Advantages and Challenges of Digital Driving for AMOLED Displays

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Outline

1. State of the Art of AMOLED Driving
2. Operation Principle of Digital Driving
3. Practical Study of Digital Driving
4. First Experimental Results
5. Conclusion

AMOLED – The Display of the Future

LG 55-inch OLED TV
[http://www.lgblog.co.uk/2012/05/oled/]

☺ Excellent image quality and design

☹ High power consumption

☹ Manufacturing problems
→ High cost

State of the Art – Analog Driving

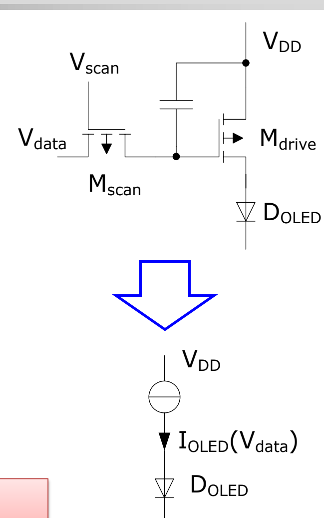
Principle

- OLEDs current controlled
  - → Insensitive to variations in OLED characteristics
- M_{drive} operated as current sink/source
  - → V_{data} generated with DAC
  - → High accuracy of threshold voltage V_T required
  - → V_T is instable and varies from pixel to pixel!

Inherent problems

- Compensation pixel circuits necessary for good image quality
- High complexity due to multiple TFTs/capacitors
  - → Low aperture ratio
  - → Low pixel density
- High energy dissipation in driving TFT
  - → Low efficiency

AMOLED still suffers from low-yield and high-power problem due to analog driving!



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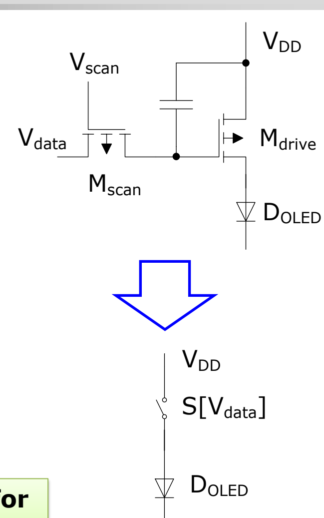
Alternative Approach – Digital Driving

Operation Principle

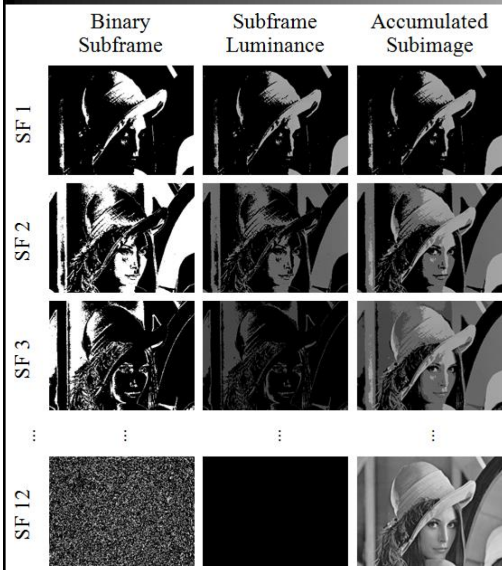
- PWM-like driving with variable on-time
- M_{drive} operated as a switch
- OLED driven with a constant voltage V_{DD}
- Subframes of variable duration $t_{SF,i}$
- In each subframe switch state S_i determines OLED pixel on/off
- Desired luminance results from summed lighting times:

$$\boldsymbol{Lum = c \cdot \sum_i t_{SF,i} \cdot I_{OLED} \cdot S_i}$$



Every image is decomposed in subframes for digital driving!

Image Decomposition Example



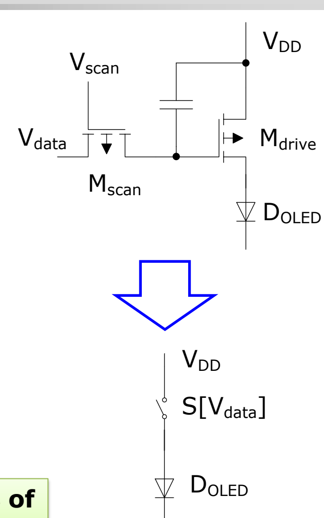
- Binary subframes determine switch state
- Subframe luminances sum to required image
- 12 subframes necessary for 8-bit grayscale due to gamma

Digital Driving – Advantages and Challenges

Advantages
- Driving TFT operated as switch
  - → V_{data} is a binary signal
  - → V_T variation and drift no more an issue
  - → Higher yield
  - → Very low power consumption in TFT
- Simple 2T1C pixel circuit sufficient
  - → High aperture ratio for bottom-emission
  - → Higher pixel density
  - → No DAC column drivers necessary

Challenges
- Multiple subframes addressing for a single frame
  - → Much higher addressing speed required
- OLEDs are voltage driven
  - → Susceptible to image sticking, aging, manufacturing and temperature variations

Digital driving may resolve the main issues of AMOLED!



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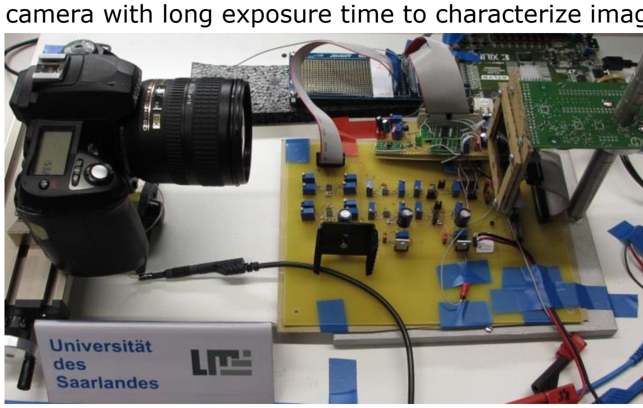
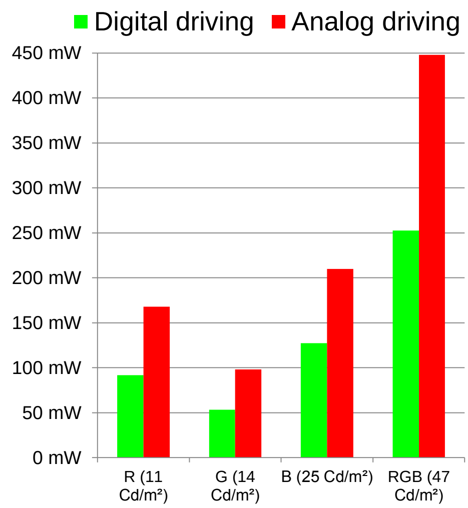
Test setup

- Digital driving prototype using 218x173RGB *Kodak AM550L* AMOLED Display
- Containing driving and measuring unit and a Xilinx Spartan-6 FPGA
- Digital driving frame frequency $\approx 5\ \mathrm{Hz}$ due to addressing speed limitation of display
- DSLR camera with long exposure time to characterize image



Power Consumption



- Comparison of power consumption for digital and analog driving
- Static power consumption $\approx 55\ \%$
- Higher loss in the storage capacitor
  - Worst case estimation $\approx 10\ \%$

$P_{digital} \leq 65\ \%\ P_{analog}$

Addressing Speed

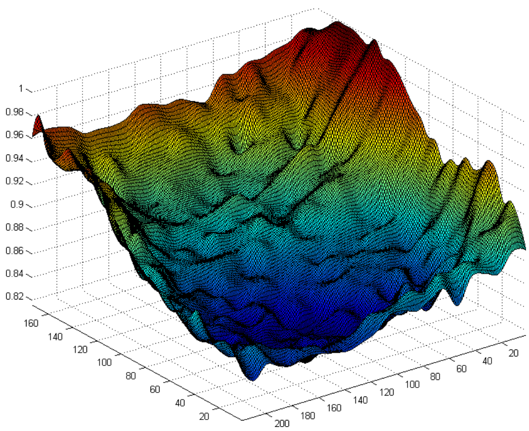
Estimation for a 320x240RGB display

- ≥ 12 subframes need to be addressed in a single frame time
- Assume $\sum t_{addr,SF} = \sum t_{drive}$
  → Double peak luminance required!
  → Average value unchanged, so just small impact on lifetime
- Assume $f_{frame} = 100\ \text{Hz}$
  - Addressing frequency of $f_{addr} \approx 800\ \text{kHz}$ required
  - On-glass shift register driving a low pass formed by scan line must meet timing constraint

  → Viable for simple state-of-the-art technology!

Sufficiently fast addressing is feasible!

Main Challenge – OLED Voltage Driving



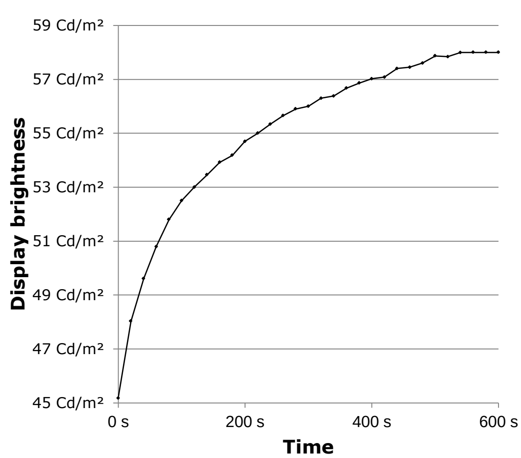
Nominal OLED current distribution

- Measured OLED current distribution
  → $\approx 20\ \%$ current variation, probably due to manufacturing factors
- Causes a linear error in resulting luminance due to

$$Lum = c \cdot \sum_i t_{SF,i} \cdot I_{OLED} \cdot S_i$$

Compensation necessary for excellent image quality!

Temperature Dependence

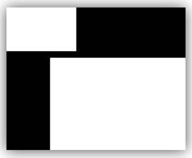


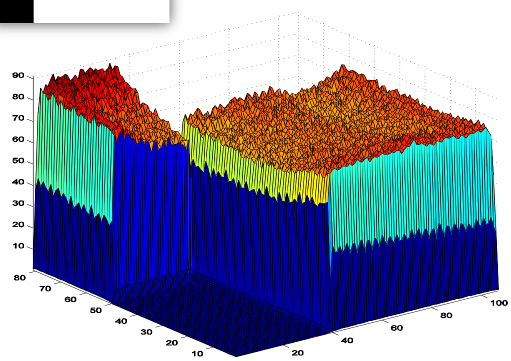
- High power dissipation in OLED causes self-heating
  → Quadratic temperature-dependence of OLED current due to voltage driving
- Temperature distribution is low-pass filtered image content

- Temperature rise by $\approx 4\ \mathrm{K}$ due to self-heating
  → Luminance rise by $\approx 25\ \%$
- Time constant of $\tau \approx 150\ \mathrm{s}$

Luminance Nonuniformity

Test image





OLED luminance distribution

- Luminance distribution of a test image with two white rectangles
- Brightest spot in the image ≈ 25 % brighter than darkest spot
- Caused by manufacturing process and self-heating

→ Negative impact on image quality!

This luminance nonuniformity must be compensated for digital driving!

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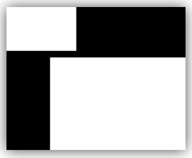
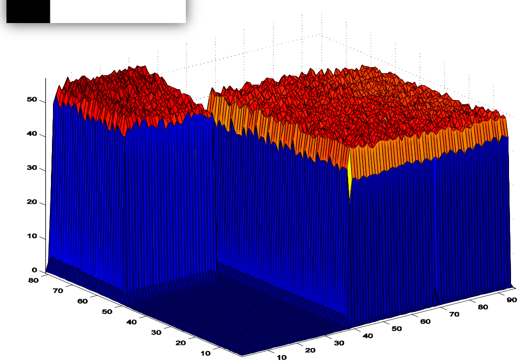
Luminance Nonuniformity Compensation

Test image





OLED luminance distribution

- Nominal OLED current measurement
  - Display segments turned on for a short time
  - Current measurement using ADC
  - Possible online during display operation
- Measurement results used to manipulate control data

Simple linear compensation reduces luminance error from 25 % to 10 %

Visual Results

Photographs of display with DSLR camera with large exposure time

✔ Good image quality confirmed

✔ Efficiency of simple nonuniformity compensation proven

✔ Power consumption reduced by 45 %

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Conclusion

Digital Driving

- Robust against threshold voltage variation
- High yield, low cost
- Low power consumption
- State-of-the-art TFT-technology applicable
- Compensation of manufacturing variation, aging and temperature feasible

Future work

- Compensating algorithm needs to be refined
- Validation on a digitally driven display allowing video operation

Digital driving may enable high-image-quality low-cost and power-efficient AMOLED displays!

Thank you for your attention!