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Design aspects of low power polymer/OLED passive-matrix displays

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Abstract

Polymer and small molecule organic LED technologies offer many attractive properties for use in a display. The highly efficient light generation at low supply voltages and the limited thickness of the display are advantageous for mobile applications. Furthermore, the large viewing angle, high contrast and fast switching speed give excellent picture quality for text and video mode operation.

Optimal uniformity of the passive-matrix display is achieved with current-driven operation. This reduces the influence of material degradation as well as voltage drops across the connection leads. Amplitude and pulse width modulation can be used to obtain grey levels.

This presentation discusses design aspects of small-size, full-colour passive-driven polymer LED matrix displays. Consequences of multiplexing, colour sub-pixelation, aperture and display parasitics are analysed and requirements for the RGB materials are formulated to obtain low power dissipation of the module.

The efficiency of red polymers, that are available up to now, is too low. This leads to an unbalanced current density in comparison with green and blue which is unfavourable for the display power consumption.

Keywords: Polymer LED; Power consumption; Efficiency

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1. Introduction

A passive-matrix poly-LED display consists of an array of transparent conductive ITO (indium–tin oxide, on a sheet glass) columns onto which a thin layer of light-emitting polymer is spin-coated. The display is completed with a structured metal cathode, which forms the rows. The crossovers of rows and columns form the pixels of the display.

In a passive-matrix poly-LED display each line of the picture is addressed sequentially and flashes brightly for a very short time. At the same time, all non-addressed pixels are kept at zero or reverse bias. By scanning the lines sufficiently fast (generating about 60 pictures per second), the eye integrates all the light flashes into a picture, and no flicker is observed as in a traditional CRT-based TV.

A consequence of this method of building up a picture is that in order to obtain normal luminance levels, the light pulses have to be extremely bright, because they occur only for a short time. In a 120-line display, for example, the light pulses will have

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to flash with a peak luminance that is 120 times the average luminance one actually perceives.

This means that high currents and voltages are needed for the light pulses, which causes power dissipation in the wires of the display. Also, losses are introduced due to the charging and discharging of the pixel capacitance at addressing and pixel switch on. Since these losses are not used to produce light, the display lumen efficacy reduces.

There are three sources of power dissipation, P_{LED}, P_{CAP} and P_{RES}:

1. Power dissipation in the LED

   $P_{\mathrm{LED}} = I_{\mathrm{OP}} V_{\mathrm{OP}}$

   P_{LED} is a product of operating current I_{OP} and voltage V_{OP} in the LED, and it is reduced when the LED efficiency is increased.
2. Capacitive losses

   $P_{\mathrm{CAP}} = aCV_{\mathrm{OP}}^2 f$

   where $a = 0.5$ for the capacity of the LED and $a = 1.0$ if we account also for capacities in the power source. P_{CAP} is the power required to charge up all the diode capacitances C in the display and can be reduced by lowering the frequency f – which can be done, for example, by reducing the frame frequency or multiplex rate. We will take $a = 1$ in our calculations.
3. Resistive losses

   $P_{\mathrm{RES}} = I_{\mathrm{OP}}^2 R$

   P_{RES} is the Joule heating in the row and column lines of the display; it can be reduced by decreasing the resistances R of these lines.

In this short note, we will concentrate on the analysis of the consequences of different efficiencies of red, green and blue materials on the power consumption. Other aspects of driving are detailed in [1–3].

2. Required monochrome peak luminance

For a monochrome display, the ratio between the peak luminance of the LED and the average (perceived) luminance of the display is given by the product of the following three factors:

- factor 2.5, to compensate for the loss in emission due to the use of a contrast enhancement filter (typically −60% for a filter on the glass of the LED);
- factor 1.25, to compensate for the areal fraction of the pixel that does emit light, here e.g. 80%; and
- factor 120, to achieve a multiplex ratio of 120 (for 120 lines).

Therefore, to get 100 cd/m^2 luminance in average, a peak luminance of 37 500 cd/m^2 is necessary.

3. Monochrome display: power consumption as a function of size and resolution

In this example, the power consumption is calculated as a function of resolution and size of the display as shown in Table 1. It is supposed that the polymer has an efficiency of 15 cd/A, a pixel surface area of 0.1 mm^2 and an averaged luminance of 100 cd/m^2.

The power consumption increases very strongly with size. There are three means to reduce the dissipation:

Table 1
Power consumption of displays of different sizes and resolutions

Resolution (column/row)	Diagonal (inch)	P_{LED} (mW)	P_{CAP} (mW)	P_{RES} (mW)	P_{TOTAL} (mW)	Efficacy (lm/W)
80 × 60	1.2	15	10	1	26	5.3
160 × 120	2.4	80	110	10	200	2.8
320 × 240	5	400	1300	300	2000	1.1
640 × 480	10	2000	18 000	8000	28 000	0.3

1. To increase the efficiency of the polymer by improving materials and device architecture.
2. To lower the resistance of the lines in the display, e.g. by shunting the ITO lines with metal.
3. To use a "split column design": here the columns are split halfway the display. In this way both the upper and lower display parts can be addressed in parallel, which doubles the line time by reducing the multiplex ratio effectively by a factor 2.

By applying these three means to the 10 inch display mentioned in Table 1, assuming that the polymer efficiency is doubled and the resistance of the lines is a factor 10 decreased, the total power consumption could be significantly reduced from 28 W down to 3.6 W.

4. Colour display: required luminance

For a colour display the peak luminance must be increased further by the following factors:

- factor 3, because of the three sub-pixels per triplet RGB;
- factor 3, because of the reduced time per sub-pixel; and
- factor 1.33, because the effective sub-pixel area is reduced from 80% to 60%.

As a result a factor of 12 higher peak luminance is needed as compared to a monochrome display.

A combination of red, green and blue is used to produce white light. The required ratios of the primary colour contributions depend on their (x, y) colour coordinates, as well as on the wanted white point. For this presentation a white point consisting of 30%/60%/10% of the R/G/B primary colour contributions of the EBU standard will be taken as an example.

5. Example of a split column 160 × 120 colour display

It is supposed here that the luminances of the R/G/B polymer materials are achieved at the same operational voltage V_{OP} Typical polymer efficiency values for recent materials at high luminance levels are 2.5/10/2.5 cd/A for R/G/B respectively. Now, the required current densities for the red, green and blue pixels can be calculated as follows.

Suppose that the average luminance to be achieved in white is 100 cd/m^2.

	Required peak luminance (cd/m^2)			
	R	G	B	
Colour balance				
30%/60%/10% R/G/B contributions	30	60	10 cd/m^2	
Pixel area factors				
Every colour sub-pixel is 1/3 of monochrome area	90	180	30 cd/m^2	
Emitting surface within sub-pixel is only 60%	150	300	50 cd/m^2	
Timing factor				
$3 \times 120/2 = 180$ (split column)	27	54	9 kcd/m^2	
	Required current density			
	R	G	B	
Polymer efficiency conversion factor				
For R/G/B = 2.5/10/2.5 cd/A	10.8	5.4	3.6	kA/m^2

Although the light contribution of red accounts only for 30% of the total output luminance, the relatively low efficiency of the red polymer results in a large current density and, hence, high power dissipation. Apparently there is a mismatch between the current efficiency properties of the various colours. Moreover, the pixel operating voltages will differ in general, which causes an additional power loss.

6. Display with optimal power consumption

To further illustrate the ratios of power consumption for the three colours, three scenarios A, B, C are discussed below.

(A) *The ideal situation.* The efficiency is large for all three colours, for example 15 cd/A, and the required luminance levels for 100 cd/m^2 white colour are achieved at the same (low) operating voltage V_{OP}:

	R 30%	G 60%	B 10%
Polymer efficiency at V_{OP} (cd/A)	15	15	15
Relative power contribution (%)	30	60	10

This ideal situation is taken as 100% reference.

(B) *Another situation.* Power consumption is equal for all three colours at the same operating voltage, for producing a white colour of 100 cd/m^2. With green as the reference, for red a factor 2 reduction in polymer current efficiency can be tolerated, and for blue a factor 6:

	R 30%	G 60%	B 10%
Polymer efficiency at V_{OP} (cd/A)	7.5	15	2.5
Relative power contribution (%)	60	60	60

Compared to the ideal situation, the power dissipation that is required to achieve the same luminance has increased up to 180%.

(C) *The practical situation.* Today's efficiencies of standard polymers are even worse with respect to the power consumption. If we include a 50% higher operating voltage for red and blue with respect to the green V_{OP} and taking 2.5/10/2.5 cd/A as values for R/G/B respectively:

	R 30%	G 60%	B 10%
Polymer efficiency (cd/A)	2.5 at 1.5 V_{OP}	10 at V_{OP}	2.5 at 1.5 V_{OP}
Relative power contribution (%)	270	90	90

Compared to the ideal situation of case (A) with well matched polymers with high current efficiency materials operating at the same voltage, the total power consumption has increased up to 450%. Important to note is that red has the largest contribution to the power consumption.

7. Conclusion

A display model for the calculation of the power consumption has been presented in this short note. Polymers with large efficiencies at high luminance levels are needed to realise passive addressed matrix displays. For material science the most important consequence of the presented analysis is to improve the efficiency of red emitting polymers. By better matching of the polymer efficiencies and operating voltages an optimised overall power consumption will be achieved for the whole system. Also, by optimally choosing the (x, y) colour point for white (e.g. by choosing another standard colour point of white than the EBU standard), the efficiency can further be increased, for given RGB electroluminescent materials. An other important point, not further addressed in this paper, is to achieve that the efficiencies and colour coordinates of the red, green and blue polymers do not change during the lifetime of the display.

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