OLED ageing modelling and compensation

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IMOLA Final Workshop
Outline

- Ageing of the OLED luminance:
  - Exponential model
  - Double-exponential model
  - Stretched-exponential model
  - Coffin-Manson ageing model

- OLED ageing compensation:
  - Time-based compensation
  - Alternative compensation algorithms

- Conclusion
OLED ageing (I)

- Emissive (A $\rightarrow$ A*) to non-emissive (B) OLED molecules at decay rate $r_d$

$$\begin{array}{c}
A \xrightleftharpoons[1.0 - r_d]{1.0} A^* \\
\downarrow r_d \\
B
\end{array}$$

- Effects (while OLED current $I$ is constant):
  - Luminous efficacy $k$ reduces
  - OLED voltage $V$ increases
- Relative luminance $L/L_0$ decreases over time $t$ as the OLED current $I$ is kept constant.
Exponential decay

\[ L = L_0 \cdot e^{-\frac{t \ln 2}{T_{1/2}}} \]

- Half-life \( T_{1/2} \approx 8000 \text{ h} \)
- Relatively bad fit to measured data
Double exponential decay

\[ L = L_0 \cdot \left( A_1 \cdot e^{-\frac{t \ln 2}{T_{1/2,1}}} + A_2 \cdot e^{-\frac{t \ln 2}{T_{1/2,2}}} \right) \]

- Half-life \( T_{1/2,1} \approx 4\,000\) h
- Half-life \( T_{1/2,2} \approx 150\,000\) h
- Amplitude \( A_1 \approx 0.14\)
- Amplitude \( A_2 \approx 0.86\)
- Effective half-life \( T_{1/2,\text{eff}} \approx 10\,400\) h
Stretched exponential decay

\[ L = L_0 \cdot e^{-\left(\frac{t}{T_{1/2}}\right)^\beta \ln 2} \]

- Half-life \( T_{1/2} \approx 12000 \) h
- Stretch factor \( \beta \approx 0.8 \)
- Effective half-life \( T_{1/2,\text{eff}} \approx 10350 \) h

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OLED ageing compensation

- **OLED luminary → Luminance** $L = \text{constant during life-cycle}$

\[ L = k \cdot I \]

- Decrease in luminous efficacy $k$ is compensated by increasing OLED current $I$

- No luminance feedback on the IMOLA module:
  - How to keep track of the luminance degradation?
Time-based compensation - Algorithm

- Every $\Delta T$ hours increase current by $\Delta I$ %

- Parameter $\Delta I$ is updated during algorithm due to the stretched exponential model

\[
\Delta I(t) = e^{\frac{\ln 2}{T^{1/2}}} \left[ (t+\Delta T)^\beta - t^\beta \right] - 1
\]
Time-based compensation - Luminance

- Example → Period $\Delta T = 1000$ h

$$\Delta I(t) = e^{\frac{\ln 2}{T_{1/2}} [(t+\Delta T)^\beta - t^\beta]} - 1$$

- Is $T_{1/2}$ equal to $T'_{1/2}$ when current varies?

$$T_{1/2} = T'_{1/2} (I) = ?$$
Coffin-Manson fatigue model

\[ L^n \cdot T_{1/2} = c_1 = \text{const.} \]

\[ I^n \cdot T_{1/2} = c_2 = \text{const.} \]

- Ageing factor \( n \)
Time-based compensation - Revisited

- Ageing compensation fails
Time-based compensation v2

- Ageing compensation fails when the current increases with time

- $\Delta I$ needs to be updated w.r.t. the ageing model

- Ageing factor $n > 1 \rightarrow$ exponential rise of OLED current

$$\Delta I(t) = e^{c\beta \cdot I^n \beta} \left[(t+\Delta T)^\beta - t^\beta\right] - 1$$
Time-based compensation v2

- Example \( n \approx 1.5 \)
- How to determine End-of-Life?
Alternative compensation algorithms

- Voltage-based compensation:
  - Increase in OLED voltage is used to keep track of the degradation

- Power-based compensation:
  - OLED is driven with a waveform ($\Delta I$)
  - $\Delta U = f(\Delta I)$ and $P_{\text{HEAT}} = g(\Delta U)$
  - $P_{\text{LIGHT}} = P_{\text{IN}} - P_{\text{HEAT}}$
  - NXP patents:
    - US 2011/0080113 A1
Conclusion

- OLED luminance decays with time:
  - Stretched-exponential → models the decay
  - Coffin-Manson → models the decay rate

- Time-based compensation needs:
  - Luminance decay parameters – $\beta$, $T_{1/2}$
  - Coffin-Manson fatigue parameters – $c$, $n$

- Alternative compensation algorithms:
  - Voltage-based
  - Power-based
Thanks!