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Development and luminance measurements of a fully screen-printed multi-segmented electroluminescent clock

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Short abstract

Screen printing is a proven printing process for many graphic and functional applications such as printed electroluminescent (EL) panels. EL illumination technology is based on the light emission of a luminescent material exposed to an alternating electric field between two electrodes. Printed EL panels therefore generally consist of a stack of superimposed printed layers. We have developed and manufactured a new layout and flexible programmable control for a multi-segmented clock printed with screen printing based on EL technology. This setup is very well suited as a demonstrator for printed electronics. We have performed first measurements with the printed EL-clocks. This shows that the luminance increases linearly in the range of 7–105 cd/m^2 with increasing brightness level of the control. When several segments are operated in parallel, however, the luminance decreases significantly, so that there is still potential for optimization here. Further measurements will be carried out and more luminescent materials will be tested.

Keywords: printed electronics, screen printing, electroluminescent panel, multi-segmented EL panel, luminance

1. Introduction and background

Screen printing is a proven conventional printing process for many graphic and functional applications. Functional screen printing is used in many areas, e.g., automotive, architecture, life science, security features, textile printing or packaging (Bodenstein, et al, 2019; Hübner, 2018; Potts, et al., 2020). Printed electroluminescent (EL) panels are used in industry for e.g., lighting applications in the automotive industry, decorative elements in interior design or on flexible substrates (Janczak, 2019; Verboven and Deferme, 2021; Zao, et al, 2020). The EL lighting technology is based on the light emission of a luminescent material exposed to an alternating electric field between two electrodes (Hirmer, et al., 2019). EL panels therefore generally consist of a stack of layers printed on top of each other (see Figure 1). A luminescent layer, e.g., made from zinc sulfide (ZnS), and a dielectric insulator, e.g., barium titanate ($BaTiO_3$), are embedded between two electrodes. The luminescent layer emits light when a voltage is applied. Through printing technology, EL panels can be reproducibly fabricated in large quantities. Mostly EL panels are manufactured by screen printing or using coating techniques. Based on EL technology, clocks with 7-segment displays were also realized as applications. However, it turns out that the temporal behavior until full illumination and the decay of an illumination is unsatisfactory for the observer. This can be improved by an elaborate optimization (de Vos, et al., 2016).

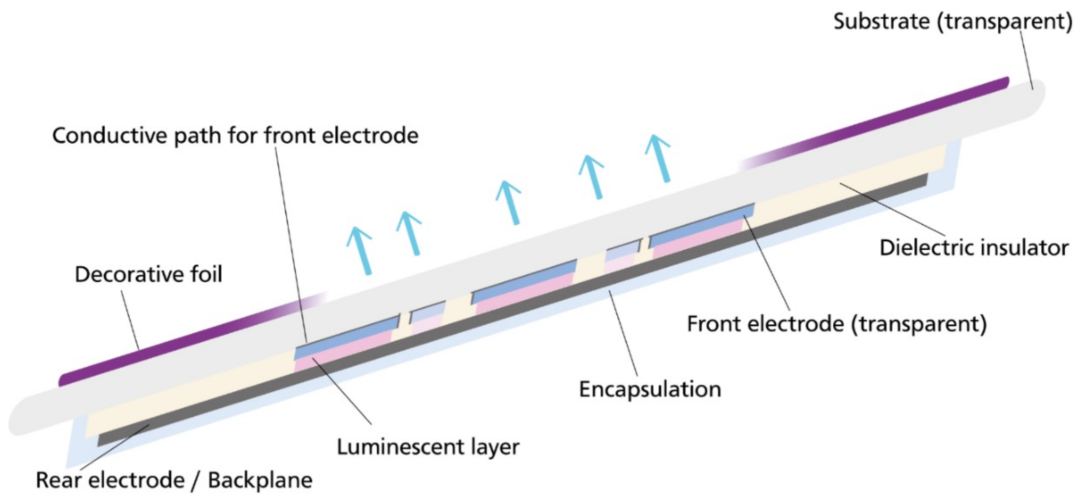

Figure 1: Schematic structure of an EL panel on a transparent substrate; between the rear electrode and the front electrode is the luminescent layer, surrounded by a dielectric layer; encapsulation is needed for protection from voltage, a decorative film provides sharp edges of the illuminated areas; printing of an EL panel usually starts on the transparent substrate

In this paper, we want to introduce a new way to design, print and electrically power a multi-segmented clock based on EL technology. This is accompanied by the following research question: Does the number of simultaneously illuminated segments with the same direct current (DC) input voltage of a screen-printed multi-segmented EL-clock influence the luminance and how can this be compensated?

2. Materials and methods

2.1 Printed components

2.1.1 Printing layout and positioning process

The printing layout consists of seven layers printed on top of each other, see Figure 2a. Between each printing step, the layers were dried at 70 °C for 10 or 60 minutes, see Table 1. On top of the printed layer stack, a decorative foil (ORACAL®751 C, ORAFOL®, Berlin, Germany) with 16 recessed elements such as lettering and clock times, was applied, see Figure 2b. The positioning of the printed layers relative to each other and relative to the contact pins of the circuit board was especially challenging. Therefore, a custom-made positioning system, i.e., a 3D printed frame, was added to the screen printing machine K15QSL, see Figure 3. First, the conductive paths for the front electrodes were printed with silver ink onto the protective film of a polylactic acid (PLA, PLEXIGLAS®XT, 3 mm, clear, Röhm GmbH, Darmstadt, Germany) panel (150 mm × 150 mm, with round edges with 42 mm radius). This step was repeated iteratively with an intermediate cleaning step, until the positioning of the contact pins of the circuit board relative to the conductive paths was satisfactory. Then, the protective foil was removed and the silver ink was printed directly onto the PLA panel. For the further inks, repositioning had to be performed manually by visual sight. The transparent poly (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) was positioned according to the conductive paths. This step was followed by printing of the luminescent material, which was printed on top of the PEDOT:PSS. We used two types of luminescent materials (8150L LUXPRINT and 8152B LUXPRINT, see Table 1). After that, two cover layers of dielectric insulator ink were applied. The rear electrode was again printed with silver ink and finally the encapsulation was applied.

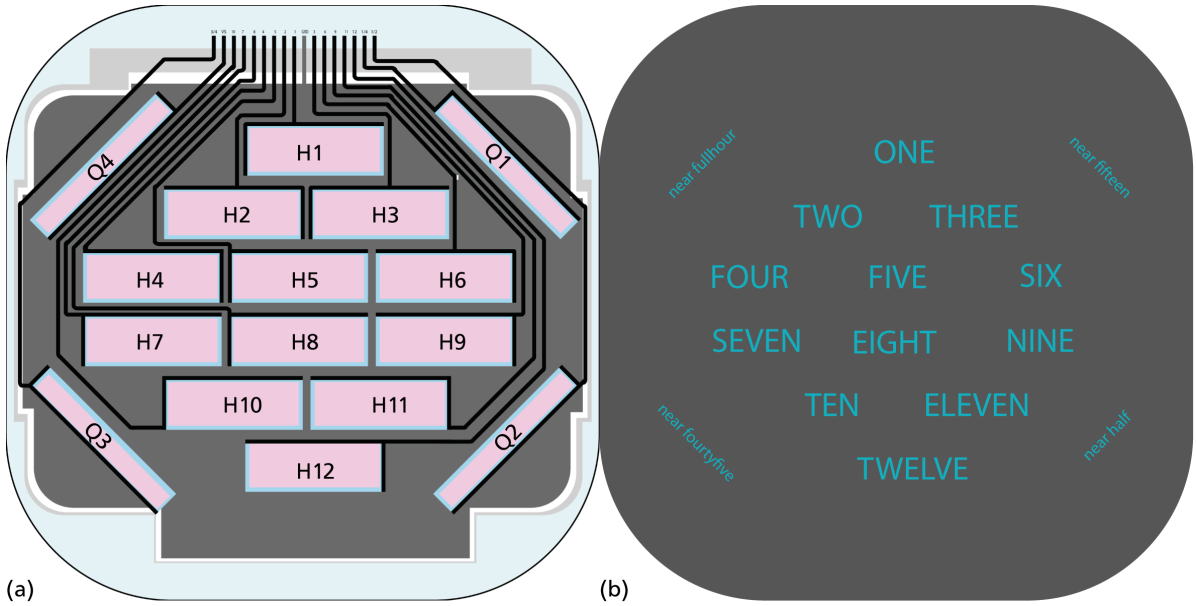

Figure 2: Design of the EL-clock; printed layer stack of seven layers with numbered segments (a) and decorative film with the design of the 16 elements to be displayed (b); the size of the clock is 150 mm × 150 mm with round edges

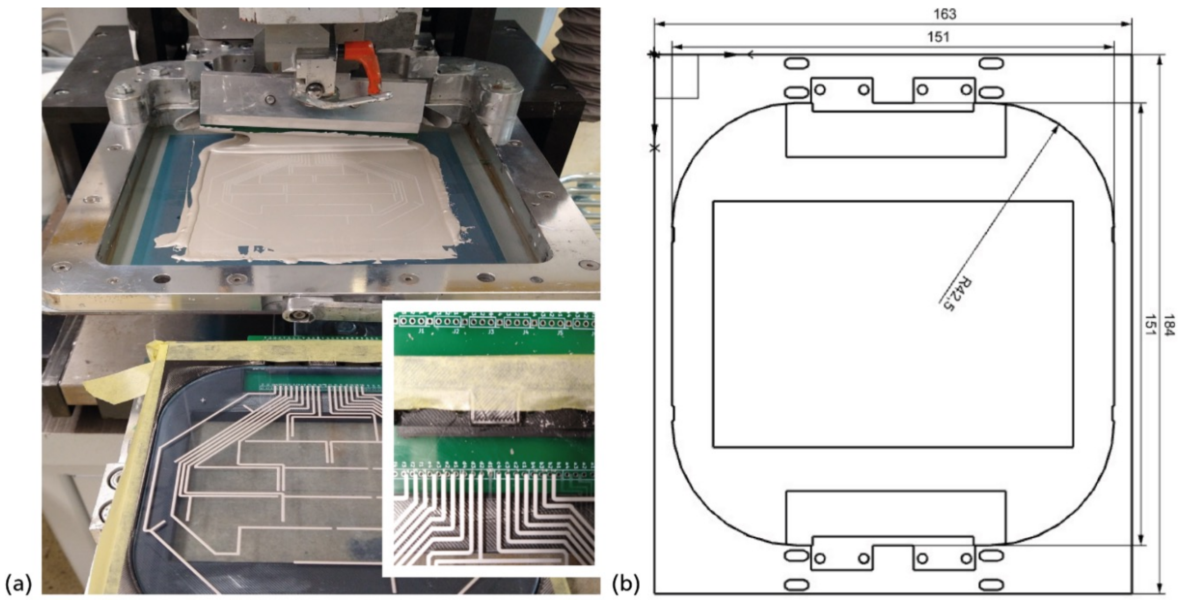

Figure 3: Screen printing machine K15Q SL and printed conductive paths on PLA panel (a) as well as technical drawing of 3D printed frame for positioning with dimensions given in millimeter (b)

2.1.2 Printing inks and printing parameters

All layers of the EL-clock were printed on a Kammann screen printing unit K15Q SL (Werner Kammann, Buende, Germany), (Griesheimer and Dörsam, 2011), see Figure 4a. Squeegee hardness was always 75° shore A. Inks from Heraeus (Heraeus Deutschland GmbH & Co. KG, Leverkusen, Germany) from Henkel (Henkel Nederland B.V., Nieuwegein, Netherlands) and from DuPont (DuPont, Bristol, UK) were used for the printing experiments. Meshes from Frintrup (Hans Frintrup GmbH, Bonn, Germany) were utilized. The choice of the printing parameters was influenced by the supplier information as well as industrial handbooks (Dupont, 2012) and was optimized iteratively, see Table 1.

Table 1: Printing inks and corresponding printing parameters

Layer #	Ink	Manufacturer	Purpose, main material	Mesh name	Mesh material; mesh opening, and thread diameter both in µm	Printing velocity in m/s	Drying time at 70 °C in min
1	LOCTITE EDAG PF 050 E&C	Henkel	Conductive paths for front electrodes, silver ink	SD+ 63/36	Stainless steel; 63, 36	0.1	10
2	PEDOT:PSS SV4	Heraeus	Front electrodes, PEDOT:PSS	140-34 Y	Polyester; 31, 34	0.4	60
3	8150L LUXPRINT	DuPont	Luminescent material, ZnS	100-40 Y	Polyester; 57, 40	0.1	10
3	8152B LUXPRINT	DuPont	Luminescent material, ZnS	100-40 Y	Polyester; 57, 40	0.1	10
4–5	8153 LUXPRINT	DuPont	Dielectric insulator, $BaTiO_3$	61-64 Y	Polyester; 90, 64	0.1	10
6	LOCTITE EDAG PF 050 E&C	Henkel	Rear electrode, silver ink	SD+ 63/36	Stainless steel; 63, 36	0.1	10
7	7165 LUXPRINT	DuPont	Encapsulation, varnish	100-40 Y	Polyester; 57, 40	0.2	10

2.2 Main electrical components and source code

An alternating electric field is required to control the 16 illuminated fields (segments). We developed a circuit board layout as well as the source code to control our screen-printed multi-segmented electroluminescent clock. The main electrical components of the circuit board are a microcontroller (ATSAML21, Microchip Technology Inc., Chandler, AZ, USA), a high-voltage regulator (HV9150, Analog Devices Inc., Wilmington, MA, USA) and a 16-channel serial to parallel converter with backplane driver (short: ’16-channel converter’) (HV528, Microchip Technology Inc., Chandler, AZ, USA). One output of the 16-channel converter supplies the backplane electrode; the other 16 outputs control the 16 EL-clock segments. A simplified circuit diagram shows further electrical components that were used to operate the EL-clock, see Figure 4, but it is not a full overview of all used components. The microcontroller is accessed via a USB-C port that supplies a voltage of 5 V DC. A regulator decreases the input voltage to 3.3 V DC, which is required for the microcontroller. Using the Arduino integrated development environment (IDE) 1.8.19, we developed a source code in the programming language C which was transferred to the microcontroller in order to operate the printed EL-clock. A power supply sequencer is connected to the regulator and sequentially activates three further components which supply different voltages to the 16-channel converter. First, a switch is activated, which supplies 5 V DC to power the backplane electrode. Second, a bias supplies 5.5 V to 6.5 V DC to power the 16 individual segments of the EL-clock and third, a switch to generate a high voltage is activated. This switch forwards a high voltage of 50 to 220 V (DC), created by the high voltage regulator, to the 16-channel converter.

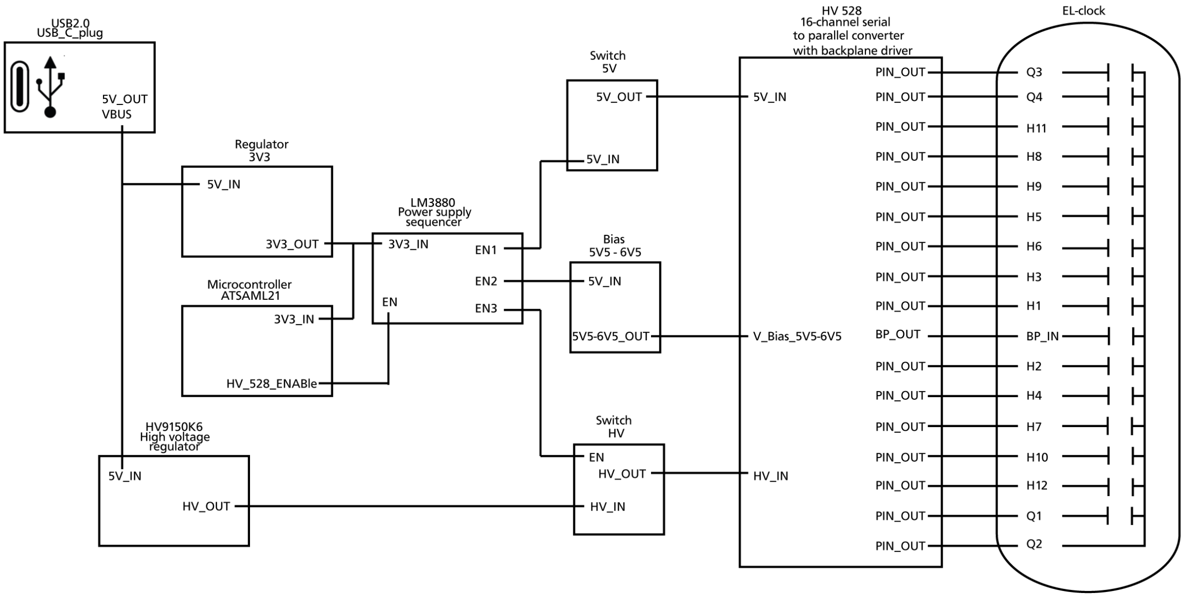

Figure 4: Circuit diagram for the screen-printed multi-segmented EL-clock

2.3 Measurements of luminance

For luminance measurements, the Gossen Mavo Monitor luminance meter (Gossen Foto und Lichtmesstechnik GmbH, Nuremberg, Germany) was used. This high-precision luminance meter for attachment measurement is classified in Class B according to DIN 5032-7, DIN EN 13032-1 Annex B and CIE 69 (Deutsches Institut für Normung, 2012; 2017; International Commision on Illumination, 1987). It measures the luminance of a luminous surface in candela per square meter (cd/m^2). Measurements were performed in a darkened room and were always taken at five different, equally spaced measuring points. An illuminated segment of size 34 mm × 12 mm, i.e., H1, without decorative foil, was measured at ten different brightness levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100 %). One segment (H1), two segments (H1, Q1) and five segments (H1, Q1, Q2, Q3, Q4) were illuminated simultaneously (see Figure 5). The excitation frequency is kept constant at 1 200 Hz and is a fraction of the microcontroller processor frequency, which is 12 MHz. This results in a constant light spectrum, in our case in a constant blue color. With increasing excitation frequency, the color changes from a greenish to a bluish tone. The maximum brightness level of 100 % was defined in the source code as ten consecutive light pulses at the given excitation frequency. Brightness level of Q1 to Q4 was always 100 %, brightness level of H1 varied from 10 % to 100 %. We restricted the number of simultaneously illuminated segments to five because the temperature of the 16-channel converter was measured over 70 °C with a FLIR One Pro infrared camera (Flir Systems, Wilsonville, OR, USA). A higher temperature could destroy the 16-channel converter.

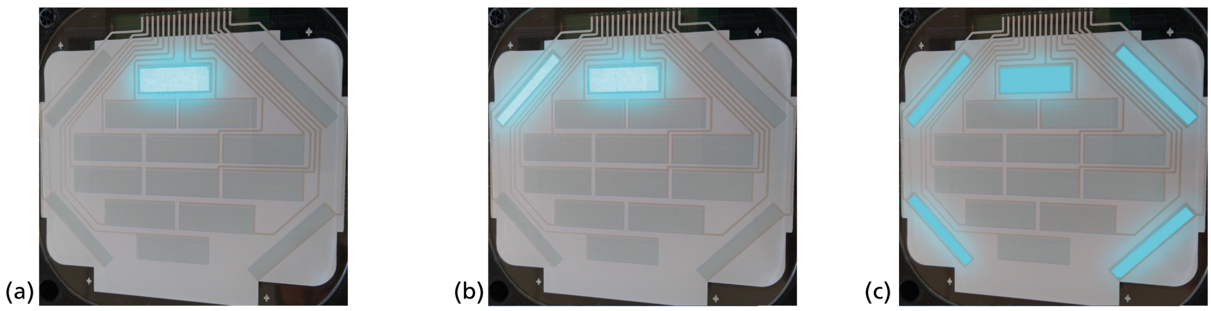

Figure 5: Illuminated measured segments H1 (a), H1, Q4 (b) and H1, Q1, Q2, Q3, Q4 (c)

3. Results and discussion

We were able to manufacture a fully functional, screen-printed multi-segmented EL-clock which can be used as a demonstrator for printed electronics. The EL-clock displays the current time in a modern design in the standard operating mode, i.e., one segment for the full hour from one to twelve and one of the four outer segments are illuminated which show quarter hours. In another operating mode, predefined lighting scenarios can be set independently of the time of day. This mode can be used for luminance measurements or to investigate further research questions. Initial measurements of luminance were made with the samples of the printed EL-clock. For the measurements, one segment was switched on and illuminated once, then two and five segments were switched in parallel and illuminated. The luminance was then measured at ten brightness levels as described in Section 2.3. During operation of the EL-clock, the voltage at the 16-channel converter was measured around 150 V. The results of the luminance measurements can be found in Figure 6. As shown, the luminance increases linearly with increasing brightness level regardless of the wiring type. It can also be seen that parallel operation of segments leads to a significant decrease in luminance. The differences between the two materials investigated are small. Further measurements, e.g., on the time dependence, are in progress.

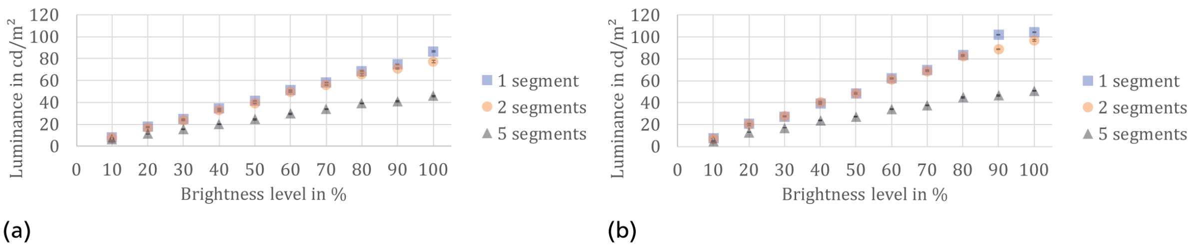

Figure 6: Luminance measurements over brightness level for luminescent materials 8150L LUXPRINT (a) and 8152B LUXPRINT (b)

In relation to our research question, we can conclude that the number of simultaneously illuminated segments influences the luminance significantly. This is an expected behaviour since an increasing number of segments leads to a voltage drop and thus to a luminance drop. Unexpectedly, the luminance drop between one and two illuminated segments was negligible whereas the luminance drop between two and five illuminated segments was significant.

4. Conclusions and outlook

We have developed and manufactured a new layout and flexible programmable control for a multi-segmented clock printed with screen printing based on EL technology. This setup is very well suited as a demonstrator for printed electronics. We have performed first measurements with the printed EL-clocks. This shows that the luminance increases linearly with increasing brightness level of the control. When several segments are operated in parallel, however, the luminance decreases significantly, so that there is still potential for optimization here. Further measurements will be carried out and more luminescent material will be tested. We also want to explore the technical limits of our EL-clock generator with regard to the maximum achievable voltage and the maximum brightness levels.

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