceptable operation of an RGBW EID is maintaining a balance between luminance gain and any associated reduction in colour saturation. RGB input data to RGBW format conversion (RRC) is an important aspect of any RGBW system. In this paper we describe a compact and efficient method of RRC that is suitable for implementing on the CMOS active matrix backplane of an OLED microdisplay.

In this context, the terms “compact” and “efficient” mean that the RRC functionality is capable of (i) insertion into the signal path, (ii) integration on the CMOS active matrix backplane of the OLED microdisplay, and (iii) consuming minimal power itself.

2. Average Pixel Usages

There is another issue on a W+CFs type RGB OLED. The optical output of OLED depends on the current density going through the emitting layer. Higher current density will shorten the lifetime of the display. Different usages on different pixels cause differential area aging issue. By applying RGBW system on OLED, WSP shares the high luminance content to average the usages of RGB subpixels. For this reason, colour subpixels do not need to drive at high current density. RGBW OLED μ PDs can benefit not just from the improved luminance and/or battery lifetime, also slow down the colour shifting issue caused by different pixel usages.

3. From RGB to RGBW

For colour EIDs, including OLED, “RGB” is the most commonly used colour model and it is an additive colour model. An output of “colour in a conventional 3-colour RGB system” (C_{RGB}) equals the sum of Red input (R_{IN}), Green input (G_{IN}) and Blue input (B_{IN}). Then, an observer perceives a colour as:

$$C_{RGB} = R_{IN} + G_{IN} + B_{IN} \quad \text{Eq. 1}$$

In the case of RGBW system, a generation of four outputs is essential. An output of “colour in RGBW system” (C_{RGBW}) equals the sum of the RGB sub-pixels and the WSP as:

$$C_{RGBW} = W_{OUT} + R_{OUT} + G_{OUT} + B_{OUT} \quad \text{Eq. 2}$$

where the “OUT” terms are defined below.

With the aim of averaging the usage of colour subpixel, any offset of white content of the RGB inputs should be replaced by WSP. Therefore, a simple RRC can be written as below:

$$W_{OUT} = \text{MIN} [RGB_{IN}] \quad \text{Eq. 3}$$

$$RGB_{OUT} = RGB_{IN} - W_{OUT} \quad \text{Eq. 4}$$

where W_{OUT} is the output of WSP that represents an offset of white content from the minimum value of RGB inputs ($\text{MIN} [RGB_{IN}]$), and RGB_{OUT} are the RGB outputs.

3.1 Issues of RRC

However, from the perspective of the observer, this subtraction does not work well on a colour reproduction of W+CFs EIDs, which is an additive colour system. First, a system reference white (W_{REF}) is based on a combination of RGB inputs to generate continuous greyscale. The W_{REF} must change with ratio of RGB. Second, the W_{OFFSET} , which is equivalent to the sum of RGB

filtered light from the white emitter at minimum value of RGB inputs, is characterized as reference white. Third, the W_{OUT} from WSP is the unfiltered emission of the white emitter and is not calibrated as RGB inputs to fit the W_{REF} . Therefore, the final optical outputs of RGB inputs in RGBW system ($W_{OUT} + RGB_{OUT}$) will not be same as the optical outputs of RGB inputs in the RGB system (Figure 1).

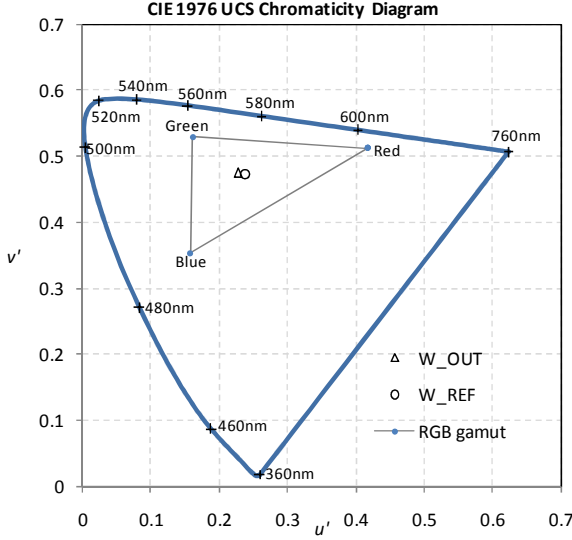


Figure 1: The colour coordinates of W_{OUT} and W_{REF} of a RGBW OLED μ PDs on CIE 1976 Uniform Colour Space (UCS) chromaticity diagram.

3.2 Corrections of RRC

In order to rectify the error in the subtraction of the W_{OFFSET} under the additive colour system, the W_{OUT} , firstly, can be treated as the 4th colour calculated by applying multi-primary colour conversion [6] to RGBW OLED. Secondly, a complexity algorithm can be used to obtain a precise output [7,8].

3.3 RRC for OLED μ PDs

Nevertheless, for OLED μ PDs, there is a limitation of system resources and the battery life in the implementation of a bulky computing. A complex RRC is intolerable in μ PDs system, especially if it needs to be integrated into the CMOS active matrix backplane. Therefore, alternative RRC is needed to fit into the unique application of OLED μ PDs. Refer to the Eq. 3 and Eq. 4, a compact and efficient RRC (CE-RRC) for RGBW OLED μ PDs with a compensation of subtraction error can be written as below:

$$W_{OUT} = MIN [RGB_{IN}] * W\% \quad \text{Eq. 5}$$

$$RGB_{OUT} = RGB_{IN} - W_{OUT} \quad \text{Eq. 6}$$

where $W\%$ is a factor to rectify the error from a subtraction in the additive colour system.

The calculation of $W\%$ is referred to as the colour and luminance information from RGB inputs. These two pieces of information merge with each other within the RGB colour model. In general, a conversion from RGB to YUV is needed before proceeding to

RRC because two pieces of separate information can help to obtain a precise result. To compensate for the limitation of OLED μ PDs, an alternative colour space conversion is used here. A simple colour mixing theory is applied to interrupt the connection between EIDs and Human vision as shown in Figure 2.

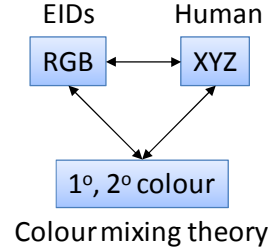


Figure 2: A relationship among EIDs, human vision system and colour mixing theory.

In the simple colour mixing theory, colours can be classified into different colour categories: Primary (1°) colour, such as Red, Green and Blue (RGB); and Secondary (2°) colour, such as Cyan, Magenta and Yellow (CMY). A colour with an equal quantity of RGB inputs is defined as neutral colour such as White (W). Every colour category can be located on a CIE chromaticity diagram (Figure 3).

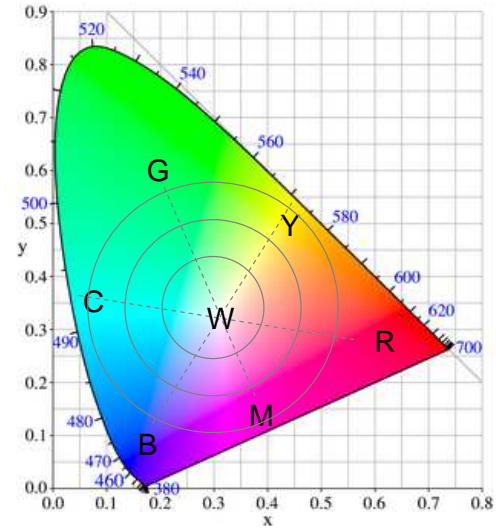


Figure 3: The distribution of RGB (1° colour), CMY (2° colour) and W (neutral colour) showed on a CIE chromaticity diagram.

3.3.1 Finding $W\%$

$W\%$ added in Eq. 5 aims to eliminate the error of the RGB outputs from changes the colour appearance by adding luminance from WSP. The $W\%$ is calculated according to RGB inputs located on the CIE colour map that represents how human eyes observe colours. All RGB inputs are sorted into different colour categories according to their colour intensity levels, ranging from High (H), Medium (M) to Low (L). This is an important step to convert the RGB inputs into colour intensity level groups that represent

different combinations of HML (Figure 4). These combinations are used as an index in a Look-Up Table (LUT) to assign a value to be $W\%$.

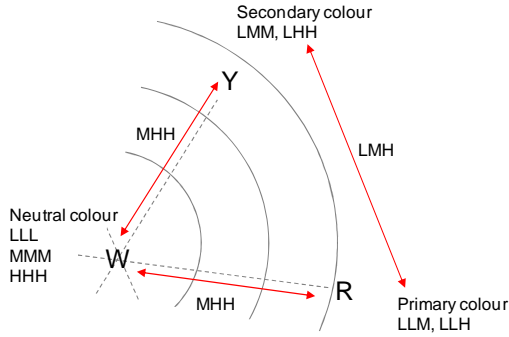


Figure 4: An illustration of a relationship between colour mixing group and intensity level group.

3.3.2 FPGA Implementation

The new CE-RRC has been implemented on a Field-programmable gate array (FPGA). The dataflow of this data conversion is illustrated in Figure 5. The Minimum detector (MIN Detector) block finds the minimum common value of the RGB inputs. The RGB inputs are classified into the colour intensity levels groups in the Level Combination LUT. Finally, according to the level index from the previous LUT, a value of $W\%$ is allocated in the WSP% LUT. This value multiplies with the minimum value of RGB inputs to form W_{OUT} , then RGB_{OUT} are obtained after RGB_{IN} are subtracted from W_{OUT} .

Dataflow of RGB-to-RGBW conversion

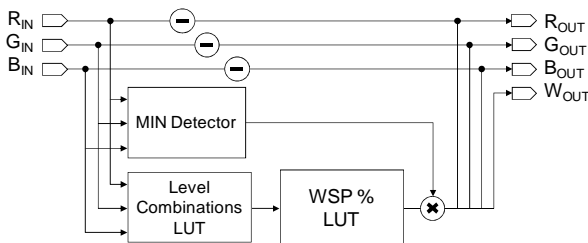


Figure 5: A dataflow diagram of the compact RRC for OLED μ PDs.

4. Results

The colour accuracy of this CE-RRC is measured by showing sample colours defined in Macbeth Colour Checker. The colour coordinates of the samples are measured before switching on and after switching off WSPs. Then, colour differences ($\Delta u'v'$) between these two conditions are calculated based on the CIE 1976 UCS $u'v'$ colour. The differences are shown in Figure 6. All $\Delta u'v'$ of sample colours can be kept to less than 0.025, is much smaller than 0.040, is considered a noticeable colour difference of a colour shown on two different screens [9].

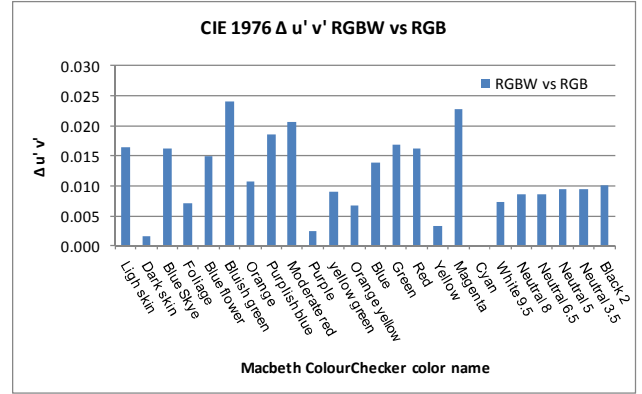


Figure 6: CIE 1976 colour difference of the sample colours in Macbeth Colour Checker between before and after the WSPs switched on.

Furthermore, when WSPs are switched on the μ PDs showing the Macbeth's colours, the CE-RRC can reduce the usages of colour pixels to 40% on average (see Figure 7).

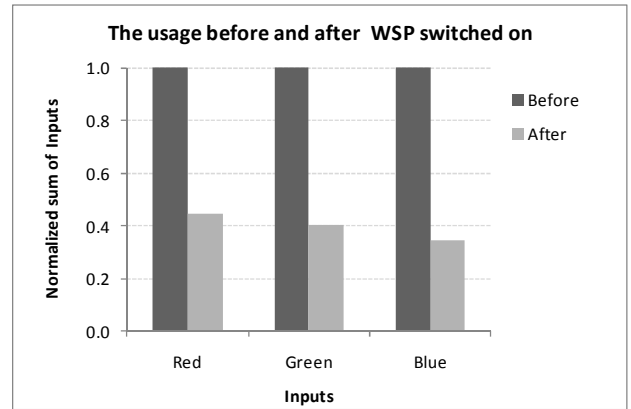


Figure 7: The usage before and after switched on WSP.

5. Conclusions

In terms of circuit design, this CE-RRC is only made up of three subtractions and one multiplication in the algorithm. No other bulky operation, such as a division, is needed. Therefore, it is fast and consumes minimal power itself in the data processing circuit. Also, it has a high potential to be integrated on the CMOS active matrix backplane of the OLED μ PD.

6. Acknowledgements

Thank you MicroOLED and Dr Gunther Haas for supply of microdisplays and technical support in this project.

5. References

- [1] M. Handschy, B. Spenner, "The Future of Pico Projectors", Information Display Vol 24, no. 12 (2008).

- [2] MED, “Datasheet of ME3204 P-OLED microdisplay”, MicroEmissive Displays Ltd. (2007).
- [3] F. Ventsch, M. Gather, K. Meerholz, ”, Organic Electronics, 11(1), 57 (2010).
- [4] J. Spindler, T. Hatwar, M. Miller, A. Arnold, M. Murdoch, P. Kane, J. Ludwicki, S. Van Slyke, SID '05 Digest, 36 (2005).
- [5] A. Arnold, P. Castro, T. Hatwar, M. Hettel, P. Kane, J. Ludwicki, M. Miller, M. Murdoch, J. Spindler, S. Van Slyke, K. Mameno, R. Nishikawa, T. Omura, S. Matsumoto, SID '05 Digest, 525, (2005)
- [6] M. Takaya, K. Ito, G. Ohashi, Y. Shimodaira, J. of SID, 13(8), 685 (2005)
- [7] M. Murdoch, M. Miller, SID '08 Digest, 791(2008)
- [8] A. Arkhipov, K. Park, B. W. Lee, C. Kim, SID '09 , 931 (2009)
- [9] VESA, Flat Panel Display Measurement (FPDM) Standard Version 2.0 (2001)