RESEARCH ACCORDING TO TRL 7 TECHNOLOGICAL MATURITY FOR A SIGNAL PANEL WITH UNIFORM LIGHTING ON BOTH SIDES

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Rezumat. *Lucrarea se referă la un panou de semnalistică cu iluminare din cant cu LED, capabil să asigure o luminiscență uniformă pe ambele fețe ale suprafeței vizibile. Structura panoului este una de tip sandwich, alcătuită din plăci din PMMA, folii backlit și folie autocolantă inscripționată, toate montate într-o ramă din aluminiu subțire. Iluminarea se realizează printr-o bandă LED de tip șnur continuu, plasată pe cantul superior, iar uniformitatea luminii este obținută prin transmiterea acesteia prin masa materialului Plexiglas Edge Lighting și prin reflexia de la foliile metalice de aluminiu aplicate pe laturile laterale. Produsul permite consum redus de energie, grosime mică 10-15 mm), conectivitate WiFi, și montaj modular în cascadă. Este destinată spațiilor interioare intens circulate, oferind o soluție modernă, fiabilă și estetică pentru semnalistică și publicitate. Cercetarea a fost efectuată în cadrul proiectului "Inovare, Cercetare și Construire fabrică de producție semnalistică" finanțat în cadrul Programului Regional POR N-E, Cod MySMiS 338462.*

Abstract. *The paper relates to a signage panel with LED edge lighting, capable of ensuring uniform luminescence on both sides of the visible surface. The structure of the panel is a sandwich type, consisting of PMMA plates, backlit foils and inscribed self-adhesive foil, all mounted in a thin aluminum frame. The lighting is achieved by a continuous LED strip, placed on the upper edge, and the uniformity of the light is obtained by transmitting it through the mass of the Plexiglas Edge Lighting material and by reflection from the aluminum metal foils applied to the sides. The product allows for low energy consumption, small thickness (10-15 mm), WiFi connectivity, and modular cascade assembly. It is intended for heavily trafficked interior spaces, offering a modern, reliable and aesthetic solution for signage and advertising. The research was carried out within the project "Innovation, Research and Construction of a Signal Production Factory" funded under the POR N-E Regional Program, Code MySMiS 338462.*

Keywords: Signage panel, LED Chip on Board lighting, PMMA Edge Lighting.

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1.Introduction

The creation of a new high-performance signage product was the idea behind over 12 years of research at RODOTEX SRL from Iași, Romania. The company's products are manufactured under the conditions of an integrated management system certified by TUV Rheinland, in accordance with EN ISO 9001, EN ISO 14001 and OHSAS 45001, and for the implementation of special projects that require traceability and sustainability.

The goal pursued in creating the new signboard product is to meet the following requirements:

- Low energy consumption,
- Illumination only at the edge of the panel,
- Perfectly uniform illumination over the entire surface of the transparent material,
- Creating a modern, lightweight technical design, with an aluminum frame and a glossy acrylic front,
- Minimum panel thickness, the goal being to achieve a size of 30 mm.
- Creating modularity for connecting multiple panels
- Easy connectivity and integration with smart wifi modules.
- Extended visibility and the possibility of simultaneously displaying two identical or different messages on both sides of the panel (front-back)

The associated benefits are the following:

- Obtaining high-quality visibility with uniform illumination across the entire surface of the transparent material
- Achieving significant savings due to reduced electricity consumption
- Using lightweight materials and ensuring all quality assurance requirements
- Constructive simplicity
- Perfectly reproducible technology
- Smart wifi connectivity
- High reliability and simple maintenance
- Modularity of components and ensuring a large number of assemblies as product variants.
- Ensuring bidirectional visibility by making double-sided signaling panels

2.State of the art

Internationally, there are numerous configurations of illuminated signs with a signaling role and illumination on one side, some of which also refer to signs with illumination on both sides [1], [2]. All solutions proposed internationally fail to achieve uniform luminescence on both sides, especially when the letters, numbers

or symbols in the personalized signaling text overlap in the same front-back area of the sign. Below we detail three such inventions.
Patent **US 9082326 B2** is one that comes close to the technical solution proposed by the current invention. The identifying elements are: Erik A. Aho, Patrick A. Thomas "Self illuminated shaped and two-sided signage for printed graphics" — which was published on 14.07.2015.
https://patents.google.com/patent/US9082326B2/en
The invention differs in that the signage includes a rotating foil with a structured surface for redirecting light and a diffuser that ensures diffusion. In the case of double-sided signage, the rotating foils receive light from an ambient light source (external to the panel) and direct the light through the structured surfaces towards the viewers of the two graphic elements to (passively) illuminate the signage. The illumination is therefore passive, external and not from the edge of the panel.

US 9163805 B2 is a patent published on 20.10.2015, authors being Joo Hun Han, Je Myung Park et al. from Samsung Electronics Co Ltd. and the title is: "LED lens and LED module for two-sided lighting, and LED two-sided lighting apparatus using same" https://patents.google.com/patent/US9163805B2/nl
The lighting principle is based on an LED lens and an LED module for two-sided lighting, capable of emitting light in two directions. One side of the apparatus has a light receiving portion; which it partially transmits upwardly due to a reflective portion, and a second portion transmits light reflected by the reflective portion in a downward direction. The light receiving portion includes a surface formed concavely in a direction in which light is incident, and has inclined surfaces extending on both sides of the concavely curved surface. The light receiving portion may further include a stepped portion extending from the inclined surface. The light-diffusing agent includes at least one of TiO, Al_2O and SiO_2. This invention differs from the present solution by placing the LED module for dual illumination, by the large number of LED lenses and by the impossibility of ensuring a small transverse size (slim).

US Patent 7233259 B2, published in June 2007, authors: Gibson et al. "Traffic control sign assembly (two-sided bread board LED light panel)", link: https://patents.google.com/patent/US7233259B2/en, claims an LED light panel with screen printing of text. The text messages are placed on the back of each of the light-diffusing panels, aligned with the LED light panel. Switching means are provided for turning on the power supply in the maintenance, flashing or off mode. It is noted that there is an LED light panel mounted in the central opening of the sign panel and that there are light diffusion panels mounted above the light panel, in front of and behind it. The difference from the current patent proposal is that the diffusion panels do not represent a special acrylic plate (PMMA –

polymethylmethacrylate) for edge lighting. This special plate ensures uniform light distribution, as it contains light-dispersing particles uniformly integrated into the mass of material.

All the solutions found in the specialized literature propose different solutions, but they fail to obtain a uniform luminescence on both sides, due to interferences in the light transmission. There are many solutions and technologies for obtaining signaling panels, but they are based on multiple lighting sources, or on the transmission of light by reflection, without achieving a uniform transmission of light through the mass of PMMA material and with illumination on only one side of the panel, between the aluminum protective frame and the edge of the Plexiglas material.

3.TRL 5: Validation of components and assembly under relevant operating conditions -industrial environment

Internationally, similar technologies for fixed signage panels include LED, LCD, E-Paper, smart lighting, IoT and AI-based interactive solutions. They are used in various indoor spaces to ensure efficiency, visibility and smart integration. The choice of technology depends on the specific requirements of the space (size, traffic, lighting conditions) and budget. Compared to other existing technologies internationally, the technology proposed by this paper involves the use of a COB (Chip-On-Board) LED strip with static display on both sides of the panel. The applications for which these panels are destinated have imposed this constraint.

The main benefits are:

- -Uniform visual appearance: Continuous light, without visible dots; Superior aesthetics.
- -High luminous performance: High brightness; Energy efficiency; Wide lighting angle.
- -Superior visual comfort: Reduced glare; No light fluctuations.
- -Versatility in use: High flexibility; Precise cutting; Dimmer compatibility.
- -Durability and reliability: Efficient heat dissipation; Long lifespan; Resistance to external factors.
- -Long-term economic efficiency: Even if the initial price is higher than that of SMD strips, maintenance costs and reduced energy consumption make them more economical in the long term.

The tests already carried out by SC RODOTEX SRL Iași and INCERTRANS SA Bucharest demonstrate that the product and its manufacturing technology fall within the **TRL 5** technological maturity level. This prototype was built, and the

components and assembly were validated under relevant operating conditions (industrial environment) [3], [4], [5].

1. U-profile (13.1 x 20.8 x 1.3 mm) made of anodized aluminum
2. Aluminum angle (20 x 20 x 2 mm) made of aluminum
3. LumyTools LT 70412 rivets
4. Self-drilling screws 4.2 x 16 mm
Components 1-4 are assembled in the form of a rectangular frame and painted in the assembled state in an electrostatic field
5. COB LED strip Arelux SLS 352 CW8 CRI90
6. Electric cable H03VVH2-F 2x0.75 mm (tinned on the terminals of the LED strip)
7. Protection of tinned connections with heat-shrink tube SRF1-127190 6.4-3.2 mm
8. Sandwich assembly consisting of:
- 2 mm XT PMMA Clear face (2 pcs, on both sides of the panel)
-foil Oracal 641 (2 pcs)
-Plexiglas Edge Lighting 0E011 L (1 pc)
-Self-adhesive aluminum metal foil, glued to the other 3 sides of the Edge Lighting plexiglass, this foil helps to preserve the reflection of the LED strip light
-Backlit film (e.g. Ikonos BUV 130 SM) being compatible with printing technologies such as inkjet and UV (2 pcs)
9. SELV power supply (e.g. BERGMEN Eco LED Compact power supply or LiFUD 24V, 30-100 W).

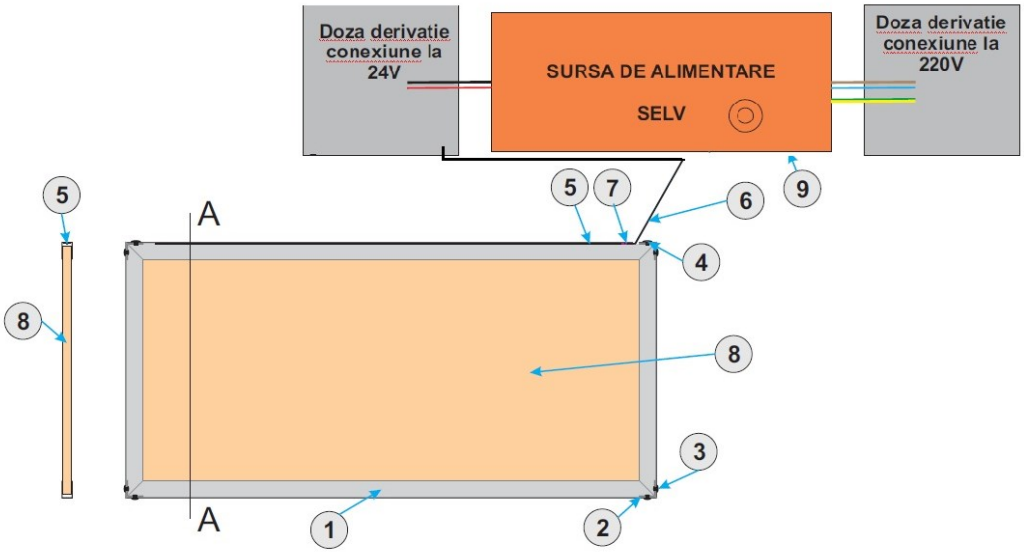

Fig. 1. Assembly and components of the double-sided signboard panel.

Applicability and limitations of the prototype designed according to maturity level TRL 5.

Examples of applications:

-Signboards for airport terminals and public parking lots.

-Fixed light indicators for public spaces.

Limitation: Signboards cannot be placed outside buildings, in conditions of excessive humidity.

The final prototype, double-sided signboard panel, was designed and built based on the results obtained on the previous stages (Figure 1). The new prototype is adapted for use in relevant environments (environment with intense human traffic, minimum temperatures 18°C-maximum 25°C, and relative humidity 30%-60%).

Advantages of the final prototype which is able to meet the **TRL7** technological maturity conditions:

- Slim assembly, 10-15 mm thick for the 2-sided panel.
- Uniform lighting due to the way the LED strip is placed and the light transmission through the white layers of the materials used (white backlit film, white sticker, white ink or any white material) which makes the light uniform on the panel surfaces.
- Reduced energy consumption by using the COB LED strip.
- Smart connectivity via Wi-Fi module.
- Possibility of mounting multiple panels in cascade.
- Modern signaling panel, designed for heavily trafficked indoor spaces.

4.Two steps to get from TRL 5 to TRL 7

Transitioning a signage panel (such as an LED-based display) from Technology Readiness Level (TRL) 5 to TRL 7 represents a critical step in technology maturation. This phase moves the product from laboratory validation to demonstration in an operational environment.

Step 1: Prototype Optimization (TRL 5 → TRL 6)

Objective: Validate the technology in a relevant, not just controlled, environment.

Key activities:

1. Design optimization – mechanical, electrical, optical refinements.
2. Thermal and photometric analysis – measurements and simulations.
3. Testing in relevant environments – exposure to temperature, humidity, vibration, UV, and dust.
4. Preliminary compliance verification – against CE, EN 60598, IP, EMC, RoHS, etc.

Outcome: A near-final prototype validated in a relevant environment with stable performance.

Step 2: System Integration and Demonstration (TRL 6 → TRL 7)
Objective: Demonstrate the fully integrated system in a real operational environment.
Key activities:
1. Build the near-series prototype – with final components and design for small-scale production.
2. Field testing – install and operate in real conditions, collect data on lighting performance, energy use, and durability.
3. Evaluate operational performance – compare actual results to specifications.
4. Full regulatory compliance – CE marking, IP/IK ratings, EN 60598, EN 55015, etc.
5. Feedback and optimization – incorporate findings from real-world testing.
Outcome: The signage panel is successfully demonstrated in a real operational environment, proving performance and reliability (see Table 1).

Table 1. Stages and objectives to be achieved [6], [7], [8].

TRL	*Stage*	*Main Objective*	*Testing Environment*	*Expected Outcome*
5	Laboratory validation	Demonstrate basic functionality	Controlled lab	Laboratory prototype
6	Validation in relevant environment	Demonstrate performance under simulated real conditions	Simulated / relevant	Near-final prototype
7	Operational demonstration	Demonstrate system in real operational setting	Field / operational	System validated in real use

Summary of the tests that are being performed for the Chip-On-Board LED double face Signage Panel [9…14]:

- Thermal testing – IR/thermocouple monitoring after 4h operation.
- Optical testing – luminance uniformity and photometric efficiency.
- Electrical testing – voltage/current stability and protection.
- Mechanical testing – vibration and ingress protection (IP/IK).
- Field operation – install in a real setting such as an airport, mall, or other spaces with intense traffic.

In the Figure 2 is presented the power supply testing: SELV power supply (e.g. BERGMEN Eco LED Compact power supply or LiFUD 24V, 30-100 W).

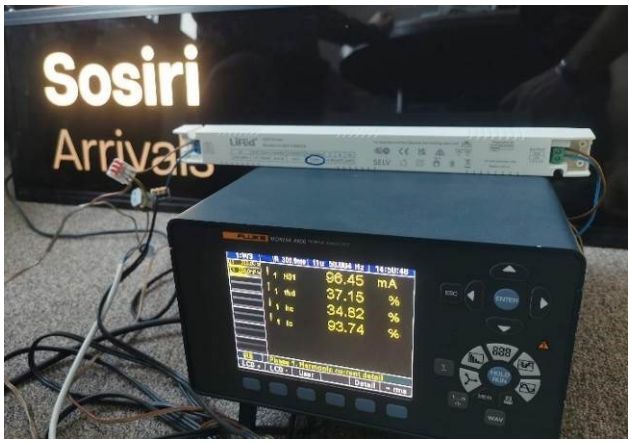

Fig. 2. Testing the panel power supply

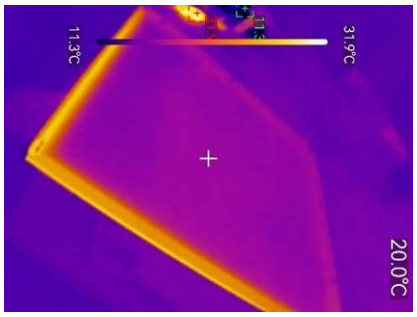

Fig. 3. Measuring the temperature of the illuminated panel

Measuring the temperature of the illuminated panel (Figure 3) was another important test, based on power/meter of the LED strip lighting.
The temperature increase due to LED strip lighting is calculated with the relationship:

$$\Delta T = P_{tot} \times R_{th} \quad (1)$$

where:
P_tot= total dissipated power (W) = 10 W × length (m) (approx. — from Arelux data).
R_th= effective thermal resistance of the construction to air transfer (°C/W).

Quick calculations (ambient temperature 25 °C):
Power per meter: 10 W/m.
The calculation of ΔT and the approximate surface temperature = 25°C + ΔT.
1 m (P = 10 W)
On aluminum (R_th = 0.5 °C/W): ΔT ≈ 10 × 0.5 = 5 °C → surface ≈ 30 °C.
On acrylic in the box (R_th = 2 °C/W): ΔT ≈ 10 × 2 = 20 °C → surface ≈ 45 °C.

5.Connection to WiFi

The new signage panel, with uniform lighting on both sides, could be connected to WiFi to ensure remote control of the device (Figure 4).

The electrical diagram for the Shelly RGBW2 + 24 V monochrome LED variant, LiFUD 45 W power supply, contains the following important recommendations:

• 230 V power supply → LiFUD 45 W (24 V DC output);
• +24 V output goes through a 3 A fuse; then +24 V powers both the V+ of the Shelly module and the + LED of the panel.
• Common GND (0 V) connected to Shelly GND and to the LED ground.
CH1 (PWM OUT) from Shelly drives the minus of the LED (the diagram uses CH1 as a PWM- Pulse Width Modulation negative output, according to the Shelly RGBW2 application);
• Calculation: 45 W / 24 V = 1.875 A → 3 A protection and a minimum 1.0 mm² cable are recommended for short runs.

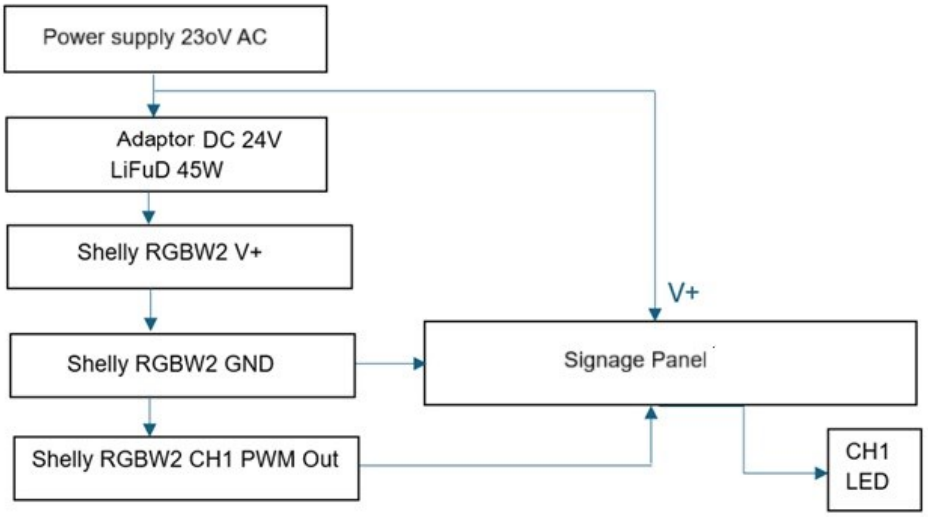

Fig. 4. WiFi connection diagram

List of necessary components:

1. Shelly RGBW2
2. Adapter / DC 24 V source
3. Acrylic panel + LED strip 24 V (specific trim-of-LED for edge lighting).
4. Inline fuse on the positive side of the source (fuse holder + fuse) — size according to the calculated current.
5. Mounting box for Shelly module.
6. Wires: red (V+), black/brown (GND), blue (CH1) — 2.5 mm² if high currents (depends on amperage).
7. Connectors

The final prototype (with different sizes and signaling messages) which corresponds to maturity level TRL 7, is shown in Figure 5.

Fig. 5. Final prototypes with custom sizes, graphics and colors.

6. Conclusions

The signaling panel proposed in this paper differs from other solutions presented in the specialized literature:

- Signage panel with LED edge lighting and uniform luminescence on both sides, is characterized in that it is made in the form of a sandwich assembly mounted in a U-profile aluminum frame, in which the following components are arranged successively, from the outside to the inside:

  – two transparent PMMA/transparent polycarbonate/transparent PET plates that form the outer faces of the panel;
  – two self-adhesive foils applied to the inner surface of the PMMA plates, inscribed according to the signaling message (in the first case).
  – two translucent backlit film foils, having a glossy side and a matte side inscribed (in the second case)
  – a Plexiglas Edge Lighting 0E011 L plate located centrally, which constitutes the light guide;

- The lighting being made with a COB (Chip On Board) LED strip or with independent diodes is mounted on the upper edge of the Plexiglas Edge Lighting plate.

The signage panel allows the cascade connection of multiple units through the "Plug & Play" system and is equipped with a WiFi connectivity module, which allows remote switching on, off and monitoring of lighting and integration into Building Management System (BMS) systems.

Acknowledgments

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