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LpR

The Global Information Hub for Lighting Technologies and Design

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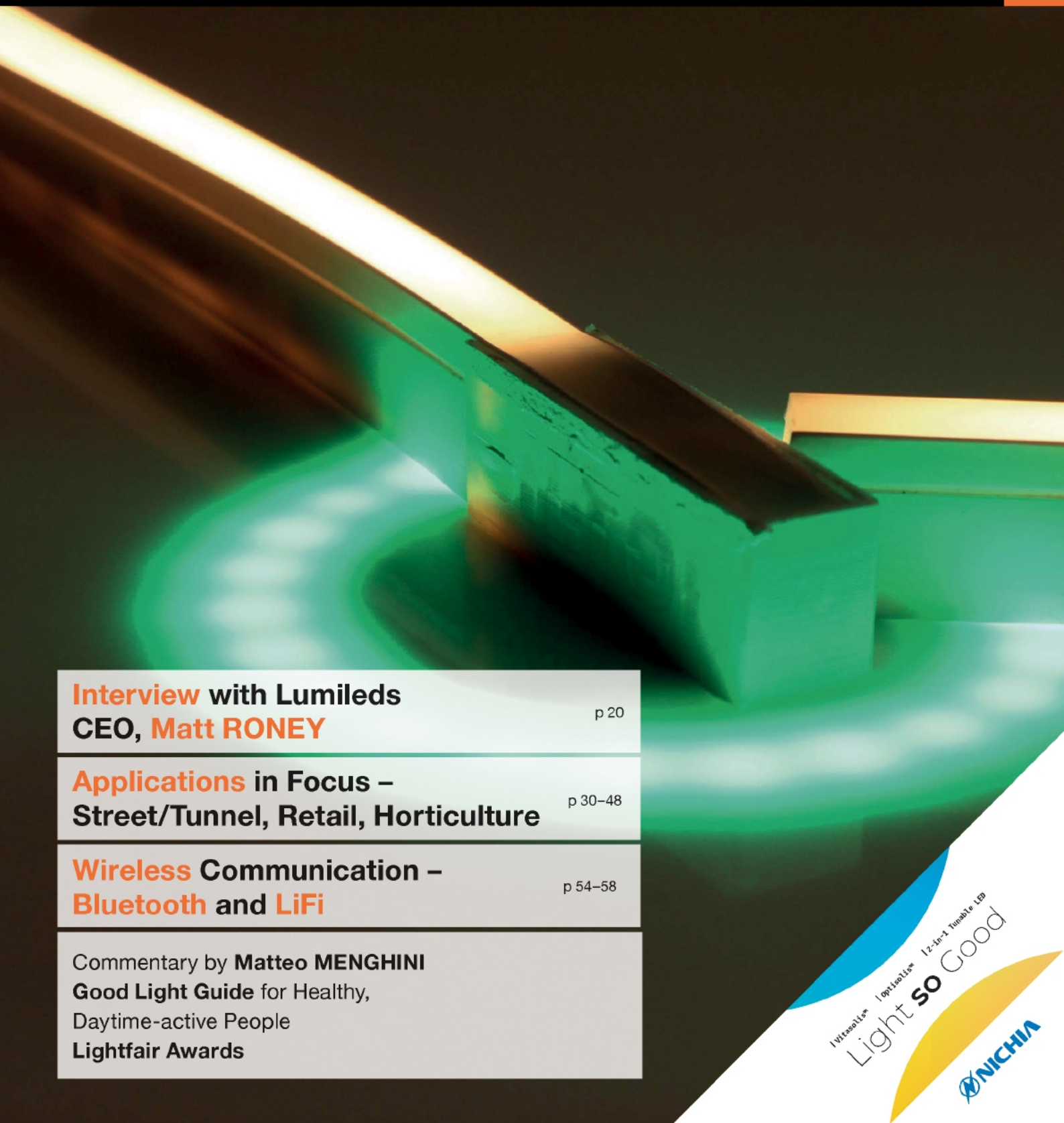


» WAGO is the perfect partner for Seoul Semiconductor LED module solutions because it's an innovative company that respects the intellectual property with top quality products and service delivery. «

Marc Juarez, Technical and Marketing Director for Europe,
Seoul Semiconductor Europe GmbH

www.wago.com/lighting

Performance in Applications

“Innovations will transition from efficacy of light sources to performance in applications.” This interview statement by Matt Roney, CEO of Lumileds, can very well be used as a motto for this issue. You can read the exciting interview with Matt starting on page 20.

In addition to technological topics, the LED professional Review will increasingly publish application-oriented reports - building the bridge between technology, application, and design, as shown in this edition.

ERCO opens our minds to flexible and sustainable co-working spaces; Nichia presents a case study in retail, and Carclo gives us their viewpoint on horticulture lighting. Infineon has thought extensively about what future smart lighting systems in street lighting could look like. Bartenbach’s study on tunnel lighting is also included here. With the Bluetooth article about Large-Scale Commercial Environment and the update on LiFi Communication, we also present you with new, creative ideas about intelligent, networked lighting solutions.

This issue also contains the Good Light Group’s Lighting Guidelines, a valuable contribution to health and well-being.

Bridging the gap between technology and application is nothing new. Nevertheless, there is great need for information and questions of understanding at this interface. This also seems to be the key point, the “innovation center” of the future in the lighting sector.

We hope you enjoy reading LpR88 and would like to take this opportunity to thank the excellent authors for their excellent contributions.

Yours Sincerely,

Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
Photonics21, Member of the Board of Stakeholders
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors
Member of the Good Light Group and the European Photonics Industry Consortium

SunLike

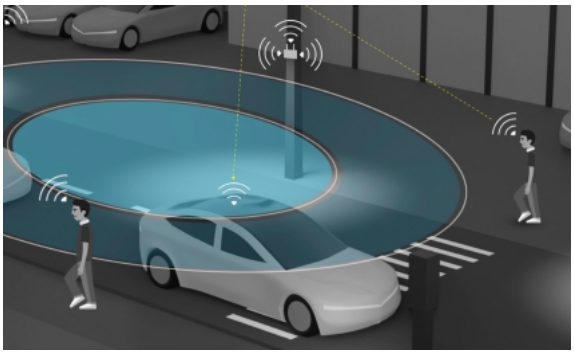
https://verify.ul.com/verifications/520

The First Diamond Certified LED

SunLike natural sun spectrum LEDs are the world's first LEDs to produce light that closely matches the spectrum of natural sunlight, delivering human-centric lighting.

The light sources with SunLike Series LEDs more accurately show the color of objects as they would appear in natural sunlight. It is optimized to natural light spectra and color rendition Rating "Diamond" based on IES TM-30-20 Fidelity intent from UL Labs.

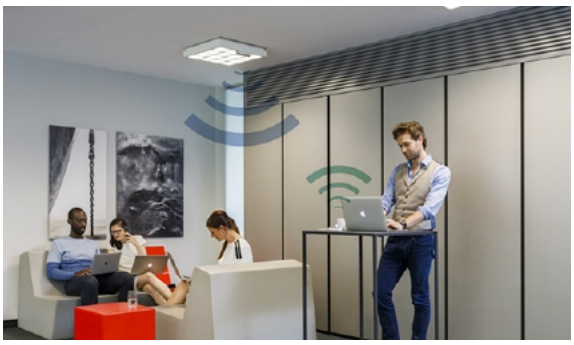
It delivers considerable benefits of significant vivid color, detail contrast, and homogeneous quality of light.



HORTICULTURE LIGHTING

BLUETOOTH NETWORKS

LIFI COMMUNICATION



GOOD LIGHT GUIDE

LED professional Review (LpR)
Jan/Feb 2022

ADVERTISING INDEX

Matteo MENGHINI

Matteo Menghini has over 20 years of experience in the lighting industry. Working for major European manufacturers of architectural lighting, he held various positions of growing responsibility in the area of marketing and sales with a broad international scope.

Since 2018 Matteo Menghini is the Global Work Cluster Manager of ERCO. He is responsible for the Work Cluster development on a global scale, ensuring the right strategic approach on the market, evolving the vision, the scope and the story according to the latest application trends.

Flexible and Future-proof Design of Co-working Spaces

Co-working spaces are now more popular than ever. Workplace operators are currently reporting a veritable boom in demand: we formerly encountered freelancers and start-ups in shared workspaces, but now large companies also aim to reap the benefits from this creative and cooperative office culture. Co-working spaces must thus be designed to be as flexible as possible to meet the changeable requirements of modern knowledge work.

Whether individual workstations in cubicles or joint brainstorming in a lounge-style landscape – co-working spaces score not only with unconventional designs, it is above all the multifunctional furniture and open space concepts that pave the way for diversity in use. This fundamental concept of flexibility must also flow into the lighting.

Downlights for track offer the perfect solution in this respect: a flexible track infrastructure makes light variable for simple adaption to changing office layouts. The downlights can be repeatedly repositioned along the track – without tools and without further wiring. They bring together the high visual comfort of downlights with the flexibility of spotlights. Furthermore, the luminaires should have good glare control, be dimmable and meet the requirements for standard-compliant office lighting (UGR<19). In combination with Bluetooth control, users can conveniently switch the light individually via their smartphones and call up different light scenes for different activities and times of day. Instead of generating wide-area light, efficient concepts can be realized that only provide light where it is needed and, also, where it is seen. Zonal lighting not only saves energy, optimally matched lighting conditions also have a positive effect on productivity and creativity and promote people's sense of well-being.

This is where the perception-oriented planning approach of Human Centric Lighting (HCL) comes in: HCL not only takes into account the visual perception of light, but also incorporates the emotional and biological effect on people by supporting their circadian rhythm. To implement this, luminaires with different light colours and light distributions are needed. Wallwashing is also an essential part of HCL concepts, because vertical surfaces determine the visual perception of people. In addition, bright walls contribute to establishing a contrast ratio between computer screens and the room, increase the impression of brightness and facilitate orientation within the architecture.

With our "AAA" strategy, Human Centric Lighting can be implemented in a practical way in co-working spaces: the formula stands for...

architecture – making vertical surfaces visible for better orientation,

activity – promoting interpersonal contact and concentrated work via good lighting, and

atmosphere – enabling pleasant lighting at all times of day. For us, this means true Human Centric Lighting, which is the basis for flexible lighting concepts in offices. ■

M.M.

ERCO is a leading international specialist in architectural lighting, using 100% LED technology. The family business, based in Lüdenscheid, in the heart of Germany, now operates as a global player with independent sales organisations and partners in 55 countries worldwide. Founded in 1934, ERCO pioneered architectural lighting across Europe in the 1960s, and today, less than 50 years later, is the first established luminaire manufacturer with a portfolio based entirely on LED technology. Around 1,000 committed and dedicated ERCO employees worldwide ensure that LED technology is developed from a pure technology into a sophisticated lighting tool.

RÖHM

We believe in reincarnation. The reincarnation of PLEXIGLAS®, at least. Because PLEXIGLAS® is so pure that it can be broken down into its basic components again to be reborn as new PLEXIGLAS®. Few plastics can achieve a rebirth of this kind – this is not downcycling, but true recycling in the interests of a circular economy! Make the most of the versatility of PLEXIGLAS® for long-lasting and more sustainable products. For inspiration, go to **www.plexiglas-polymers.com.**

For PLEXIGLAS®, reincarnation is old hat. We call it "recycling."

PLEXIGLAS®

THE ORIGINAL BY RÖHM

LIGHTFAIR AWARDS 2021

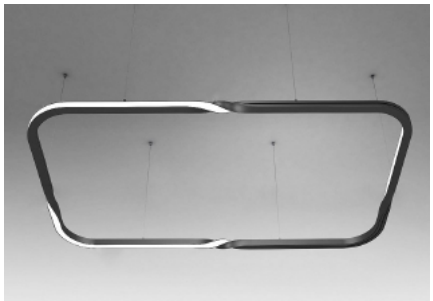
Most Innovative Product: Lazer Line

Lazer Line – Pureedge Lighting
https://www.pureedgelighting.com/

Lazer Line creates a paradigm shift with how we use lighting design within our environment. Lazer Line, an LED lighting system, connects wall-to-wall or wall-to-ceiling, up to 60 ft. before refeeding, with no visible pixilation. It utilizes heatsink tape which is fastened and tightened by turnbuckles plastered into the wall or ceiling for a seamless look. it allows the light to go up, down, or both, achieving ambient uplight and also functional lighting. It enhances any space with pleasant soft light and delivers designer quality color rendering, creating a space that is visually spectacular

It allows anyone to play with light and create multi-dimensional and multi-directional effects. With Lazer Line you can connect wall-to-wall or wall-to-ceiling. It uses aluminum heatsink tape tightened by turnbuckles, providing uplight and downlight. ■

Design Excellence Award: Infinity



Infinity – Edison Price Lighting
https://epl.com

Infinity is the first linear/curve lighting system with limitless design possibilities. Any length or degrees can be configured, in any combo of linear, curved, or twisted models. Infinity can be suspended, recessed, surface or wall mounted. Form shapes such as interlocking loops, half moons, linear waves, and architectural swirls. Each model is available in different light source directions, achieving multi-directional lighting when combining models for a luminaire that doubles as an architectural element and a powerful source of illumination. With Infinity, any imaginable design is possible.

Traditional linear slots and curved linear slots are limited in design. With Infinity, any imaginable shape can be formed. Infinity can go anywhere: suspended, recessed, surface or wall mounted. Available in up to 750 lumens, for virtually any space. ■

Technical Innovation Award: TruTrack

TruTrack – Pureedge Lighting
https://www.pureedgelighting.com/

TruTrack is a patented, recessed track lighting system that installs cleanly into the ceiling, achieving a truly flawless finish. Our innovative system easily installs into 5/8" thick drywall, eliminating the need for joist modification. TruTrack can incorporate an integral LED strip which is field cuttable for customized lengths. Adding minimal architectural track heads make TruTrack perfect for residential and commercial applications. TruTrack lighting is available in Warm Dim to promote relaxation and wellness, as well as standard static white and multiple color temperatures

The TruTrack lighting system takes the worry out of finding joists for installation. By cutting into the ceiling drywall and installing a channel, easily drywall over it and then install the track heads. This minimal profile achieves ideal room lighting. ■

Product Category Winner: The Lighting Library

Non-Luminous: Research, Publications, Software and Specialtiy Hardware

The Lighting Library® is the comprehensive set of Illuminating Engineering Society standards plus Handbook content updated for 2020 in an online, subscription based service. It contains nearly 100 annotatable standards and includes two exclusive features: the Reference Retriever for finding links to the references themselves, and the Interactive Illuminance Selector that allows users to quickly find lighting criteria that can be saved in an unlimited, user-defined project library. The Lighting Library is the first globally accessible online platform for continuously updated lighting standards.

The Lighting Library – Illuminating Engineering Society (IES)
www.ies.org

This innovation brings the complete set of IES standards to the industry in a platform that saves time and is always up-to-date, with interactive tools for annotating documents and quickly finding references and lighting recommendations. ■

Product Category Winner: Smart Current Drivers

Ballasts, Transformers, Drivers, Systems and Kits

Smart Current Drivers – Keystone Technologies
https://keystonetech.com/

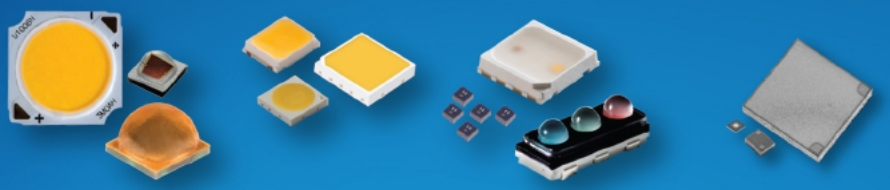
Keystone Smart Current LED Drivers don't need any special hardware for the user to make adjustments – you can just plug them into a computer or smart phone with a USB-C cable and set up the driver to your specifications. This feature makes the driver even more convenient to install in the field, since there's no need for computers or special software. It's available in multiple output power options, features a dim-to-off mode – enabling dimming to 1% – for precise tuning of output current, and includes a 12Vdc/200mA max auxiliary power output.

Forget about special hardware. The Keystone Smart Current LED Driver can be adjusted by

New name. New breakthroughs. **All LED.**

Cree LED™ has a new name, one that reflects the singular pursuit of innovation in LED technology. Get ready for new products, new applications, and new performance milestones —just what you'd expect from the Cree LED team.

CREE LED



XLamp® LEDs | J Series® LEDs | High Brightness LEDs | LED Chips *not to scale*

SEE THE COMPLETE PORTFOLIO AT CREE-LED.COM





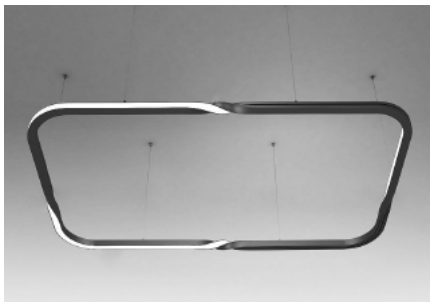





simply connecting it to a smart phone or computer with a USB cable, making installation simple, especially out in the field. ■

Product Category Winner: Infinity

Indoor Decorative



Infinity – Edison Price Lighting
https://epl.com

Infinity is the first linear/curve lighting system with limitless design possibilities. Any length or degrees can be configured, in any combo of linear, curved, or twisted models. Infinity can be suspended, recessed, surface or wall mounted. Form shapes such as interlocking loops, half moons, linear waves, and architectural swirls. Each model is available in different light source directions, achieving multi-directional lighting when combining models for a luminaire that doubles as an architectural element and a powerful source of illumination. With Infinity, any imaginable design is possible.

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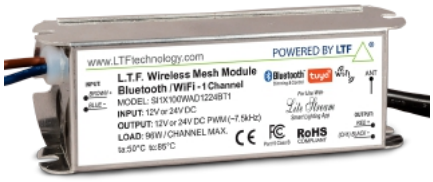
Product Category Winner: SI C Series (Smart Interface Control)

Control Components & Hardware



SI C Series (Smart Interface Control) – LTF Technology
https://ltftechnology.com/

SI C series are unique and easy to install wireless control devices for IoT applications with a high power density of 30W / Cubic Inch. SI C series can be added at the output of any standard constant voltage driver. Every standard LED driver can be converted to a Wifi/Bluetooth IoT device, enabling two-channel Color tunning, Dimming, Zone controls, Scheduling, Google Voice control, Alexa & RGB controls via Bluetooth or Wifi protocols. SI C series products are offered in three models; 2-Channels 200W for color tunning, 4-Channels 300W for Zone controls, and 5-Channels 300W for RGB+W controls.

First in the industry, LTF's SI C series provides wireless CCT tunning, dimming, zone controlling, and RGBW to be added to any standard constant Voltage LED driver. No need for two-channel LED drivers or sophisticated control modules and wiring. ■

Product Category Winner: Lazer Line

Dynamic Color, Theatrical, Cove, Strips & Tape

Lazer Line – Pureedge Lighting
https://www.pureedgelighting.com/

Lazer Line creates a paradigm shift with how we use lighting design within our environment. Lazer Line, an LED lighting system, connects wall-to-wall or wall-to-ceiling, up to 60 ft. before refeeding, with no visible pixilation. It utilizes heatsink tape which is fastened and tightened by turnbuckles plastered into the wall or ceiling for a seamless look. it allows the light to go up, down, or both, achieving ambient uplight and also functional lighting. It enhances any space with pleasant soft light and delivers designer quality color rendering, creating a space that is visually spectacular

It allows anyone to play with light and create multi-dimensional and multi-directional effects. With Lazer Line you can connect wall-to-wall or wall-to-ceiling. It uses aluminum heatsink tape tightened by turnbuckles, providing uplight and downlight. ■

Product Category Winner: Color Select Power Select HID LED Replacement Lamps

Lamps: Conventional, Retrofit and Replacement

Color Select Power Select HID LED Replacement Lamps – Keystone Technologies
https://keystonetech.com/

Keystone's Color and Power Selectable LED HID Replacement Lamps feature energy-saving LED technology and are an ideal replacement for conventional metal halide lamps. More importantly, Keystone's Power Select and Color Select technologies allow users in the field to quickly select from three lumen output and three color temperature options with the flick of switches located on the lamp housing – a versatile feature that allows substantial SKU reduction for distributors. A simple connection for SmartPort LED sensors (available separately) allows users to further control and customize the lamp.

With Keystone's Power Select and Color Select technologies, one lamp can replace 9 SKUs – simplifying stocking for distributors and installation for customers. In addition, SmartPort motion sensors can be added easily with a simple aux jack input. ■

Product Category Winner: TruTrack

Track, Display, Undercabinet and Shelf

TruTrack – Pureedge Lighting
https://www.pureedgelighting.com/

TruTrack is a patented, recessed track lighting system that installs cleanly into the ceiling, achieving a truly flawless finish. Our innovative system easily installs into 5/8" thick drywall, eliminating the need for joist modification. TruTrack can incorporate an integral LED strip which is field cuttable for customized lengths. Adding minimal architectural track heads make TruTrack perfect for residential and commercial applications. TruTrack lighting is available in Warm Dim to promote relaxation and wellness, as well as standard static white and multiple color temperatures

The TruTrack lighting system takes the worry out of finding joists for installation. By cutting into the ceiling drywall and installing a channel, easily drywall over it and then install the track heads. This minimal profile achieves ideal room lighting. ■

Product Category Winner: NEBULA

Parking, Roadway and Area Luminaires

NEBULA – NERI North America
https://www.nerinorthamerica.com

NEBULA by NERI - designed in collaboration with Architects Skidmore, Owings & Merrill - provides pole and ground mounted, high performance lighting solutions including numerous beam patterns for architectural effects lighting as well as area/site lighting. Source illumination choices include dimmable, remote controllable, warm white LED, tunable white LED, RGBW LED and "turtle friendly" LED illumination. Non-lighting functions can include speakers, cameras, WiFI, distress stations, planters, banner arms and motion/proximity sensors. Sleeve & core pole system delivers strength & flexibility.

NEBULA by NERI is the first product designed & developed with inspiration from North America; quality, artistry and artisanship from Italy; and made for the World. It's elegant simplicity is matched by it's technical prowess and easy customization. ■

Product Category Winner: NatureConnect

Commercial Indoor: Troffers, Suspended and Surface Mounted

NatureConnect – Signify
https://www.signify.com/

NatureConnect is a lighting innovation inspired by nature to make people feel happier and healthier. The system is built on biophilic design principles, which use elements of nature in interior spaces to create healthy, engaging, and inspiring environments. NatureConnect combines various LED luminaires: Daylight, Skylight and Lightscape with intuitive control to create lighting scenes tailored to people's needs based on proven and valued natural experiences such as mimicking the rhythm of the sun, providing a view to the sky, mimicking the colors and dynamics of natural environments.

NatureConnect is a unique integrated system & immersive biophilic experience bringing the benefits of daylight indoors. NatureConnect may contribute up to 14 points towards meeting WELL requirements in three features: light, mind and movement. ■

Product Category Winner: ITM

Control Enabling Technology, Connectivity & Software

https://www.samsung.com

Samsung ITM is a compact dual-protocol wireless IoT module that provides fast and easy lighting conversion to smart luminaire in residences, representing the best of smart home connectivity such as ZigBee and BLE. ITM has an embedded firmware that supports flexible onboarding via SmartThings App either

with or without a hub. ITM also has a native functionality to enable connectivity to ZigBee speakers from Amazon or BLE speakers from Google. ITM is unique in that it supports the highest level of smart home lighting connectivity and functionality at the module level for luminaire makers.

As an unique compact BLE and ZigBee-based module, ITM enables fast and easy luminaire conversions to smart lighting with an embedded firmware supports flexible onboarding via major smart home platform apps using a smartphone, speaker, or a hub. ■

Product Category Winner: H6 Series

LED/OLED, Chips and Modules

H6 Series – NICHIA
http://www.nichia.com

Nichia, the world's largest LED manufacturer and inventor of the high-brightness blue and white LEDs, announces its H6 series. The new family of LEDs deliver the highest multi-level boost in color rendition and efficacy while maintaining the outstanding lifetime expected from Nichia. The H6 series delivers a color rendering index (CRI) of 90 while maintaining a level of efficacy seen in standard 80 CRI LEDs.

The new H6 series takes advantage of a unique narrow band red phosphor technology to develop LEDs which achieve a color quality better than traditional 90 CRI LEDs with R9 content greater than 50, while maintaining an efficacy as good as 80 CRI LEDs. ■

Product Category Winner: M2 LED Recessed Downlights

Recessed Downlights, Wall Washers and Multiples

Nora's M2 Mini offers an array of exclusive features in a small aperture package without the need for a housing. M2 luminaires come ready to install with pre-wired junction box and quick connects. Delivering up to 850 lumens per luminaire in round or square apertures with numerous accessories for multiple appearances. Available in 2700K or 3000K at

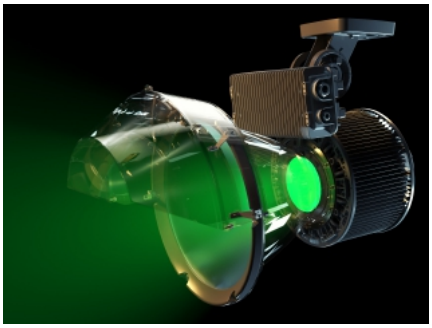
M2 LED Recessed Downlights – NORA Lighting
https://noralighting.com/

90+ CRI and modular system accepts accessories for greater customization. Trim options include open downlight, recessed or adjustable gimbal, elbow, lensed downlight and multiple lighting systems.

Nora's inventive M2 LED downlights does not require a housing, saving time and labor, and its modular design allows multiple functional and decorative options, including multiple lighting systems. Downlights are available in round or square apertures. ■

Product Category Winner: Chromabeams LED 900

Sports, Step, Landscape, Pool & Fountain Luminaires



Chromabeams LED 900 – Sportsbeams Led Lighting
http://sportsbeams.com/

Sportsbeams is changing the way that facilities and venues are lit. Rather than throwing a bunch of white light on a surface, Chromabeams' advanced technology allows facility owners to light their venues as they would a stage. Powerful color can saturate the facility, evoking emotions and excitement like never before. These same fixtures also provide the highest quality of glare-free lighting available for any activity. Combining both attributes in one affordable fixture is changing the way that sports and events are presented.

Typically, facilities and venues are lit with mostly white only fixtures and a few separate RGB fixtures. With Chromabeams, a facility owner can instantly switch from high-quality white light to one of millions of colors instantly on every fixture. ■

Product Category Winner: Invisi-X Exit Sign

Industrial, Germicidal, Vandal, Emergency & Exit

Invisi-X Exit Sign – Concealite Life Safety Products
https://www.concealite.com/

Invisi-X Exit Signs offer a new invisible solution for building directional egress signage which illuminates only the visible EXIT of the Code-required directional signage. It features a patented, cloaking design which causes the remaining signage to disappear from view. Multiple mounting options for blending into wall and ceiling materials including gypsum board, marble, granite, brick, concrete, and sloped ceilings. Features long-life, illuminated, flat screen directional image and smart emergency power technology. Quick and seamless installation for new and retrofit projects.

The new invisible solution for building directional egress signage illuminating only the EXIT of the Code-required signage. Patented design cloaks the signage in other viewing angles. Wall and ceiling mounts are available for all building materials. ■

BUSINESS NEWS

Signify Announced the Company's Third Quarter 2021 Results

"I am encouraged by the strong demand for connected lighting and the performance of our growth platforms in what has been a particularly disrupted external environment this quarter. This is evidenced by a healthy order book, which increased by 90% in comparison to the same period last year. At the same time, global supply chain issues caused by component shortages and logistics challenges impaired our ability to meet the high demand. We swiftly took multiple mitigating actions, while simultaneously managing our prices to offset the structural part of the inflation. These actions have enabled us to deliver a double digit adjusted EBITA margin, while continuing to invest in our digital initiatives," said Eric Rondolat, CEO of Signify.

"With the understanding we have today of the external uncertainties for Q4, we are set to achieve the lower end of our 2021 guidance range. We have the plans in place to deliver backlog orders and minimize disruption to our customers. We believe that these unprecedented supply chain issues are transitory and are confident in our ability to convert demand into sales growth as the situation stabilizes. The fundamentals of our business are stronger than ever, driven by the ever-growing need for energy-efficient and digital lighting technologies."

Third Quarter 2021

- Signify's installed base of connected light points increased from 86 million in Q2 21 to 92 million in Q3 21
- Sales of EUR 1,643 million; Comparable Sales Growth of -4.8%, impacted by global supply chain disruptions
- Order book increased by 90% in Q3 21 vs. Q3 20
- LED-based sales represented 83% of total sales (Q3 20: 82%)
- Adj. EBITA margin of 11.1% (Q3 20: 11.5
- Net income of EUR 94 million (Q3 20: EUR 90 million)
- Free cash flow of EUR 85 million (Q3 20: EUR 214 million)
- Net debt/EBITDA ratio of 1.8x (Q3 20: 2.2x)

Brighter Lives, Better World 2025

In the third quarter of the year, Signify celebrated one year of carbon neutrality in its operations and has continued to

progress on all of the Brighter Lives, Better World 2025 sustainability program commitments:

Double the pace of the Paris agreement: Cumulative carbon reduction over value chain was 48 million tonnes, ahead of track. This was mainly achieved by an accelerated shift to energy-efficient and connected LED lighting in the first three quarters of 2021, thereby decreasing Signify's carbon emissions in the use phase.

Double our circular revenues to 32%: Circular revenues increased to 24%, compared with the 2019 baseline of 16%. Signify is on track for the 2025 target of 32%. This is mainly driven by the strong portfolio of serviceable luminaires and the further expansion of both the home luminaire and modular businesses.

Double our brighter lives revenues to 32%: Brighter lives revenues were 26%, making good progress towards the 2025 target of 32%. This positive trend can be explained by a strong contribution of the wellbeing portfolio, including 'quality of light' EyeComfort, Hue and WiZ products.

Double the percentage of women in leadership to 34%:
The percentage of women in leadership positions was 25%, stable compared with last quarter, while slightly below our 2021 intermediary step to reach the 2025 target of 34%. In Q3, Signify signed the UN Women Empowerment Principles to emphasize its commitment to gender equality and it continued to diversify the talent pipeline while ensuring equal opportunities, fairness and impartiality for all.

Eric Rondolat, CEO at Signify

Outlook
Signify expects that electronic components shortages and logistics disruptions will continue to have an impact over the coming months. As a result, and with no further deterioration of the supply chain, the company expects to end at the lower end of its 2021 guidance ranges of 3-6% comparable sales growth, an adj. EBITA margin of 11.5-12.5% and free cash flow exceeding 8% of sales. ■

Fagerhult Group – Interim Report January-September 2021

The third quarter:

- Order intake was MSEK 1,895 (1,664), an increase of +13.9% adjusted to +14.5% for currency effects of MSEK -7, acquisitions of MSEK +3 and disposals of MSEK -5
- Net sales were MSEK 1,745 (1,700), an increase of +2.6% adjusted to +3.7% for currency effects of MSEK -5, acquisitions of MSEK +4 and disposals of MSEK -16
- Operating profit was MSEK 184.2 (66.8), an increase of +175,7% with an operating margin of 10.6 (3.9)%
- Q3 2021 operating profit was MSEK 184.2 compared to a Q3 2020 adjusted operating profit of MSEK 144.1, an increase of +27.8% with an operating margin of 10.6 (adjusted 8.5)
- Earnings after tax were MSEK 127.6 (4.9)
- Earnings per share were SEK 0.72 (0.00)
- Cash flow from operating activities was MSEK 201.8 (388.8)

Comments from CEO Bodil Sonesson:

- We are delighted with the continued strong organic order intake, where, despite the supply chain challenges, the service to our customers is at a good level.
- Order intake in the most recent three quarters is more than 1 BSEK ahead of the previous three quarters, evidencing the recovery from the pandemic.
- The year to date operating margin at 10.4 (adjusted 6.0)% remains strong and at a good level compared to the market, despite the supply chain challenges.
- The Group continues the focus on developing industry leading sustainable solutions. A great example of this is "Vitality ReLight" from Whitecroft which delivers solutions that regenerate and re-use rather than replace or re-new.
- The Group's connected solutions, Organic Response and Seneco continue to grow. Organic Response volumes to the end of the quarter are almost at 100
- Now that we have acquired the remaining shares in the North American subsidiary, we can move forward with a focused long-term strategic initiative in the region. ■

Luminii Acquires Precision Lighting and Remote Controlled Lighting

Precision Lighting and Remote Controlled Lighting, two British lighting manufacturers, are pleased to announce that Luminii, a Chicago-based manufacturer of industry leading specification-grade architectural LED lighting systems, has acquired the companies.

Precision Lighting and Remote Controlled Lighting are sister companies under common ownership and management. Bringing both into the Luminii fold allows the companies to broaden their global reach into new territories, while enabling Luminii to further innovate by engineering new LED lighting technologies and products that service commercial and residential markets.

"With Precision Lighting's micro-lighting products and systems, we can now offer a broader range of micro-LED solutions while also expanding opportunities in major hubs including London, Europe, and the Far East," said Precision Lighting and Remote Controlled Lighting founding CEO Alex Ruston. "Remote Controlled Lighting also brings a new category of remote-control lighting solutions, opening doors to be specified into applications we were previously unable to support."

Ruston added, "This strategic company

advancement with Luminii helps us further diversify our customer base, expedites our product visibility in the U.S., and gives us the momentum we need to bring our world-class products to new markets." ■

GE Current Announces Plan to Acquire Hubbell Commercial and Industrial Lighting Business

GE Current announced that it has entered into a definitive agreement with Hubbell Incorporated to acquire Hubbell's commercial and industrial (C&I) lighting business to create a premier end-to-end lighting solutions business.

The Hubbell C&I lighting business, based in Greenville, South Carolina, is a leading provider of professional lighting, lighting controls and connected lighting. The business offers a comprehensive range of indoor and outdoor lighting products for industrial, commercial, and institutional applications. The Hubbell C&I lighting business has a strong collection of trusted brands including Area Architectural Lighting, Beacon, Litecontrol, Kim, Columbia, Prescolite, Alera, Dual-Lite, Compass, Hubbell Outdoor Lighting, and Hubbell Controls Solutions.

"This announcement is a win for the industry, combining two leading companies with over 150 years of innovation. We intend to use our combined resources to drive new investments that create solutions for the continuously evolving needs of our customers," said Manish Bhandari, CEO, Current. "The values and customer-centric culture of the Hubbell C&I lighting business are well aligned with Current. We look forward to welcoming the Hubbell C&I team."

Together, the two businesses' product and controls portfolios will be positioned to capture growth driven by continued conversion to LED and demand for connected light controls systems through the diversified go-to-market channels.

After closing, Current and the Hubbell C&I Lighting business will maintain separate agency networks with dedicated resources and distinct brands. Both businesses will be able to strengthen their respective portfolios through innovation, leveraging the best commercial tools for speed and driving efficiency through combined scale.

Ropes & Gray LLP is serving as legal counsel to Current. Closing is expected to take place in the first quarter of 2022 subject to regulatory approvals and other customary conditions. ■

Skyview Capital Acquires Digital Lumens and Encelium Lighting Solutions Business

Skyview Capital, a global private investment firm, announced that it has acquired the Digital Lumens and Encelium businesses from Osram Licht AG. Terms were not disclosed. Digital Lumens and Encelium's advanced Lighting Controls solutions provide leading-edge software and hardware to improve and automate the lighting of commercial and industrial facilities. Skyview Capital has formalized the new company, Digital Lumens, Inc., and will invest in this entity to accelerate the growth, innovation, adoption, and support of these solutions.

Digital Lumens has emerged as a leader in the Intelligent Lighting, Advanced Lighting Controls, Smart Devices, and Facility Insights space, selling to hundreds of blue-chip customers globally across multiple industrial verticals, including Manufacturing, Warehousing, Food Processing, and Transportation. Digital Lumens' lighting and SiteWorx software solutions have helped customers improve workplace productivity, safety, and environmental sustainability by metering utilities, monitoring their entire facility, and observing critical areas.

For over 20 years, Encelium's advanced network lighting controls solutions have been transforming healthcare centers, office buildings, educational institutions, and commercial properties with advanced light management systems. Encelium X, its latest and most advanced system, is simple to install and intuitive to use, helping customers make significant leaps in comfort, control, code compliance, and energy efficiency. More information can be found for both brands at www.digitallumensinc.com.

"We are excited to partner with Digital Lumens, Inc. to serve the IoT and Connected lighting markets. We are looking forward to helping the team expand and enhance the business in all ways," said Alex Soltani, Chairman and CEO of Skyview Capital.

"We now are very well-positioned to grow the Digital Lumens and Encelium business lines. We have innovative software and hardware technology and now the financial backing to help realize our global strategy. There is a significant opportunity to expand our services to new customers and geographies," said Brian Bernstein, CEO of Digital Lumens. ■

Bartenbach & EGLO – Illuminating the World Together

EGLO's CEO, Rene Tiefenbacher (left) and Bartenbach's CEO, Christian Bartenbach (right)

Bartenbach wants to take this opportunity to welcome the company EGLO as a strategic partner. EGLO took over as a majority shareholder in the Bartenbach Holding on August 24, 2021.

EGLO, like Bartenbach, is a family-owned company with a history of more than 50 years as the largest residential lighting supplier in Europe with a consolidated turnover of

approximately €700 million. EGLO expects that this investment will enable them to further expand the EGLO Group's technical lighting expertise in its segment and will further strengthen and expand Bartenbach's technical and scientific expertise in the future. With their strategic and financial background, EGLO will contribute significantly to the international growth of the Bartenbach Group.
The Bartenbach brand and DNA will continue to exist, and Bartenbach will remain true to their mission statement, "Noticeably better light for a better quality of life" in the future.

Consequently, more than ever, Bartenbach will carry out high-quality lighting planning and complete lighting solutions in the top segment, offer innovative product developments for the leading luminaire industry, and continue to conduct research in the field of lighting applications for artificial light and daylight.

Bartenbach will remain independent at the Aldrans site with approximately 100 employees as a neutral service provider and development partner. ■

How Zhaga Addresses Sustainability and the Circular Economy

The Zhaga Consortium has published the White Paper "How Zhaga addresses Sustainability and the Circular Economy". The publication points out that durable, repairable, and upgradeable LED luminaires are key elements to sustainable lighting. It explains that Zhaga is developing and standardizing interface specifications for components of serviceable luminaires, to help facilitate a new market framework called "Circularity Lighting".

Sustainable action in the lighting industry means, above all, the provision and continuous development of energy-efficient lighting solutions and the resource-saving design of durable and serviceable products. Serviceable products and systems are characterized by properties like repairability, upgradeability, replaceability, being future proof and durable. Such products and systems are designed in a modular way and the interfaces of the components used are based on standardized and widely recognised specifications.Zhaga uses the term 'Circularity Lighting' for a market framework with products and systems that support the aims of the circular economy through enhanced serviceability.

White Paper

The White Paper describes various problems to be addressed:

- The different life cycles of luminaires and connectivity solutions
- Even luminaires of high quality and durable design can experience an early failure
- An upgrade of product features may be desired

Solutions are illustrated referencing to the Zhaga specifications:

- Book 18 and Book 20 about intelligent interfaces between outdoor resp. indoor luminaires and sensor /communication modules
- Book 24 and Book 25 that allow programming of LED control gear from different manufactures by using unified NFC programmers.
- Book 21 and Book 26 about linear socketable LED modules that allow the selection of modules with desired characteristics (efficiency, colour temperature, CRI, etc.) ■

DALI-2 Emergency Lighting Control Strengthens Interoperability for Safety-critical Applications

The DALI Alliance has extended its highly successful DALI-2 certification program to include control gear for self-contained emergency lighting. Focused on device interoperability, DALI-2 certification is built on open, international standards.

DALI emergency lighting is widely used as a robust and reliable solution that meets safety-critical requirements in buildings throughout the world. The DALI protocol enables integrated, digital control systems that combine illumination and emergency lighting. DALI-2 Emergency further extends interoperability of lighting-control devices and facilitates integration with building management systems, which can access DALI control and querying capabilities including automated testing and reporting.

"While the industry has enjoyed the benefits of DALI emergency lighting for many years, the introduction of DALI-2 Emergency is a huge step forward. For DALI-2, the level of testing has increased dramatically, and the results are independently verified. This means that the industry can have a great deal of confidence in the interoperability of certified DALI-2 devices," said Paul Drosihn, DALI Alliance General Manager.

Emergency lighting, which provides light when the mains supply fails, is a critical feature that is mandated by various regulations. "Self-contained" means that the battery – which provides power during an emergency – is inside, or placed next to, the luminaire.

In many countries, there is a legal requirement for periodic testing of emergency lighting. DALI enables self-contained emergency tests to be automated, triggered by DALI commands or by an optional timer. Emergency control gear must implement both a function test and a duration test. The function test is a quick test of the battery, charging circuit, driver/relay and lamp, while the duration test ensures that the battery will be able to operate the lamp for the full rated duration (for example 1 hour or 3 hours).

DALI-2 Emergency certification requires the product to successfully pass a rigorous and comprehensive set of tests based on the international standard IEC 62386. The DALI Alliance independently verifies the test results, and then lists each certified product in its online product database (www.dali-alliance.org/products), providing public traceability. The first certified DALI-2 Emergency devices, which are entitled to use the DALI-2 logo, are expected very soon.

The DALI-2 Emergency tests developed by the DALI Alliance are based on Part 202 of IEC 62386. Control gear in Part 202 are also known as device type 1 (DT1). Devices implementing Part 202 can also optionally

implement other features such as the luminaire, energy and diagnostics data in Parts 251-253. Also, the ongoing development of 'DALI+ with Thread' certification opens the possibility of future standardization for wireless control of DALI emergency lighting.

"As a manufacturer participating in its development, we have witnessed DALI becoming widely established as a robust and trusted basis for digital control of the complete lighting system environment," said Richard Beesley, Chief Technology Officer of Mackwell. "With the introduction of DALI-2 certification for emergency devices, we are pleased that this brings updates to the protocol that remain perfectly aligned with the safety-critical requirements of emergency lighting."

"The improved interoperability resulting from the inclusion of Part 202 in the DALI-2 certification program will help facilitate the advanced integration of emergency lighting in building management systems," said Mustafa Oktay, Product Manager LED drivers at Signify. "This represents an important step forward by the DALI Alliance."

"Tridonic has always placed great emphasis on the interoperability of lighting technology, and has therefore been an active member of the DALI Alliance from the very beginning," said Thomas Ender, Vice President of Product Marketing at Tridonic. "Contributing know-how to the industry and helping to define new standards such as Part 202 for self-contained emergency control gear are important factors in promoting interoperability. These efforts are supported by developing and launching components which comply with these industry standards."

"The update of Part 202 now brings emergency lighting in line with other DALI-2 devices, thereby ensuring emergency lighting follows a certification process that allows for interoperability between manufacturers and giving the assurance that control companies like zencontrol can access the full features of compliant emergency lighting," said Stewart Langdown, Business Development Director of zencontrol. "As a company actively involved in the control and management of lighting, we feel this is a great step forward in the adoption of DALI-2 as the protocol of choice for 'Smart Emergency' and even smarter buildings." ■

Global Lighting Association Releases Regulatory Guidelines for an Effective Transition to Energy Efficient Lighting in Emerging Economies

The Global Lighting Association (GLA) has published a document containing a recommended set of regulatory guidelines for general service and linear LED lamps. Based on international standards, the guidelines are intended for use by regulatory authorities in developing and emerging economies considering national legislation and associated regulations to accelerate the transition to energy efficient lighting.

GLA's Regulatory Guidelines are designed to not only drive energy savings, but also enable affordable and effective market enforcement, thereby protecting consumers and encouraging fair competition.

In contrast to other initiatives proposing rule making for energy efficiency transitions, the Regulatory Guidelines offer a simple, practical and balanced approach based on GLA members' decades of expertise and experience in the consumer and professional lighting markets. The Regulatory Guidelines define only seven essential requirements to be regulated covering the key elements needed to facilitate a smooth transition to energy efficient lighting of assured product quality. This makes them easy and fast to implement and enforce.

'Pushing overly-ambitious regulations with a high degree of complexity in countries that have yet to build experience in product testing and effective market enforcement has been shown to be counterproductive. We've seen how that hinders consumer ability to purchase compliant products and, in turn, how it promotes illegal trade of non-compliant and less efficient lighting products', said GLA's Secretary General, Bryan Douglas.

'The GLA firmly believes that simple, harmonised and well-enforced regulations are the only feasible path to implement the transition to energy efficient LED lighting in emerging economies,' he said.

The Global Lighting Association's document GLA Regulatory Guidelines for an Effective Transition to Energy Efficient Lighting – General Service and Linear LED Lamps may be downloaded from the Association's website. ■

“We Do The – Never Before Possible” Matt RONEY, Chief Executive Officer of Lumileds

Matt RONEY
Prior to joining Lumileds, Roney served as Chief Operating Officer for Stanley Infrastructure, a division of Stanley Black & Decker. Previously, Roney was the President of Paladin Attachments, which was acquired by Stanley Infrastructure. He also spent eight years at TRW Automotive, now known as ZF TRW, in roles of rising responsibility, including Vice President and General Manager of its $2.5 billion Global Steering Business. Roney has a BS in Electrical Engineering from Cornell University, an MSE in Mechanical Engineering from Purdue, and an MBA from Harvard Business School.

LED professional was pleased to have a conversation with Matt Roney, CEO of Lumileds, about the lighting business, products, and innovations. Most impressive to us was the complete focus on customer innovation and a business model that defines sustainability as a central focus. Matt also explained the different partnering models to innovate with Lumileds in the lighting space. The interview also gives a good overview of significant trends in the lighting industry in the coming years.

LED professional: Thank you for your time and the opportunity to do this interview with you.

Matt RONEY: I am pleased to speak with you today.

LED professional: Before we get to business, I'd like to ask you to tell us a little about your background and career.

Matt RONEY: If you look back far enough, you'll see that I got my start in the auto industry as an engineer at Ford, and I think that's where I started developing a passion for innovation and technology. From there, I've made a few steps through management consulting, strategy, and general management in companies that are primarily undergoing transformational change. I led a multi-billion-dollar division of TRW Automotive through the transition from hydraulic steering and into electronic steering in support of vehicle electrification and also navigated the roll-up of several industrial tool companies into an innovative, professional business that ultimately became part of STANLEY Black & Decker. Throughout these career stops, I've been drawn to companies and opportunities that believe in innovation as a path to transformation and act on that belief.

On the surface, Lumileds may appear to be a solid-state lighting manufacturer and automotive lighting company, but if you look a little deeper, it quickly becomes apparent that Lumileds is an innovation company born in a sector that has transitioned over the last twenty years and is poised to be transformational in the coming decades building on what is now more than 100 years of innovation.

When Lumileds **[1]** was formed in 1999, the company's motto was "Never Before Possible", and I think as we look ahead, that sense of purpose has never been stronger or more alive in the company. This is true not just because we're an LED pioneer. With the integration of Philips Automotive Lighting, we gained 100 years of perspective, and we became even more driven to transform conventional lighting to solid-state illumination, develop innovative system solutions that draw on all our application expertise, and explore where lighting can take us.

LED professional: What was the formation history of Lumileds, and what ownership structures exist today?

Matt RONEY: Tracing its roots back to the optoelectronics division of Hewlett Packard and its subsequent spinoff of Agilent Technologies, Lumileds was formally established in 1999 as a joint venture between Agilent and Philips Lighting. In 2005, Philips purchased Agilent's share of Lumileds, and the company became Philips Lumileds. In 2015, the Philips Lumileds LED business and the Philips Automotive Lighting businesses were combined into a standalone operating entity – Lumileds. In 2017, Apollo Global Management purchased 80.1% of Lumileds and Royal Philips retained 19.1% of the company.

Today, Lumileds is achieving Apollo's vision by creating added value in the automotive lighting, specialty, and general illumination market segments. It does this through its sophisticated technological capabilities, significant R&D investments, and strong customer relationships.

"Innovation will transition from efficacy of light sources to performance in applications."

MATT RONEY

LED professional: What is the overall vision and strategy of Lumileds? What target markets do you address?

Matt RONEY: We continue to build on the mantra of making the never before possible, possible. However, as we shift into the next phase of the SSL market's growth, it has become apparent that innovation will transition from efficacy of light sources to performance in applications. Therefore, we're focused on Customer Intimacy and application expertise so we can deliver tailored solutions to the market in partnership with key customers. We strive to be the company customers choose to work with to jointly develop system solutions to achieve breakthroughs. That approach works well in each of our four key market segments: Automotive OEM, General Illumination, Specialty Consumer Electronics, and Automotive Aftermarket.

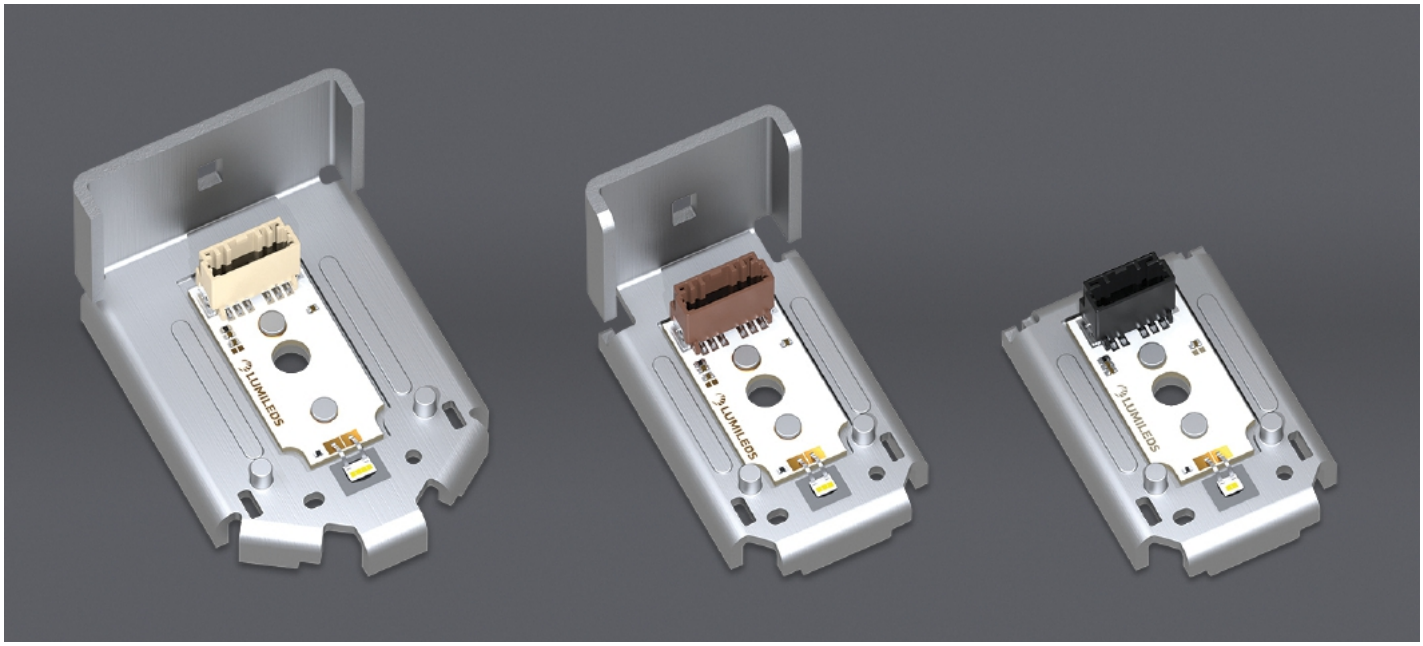


Figure 1: LUXEON Go – a high-beam low-beam module – is an example of Lumileds' forward integration strategy combining top-contact LEDs, a heatsink, board and connector for the automotive lighting industry.

Working closely with automotive OEMs, we get products like LUXEON Go (**Figure 1**) **[2]**, a halogen replacement HB/LB solution in reflector headlamp systems; we get solutions for ADB and digital headlights, and we get 3D LED for car body lighting.

In general illumination, high power and color development, color proliferation, horticulture, and human-centric lighting, like LUXEON® SkyBlue™ (**Figure 2**), are customer-driven advancements. In the Specialty segment, mobile phone flash, displays, and MicroLED for AR and small direct-view displays like smartwatches are all product categories in which joint development with customers is already the norm. Even in the Auto Aftermarket, the brands, retailers, and distributors we work with share our interest in advancing the application of LED retrofit technology and the continued advancement of halogen and signaling performance upgrades.

LED professional: What product areas do you offer in the value chain? Will there be new ones in the future?

Matt RONEY: There is a lot of value to bring in terms of intelligent integrations. We are innovating with our customers' needs in mind. So, how do we make components and/or subsystems that add value for our customers? I'll give you a good example: our LUXEON Go product, which is a high-beam low-beam module comprised of top-contact LEDs and a heatsink with the board and connector. The solution is a plug-and-play module for reflector-based headlamp systems that save the tier-1 set makers significant R&D effort in time and integration into the headlamp.

The MATRIX product line **[3]** is really a kind of a catch-of for all our level-2 assemblies in illumination. If you think about our LUXEON Fusion product **[4]**; that's one where you can create completely tunable solutions, and therefore, for applications like Human-Centric Lighting it becomes a great module that can be applied more easily by luminaire manufacturers into installations.

So again, we do forward integration into level-2 where there is a substantial added value and strong rationale for our customers.

"Our application teams are customer-facing engineers who do the design-in support and work hand-in-hand with customers to co-develop new applications."

MATT RONEY

LED professional: Are these collaborative developments exclusive?

Matt RONEY: When we talk about tailored solutions, it does span a range of possibilities. For example, we'll create certain product families that have a level of modularity to them such that we can engage with customers and then apply and tweak the product to the specific application needs. It creates a modular building block for our customers.

A second way is where we work hand-in-hand with a customer-partner to develop a product. A good example of that is BIOS **[5]**. In the Human-Centric and Ciradian lighting segment, we partnered with BIOS who is an expert in the biology of circadian rhythms; we are an expert in lighting and LEDs. Together we created LUXEON SkyBlue that is targeted at the right spectrum and that is backed by the science that a company like BIOS can bring to it. That's a good example for an exclusive development because we have developed it in partnership together. The concepts that we have learned can then be applied into other areas.

And then in other cases, we develop core technologies and make the first launch with the partner. After the initial developments are done we can apply the building blocks of these technologies into other areas and different segments.

There is a broad range of forms for these partnerships.

LED professional: What is the best way for customers to start their specific product developments with Lumileds?

Matt RONEY: If you look at how we are organized: we have our sales teams, marketing teams, our core R&D and product development teams, but in between all of that, we have our applications teams. We have application teams for automotive in each region of the world and then specific teams for illumination. These are really the customer-facing engineers who do the design-in support and work hand-in-hand with customers to co-develop applications. These teams have pretty deep expertise in the application fields. They can sit with the OEMs and set makers and talk about the possibilities of our product roadmap, the technology roadmap, and their desire for next-generation systems. And then together, we can jointly create a path for co-development.

The path to unlocking these resources for customers is obviously through their account managers, and we can bring those resources to bear.

LED professional: How do you see the market growth in the different segments?

Matt RONEY: It's clear that we are seeing growth in lots of market segments. Automotive, subject to supply chain issues, is roaring back, and there are groundbreaking uses of light that are driving a new sense of excitement and possibilities – the public will be wowed. With electrification and autonomous driving upon us, the role of lighting for vehicle safety opens up amazing applications for the future. And it's being said that "light is the new chrome" for vehicle styling, especially as carmakers look to differentiate the styling of their electric vehicles. These trends will keep automotive lighting growing at a robust pace for many years to come.

In general illumination, horticulture, after a bit of a slow start 6 or 7 years ago, has really come to life, and with that, so has our portfolio designed to support global efforts in that category. With simpler and more accessible control solutions, we see growth in the entertainment markets. We're well-positioned with the broadest range of colors – direct and phosphor-converted – in the industry. We are also seeing tremendous growth and interest in the architectural space where color and spectrum control support development and infinitely more engaging spaces that can be tuned and re-tuned at will. And human-centric lighting is a solid opportunity that will keep the illumination market growing. More importantly, Lumileds is focused on the growth areas of illumination and not as much in the maturing segments like residential.

And finally, a significant revolution is on the horizon in the display market with the potential of MicroLEDs for self-emissive displays. Once some of the key technology challenges are solved, the growth in this segment could be enormous.

LED professional: What is the state of play with MicroLEDs today and when do you expect greater market penetration?

Matt RONEY: There are three applicationareas we keep our eye on. One is automotive headlighting, where we will start to see pixelated LED headlights with about 20,000 pixels-arrays come to market in the 2024 time frame. These core technology building blocks will apply in the following two areas in the consumer electronics display field.

One being small direct viewing displays in the 2025 to 2026 time frame such as watches and smartphones, and then augmented reality within the 2026-2027 time frame with products like smart glasses. If we think about that kind of progression, we are not that far away. We are making good progress along these lines down to the single microns pixel size. Next is the mass transfer technology to place either chip-to-wafer or wafer-to-wafer and hybridize an entire panel. That's the next challenge the industry is working through.

One of the ways to think about the progression in the application is simply pixel size.

LED professional: What are the significant trends we are dealing with in the lighting industry right now? What are the challenges, and what are the opportunities in the lighting business?

Matt RONEY: We saw supply shortages early and started to mitigate them, which has allowed us to continue to serve customers with better lead times than many others. Close collaboration with our channel partners has been critical and has allowed us to keep customers' lines running. While the immediate challenges are short-lived, the opportunities ahead are exciting. New technologies and capabilities are being integrated at the LED level, like beam steering at the LED level for adaptive headlighting; we're creating more beautiful environments with tunable

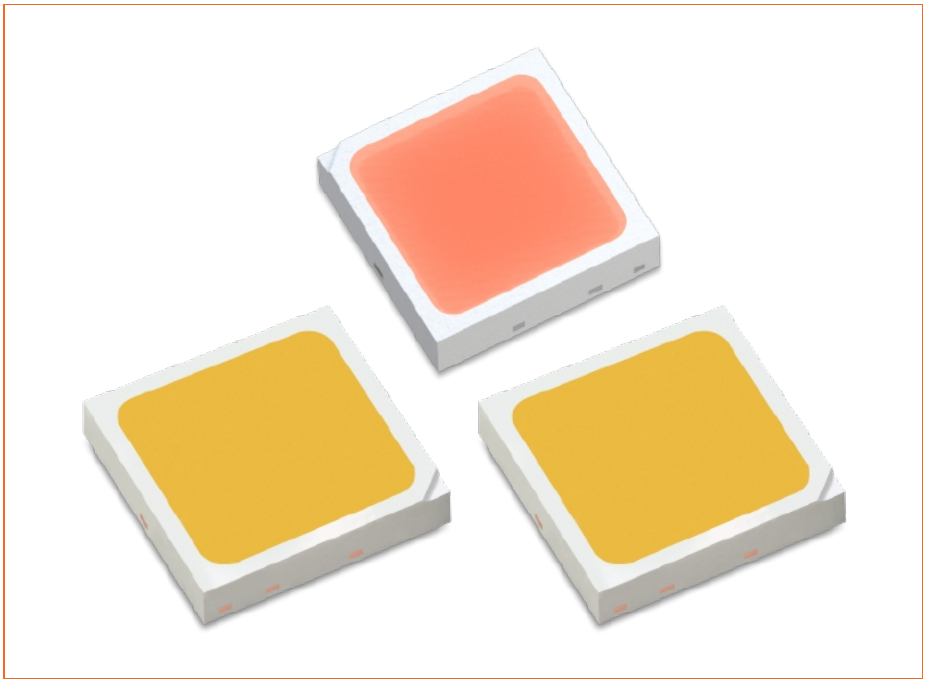


Figure 2: Lumileds LUXEON® SkyBlue™ LED kit uniquely simplifies human-centric and circadian lighting for luminaire manufacturers.


Matt RONEY

light source solutions and better beam control with higher intensity LED sources.

These are just a few of the opportunities that lie ahead. And, importantly, we are listening closely to scientists for direction on how to optimize the spectral distributions of our products for better color perception, well-being, and plant growth.

LED professional: Are there new requirements from applications, designers, and users?

Matt RONEY: There are new requirements that are legislative as well as those driven by our customers and their customers. In September, European Ecodesign regulations went into effect. Our teams are closely aligned with the European lighting industry and prepared carefully for the legislation. When the legislation went into effect on September 1, we released public tools to make it as easy as possible for our customers to proceed with their development.

Our customers, designers, and users continue to drive us and the industry to expect more from LED solutions and to be able to do more. This is as true in the automotive market as it is in the camera flash and illumination segments, and it fuels our innovation. The tight feedback loop with our customers and the market drives a cycle of continuous innovation that makes us more partner than provider with our customers.

LED professional: Sustainability and eco-design are modern buzzwords in the lighting world. How do you see this, and what answers does Lumileds offer to the challenges in these topics?

Matt RONEY: For us, sustainability is not a separate program; it's at the core of our business (**Figure 3**). It's also aligned with our purpose, making the world safer, more beautiful, and more sustainable with light. We identify nine priority issues under the sustainability umbrella, including Employee Health and Safety, Climate Change and Carbon Footprint, Product Energy Efficiency, Circular Economy, and others that are identified in our annual sustainability report **[6]** and on our website. We're proud that in 2020 6.42 million metric tons of use-phase CO_2 were averted through the use of our LED products.

We achieved our 2015 Sustainability Goals and have set several new ambitious goals for 2025. Our scientists and engineers will continue to increase product performance while achieving significant reductions in energy use, carbon emissions, waste generated, and water consumption. At the end of the day, sustainability is a key factor in every advancement, innovation, and solution our global team develops.

"For us, sustainability is not a separate program; it's at the core of our business. We're proud that in 2020 6.42 million metric tons of use-phase CO_2 were averted through the use of our LED products."

MATT RONEY

I must be clear though, our top priority is our employees' health and safety, and never has this been more true or required more effort than over the last

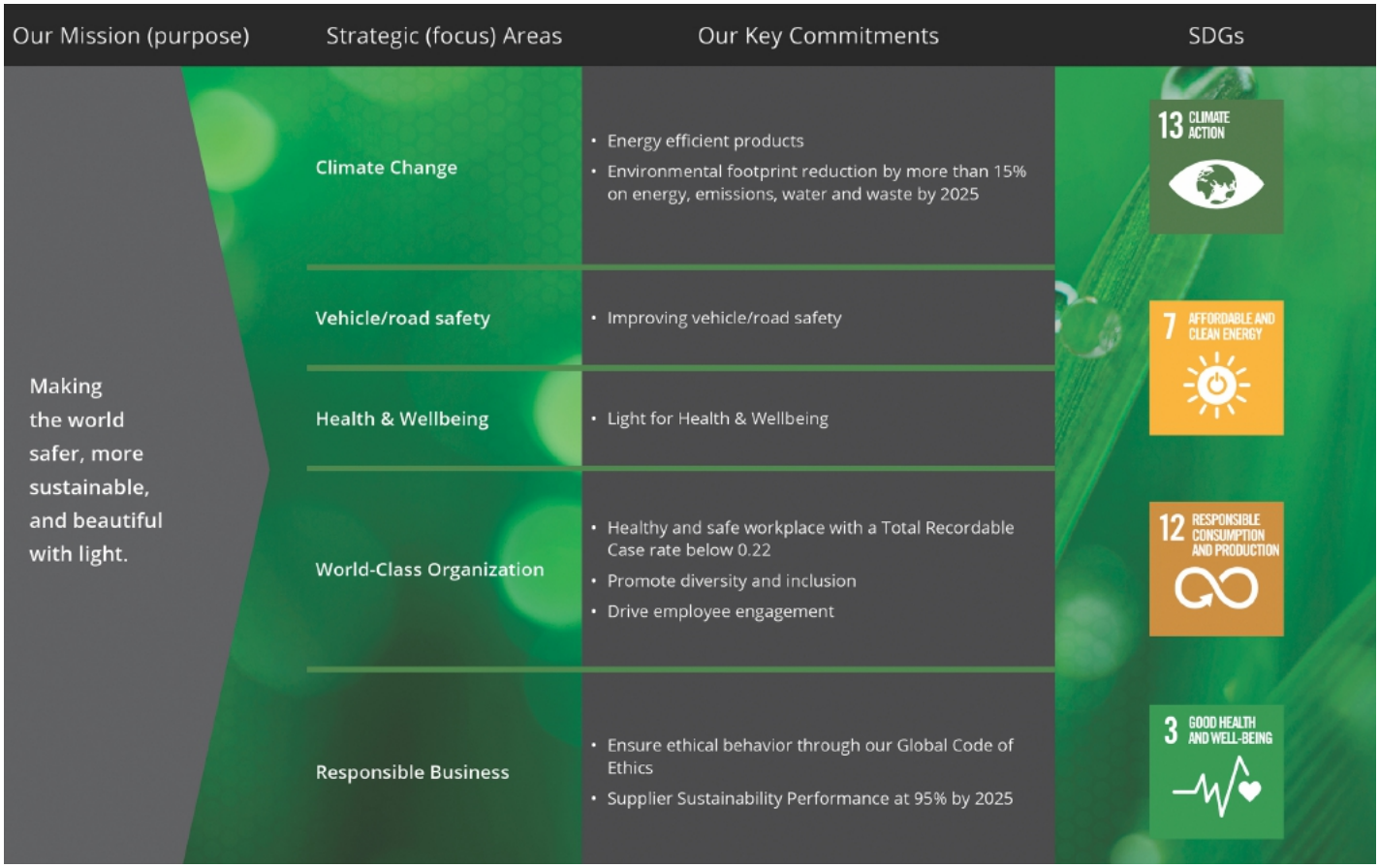


Figure 3: Lumileds Mission, Strategic Areas, Key Commitments, and Sustainable Development Goals (SDGs) were published in their 2020 sustainability report.

18 months. I couldn't be prouder of our employees who have adapted to the constantly shifting market dynamics, site shut-downs and re-openings, safety protocols, supply-chain challenges, and more. All while staying healthy and continuing to set new performance quality and availability benchmarks. To date, we've had no COVID transmission at any of our sites around the world.

LED professional: Could partnerships with other subsystem manufacturers or even system manufacturers generate further potential in terms of sustainability?

Matt RONEY: The next frontier we see is "getting the light where it needs to be when it needs to be there." That's when partnerships with building designers, architects, and system manufacturers come into play. We can bring some innovative ideas to the overall system design, such as beam control. That requires more collaboration within the value chain.

Vehicle electrification is an excellent example of this, where the energy budget is becoming very important because energy is now equated with the range of the vehicle. There is a natural pull to increase energy efficiency in the automotive industry, but for smart buildings and controls, broader collaboration is required.

LED professional: Design-in services can play an important role. How does Lumileds support customers in this regard, and how is that done through your distribution partners?

Matt RONEY: When we launch new products, like the recently introduced LUXEON 7070, we ensure that matching products like optics and drivers from industry partners are available from the day of launch. Our distribution partners play a crucial role with design-in and logistical solutions to make it easy for our customers to use our products. In addition to our distribution partners, we have a very experienced team in the field directly supporting customers with technical advice. On the Automotive side design is a critical consideration in products like LUXEON Go because the mechanical design features of the Top Contact solution on a heatsink greatly simplifies headlight reflector system integration. Our application teams for Automotive, Illumination, and Consumer segments continue to inspire our customers and help them bring innovative lighting solutions to market. I firmly believe that this approach sets us apart from our competition. When customers engage with Lumileds, they are not just getting a part from a catalog, they are getting 100 years of application expertise to tailor the right system solution for their needs.

"We understand very well that the moments in our company that make us proudest were all realized in close collaboration with customers."

MATT RONEY

LED professional: How important is collaboration with lighting designers and even architects?

Matt RONEY: As specifiers for our customers' illumination products, we pay close attention to their needs and trends in architectural lighting design. We play an important role in helping realize the architect's or designer's vision. Sources that deliver consistent light distributions with accurate colors and long-term stability eliminate surprises when a project reaches completion and are essential for first-class user experiences. Our main mode of operation is to work with and support our direct customers, the fixture makers. So, for lighting designers and architects, most of our contact may be indirect, but ultimately, we are applying our application expertise to meet their real-world needs.

LED professional: Are there any new groundbreaking developments from Lumileds that you would like to highlight for our readers?

Matt RONEY: As an innovator with a long list of industry firsts, Lumileds always has a few groundbreaking developments in the hopper. We have both a mix of core LED developments as well as system solutions based on our comprehensive application knowledge and background with conventional lamps. One good example of this system approach is our 3D-LED product for automotive, which opens up a wide range of options for car body lighting with a fully flexible strip of individually addressable LEDs encased in silicone. This product is easily integrated, enables animation, and stands up to the rigors of the exterior body environment of a vehicle. Next,

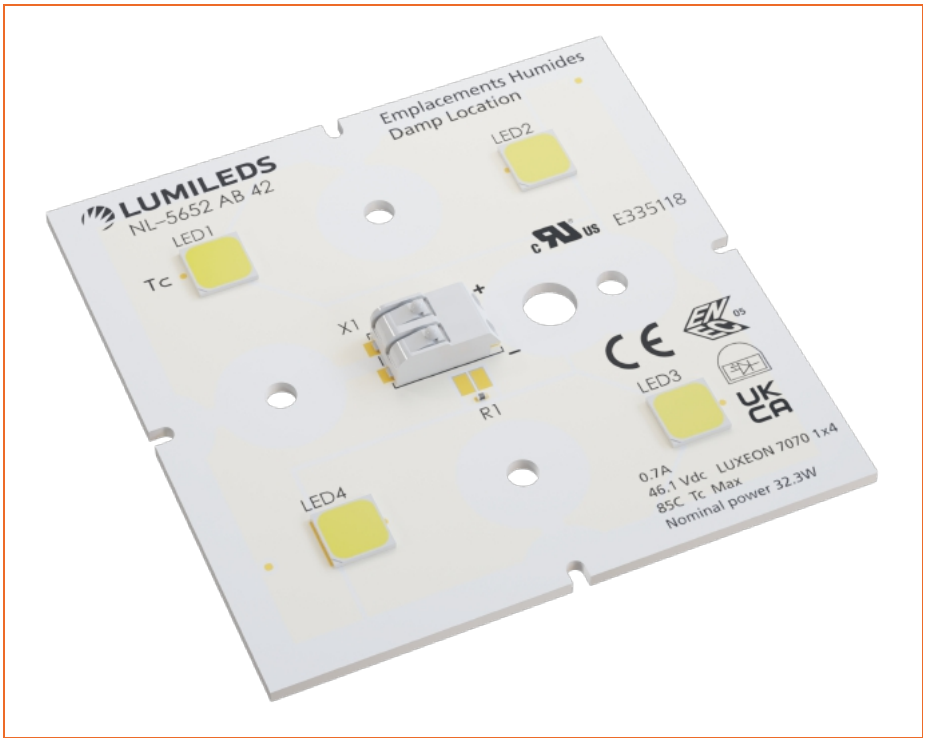


Figure 4: Brand new level-2 Matrix module XR-7070 SQR uses LUXEON 7070 LEDs for high light output and efficacy in a robust multi-die package for demanding applications such as stadium lighting.

with the trend to adaptive headlighting now in full swing, we have a couple of exciting offerings. First, our NeoExact product is a unique offering in the industry. It enables completely customizable ADB arrays in a small form factor via LED placement with very close 50 µm spacing.

Because of the challenges with placing individual LEDs this close together, we have developed a full Level 2 system solution that setmakers can easily adapt into headlamp designs. Next, we are ready for the next phase into fully digital headlighting with our MicroLED approach, creating a fully pixelated field with over 20,000 individually addressable pixels. That technology is, of course, a key enabler to open up possibilities in display and augmented reality applications, where we continue to push the limits of performance gains through EQE advancements at pixel sizes down to 1 µm LEDs with both InGaN and AlInGaP technology.

"With our MicroLED approach, we create a fully pixelated field with over 20,000 individually addressable pixels."

MATT RONEY

In the lighting market too, our innovation spans both technology and solutions. We have a long history and deep knowledge of phosphors and phosphor technology, and we're using that to develop meaningful improvements in spectral engineering. For example, we released a narrow-band red phosphor that delivers a significant performance bump in 90 CRI products. And, of course, our LED die technology is in a mode of continuous performance improvement. Our close work with customers on the solution side is also creating new opportunities. Our work with BIOS to develop LUXEON SkyBlue is just one example in which we partner with a customer and apply their expertise – circadian lighting in this case – with our LED and phosphor knowledge to deliver a solution that significantly improves performance and simplifies and speeds time to market.

We see similar advances in all areas that involve spectral tuning. Our collaboration with SUMMA [7] delivers new lighting experiences to end-users based on our LUXEON Fusion technology. Truly groundbreaking advances in illumination will be the result of applying our technology knowledge with customer expertise in their areas of interest.

LED professional: Is there a key message you would like to share at the end of our discussion?

Matt RONEY: The importance of the relationships that we have with our customers. We invest heavily in application and system knowledge to create deep partnerships with our customers to develop unique innovations together. Our inventions by themselves do not create market-changing innovations. We understand very well that the moments in our company that make us proudest were all realized in close collaboration with customers. Examples are the first LED RCL, LED-based DRL and low and high beam, first LCD TV backlit with LEDs, L-prize, and first LED flash function on a phone. And I believe that the same will be true of adaptive headlighting, opportunities with MicroLEDs, and the continuing development of managed and custom spectrum. This close customer collaboration and building long-term relationships motivates us and gets the best out of each of my colleagues.

Innovation based on a deep understanding and relationship with our customers and understanding their objectives is our goal.

LED professional: Matt, this has been an exciting interview journey! Our readers will enjoy it. Thanks again!

Matt RONEY: From my side, also many thanks and all the best to you, the LED Professional team, and your readers. ■

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About Lumileds:
Technology advancements in lighting, especially LED, are creating tremendous opportunities in the field of light. Lighting solutions today not only need to work and to last, they need to give customers a competitive edge. Companies developing automotive, mobile, IoT and illumination lighting applications require a partner who can collaborate with them to push the boundaries of light. With more than 100 years of inventions and industry firsts, Lumileds is a global lighting solutions company that helps customers around the world deliver differentiated solutions to gain and maintain a competitive edge. As the inventor of Xenon technology, a pioneer in halogen lighting and the leader in high performance LEDs, Lumileds builds innovation into everything it does. What's more, quality and reliability are guiding principles for Lumileds. The company demonstrates this by maintaining control over materials, processes and technologies and by helping customers engineer the best quality of light for their application to achieve the highest levels of performance. The best innovation happens when great minds work together. Lumileds acts with integrity as a trusted partner to its customers, honoring commitments, offering deep expertise, and going the extra mile — making the world better, safer, more beautiful — with light.
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Technical Design Considerations for Smart Lighting: Under the Hood of Smart Streetlights

by Stephan WEGSTEIN and Hakan YILMAZER, Infineon, Germany

In our commentary: "The Future of Lighting", (published in the Sept/Oct issue of LpR), we explored the business case for smart lighting and key considerations manufacturers designing such systems need to take into account. In this article, we will explore the technical considerations of smart lighting.

There are many types of smart lights – consumer lightbulbs, industrial lighting, and environmental lighting, to name a few. Smart streetlights are of particular interest because they are an enabling technology for autonomous driving. And, as they continue to evolve, smart streetlights will be able to cover a wide range of use cases (**Figure 1**), including:

- Efficient and sustainable illumination
- Safety illumination
- Parking assist
- Traffic monitoring and reporting
- Data source for autonomous vehicles
- City surveillance
- IoT hub/access point
- Communication link (for city fire department and other agencies)

With artificial intelligence and machine learning (AI & ML) advancements, the information that can be collected from a network of smart streetlights expands the possible use cases:

- Intelligent management of city lighting based on real-time usage and local behaviors
- Predictive maintenance
- Predictive surveillance (e.g., real-time determination of best routes)

to achieve these incredible capabilities [1], smart streetlights will need to integrate more communication interfaces, sensors, a controller/MCU with compute capabilities, secure memory, and scalable power supplies (**Figure 2**). Because they are connected to the internet, they also need robust security to protect code and data from hackers. Finally, because these systems must operate with little maintenance for decades, future proofing designs is important as well. Designers must pay special attention to the reliability of the chosen components since streetlights must work in extreme environments across a wide temperature range, all the way from the freezing temperatures of Iceland to the searing heat of Death Valley.

Communications

Access to the internet and cloud are necessary for smart streetlights to create a network. Depending upon the use case, the streetlight needs different kinds of access. Wi-Fi enables streetlights to transfer large amounts of data when latency isn't an issue, such as uploading the day's log or downloading a code update.

Wi-Fi also enables streetlights to communicate with each other, either to share information (a pedestrian is coming your way, turn up your intensity) or to serve as a mesh (i.e., one streetlight has a backhaul channel and serves as a connection point for the other streetlights in the area). If backhaul is not an issue, smart streetlights could serve up a city-wide Wi-Fi hotspot. Wi-Fi, however, is potentially unreliable for real-time applications, depending upon the environment. Consider the bandwidth contention for a streetlight within range of an apartment building in the evening when everyone is streaming video. This is one of the reasons why 5G is an important communications technology for smart streetlights.

While LTE and 4G will continue to provide connectivity to systems that are not easily connected by wire to the internet, the higher data rates and spectrum efficiency of 5G will increase wireless capacity substantially. This means every streetlight can be connected, no matter what utilities and services are available in the area.

5G is already making its way into urban settings [1]. It will also be supported by Critical IoT, a standard that supports time-critical communications for use cases that require guaranteed data delivery within specified latency limits. With Critical IoT in place, time-critical services become possible. With these capabilities, a smart streetlight can serve as a 5G radio head. It could then act as a connectivity hub for sensors and other smart infrastructure in the surrounding area.

Consider the smart streetlight as an external sensor for autonomous vehicles. Each streetlight could monitor the objects and potential hazards within its range. An autonomous vehicle would not be able to sense a child walking into the street from between cars until the child was actually in the road. A smart streetlight could identify and track the child. It could alert vehicles coming down this street of the child's presence. If the child moves off the sidewalk, the streetlight would know this before the car could, and those precious seconds could save a life.

To support communication with vehicles, streetlights will need Dedicated Short Range Communications (DSRC). DSRC is a wireless communications technology that connects vehicles directly without the need for cellular or other wireless infrastructure. DSRC has a range up to 1 km and supports vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications. A streetlight that can communicate across all three could serve as an information hub and link to the cloud. This would then enable applications such as clearing traffic off certain roads for incoming emergency vehicles.

Sensors

Sensors are the eyes and ears of electronic systems. Simple sensors like temperature and humidity sensors will enable a network of smart streetlights to map the microclimates of the city. Such sensors can also directly contribute to safety. For example, a temperature sensor that suddenly spikes may be sensing a nearby fire. Sensor data from other streetlights could be collected to determine if a single fire engine - or several - should be sent out.

There has been tremendous innovation in sensor development from Advanced Driver Assistance Systems (ADAS) for autonomous vehicles. Developers have access to an impressive range of sensor technologies and production-ready modules.

An essential sensor is one that tracks ambient light. This allows the streetlight to provide lighting appropriate to the moment. With an ambient sensor, a streetlight can dynamically adjust when it turns on and off based on the season (operating earlier in winter) and weather (storm front coming in). Three key sensors for smart streetlights are radar, LIDAR, and cameras. Used together, they give the streetlight a sense of vision. Radar can be used for basic car and pedestrian detection, among many other types of functions. LIDAR uses lasers with a much lower wavelength than the radio waves used by radar, so it has better accuracy and precision. This enables the detection of smaller objects with more detail and can be helpful in the identification of objects.

When an object has been detected, the vision system can be engaged to identify the object. Together, these sensors can track the object's movement. With AI capabilities, the streetlight could potentially predict how the object will act in the coming moments. This will also enable the streetlight to proactively act such as to trigger an alert, notify an oncoming vehicle of a hazard, etc.

Cameras in streetlights are subject to a

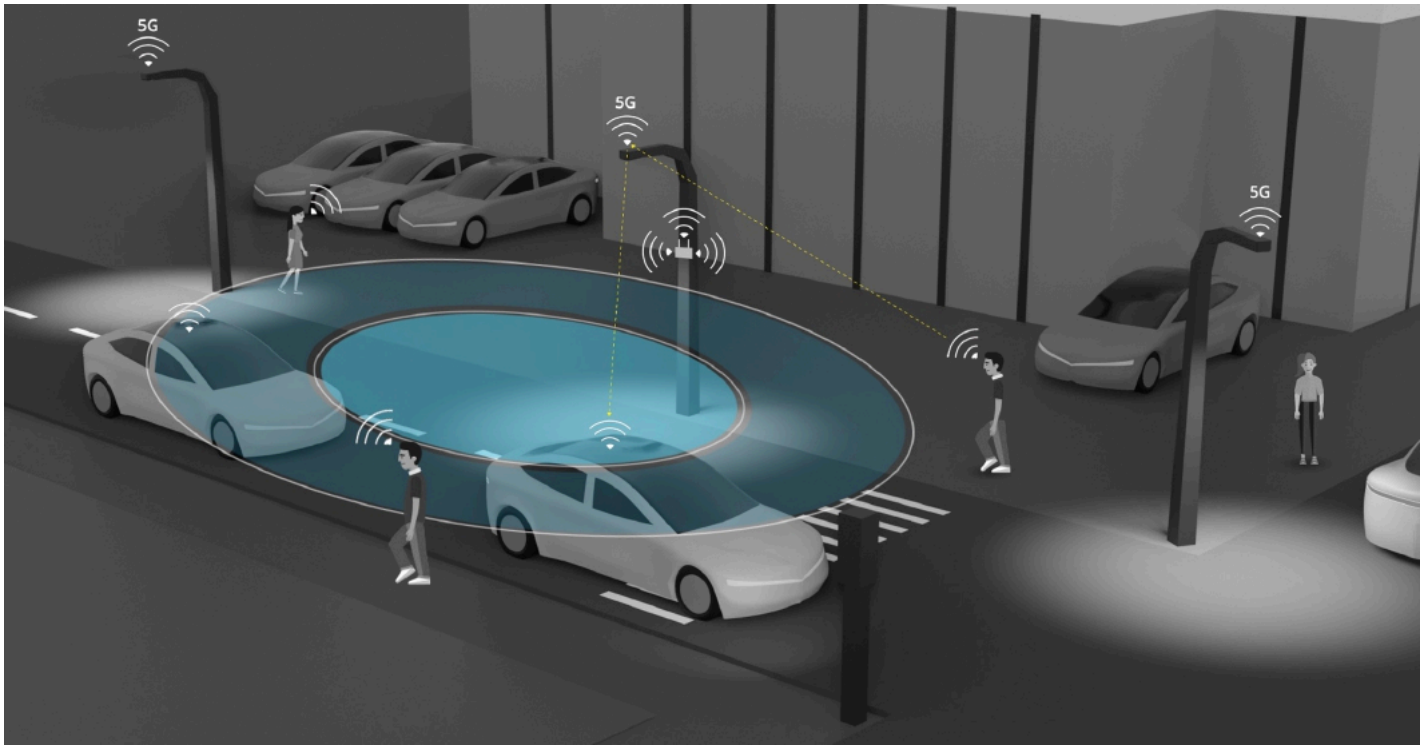

Figure 1: Smart streetlights utilize a wide range of technologies to support a great variety of use cases.

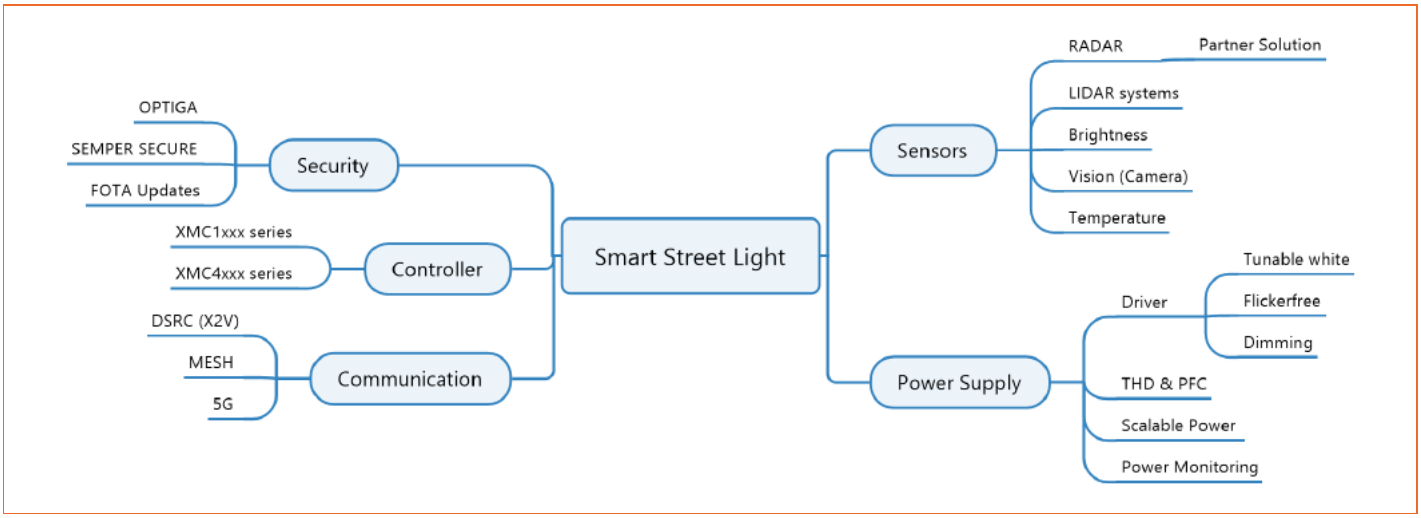

Figure 2: Smart streetlights integrate numerous technologies, all of which must be protected by a robust and secure architecture.

high level of scrutiny in terms of privacy. They cannot be connected to the internet like a webcam. Access to the camera must be protected and secure to prevent hackers from seeing the street. The video collected must be protected to a degree as well. Video that is used and immediately discarded isn't at risk. Any video that is stored will need to be protected. Ideally, the system is architected so that the camera and video data can only be accessed through the host MCU. This, in turn, means the MCU itself must be protected and secure (see below).

Compute Resources

The original conception for AI was that a device would send data up to the cloud for processing and a decision would be sent back to the device. This model fails for several reasons. For smart streetlights, the cost of communications bandwidth limits how much data can be sent upstream. Because numerous smart streetlight capabilities involve processing video (i.e., object identification and tracking), there is simply too much data to send to the cloud. Thus, smart streetlights need to be able perform a relatively high level of video processing locally.

Another factor is latency. Many capabilities, such as object movement prediction, are tied to real-time responsive. Tracking a car moving at 50 km/h may require faster responsiveness than is possible when a roundtrip to the cloud is involved. Similarly, being able to predict a child will walk into the street loses value the longer it takes to evaluate the result. Thus, smart streetlights will need substantial AI capabilities.

The MCU must also be able to accommodate dynamic operation of the vision system. For example, on a cloudy day (as detected by the ambient light sensor), visibility is reduced, making object identification and tracking more difficult. To compensate for lack of visibility, the camera can begin capturing frames at a faster rate and higher resolution as an object speeds into the area.

Because the amount of processing required for object identification and other functions can vary greatly, a robust smart streetlight needs to be designed around a flexible, high-performance MCU. In addition, the MCU must have enough I/O to accommodate the streetlight's many sensors. Industrial MCUs like the Infineon XMC 1000 (Cortex-M0) [2] and XMC 4000 (Cortex-M4) [3] provide the level of 32-bit processing and connectivity required to implement a wide range of smart functions (**Figure 3**).

Security

As with any connected device, security is a crucial design consideration. However, the advanced capabilities of a smart streetlight – that it provides eyes throughout a city – make robust security an absolute necessity to prevent misuse of the technology. Because each of the sensors is controlled by the MCU, the MCU's security architecture and the specific measures that will be used to implement security which is required to be considered when first defining a secure system architecture.

If the firmware or application code of the MCU is compromised and no further measures have been taken, attackers will have access to all of the smart streetlight's capabilities, including being able to reach out to other streetlights within the network. Thus, the MCU must be confident it is executing the correct code. This is known as a "zero trust" approach: no code is executed before it can be authenticated.

MCU security begins with a root of trust. This can be an area within the MCU that cannot be altered or also an external (sometimes externally certified) secure element for additional security and ease of implementation. An external secure element like the Infineon OPTIGA™ Trust M or OPTIGA™ TPM, with additional anti-tampering mechanisms built into its hardware, enables important security use cases required for critical infrastructure.

Before firmware is executed, the MCU authenticates the firmware code using security keys embedded within the root of trust. Thus, only code associated with these keys can be executed – in turn this also highlights the importance of keeping those keys securely stored within a trust anchor. After trust in the firmware is established, the application code is similarly authenticated. In this way, all code on the MCU is known to be good.

A key challenge for developers is updating code over the internet. Known as over-the-air (OTA) updates. Updates must be protected from attackers and this is accomplished by authenticating the source code source using the embedded keys. Key and device identity creation is another topic which is a concern in the security architecture. Keys/Identities can be created when the MCU is first programmed, effectively linking the MCU with the manufacturer, who holds the complementary keys. When it is time for an update, the MCU and manufacturer authenticate each other. Only then is encrypted code sent to the MCU. The MCU stores the code in memory in a secure manner (see memory below), thus maintaining the chain of trust. To implement authentication in this manner requires specific knowledge (e.g. operation of a PKI infrastructure).

Additional services can ease system design, such as device personalization with keys and device identities in Common Criteria certified sites available on OPTIGA™ Trust M. This means this critical step is not needed to be specifically considered at own or EMS manufacturing sites.

To summarize: Establishing and building a root of trust is a critical capability for secure systems. Either an external secure element

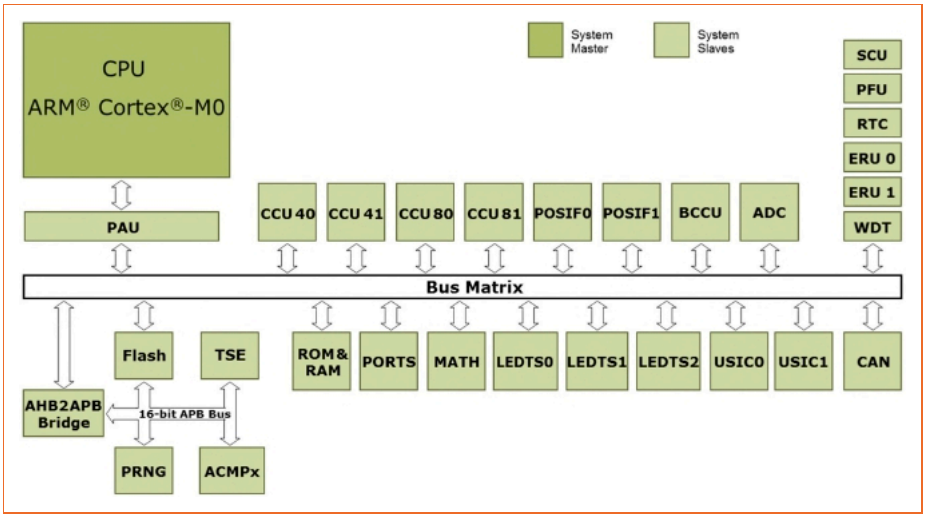

Figure 3: A robust smart streetlight needs to be designed around a flexible, high-performance MCU like the Infineon XMC 1000/4000 with enough I/O to accommodate the streetlight's many sensors.

or an internal root of trust to the MCU can be used as the security foundation of the system. Either way these topics need to be considered early on when designing a secure smart streetlight.

Secure Memory

Because of the many capabilities a smart streetlight supports, there is an increased need for secure memory storage. For example, consider the AI underlying even simple object detection.

AI can be thought of as having two stages. The first stage (training) utilizes large amounts of data to create an accurate inference model. The second stage involves running data through the inference model to make decisions.

Smart streetlights implement AI by running inference models. One aspect of AI is that the inference model can be improved with more data. Thus, these models are not static and the streetlight will need to be able to download and replace new models over time. In fact, smart streetlights will collect data that can be used to create more accurate inference models over time.

Depending upon how much AI a streetlight supports, more memory storage will be required. These AI inference models must be stored in non-volatile memory, much the same way application code is stored, so they persist in the event of a power outage.

Smart streetlights will also need non-volatile memory to store critical systems parameters as well as sensor data and operation logs (i.e., the objects the streetlight identified, the vehicles it communicated with, etc.) Thus, smart streetlights will need substantially more non-volatile memory than an MCU can provide.

Battery-backed SRAM is not a feasible option, given the additional maintenance required to replace aging batteries. In addition, the memory itself needs to be secure to prevent hackers from accessing application code or data. Furthermore, reliability and functional safety are required for streetlights and other smart lights.

To meet these requirements, Infineon offers SEMPER™ Secure NOR Flash. SEMPER™ Secure is built on proven MIRRORBIT™ NOR Flash technology and integrated with security and reliability capabilities (**Figure 4**). With its EnduraFlex architecture, the SEMPER™ family provides both, high endurance for data logging (1M+ program/erase cycles at 512Mb density) and extended data retention for code storage (25 years) for best-in-class reliability. It also features safe boot, error code correction (ECC), cyclic redundancy check (CRC), and self-diagnostics to ensure memory integrity.

SEMPER™ NOR Flash is also the world's first NOR Flash with functionality safety capabilities integrated into the architecture such as real-time safety diagnostics and reporting (**Figure 5**). Designed to ISO 26262 standards, SEMPER™ achieves ASIL-B compliance and is ASIL-D ready. High density options (up to 4Gb), JEDEC compliant xSPI interface, and a broad partner ecosystem simplify design. Designers also have access to a powerful software development kit (SDK) to simplify development and speed time to market. The SEMPER™ NOR Flash family is also part of Infineon's Longevity Program, which guarantees devices will be supported for more than 10+ years.

Part of what makes SEMPER™ Secure an ideal memory for smart streetlights is that it is a smart memory. It integrates an ARM Cortex-M0 processor. This processor enables the memory to perform security functions without having to expose data to the MCU. For example, when performing an OTA update, SEMPER™ Secure can authenticate itself with the update cloud service managed by the manufacturer. This effectively moves control away from the edge to a trusted entity in the cloud. As a result, OTA updates are managed by the

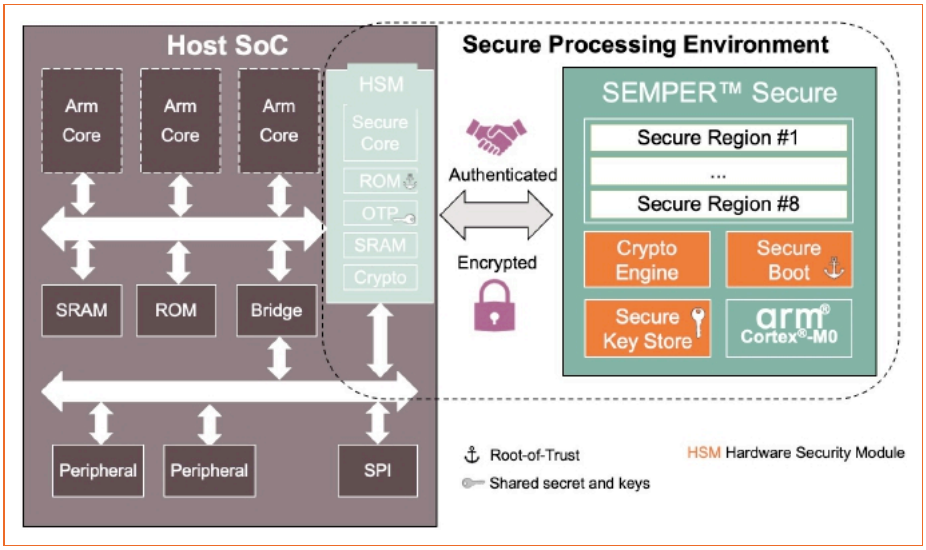

Figure 4: SEMPER™ Secure is built on proven SEMPER™ NOR Flash technology and integrated with security, reliability, and functional safety capabilities.

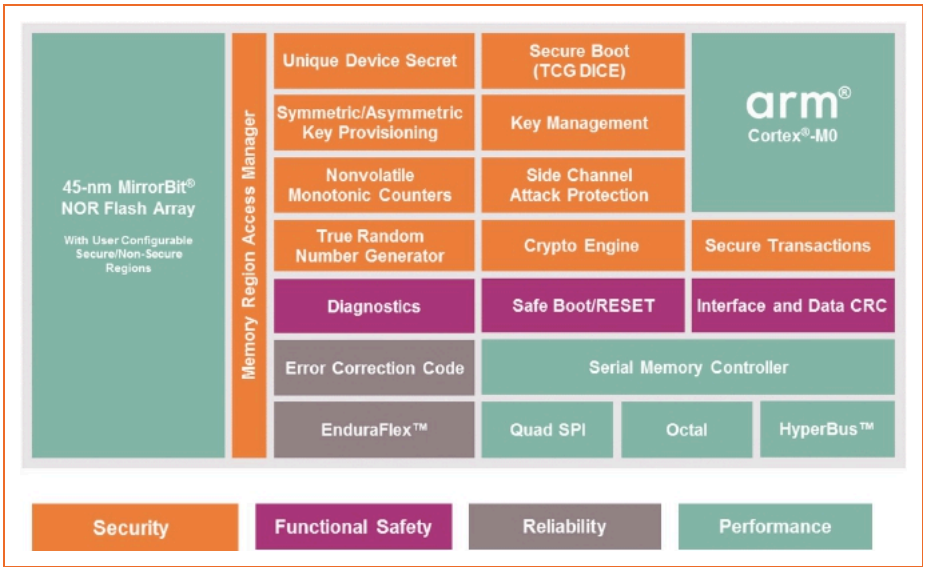

Figure 5: SEMPER™ Secure NOR Flash is the world's first NOR Flash uses a Cortex M0 to enable functionality safety capabilities integrated into the architecture such as real-time safety diagnostics and reporting.

MCU but the MCU never has access to the unencrypted code (**Figure 6**) while writing because it does not possess the cryptographic keys. Thus, SEMPER™ Secure NOR Flash can assure the authenticity of the code update.

An additional consideration is that while NOR flash have always been seen as a commodity that is easy to replace, how it is architected into the system is changing. For MCU technology nodes at 22 nm or below, Flash can no longer be embedded. Thus, Flash must be placed outside the MCU. By embedding a processor with the memory, secure memory can become an integrative part of the architecture and offload memory security tasks from the MCU.

Power and Light

With the additional electronics required to enable smart capabilities, power supply and driver design must take into account the increased power load on the overall system.

First, we cannot forget that the primary function of a smart streetlight is to provide light. Today's LED drivers [4] have evolved to deliver high quality light efficiently. To minimize power consumption, drivers support multiple operating modes and features, including flicker free, dimmable, and tunable operation.

The ability to dim streetlights when no one is around can substantially reduce energy consumption and cost of municipalities. However, to support dimming, the streetlight must be smart enough to return to full intensity when the light is needed (i.e., when it detects a pedestrian or oncoming vehicle). Tunable streetlights are able to adjust light frequency to better match the specific environment and needs. There is also the possibility of considering biodynamics and how light affects people. For example, consider a car sales lot. During the evening, inviting lighting can be used to make the lot more welcoming.

Smart streetlights also require scalable power to accommodate the varying load on the power supply. Load can vary from relatively inactive in the day (LEDs off, radar only for detecting objects) to highly active at night (LEDs on, many objects been tracked, DSRC to nearby vehicles, communicating with adjacent streetlights, etc.)

When power is being drawn at the lower edge of the power region, this leads to a higher total harmonic distortion (THD) and lower power factor, resulting in lower power conversion efficiency (i.e., higher utility cost).

A scalable power supply scales power to actual usage to minimize losses. Such power supplies contain power factor correction (PFC) at low load conditions. An additional benefit is that using scalable power results in cost savings as the design team will be able to design with fewer power supplies.

Smart streetlights also need a way to monitor their own power consumption. One immediate benefit is that cities will be able to track energy consumption down to the individual or a group of streetlights. This enables more accurate utility billing as well as provides insight for advanced budgeting and planning. One long-term benefit of power monitoring is predictive maintenance. By tracking how much power the streetlight uses, it is possible to anticipate technical issues before they impact operation. For example, a streetlight in a highly active area like a downtown promenade will run on high output mode for more time than the average streetlight.

Monitoring power output over a city's worth of lights also enables technicians to predict how LEDs are aging. To put this in context, an LED with a lifetime of 50,000 hours operating 10 hours a day can be expected to operate for over 13 years. However, as LEDs age, they degrade, producing less luminosity and, as a result, consume more power to achieve the same level of output. With power monitoring, LEDs can be replaced when they become inefficient and the cost/benefit of replacing them makes sense.

Future Proofing

Smart streetlights have an extended operating life. However, technology progresses quickly, so it is essential for smart architectures to have the flexibility and headroom to adapt over time as new functions and use cases are developed. In many respects, developers need to anticipate how they

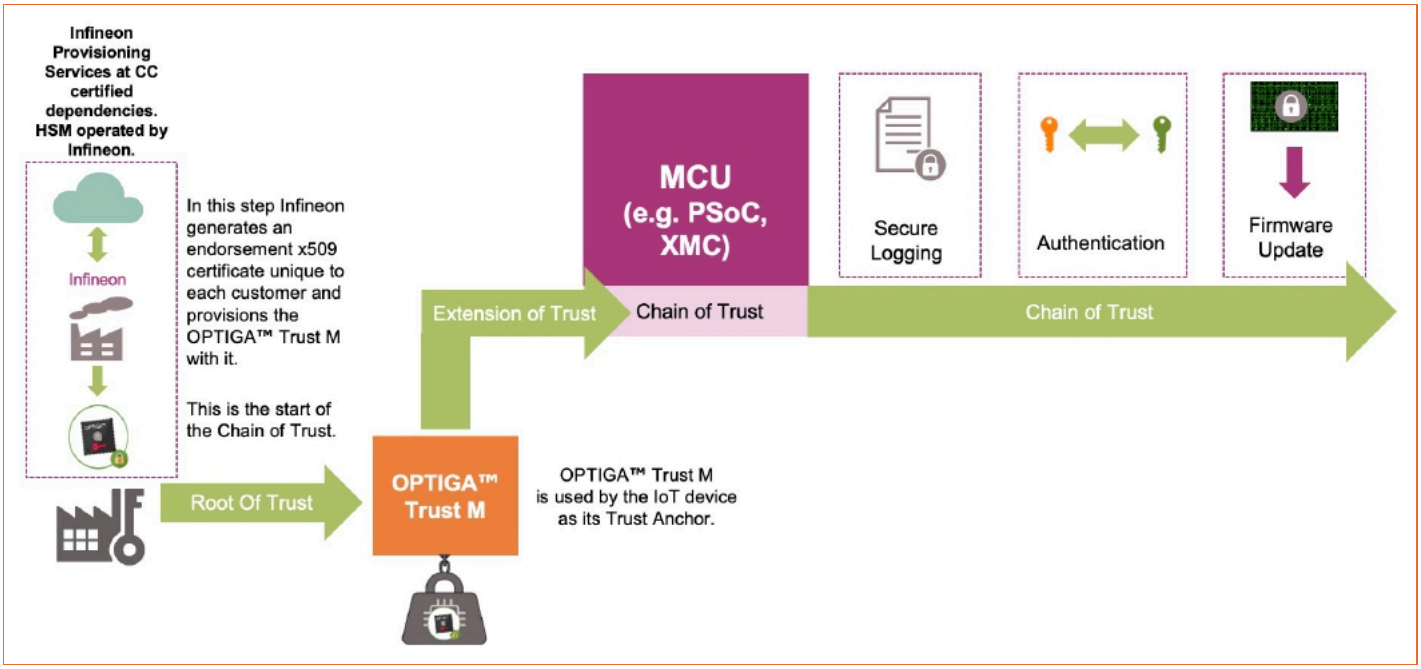

Figure 6: Device credential provisioning and chain of trust concept based on a HW trust anchor (OPTIGA™ Trust M) and extension through the MCU; This concept can be further extended/complemented through features of SEMPER™ Secure.

think the industry will change over the next five, ten, and fifteen years.

From an efficiency standpoint, smart streetlights will capture data that can be used to improve their efficiency and capabilities. For example, tracking real-world pedestrian and vehicle traffic can provide insight to city officials as to where new lights will provide the most benefit. Even simple AI that tracks usage will make it possible to optimize and reduce utility costs. More complex AI will enable predictive maintenance where lights alert technicians before there is a problem and they break down. The result is reduced downtime and lower operating costs.

AI is a young field with tremendous potential and growth. The MCU and memory subsystems must be flexible enough and have sufficient headroom to accommodate new AI models and ways of using sensor data.

Security is another factor to consider from a future perspective. As hackers become more sophisticated, security must evolve to address their new exploits. The embedded processor integrated within SEMPER™ Secure NOR Flash enables the memory to future-proof the security of the system. Without an embedded processor, such a secured memory cannot be realized. Consider a memory with a fixed security implementation. If an exploit was uncovered, the memory would be vulnerable. With its embedded processor, SEMPER™ Secure can adapt its security implementation to address exploits. Thus, SEMPER™ Secure is able to evolve and secure data not just today but into the future.

With a flexible design, it is possible to choose to not equip every streetlight with every feature. For example, full object detection, identification, and tracking could be implemented in streetlights at busy corners. Streetlights in the middle of residential blocks could have lighting and power efficiency capabilities but no camera. However, these streetlights could be upgraded in the future by adding the appropriate sensors and updating code when the benefit of smarter lighting in this location makes sense.

Smart streetlights, and smart lighting in general [5], has the capacity to change our lives. Initially, they will promote sustainability by substantially reducing energy consumption. As more AI is implemented at the edge, streetlights will become smarter. They will make our world safer by protecting pedestrians, enable autonomous vehicles to see beyond the limitations of their sensors, and even influence traffic to speed emergency vehicles to their destination.

Learn more about Connected and Smart LED Lighting for IoT [6]. ■

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He has been working for Cypress / Infineon Technologies for more than five years as the Business Development Manager for Flash Memories where he is responsible for the European market.

Author: Hakan YILMAZER
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Lighting and Surface Design of Tunnels

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Visual perception is crucial for safety when driving through tunnels. In co-operation with ASFINAG (Austrian Autobahnen - und Schnellstraßen - Finanzierungs-Aktiengesellschaft), Bartenbach has conducted numerous visual perception studies on different tunnel designs in models and on real tunnel installations. The results of these studies are a foundation for tunnel designs in which an optimal compromise between perceptual performance (= safety) and economic efficiency is achieved. Based on this state of the art, the study "Lighting and Surface Design of Tunnels" investigated from a perception-psychological, lighting-engineering, and economic perspective what possible improvements can be made to tunnel surfaces, especially regarding pollution.

Figure 1: Lighting with sodium lamps (top), metal halide lamps (middle), and LEDs (bottom).

Introduction

LEDification

In tunnel lighting the switch from conventional light sources (fluorescent lamps, metal halide and sodium vapor lamps) to LEDs has also taken place in recent years. While high-pressure sodium lamps (NAV) with a luminaire spacing of approximately 12 m to 18 m were still used until about 2006, only white LEDs are used now (**Figure 1**). At the same time, the brightness level in tunnels has increased significantly from approx. 0.5–2 cd/m^2 up to 6–8 cd/m^2.

LED technology technically enables the implementation of basically any desired tunnel lighting. In principle, almost any light distribution and spectrum can be generated. In practice, the optimum compromise between quality and cost must be found. It is therefore even more important to clarify the requirements, which should be made primarily from the perspective of the tunnel user's perception.

Risk of Accidents and Lighting

The influence of street lighting on the occurrence of accidents, in general, is intuitive and is widely documented, at least qualitatively, by international studies.

The Federal Roads Office FEDRO of the Swiss Confederation estimates that with an increase in mean road surface luminance from 2 cd/m^2 to 5 cd/m^2, the accident rate in tunnels can be reduced by 24% [1].

The Norwegian Road Safety Manual [2] cites studies that show a 35% accident reduction is achieved by lighting in tunnels compared to unlit tunnels.

And a study of accident statistics in real tunnels by ASFINAG [3] showed that simply improving longitudinal evenness (halving luminaire spacing from 17.8 m to 8 m) and spectral quality (replacing high-pressure sodium lamps with metal halide lamps) significantly shortened braking responses, reducing accident risk by 5%.

A decisive role is played by the information design (hierarchy of visual objects) with which the attention is influenced [4]. With a so called eye-tracker and a saliency map (**Figure 2**) this information processing can be investigated. In some of the tunnels studied by Bartenbach, such analyses were carried out [5,6].

Figure 2: Illustration of the hierarchy of visual objects by a saliency map using an eye tracker.

It was confirmed that an information structure that is as clear and uncluttered as possible significantly facilitates the absorption of information. It was also confirmed that visual guidance influences driving behavior, especially at low brightness levels, while at higher brightness levels there is a transition to overall spatial perception. For example, right-hand edge marking helps road users to keep more to the right in their lane, especially in dark light conditions, which can help to reduce accidents, particularly in oncoming traffic sections.

Visual Perception in the Tunnel

Spatial Perception and Optical Guidance

The lighting in tunnels should ensure, as far as possible, that the elementary physiological visual functions (e.g., perceptual speed, visual acuity, differential sensitivity, accommodation, and adaptation) function sufficiently to provide visual perception (= mental processing) with the necessary "data" (a necessary but not sufficient prerequisite for visual perception) [2].

In addition to the physiological visual functions, the overall perception in the tunnel (entire visual field) is crucial. The largely unconscious mental processing of the visual stimuli occurring in the visual field should be able to occur as "relaxed" and error-free as possible. To this end, the lighting must comply with certain photometric values (in particular luminance levels in the visual field) in order to create the best possible visibility.

At low brightness levels (in "darkness" and in the transitional range, the so-called mesopic brightness range), where overall spatial perception is not possible or only possible with difficulty, optical guidance is mainly provided by orientation on the marking lines. Above a certain brightness level, there is a transition to guidance by overall spatial perception in the tunnel (spatial perception).

In most tunnels, spatial perception is incomplete (**Figure 3**); supporting perception by visual guidance in the tunnel significantly increases safety. However, if drivers are misled or confused by unclear visual guidance, for example by faulty or interrupted markings, then this can actually increase the risk of accidents.

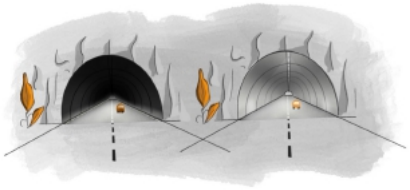

Figure 3: Schematic illustration of spatial perception in tunnels (left: missing room perception).

In addition, certain design requirements (order of information in the visual field) from the psychology of perception must be taken into account. An unordered "information overflow" (**Figure 4**) makes spatial perception and information processing more difficult.

Figure 4: Exemplary situation in the tunnel; luminance levels and information in the visual field.

The emotional components of human behavior must also be taken into account when designing tunnel facilities. For example, many people experience feelings of stress and anxiety when passing through a tunnel, which increase with the length of the passage and lead to a reduction in attention and concentration. This stress is exacerbated in longer tunnels by the monotony, especially the rhythmic "flickering" caused by the spacing of lights [5,6,7].

On behalf of and in cooperation with ASFINAG, Bartenbach has conducted numerous studies on the perceptual-psychological requirements in tunnel facilities starting in 2001; among other things, existing facilities were photometrically measured and perceptual-psychologically evaluated. Furthermore, the effects of different lighting and surface designs were scientifically investigated with the help of test subjects, working with virtual tunnel models (computer simulations) in the laboratory.

Then, starting in 2011, extensive investigations were conducted in real tunnel facilities (field studies) [3,6,7] in order to scientifically evaluate the qualitative improvement measures that were continuously implemented (higher brightness, better uniformity, better spectral quality, etc.). The main results of these laboratory and field studies are summarized below (with exemplary detailed results).

Brightness Level

An important objective of tunnel lighting is to generate a basic brightness (luminance) in order to achieve the best possible spatial perception. In a laboratory study conducted by Bartenbach together with ASFINAG in 2002, using a virtual tunnel passage simulated by computer, it was shown that increasing the roadway luminance has a positive effect on several aspects of human perception [6]. The feeling of monotony during driving is reduced, the feeling of safety is increased, and the subjective satisfaction with the tunnel lighting is also significantly increased.

Figure 5 shows an example of an important detailed result: as expected, with increasing roadway luminance, visual performance also increases, which is reflected in the number of correct responses; with increasing brightness, this curve flattens out (saturation). The upper measured values are for the entire sample of test subjects, the lower for the subgroup with an age above 50 years (50+). It is confirmed that the pure visual performance (here orientation of a Landolt ring) strongly decreases with increasing age.

A similar correlation is also seen with regard to the other parameters surveyed (e.g. reaction speeds), which is why roadway brightness of approx. 8 cd/m^2 is a good compromise between perceptual performance and economy.

This is plausible since, on the one hand, the physiological visual functions (contrast sensitivity, visual acuity, etc.) are already well developed here, and on the other hand, there is already sufficient spatial perception. Also, with these brightness levels, the mesopic perception range (transition from night vision to day vision, up to approx. 3 cd/m^2) is already left in the direction

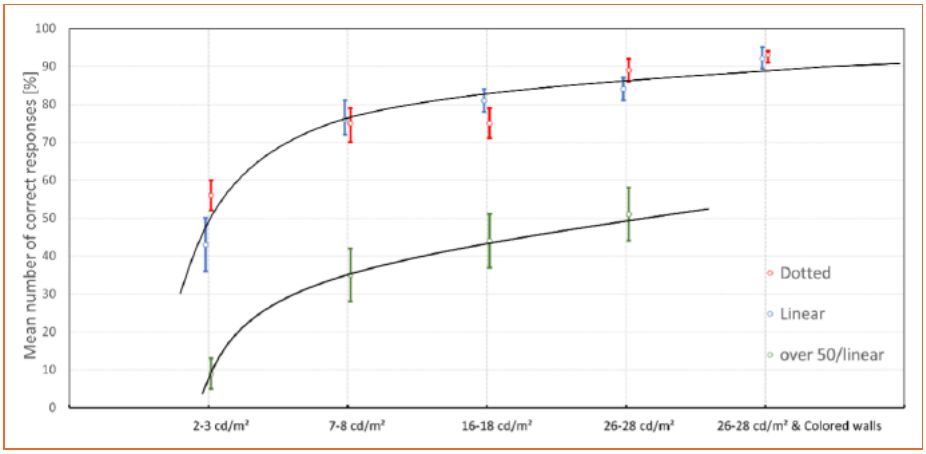

Figure 5: Correct responses as a function of mean road luminance for all subjects (upper curve) and for the older subgroup age 50+ (lower curve).

of day vision, which reduces the risk of relative glare and associated visual disturbances.

Together with the switch to LED technology, the luminance level (average roadway brightness) has now been raised from approx. 1–2 cd/m^2 to approx. 6–8 cd/m^2 in most new or renovated tunnel installations.

Uniformity, Light Point Distance, Spectral Quality

The large distances between the tunnel lights create a very unpleasant "flickering" effect when driving through the tunnel, e.g. on the dashboard of vehicles or on the backs of the vehicles in front, which reduces the visual performance and attention of drivers and greatly increases the feeling of monotony. In this respect, illumination by means of a continuous light strip avoids flickering and additionally creates a complete uniform illumination (appearance of the tunnel). The studies confirmed that drivers feel more safe this way.

Figure 6: Poor visibility due to excessive luminaire spacing.

Figure 7: A continuous light strip as an innovative high-end solution.

In cooperation with and on behalf of ASFINAG, four tunnel facilities in operation in Austria were evaluated in 2011 - 2012 **[3,5]**. The facilities (**Figure 8**) were selected in such a way that they had sufficient length (sufficient test duration during passage) and allowed a comparison between poor and good design regarding uniformity and spectral quality.

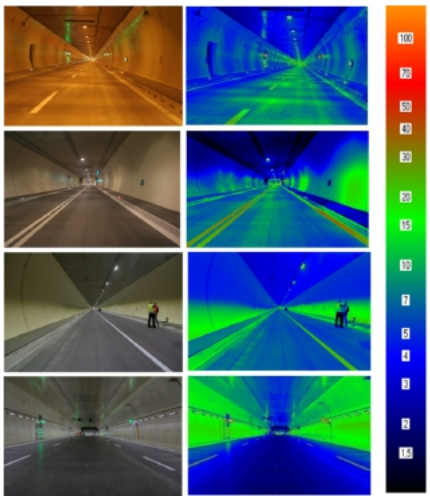

Figure 8: Four tunnel systems for evaluation with a test vehicle. False-color images show the different luminance distributions. (1) Symmetrical NAV (top); (2) Symmetrical HCI (2nd from top); (3) Symmetrical LED (3rd from top); Asymmetrical in direction of travel (bottom).

In the study, approx. 40 test subjects drove through the entire tunnel several times in an adapted test vehicle (**Figure 9** and **Figure 10**) during which time special attention and visual performance tests were performed. Before and after the tunnel passages, additional surveys were conducted on subjective well-being.

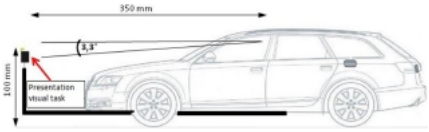

Figure 9: Used test car for driving through the tunnel. Equipped with visual tasks to measure perception performance.

Figure 10 shows a detailed view of the visual tasks for the attention test and the visual performance test. Among other things, significantly different reaction times in the different tunnels could be detected (**Figure 11**).

With these test drives, it was possible to prove that with increasing uniformity of lighting and increasing spectral quality, visual performance, attention, subjective perception of safety and perceived brightness improve when driving through the tunnel.

By replacing antiquated lamp types (e.g. the "yellow" sodium lamp) with LEDs, the spectral quality meanwhile has also increased to a sufficient level (CRI > 80). In many tunnel systems, the luminaire spacing has also been greatly reduced in the meantime; a continuous strip of light has not been realistic up to now for cost reasons.

Figure 10: Visual tasks during the test (flashing light for reaction time measurement, Landolt ring for visual performance test).

Color Designs

In his first tunnel study in 2003 **[6]**, Bartenbach, together with ASFINAG, also looked at the color design of tunnels. It was shown in the simulations that special color designs improved attention and reduced stress levels. A few international studies by other institutes with tunnel simulation methods also dealt with color design and came to similar conclusions. For example, **[8,9]** the effect of colored tunnel walls on the feeling of safety and the stress level of the test persons was investigated with a tunnel simulator. The test persons drove through several tunnels with differently colored walls in a simulator, and their heart rate was constantly measured. The studies came to the conclusion that the stress level of drivers passing through tunnels can be reduced by color design.

Due to the limitations in the research methodology (simulations on the screen), we believe that further research is needed to corroborate such indicative results and to better assess their significance for real tunnel facilities. Additionally, we have to consider some other aspects, e.g. the dirt effects and some individual and trend dependent color preferences of people.

Pro-beam Lighting

In the previous standards, requirements were primarily placed on the roadway luminance. In the interior of tunnels, the so-called "counter-beam principle" (flat radiation against the direction of traffic, see **Figure 12**) was therefore used, as with

this direction of radiation considerably less luminous flux and thus electrical power is required for the same roadway luminance.

The basis for this principle is based on the slightly specular road surface (for example R3). As a result, roadway areas that are specularly illuminated towards the observer "shine". The flatter they are illuminated, the higher the luminance of the roadway due to this "specularity effect".

In the USA, studies in the 1960s led to the concept of "Small Target Visibility" (STV) **[10]**. Subsequently the "Visibility Level" (VL) derived from this was introduced as the main criterion for the quality of street lighting **[11]**. Small vertical panels were set up on the road surface as visual objects and illuminated against the direction of travel, and the visibility was evaluated as a function of the illumination in a stationary manner. The observer sees the visual object (panel) from its shadow side (negative contrast), while the road appears bright. Visibility now depends on the difference in luminance between the object (panel) and its background (road surface) and is better the greater the background luminance (road surface luminance) **[12]**.

These considerations were based on obstacles on an empty roadway; today's situation in densely trafficked tunnels is completely different; here it is more a matter of spatial perception, optical guidance, and visibility of the vehicles ahead.

The counter-beam principle **[13,14]** aims solely at achieving a target value for the roadway luminance (standard) as efficiently as possible but disregards an overall perception of the tunnel space. Uneven luminance on the carriageway and in the field of vision, glare, and poor object recognition (the rear of vehicles ahead is dark, see **Figure 12**) are the result of this lighting principle, and a "stable" spatial perception cannot be achieved with it.

In the pro-beam principle **[6,13]**, the high vertical illuminance levels provide very good spatial perception and object recognition. The optimized pro-beam luminaire is perfectly glare-free and is not perceived directly by the driver, there is no longer any increased luminance in the field of vision, and optimal adaptation (stable perception) occurs (**Figure 13** and **Figure 14**).

In the dynamic tunnel model at Bartenbach in Aldrans, you can see these effects for yourself (**Figure 15**). Instead of the vehicles, the lighting moves in this model. When looking in, the deceptively real impression is created that the vehicles and the observer are moving through the tunnel. By appropriately controlling individual optics with different light distributions that are arranged very closely together, different speeds of passage can be simulated with different intensities, beam distributions and luminaire spacing.

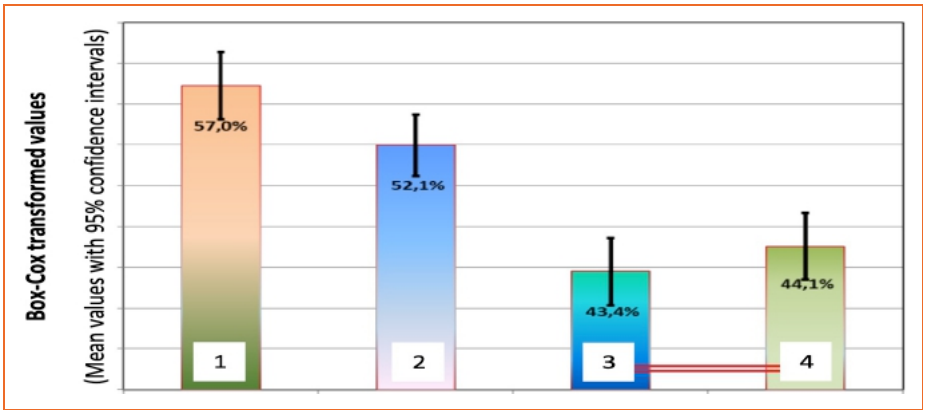

Figure 11: Relative reaction times for correct responses in the visual performance test (numbering according to Figure 8). The differences are highly significant, the third and fourth variants are equivalent (red crossbars).

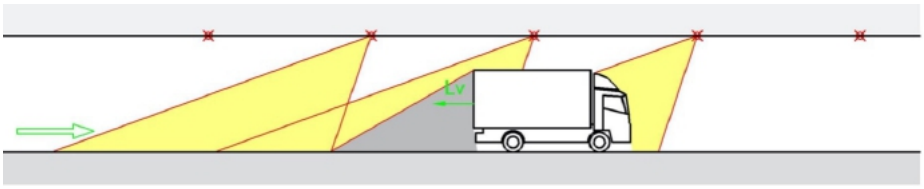

Figure 12: Concept counter-beam principle.

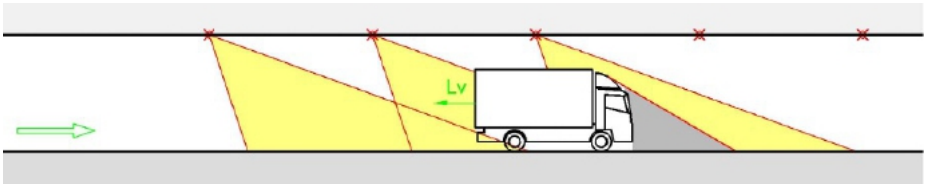

Figure 13: Concept of the pro-beam principle.

Figure 14: Counter-beam (left) and pro-beam (right) lighting in the dynamic tunnel model Bartenbach.

A significant improvement of the actual situation would be a so-called "adaptive tunnel lighting" as a compromise between the "high-end solution in terms of perception psychology" (pro-beam principle) and an economically reasonable solution under the current standardisation situation: in the entrance areas, where a high adaptive luminance (transition from the bright outdoor area to the dark indoor area) is most important, the counter-beam principle could be applied; in the indoor area, depending on the traffic density, a mixture of co-beam (high traffic volume) and counter-beam (low traffic volume) lighting could be used.

Figure 15: Dynamic tunnel model at Bartenbach.

Surfaces and Pollution of the Five Tunnels

Current State Analysis of Five Tunnels

To analyze the current state of tunnels in Austria, on behalf of ASFINAG, five different tunnel facilities were selected (**Table 1**), which have a high traffic volume (cars and especially trucks), and are equipped with LED lighting and at least 750m long. In these five tunnels, photometric measurements and evaluations were then carried out over a period of two years before and after the semi-annual tunnel washings (in spring and autumn) in order to obtain reliable data on the effects of pollution.

In order to be able to compare different wall coatings, identical sample panels were installed in each tunnel in the entrance, middle and exit areas. These sample panels were coated with four different coating materials (**Table 2**) and then examined for their degree of pollution.

Photometric Survey

Following a thorough cleaning by the ASFINAG (**Figure 16**), the five tunnel installations were photometrically documented. For this purpose, illuminance and luminance distributions were measured (**Figure 17**), and the luminous intensities and spectra of the luminaires were recorded. The luminance measurements showed an average luminance value on the roadway of approx. 6 cd/m^2 in all facilities, which corresponds to the specifications according to RVS **[15]** and also to the state of the art. The following orders of magnitude apply more or less to all five tunnel installations: ceiling 25 lx and 1 cd/m^2, walls 50 lx and 10 cd/m^2, street: 100 lx and 6 cd/m^2.

Figure 16: Photo tunnel PF.

In three of five tunnel systems, a color temperature of close to 5100 K was measured, in tunnel Q this was approx. 4600 K and in tunnel PL approx. 3900 K. The general color rendering index Ra varied between 70 and 80.

Tunnel	Length	Execution	Supplier	Material designation	Coating	Reflectance ρ	RAL tone
Tunnel PF	6750m	2011	Company B	Product B2	Water dispersed epoxy resin	0,73	1015
Tunnel L	2350m	2018 / 2019	Company A	Product A2	Epoxy resin	0,70	1015
Tunnel Q	750m	2018	Company A	Product A1	Polyaspartic resin	0,69	1015
Tunnel PE	2950m	2017 / 2018	Company B	Product B1	Pure-epoxy resin	0,60	1015
Tunnel PL	10000m	2017 / 2018	Company B	Product B2	Polyurethane - lacquer	0,50	1015

Table 1: Selection of five tunnels.

Manufacturer	Designation	Coating	Layer thickness	Surface finish	Gloss level	Diffuse reflectance
Company A	Product A1	Polyaspartic resin	0,4mm	Robust surface (sprayed and re-rolled)	Very glossy	72%
Company A	Product A2	Epoxy resin	0,3mm	Surface chalked and yellowed (sprayed and re-rolled)	glossy	71%
Company B	Product B1	Pure epoxy resin	0,3mm	Surface chalked and yellowed (sprayed and re-rolled)	Relatively matt	72%
Company B	Product B2	Polyurethane lacquer	0,15mm	Robust surface (sprayed and re-rolled)	Matt	66%

Table 2: The four most common wall coatings currently used on the sample panels.

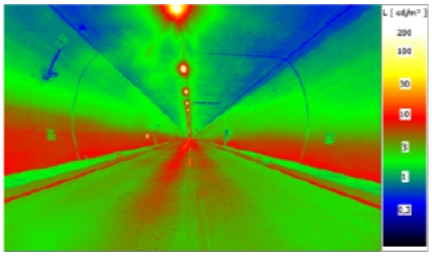

Figure 17: Tunnel PF false color image of luminance levels (ceiling / walls / street = 1 / 10 / 6 (cd/m^2).

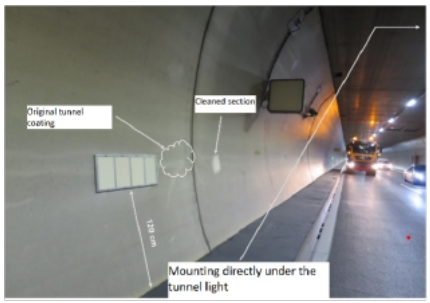

Figure 18: Sample panel in tunnel PF.

Analysis of Tunnel Coatings

In addition to the analysis of the existing tunnel lighting and wall surfaces, the four most common wall coatings currently in use were examined using sample panels (**Table 2**).

The four different coatings were applied to the sample panels (**Figure 18** and **Figure 19**) and then examined in the laboratory, as well as on site in the five tunnel facilities. For this purpose, the spectral reflectance, the gloss level and the reflectance curve of the coatings were measured in a soiled and cleaned state.

Surface Topography

A tunnel coating generally consists of the components listed in **Figure 20**. A distinction is made between hydrophilic (water-loving), hydrophobic (water-avoiding) and superhydrophobic (with lotus effect) surfaces with regard to the soiling of surfaces. For a surface to be hydrophobic, it must have a very fine coarseness (**Figure 21** and **Figure 22**). To minimize dirt deposits and facilitate cleaning, the coarseness must be smaller than the dirt particles.

An analysis of the surface coarseness of the respective materials by means of microscopy revealed a coarseness of 2–6 µm. In comparison, the particle size of the fine dust in the tunnel is approx. 0.1–1.0 µm, i.e., the surface coarseness is still too large to prevent the accumulation of these dust

particles. As the measurements showed, the surfaces used differ only insignificantly in terms of their soiling behavior.

Figure 19: Sample plate in the Bartenbach laboratory.

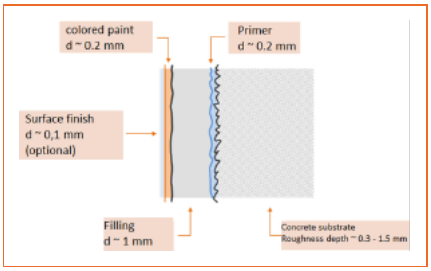

Figure 20: Structure of tunnel coatings [16].

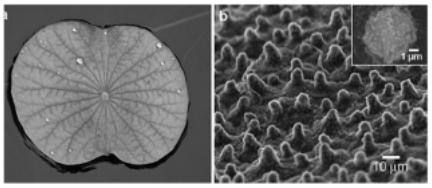

Figure 21: Microscopic view of a lotus leaf.

Figure 22: Symbol representation of the deposition of small dirt particles.

Gloss

An essential factor for the detection of obstacles and vehicles (visual performance) and for spatial perception in the tunnel is the gloss (specular reflection) of the tunnel surfaces. Gloss generally makes it more difficult to perceive a surface by superimposing mirroring ("flashes") and can cause glare. The use of materials with as little specular reflection as possible for the wall coating is one way of providing drivers in tunnel facilities with as few distractions as possible and a high sense of safety.

The materials listed in **Table 2** were therefore also examined in the course of the study for their properties with regard to reflection. For this purpose, luminance images were created in the laboratory with the help of a real linear tunnel luminaire in order to determine the ratio of the average luminance between the areas with maximum specularity (direct mirroring of luminaire in the material) and areas outside mirroring in a practical manner.

The mirror images in the tunnel walls caused by the linear tunnel luminaires are shown in the sample panels of the four different coating materials of company A and company B as in **Figure 23**. It can be clearly seen that sample 4 has the lowest reflection; the worst performance in this examination is achieved by the first sample, where a clear reflection of the luminaire can be seen.

Pollution

As already described, the reflection behavior of the tunnel coating is an important factor for the perception of the tunnel space and for the energy efficiency of the lighting. This coating is exposed to a wide variety of influences such as water, de-icing salts and exhaust gases, UV radiation, etc., the predominant influencing factor being exhaust gas pollution.

The amount of exhaust gases present is primarily determined by the number and type of vehicles passing through the tunnel (high or low traffic volume with trucks or cars). Secondly, any inclines or declines in the roadway of the respective tunnel facility are decisive (high or low pollutant emission).

While pollution can be reversed by cleaning, the associated ageing is long-term and irreversible (e.g. chalking, see **Figure 24** and **Figure 25**).

Figure 26 shows the influence of soiling on the reflectance schematically: the original reflectance (new value) of the coating decreases exponentially due to soiling, and is raised again to near the new value by machine washing. The difference to the new value results from residual soiling, which can still be subsequently removed by manual cleaning.

This periodic soiling and cleaning process is superimposed by a long-term ageing of the coating, caused mainly by yellowing, chalking, separation of color pigments

Figure 24: Old lacquer with chalking due to abrasion (color pigments come off).

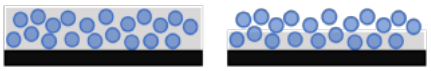

Figure 25: Left: new paint (color pigments in binder); Right: old paint (color pigments partially dissolved). Color pigments should be surrounded by the binder.

during cleaning, and roughening of the surface.

The reflectance ρ_{dirty} can therefore be determined via:

$$\rho_{dirty} = \rho_{cleaned} \cdot v^m \quad (1)$$

$$\rho_{cleaned} = \rho_{new} \cdot v_{residual} \cdot v_{aging} \quad (2)$$

whereas

ρ_{dirty}	Reflectance of the tunnel wall coating in the soiled state
ρ_{clean}	Reflectance after machine washing
ρ_{new}	Reflectance in the completely new state
v	Pollution factor per month (measured 0.89 - 0.94)
m	Number of months since last machine wash
v^m	Pollution factor after m months
$v_{residual}$	Factor for residual soiling after machine washing that can still be removed by hand (measured 0.42 - 0.95)
v_{aging}	Ageing factor per month (factor 1, because measurement period too short)

With these quantities, the reflectance can be determined mathematically as a function of the operating time since the last washing, the residual pollution and the ageing.

Figure 23: Real mirror image of a linear tunnel luminaire (measurement set-up in the laboratory)

In the five selected tunnel facilities, photometric reference values were measured at half-yearly intervals (autumn 2019 to spring 2021) before and after machine washing at night in order to quantify the influence of the contamination on the surfaces and on the luminaires.

These machine washes resulted in a clear improvement in reflectance and luminance, but only between 42% and 95% of the original reflectance of the tunnel walls and sample panels was restored. By means of additional manual cleaning, the original condition of the tunnel walls could be restored (**Figure 27**).

An irreversible ageing process, which, as expected, can only be measured over longer periods of time and is strongly dependent on the structure of the coating and the environmental conditions, could not be detected.

Depending on the washing and surface quality, the measurements in the different tunnels showed strongly deviating values. The measurement results show that:

- The soiling of the 4 surface samples (sample panels) was the same as that of the tunnel wall.
- There were only minor differences between the various surface types in the sample panels.
- No systematic correlation could be found between the degree of soiling and the location of installation in the tunnel (entrance, middle and exit areas).
- The monthly reflectance losses due to pollution assume values between 6% - 11%, i.e. the monthly pollution factors are between 0.89 - 0.94.
- The remaining pollution depends very much on the quality of the machine washing, the measured factors vary between 0.42 - 0.95.
- No ageing process measurable due to the short measurement period (2 years).

Together with the surface measurements, the luminous intensities of the luminaires were also measured before and after the mechanical washing, which was only carried out at annual intervals for the luminaires. The reduction factors measured in relation to this annual interval varied greatly between the values 0.67 - 0.91 (corresponding to 0.8% - 3% reduction per month or 5% - 17% per half-year), but no systematic correlations with seasons, installation locations, etc. can be derived from this.

Summarising the effects of pollution the half-yearly decrease in luminous intensity of the luminaires is on average approximately 11%, and the half-yearly decrease in the reflectance of the tunnel walls is on average approximately 35%, together this means a decline of almost 50%.

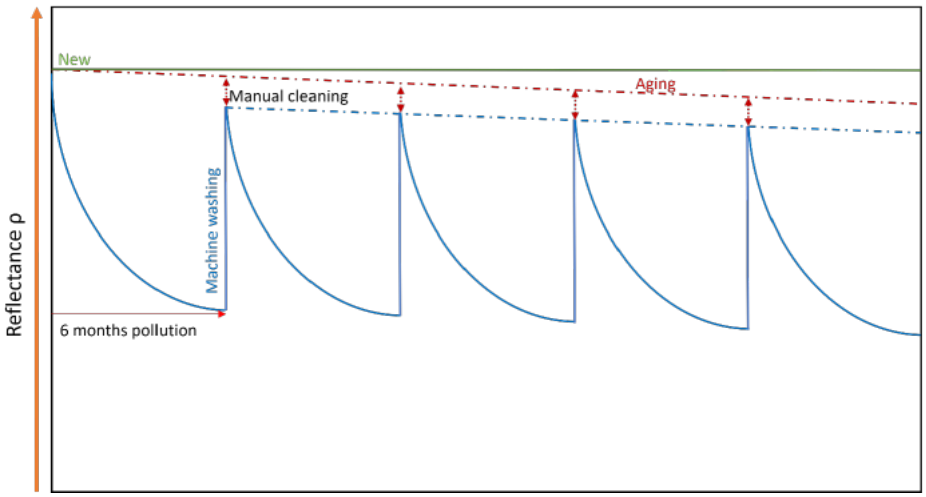

Figure 26: Pollution effect on reflectivity over time and after cleaning.

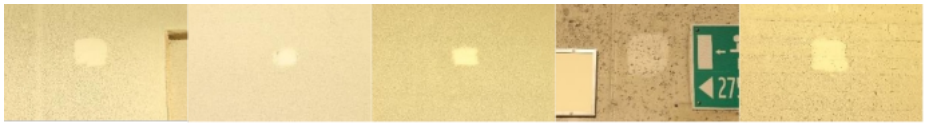

Figure 27: Painting of the tunnel walls after machine washing (small areas also cleaned manually with rags) - from left to right Tunnel L, Tunnel PE, Tunnel PF, Tunnel PL, Tunnel Q.

Summary

The history of tunnel lighting in Austria can be summarized as follows: while until 2006 mainly high-pressure sodium lamps (NAV) with a luminaire spacing of about 12 m to 18 m were used, from 2007 white light sources with a color temperature of more than 3000 Kelvin and a color rendering index greater than 70 (metal halide lamps and fluorescent lamps) were increasingly used. In the meantime, only LEDs will be used with high spectral and flicker-free quality. In addition, uniformity and brightness have also been improved. For the future, final improvements could be made by creating bright tunnel lighting (including walls and ceilings) with a clear information structure that facilitates spatial perception and mental information processing.

In this respect, a bright tunnel wall is very important for the perception of the tunnel space and cannot be replaced by edge markings. As the brightness of tunnel surfaces increases, orientation takes place in the course of an overall spatial perception and no longer mainly via floor markings and curb reflectors, which can only be a guidance aid in the absence of spatial orientation. It has been shown to increase the sense of safety and reduce the stress experienced by 1/3 of men and 2/3 of women when passing through a tunnel **[17]**. Additionally, it increases the visibility of hazardous situations. In this context, the tunnel surfaces should be as gloss-free as possible (without specular reflections) to ensure stable perception of the surfaces.

The investigations show that the reflectance of the tunnel walls decreases strongly with increasing contamination: together with the luminaire soiling, the brightness of the tunnel wall decreases by almost 50% in half a year. After machine washing, significant residual contamination may remain. A six-monthly washing cycle therefore seems reasonable, with particular attention to the quality of the cleaning.

The available surface coatings already have sufficiently high reflectance levels, and are very resistant to soiling and cleaning. Potential future improvements in the coatings are in the degree of soiling (lower coarseness), in the cleanability and in the specular reflection (less gloss). ■

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Lighting in Retail — How it Increases Sales

by Giovanni VECCHIO, NICHIA Europe

With professional support, a store's owners in Germany implemented a lighting concept based on NICHIA LED technology [1] that shows all the merchandise at its best, and contributes to consumers' shopping experience. Increased sales figures prove the value of their investment.

Supermarket Upgrades Lighting

Traditionally, retailers have viewed lighting primarily from an economic perspective, with cost and energy consumption usually the top priorities. Many retailers have therefore already switched to LED technology.

But the influence of light on people is still underestimated by many retailers, even though it has been scientifically demonstrated. With over 30 years of experience in the industry, however, it was clear to the owner family of several Edeka stores in Wiesbaden, Germany that the lighting of their merchandise was crucial to the customer's shopping experience.

For example, a key metric in retail is 'dwell time' — the average time shoppers spend in a store, or in a particular area. By increasing dwell time, stores can increase their sales, and hence their profitability. In order to achieve the desired dwell time of around 30 minutes in a store of this size, optimized lighting quality plays a significant role. However, lighting that varies between warm and cold, as has already been introduced in stores over the past 20 years, is not sufficient for this. To optimize the lighting at the largest Edeka store in Wiesbaden, with a sales area of 3,000 m2, the owner family consulted Prof. Dipl. Phys. Werner Lorke and his interdisciplinary team of experts. Founded more than 110 years ago, Edeka is one of the leading food retailers in Germany, with more than 11,000 stores and 400,000 employees, and sales of €61 billion in 2020 [2].

Lorke has been working in this field for many years. Within the framework of his consulting office iO Interdisziplinäre Objekte, he creates, conceives, plans and realizes 'non-standard' projects, and brings together the fields of architecture, technology and art.

The owner family tasked Lorke with developing and implementing a lighting concept that presents the store's merchandise in the best possible way, and creates a positive shopping experience for the customer. A good lighting design considers, among other things, the amount of light, the contrast range, the quality and the differentiation of light in the various areas at the point of sale (PoS).

New Possibilities with "Light so Good"

In their search for suitable lighting technologies, the team of experts came across NICHIA's products. To meet the requirements of the Edeka store, Lorke selected NICHIA's 'Light so Good' technologies, which significantly enhance the quality of light. His design used products from three families: 2-in-1 Tunable White, Optisolis, and Vitasolis.

As the market leader for high-performance LED solutions, NICHIA specializes, among other things, in the development of LEDs for highly efficient, circadian lighting and the imitation of natural light. The company developed the world's first high luminous nitride blue LED in 1993, and followed this in 1996 by combining the blue LED with a yellow phosphor — creating the world's first white LED. Since then, it was built on this history, to continue innovating in LED technology.

Good Contrast and Dynamic Lighting

"In the confectionery department, we have started to replace standard LED lighting with a variable color temperature control, or 'Tunable White', concept," says Lorke. With NICHIA's 2-in-1 technology, he and his team have succeeded in creating a good contrast between the merchandise on display and the aisles, as well as installing dynamic lighting where the color temperature changes throughout the day. Lorke explains, "We have now developed 26 different lighting scenarios here, which we are currently changing weekly for further optimization." Conventionally, separate light sources of different color temperatures are used for variable color temperature control of lighting. Most commonly, this would simply consist of mounting multiple LEDs on one board, including both warm white and cool white LEDs. This means the board needed is larger than if a single color LED was used, and extra secondary optics are required, such as a reflector and lens. However, NICHIA's LED technology makes it possible to implement color temperature control based on a single light-emitting surface (LES) with two separately controllable channels, thus enabling the color of the light to change from cool white to warm white. Being able to color tune and mix within a single package simplifies the production of color-tunable fixtures, as well as integration into edge-lit waveguides, and enables smaller fixtures.

This innovative concept allows the development of completely new dynamic lighting designs, that were previously difficult or impossible to achieve with color temperature control. With a single LES, the need for additional optics or diffusers can be reduced, while maintaining good color homogeneity. The 2-in-1 LED does not only simplify mixing and tuning it also overcomes the limitations in the lumen output for a single luminaire that can be a problem when using two separate LEDs.

NICHIA's 2-in-1 technology can also deliver higher color quality, with a Color Rendering Index (CRI) figure of up to 90 in the Correlated Color Temperature (CCT) areas. CRI figures can range from 0 to 100, and a high CRI figure ensures that colors look natural under the light source, compared to how they would appear in sunlight. While a CRI figure of 80 is generally considered acceptable in many applications, a higher rating contributes to a more natural, appealing lighting experience for the shopper.

A Positive Effect on Produce and Mood

To illuminate the fruit and vegetables in the store, the team of experts relies on Optisolis LEDs, which can generate a light spectrum that is very close to that of the sun, and that also do not emit any harmful ultraviolet (UV) light. As a result, Optisolis has a positive effect on perishable goods, helping them to stay fresh longer, while fruit and vegetables are shown in the best possible light.

The Optisolis range also features a high level of light output compared to the input electrical power, which can be expressed as a lumen-per-Watt value. This high efficiency reduces the input power required, which delivers significant energy savings, and therefore reduces running costs. Designed to replace halogen and conventional LED lights, Optisolis provides an exceptionally high CRI of 98, at full intensity, which means it makes the store's products look more natural and thus more appealing. This compares to the 80 to 90 CRI figure of the lighting which is typically used in retail applications. Optisolis also delivers R9 red content of over 94, which is an important saturated solid color that is not measured by CRI.

In addition, Optisolis allows the retailer to connect with the shopper emotionally. "Optisolis is able to recreate the feeling of the warm light of the evening sun and presents the merchandise in the best possible way visually," Lorke says. In general, he believes the technology is ideal for illuminating all products. So far, it has been retrofitted in the meat and sausage department as well as in the cereals, coffee and tea departments, among others.

In the vinegar, oil and spices section, Optisolis is used in combination with the Tunable White products. An analysis of the aisles has shown that customers visit this product area, which is located in a dead-end, far more often than before optimized lighting was installed.

Figure 1: BEFORE LIGHTING UPGRADE.

Figure 2: AFTER LIGHTING UPGRADE – Fruits and vegetables are illuminated with Optisolis products, which can be used to produce a light spectrum comparable to the sun, with a low UV content.

Bright White to Take the Strain Off the Eye

The third LED technology, Vitasolis white LEDs, uses a special mixture of phosphors to increase the cyan content in the resulting natural white light, with a significant amount of energy in cyan from 470 nm to 520 nm. In comparison, standard LEDs have a very low cyan content to achieve high luminous efficacy.

Vitasolis enables a brilliant white light with a wider wavelength spectrum without sacrificing efficiency. The result is an invigorating illumination that is nevertheless perceived as pleasant, as the cyan component has a positive effect on people's circadian rhythms.

"Only a few years ago, science discovered new receptors in the eye and found that the cyan component in light has a stimulating effect on people," explains Lorke. "A lack of cyan in light makes people tired — a phenomenon that affects dwell time in retail."

The crisp white provided by Vitasolis reduces strain by improving the response of the eyes to light. This kind of human-centric lighting can reduce tiredness and stress, as well as promoting well-being and alertness.

Aisles illuminated with Vitasolis, in combination with Optisolis product lighting, create an atmosphere for shoppers that is both inspiring and pleasant — a solution ideally suited, for example, in the dairy section.

"Vitasolis is a fantastic light and something relatively new," explains Lorke. He uses this technology for two reasons: firstly, to create a good contrast between the space and the merchandise thanks to its broad spectrum and low level of yellow light. Secondly, its quality of light is extremely easy

on the eye. As such, the technology also perfectly meets the needs of any counter areas, as the comfortable lighting makes waiting times more pleasant for shoppers. Due to a design that provides backwards compatibility, it is quick and easy to replace Nichia 757 series and 3030 LEDs in existing fixtures with new Vitasolis LEDs. To do this requires no changes in power, driver compatibility, beam shape or safety testing and no need to adapt or redesign fixtures.

Lighting Boosts Sales and Profits

"Ultimately, every product group at the PoS in the store requires its own lighting concept," says Lorke. "The secret lies in the optimal mix of color temperature, color spectrum, CRI and contrast. Currently, for me, there is no alternative on the market to NICHIA products to achieve such a high quality of light as we have managed to create here."

In his view, the most important thing is coherent communication for the respective product categories. Product groups, and especially the brands associated with them, communicate qualities that go beyond the immediate benefit and are therefore bought more by consumers — leading to higher sales, and hence increased profits.

Putting merchandise in the 'right light' is the central element of this communication at the PoS. If brand statements and the perception of the products on the market shelf do not match, this often has a negative influence on the purchase decision.

Now, the owner family has gradually updated their store in terms of lighting so that around 100 Optisolis, Vitasolis, and Tunable White luminaires and 15 Vitasolis luminaires are used. For this Edeka store, above average sales figures prove that the influence of light on people is enormous, and lighting therefore represents a great opportunity for retailers. The owner family is so satisfied with the project that they have equipped their latest Edeka store with lighting based entirely on NICHIA LED technology right from the start. Thus, a total of 500 luminaires of all three 'Light so Good' technologies are installed at the new store, in Wiesbaden-Sonnenberg, which opened its doors in May 2021.

"We are proud to say that all our activities here, in introducing new illumination, have more than paid for themselves within a few months, and had a positive impact on the store's bottom line," Lorke concludes. "In terms of turnover, this store is well above average compared to other Edeka stores. Based on this experience, our advice to retailers, in general, is to look at lighting as a sales tool rather than as an expense." ■

Figure 3: Vitasolis creates a good contrast between the space and the merchandise thanks to its broad spectrum and low level of yellow light. As such, Vitasolis meets the needs of any counter area, as the comfortable lighting makes waiting times more pleasant for shoppers.

Figure 4: NICHIA specializes in the development of LEDs for highly efficient, circadian lighting and the imitation of natural light. Optisolis allows to recreate the feeling of the warm light of the evening sun.

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Mr. Giovanni Vecchio has more than 20 years' experience in the semiconductor industry and has been with Nichia for the last 10 years.

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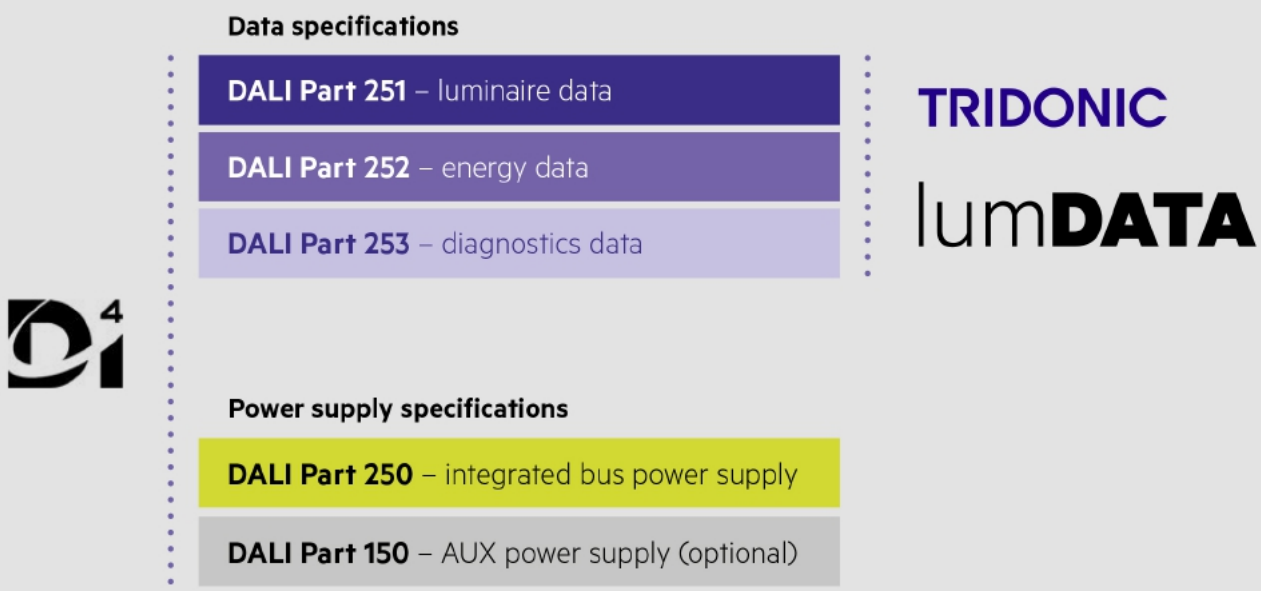
lumDATA

Tridonic bundles three DALI-2 data specifications

Tridonic has combined three DALI-2 extensions under the lumDATA concept. These specifications regulate the storage of various types of data, which considerably simplifies commissioning and maintenance of luminaires. Energy consumption and possible errors can also be more easily traced.



Features and possible uses

DALI–2 Part 251 luminaire data	DALI-2 Part 252 energy data	DALI-2 Part 253 diagnostic data
__ OEM identification number __ OEM GTIN __ Luminaire port, power & voltage __ Luminous flux __ CCT & CRI __ Light distribution __ Luminaire colour	__ Active power and energy	__ LED driver information: Operating hours, switch-on counter, input voltage and frequency, temperature and output current. __ DC (secondary) connector __ Information: Forward bias, switch-on counter LED module, operating hours LED module
State-of-the-art automated commissioning will become possible using this data. The data allows facility managers to efficiently monitor and control the installed luminaires.	Reports the power consumption of every luminaire in the entire installation. Energy consumption dashboards can be created using this energy data.	This data enables predictive maintenance, simplifies complaints management and makes fault identification easier in defective devices (e. g. overvoltage, overtemperature).

Optics and Outlook for Horticulture Lighting

by Bernie DANIELS, OEM Sales Manager and Sadi SAFARALIEV, Optical Design Engineer; Carclo Optics, United Kingdom

Turmoil across the globe has raised concerns about international trading and environmental issues, and the ability to manage localized production of food with minimum waste is becoming more and more important. Horticultural lighting is, as well as being the natural progression in combined lighting technologies, a response to these concerns and a market driven step towards a brighter future. Climate change has shortened growing seasons, necessitating an increase for indoor growing. The positive response to this is a huge global focus on maximizing the use of resources, driving the innovation of technologies that were previously only the subject of imagination.

The Horticultural LEDs market has seen many developments. The important role of innovation with companies such as Carclo [1], is enabling the industry to make further advancements in horticultural lighting through precision engineering, design and development of high quality, high efficiency secondary optics. Add to this the latest fixtures and power routing solutions, and it all equates to a far more economical and environmentally friendly future for this rapidly expanding industry.

LEDs have long been understood to reduce the carbon footprint of all lighting scenarios and with the advent of horticultural lighting on a global scale, is also severely reducing the air miles by growing essential crops in a huge number of locales. Secondary optics are available to optimize the set up and come in many forms – all offering slightly different beam patterns and coverage. A correctly positioned optic prevents light from illuminating crop-less spaces, therefore increasing efficiency and yield, whilst reducing space required and cost of illuminating the desired space. Expertise, custom design and cost-effective optics are available from companies – whether an off-the-shelf, semi-custom or fully custom solution is required.

Optics

Bubble Optics

The wide beam angles and batwing distributions offered by bubble optics result in broad coverage and high uniformity, promoting greater yields. This makes them an excellent choice for horticulture lighting.

Freeform Optics

Available as single, 1x3, 2x2 & 2x3 arrays, freeform optics offer a range of beam types from narrow spots to wide and square. A cost effective, space saving solution for all horticultural applications.

Strip Optics

The directional distribution over the length of the strip is ideal for vertical farming - minimizing light spillage, thus conserving energy and keeping costs down whilst maximizing growth.

33Up Optics

Cost effective, easy fit and perfect for larger luminaires, 33UP arrays (3 rows of 11 optics all on one moulding) have great uniformity and are an excellent choice for horticulture – especially greenhouse top lighting. It is possible to increase yield and variation that extends way beyond what would usually be possible using just natural sunlight. Well-designed facilities can provide flexibility through 24/7 lighting and climate control, all of which can be combined to create near perfect environments to grow almost any crop.

Choosing The Right Secondary Optic

Secondary optics are essential to control the powerful light emitted by today's LEDs. Depicted in **Figure 1**, light from LEDs without a lens streams out in all directions. This wastes both energy and finances. The yield increase requires high uniformity and with results above 90%, it's clear that high quality secondary lenses are the essential requirement for any horticultural lighting project.

Parameters To Consider

- **Spatial distribution of light:** The general light distribution will vary across optic types.
- **Optical efficiency:** Imperative to ensure no light wastage.
- **Dimensions of the lens / reflector:** Each luminaire will have a finite space into which the optic must fit. There are numerous mounting options such as glue, tape or holders and some optics have legs. The results can vary dependent on the height at which the optic is mounted.

Environmental and Business Considerations

Obviously, these are both great reasons to invest in modern horticultural lighting set ups, but they are not the only reasons. The crops, when carefully farmed, have a far higher nutrient content, better appearance, more vibrant colors, and enhanced flavours. So, whether you're creating daffodils to celebrate the arrival of spring, cabbages to accompany the family roast or potatoes from which to extract the perfect freedom fries, custom made growing environments provide the best outcomes.

Previous growing environments often resulted in a large percentage of crop failure due to a variety of non-controllable external factors, such as weather and pest infestation. Alongside the previously listed benefits, suitably managed crops can also develop a higher resilience to some of the standard threats to plants without the need for excessive pesticides.

Current horticultural LEDs produce the exact wavelength of light, albeit untamed, throwing it out in all directions. This is where the secondary optics come in to play. They focus and control the beam and the combination is housed in a luminaire which is positioned to provide optimal results.

The technology and understanding have advanced to the point that the lighting can be programmed to mimic the spectrum changes found in the natural environments for each plant type.

The latest phosphor technology can lower horticulture lighting costs by up to 60%, simply by reducing the number of LEDs required to achieve the same results possible with older LEDs. The mechanical construction of new generation LEDs also improves reliability and even extends the lifespan in harsh conditions such as greenhouses.

With that in mind, be sure to check that the optics you choose are UV stabilized. It is important to note that not all secondary optics are created equal! There are many cheaper imitation optics available so make sure the information about the materials used is readily available. UV stabilized polymer costs a lot more than non-stabilized and is used to reduce degradation of the lenses, where optics are likely to be subjected to high UV levels.

Recent advances in power management have seen a change from powering each fixture independently to a main power unit that can be stored outside. The excess heat can be dispelled by directing it externally, or, during the winter months, the heat can be directed into the growing area as a vital part of economic climate control. This saves a lot of energy and can produce a much higher ROI.

For luminaire manufacturers, producing standard base units that are compatible with a wide choice of LEDs, PCBs and secondary optics combinations is far more economical. This enables one base unit that can be utilized in multiple sectors throughout the horticulture sphere.

Although LEDs have seen a massive adoption in a short period of time across the horticultural industry, there are still many established growing facilities that have yet to make the switch. At the time of writing, it is estimated that LED currently only represents 10% of this burgeoning industry, meaning that a huge 90% is still running on older less efficient technologies with metal halide and high-pressure sodium still dominant.

By just updating the lighting already in existence would result in a huge expansion of the sector, but given the positive opportunities going forward, new businesses will also no doubt spring up and add dramatically to this expansion. The current projections are that the LED lighting market will grow at 5% compound annual growth rate, and horticulture lighting 27% by 2022.

The following definitions are often used when horticultural lighting is discussed. We have explained each term below.

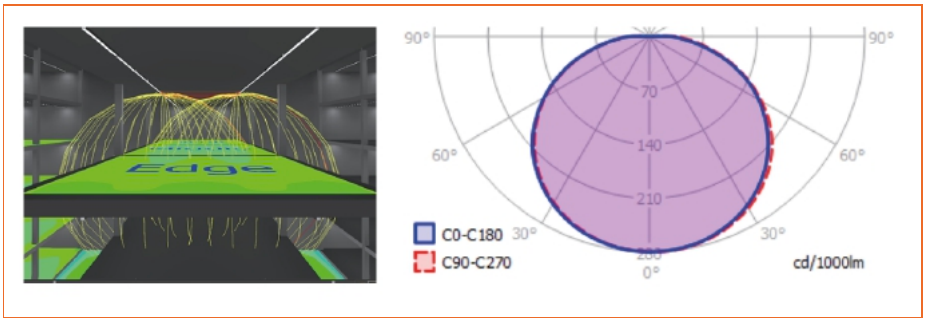


Figure 1: Light distribution without secondary optics.

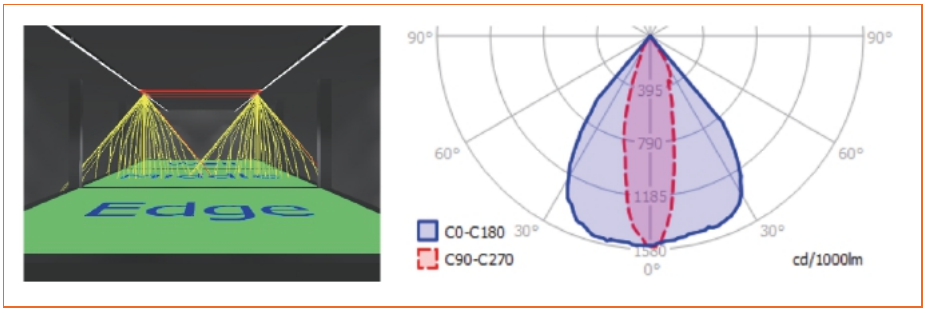


Figure 2: Light distribution with secondary optics. All results displayed in this article are based on a room size of 5m x 10m x 3.2m.

Horticultural Lighting		General Lighting	
PAR	(400nm - 700nm)	VISIBLE SPECTRUM	(380nm - 750nm)
PPF	(Unit: µmol/s)	LUMINOUS FLUX	(lm)
PPFD	(Unit: µmol/s-m²)	ILLUMINANCE	(lx)
PPE	(Unit: µmol/J)	EFFICACY	(lm/W)

Table 1: Similarities between horticultural and general illumination lighting terms.

Terms & Definitions

PAR – Photosynthetically Active Radiation

400–700 nm is the spectrum range that plants use for photosynthesis and corresponds roughly with the light visible to the human eye.

PPF – Photosynthetic Photon Flux

Unit: µmol/s

Amount of PAR produced by a light source per second OR the total number of photons per second with wavelengths between 400–700 nm.

PPFD – Photosynthetic Photon Flux Density

Unit: µmol/s·m^2

Amount of PAR landing on a square meter per second OR density of PPF on a target surface.

DLI – Daily Light Integral

Unit: mol/day·m^2

Total amount of PAR that lands on a square meter surface per day.

PPE – Photosynthetic Photon Efficacy

Unit: µmol/J

Efficiency of a light source for converting electrical energy into PAR light.

PBAR – Plant Biologically Active Radiation

280–800 nm

According to ASABE[1], plant biologically active radiation covers a more substantial range of light that affects plant biology.

Table 1 shows the similarities between horticultural and general illumination terms.

[1]The American Society of Agricultural and Biological Engineers is an educational and scientific organisation dedicated to the advancement of engineering applicable to agricultural, food, and biological systems. Founded in 1907 and head-quartered in St. Joseph, Michigan, ASABE comprises members in more than 100 countries. Agricultural, food, and biological engineers develop efficient and environmentally sensitive methods of producing food, fiber, timber, and renewable energy sources for an ever-increasing world population. ASABE membership is open to all—engineers as well as non-engineers—who are interested in engineering and technology for agricultural, food, and biological systems.

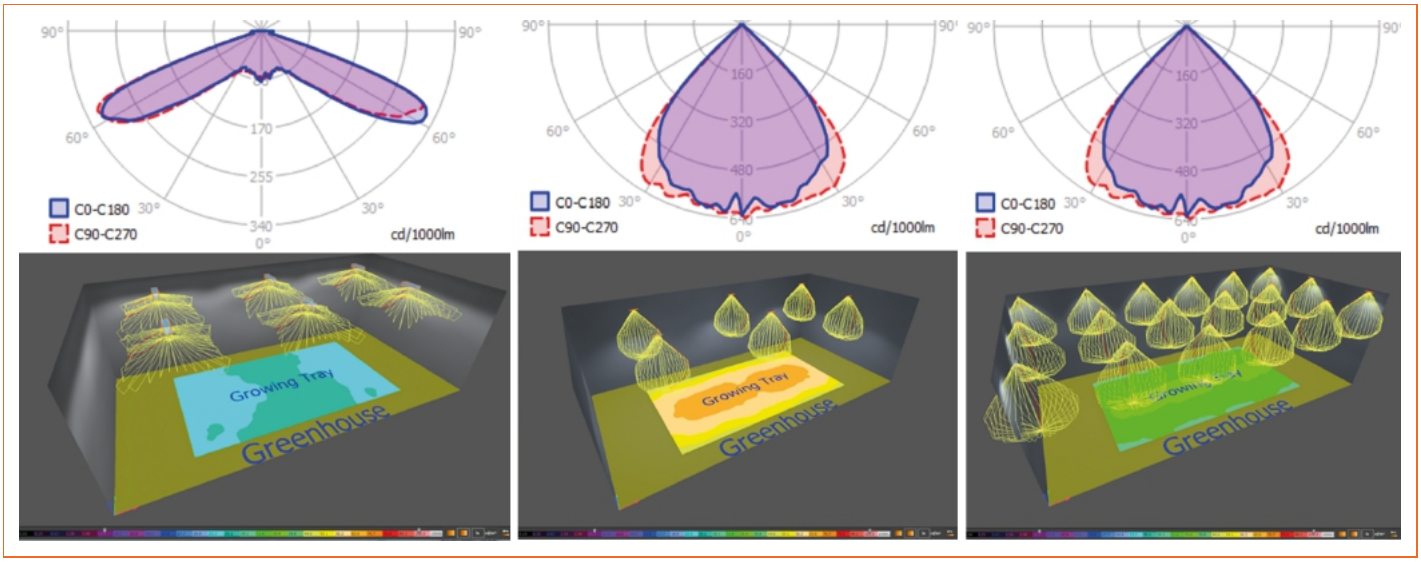


Figure 3: Three Greenhouse TOP Lighting examples.

PARAMETERS	EXAMPLE NO.1 • 12781	EXAMPLE NO.2 • 12917	EXAMPLE NO.3 • 12917
Average PPFD (µmol/s-m^2)	25.0	59.3	34.1
PPFD Uniformity	93%	79%	91%
Total PPF Produced (µmol/s)	3,378	3,378	2,538
Total Power Consumption (W)	1,188	1,188	900
ADVANTAGES	>90% PPFD uniformity	Very high PPFD values	>90% PPFD uniformity
	Less luminaires	Less luminaires	High PPFD values higher than Ex1)
	Less installation & maintenance costs		Similar or less power consumption

Table 2: Comparison of three Greenhouse TOP Lighting examples according to Figure 3.

Main Sectors in Horticulture Lighting

Greenhouse Top Lighting

Whilst industrial greenhouses are nothing new, modern construction sees the design based around the available new technology. Interchangeable luminaires allow the grower to change the crop type according to demand. For example, if demand for a type of tulip is high, they can be produced and if that changes, once the current crop is harvested, the luminaires can be swapped to optimise the conditions for a different type of plant entirely. These seasonal growing opportunities allow for localized production and this in keeping with the current trends in consumer opinion (**Figure 3** and **Table 2**).

Vertical Farming

This refers to effectively 'stacking' rows of plants above one another. This allows crops to grow in the same space when compared to traditional single level farming techniques. With space at a premium, it makes sense to stack plants wherever possible as this hugely increases the yields per square foot and provides the opportunities for a much higher ROI.

Whilst this obviously requires lighting per shelf, there is a wide variety of LEDs, secondary optics and luminaires designed specifically for the job. The optimal patterns for this feature extended longitudinal beams in comparison to the horizontal beams. Any light that falls over the edge of the shelving is wasted, and the secondary optics ensure this is fully eliminated, or, at the very least, kept to an absolute minimum. Techniques encountered in vertical farming set-ups are often soil-less methods such as hydroponics, aquaponics and aeroponics (**Figure 4** and **Table 3**).

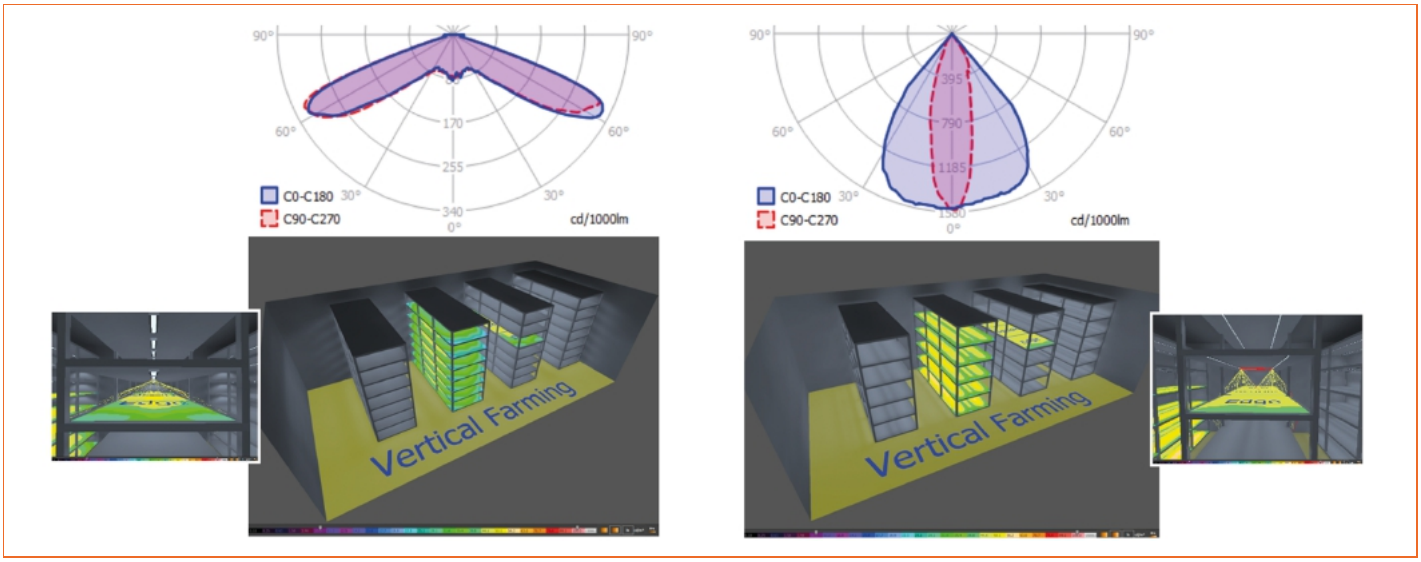


Figure 4: Two Vertical Farming Lighting examples.

RESULTS	EXAMPLE NO.1 • 2x2 MINI HUBBLE • 12781		EXAMPLE NO.2 • 11mm STRIP OPTIC • 10398	
PARAMETERS	MIDDLE TRAYS	EDGE TRAYS	MIDDLE TRAYS	EDGE TRAYS
Average PPFD (µmol/s-m^2)	48.8	42.3	48.2	47.0
PPFD Uniformity	92%	73%	98%	93%
Total PPF per shelf row (µmol/s)	196		198	
Total Power per shelf row (W)	72.1		72.6	
ADVANTAGES	>90% PPFD uniformity on all middle trays		>90% PPFD uniformity even on end edges	
	More space (7 Rows compared to 5 rows w/10398)		Higher PPFD values (~30% higher on average)	
	Similar PPFD values as 10398 on middle trays		Same electrical power, but more light on trays	

Table 3: Comparison of two Vertical Farming Lighting examples according to Figure 4.

Greenhouse Intra-Canopy Lighting

The term intra-canopy is applied when the lighting is suspended amongst the vegetation. Examples include cucumbers and tomatoes. The fixtures for intra-canopy lighting are often extended lengths and extruded optics, and can be utilised to great effect (**Figure 5** and **Table 4**).

Cannabidiol (CBD)

Changing attitudes towards CBD have seen a huge surge in the growing of cannabis in areas where mass production of the crop has become legal. Whilst previously only associated with home growers or enthusiastic entrepreneurs, the explosion of this industry has fueled substantial investment in research to increase the yield and return on investment by using highly specialised luminaires, LEDs, and secondary optics. With the technology currently available, the LEDs can control the spectrum of light required to optimise the growth of any given crop. This output can then be precisely focused by high end secondary optics to ensure the minimum amount of energy is wasted. The medical properties of the oil produced have led to its inclusion in multiple products that are legally available in regions where the growing of the crop itself is still illegal. This is set to increase over the coming years as more consumers experience the positive results of CBD, you can expect the market to reach corresponding new highs.

Conclusion

In conclusion, the growth of the horticultural lighting industry shows no signs of slowing. With the nutrients and origins of food mattering more to the consumer than ever before, only the healthiest, tastiest crops will do. In addition, new attitudes towards the environment and reactions to research carried out into the benefits of CBD, are all positives in the very bright future of this sector. ■

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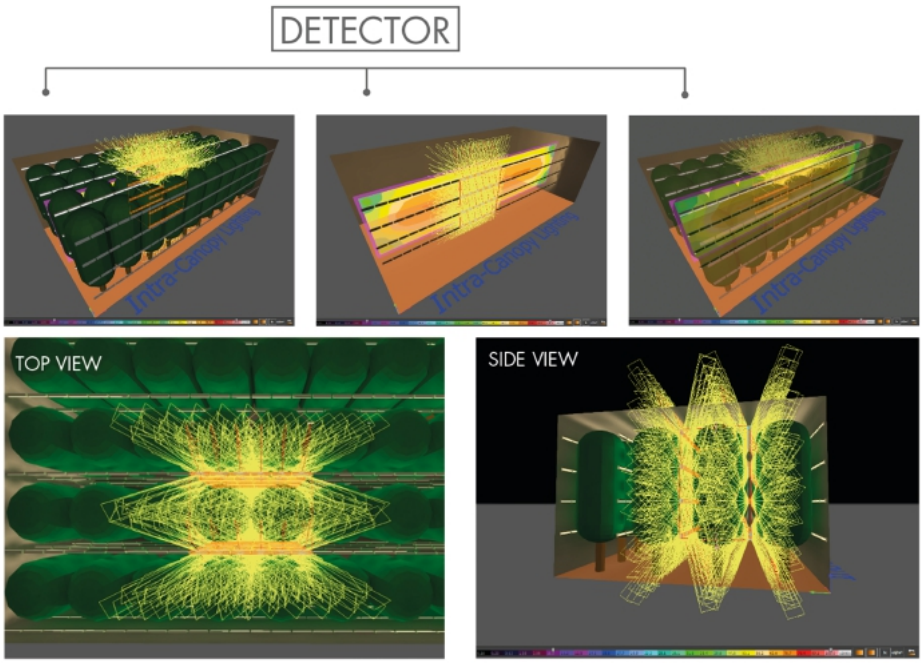

Figure 5: Greenhouse Intra-Canopy Lighting example including top and side views.

PARAMETERS	RESULTS ON DETECTOR (12781)
Average PPFD (µmol/s-m²)	59.0
PPFD Uniformity	58%
Total PPF Produced (Whole Room) (µmol/s)	19,200
Total Power per shelf row (W)	6,720

Table 4: Measuring results from the Greenhouse Intra-Cnopy Lighting detectors according to Figure 5.

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Bernie Daniels is the OEM Sales Manager for Carclo Optics with thirty years' experience working in technical sales for the electronics industry, over half of that time has been devoted specifically to LED lighting. Bernie enjoys working with customers to find solutions for their optical requirements and relishes the challenges every new project brings as he firmly believes that no matter how experienced you may be there is always the opportunity to learn something new. Bernie is a self-confessed petrol head who enjoys music and long walks in the countryside with his family and two dogs.

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Sadi has seven years' experience in the LED lighting industry. He has worked on a broad range of projects, from optical design of LED luminaires to opto-mechanical design of lenses and reflectors for LED lighting applications. A detail-oriented engineer who enjoys working on new and challenging projects, Sadi loves spending time with his family. He is also a keen science and technology content creator.

Carclo Optics was originally known as Combined Optical Industries and founded by Arthur Kingston in 1936 – inventor of the plastic lens. The LED specialist team was formed in 2003 and re-branded Carclo Optics in 2012 to better portray the Company's capabilities. Custom optics, modules and systems are created by Carclo's industry leading design experts.

Optic Select

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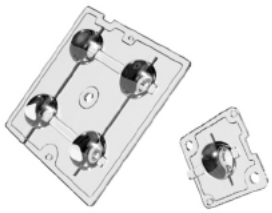
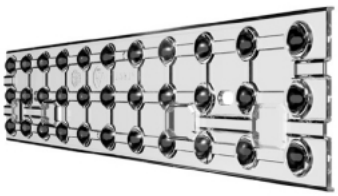


MINI HUBBLES

STRIP OPTICS

BUBBLE OPTICS



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Carclo offer a wide variety of optics suitable for horticultural lighting including optimal solutions for greenhouse top lighting, vertical farming and greenhouse intra-canopy lighting.

For more information please refer to www.carclo-optics.com or contact the team directly:

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9 Resources That Showcase the Realization of Bluetooth Networked Lighting Control in Large-Scale Commercial Environments

by Jason MARCEL, Bluetooth SIG, USA

Earlier this year, we released an article [1] that outlined how networked lighting control systems can deliver a combination of energy savings, an enhanced occupant experience, and more efficient building operations. Deployed in offices, retail, healthcare, factories, and other commercial facilities, Bluetooth® networked lighting control systems can also enable more efficient operation of other building systems and serve as a building's central nervous system.

While, at length, we looked at why Bluetooth wireless lighting control networks are well-positioned to take over commercial lighting, there is no better proof than real-world use cases and implementations that verify the efficacy of a Bluetooth networked lighting control system.

Here are nine recent examples that showcase the realization of Bluetooth networked lighting control in large-scale commercial environments.

Maximizing Energy Savings with Smart Lighting

This case study [2] by Sylvania outlines how Atalian, a global leader in facilities management services, replaced their outdated luminaires with Sylvania's Bluetooth enabled connected building solution. Capturing real-time energy consumption of the existing and the new lighting solution, Atalian can monitor the performance of the new solution and verify the achieved savings against the target ROI.

The case study states that, during the period of monitoring, switching to LED saved 50 percent on initial energy costs. The usage of Sylvania smart controls combined with precise motion detection in every fixture, daylight harvesting and task tuning, generated additional savings (69 percent on top of LED savings) to bring total energy savings to 84 percent compared to the old installation. Translated to carbon emission data, this new installation can reduce around 4t of CO_2 every year without any compromise on occupant comfort levels.

"No additional cabling is required, unlike a system that is not integrated into the luminaire – this is unique," said Abdel Hamroun, Atalian operations manager. "Also, we could easily add battery- and maintenance-free, kinetic-powered wireless wall switches to rooms, to allow users to adjust light levels and set scenes, simply and easily."

Read the full case study.

Turning an Existing Installation into an Intelligent Light Management System

Tasked with finding a simple, quick-to-implement, and cost-effective solution to modernize an old, ailing lighting system in an office building in Kolding, Denmark, OSRAM chose a Bluetooth® enabled wireless lighting control solution. Thanks to the ease of installation inherent in Bluetooth mesh and its decentralized architecture, the existing installation could be reused and the new system put into operation quickly and with minimal downtime. This meant that the present infrastructure could be used without costly and time-consuming rewiring and without a gateway or other complex IT elements.

Office building employees now benefit from greater comfort and convenience, and building operators can take advantage of significantly increased energy efficiency thanks to daylight control and presence detection.

Read the full case study.

The Largest Bluetooth Mesh Lighting Control Installation in the World

Teaming up with Silvair technology partner McWong International, Energy Management Collaborative (EMC) designed a luminaire-level lighting control solution to provide occupancy, scheduling, and vacancy control scenarios commonly used in tenant offices and open spaces. The goal

was to maximize efficiency while taking into consideration how users interacted with their individual spaces.

According to the case study [3], the installation required 3,685 Bluetooth mesh lighting controllers installed throughout 17 floors of a 470,000+ square-foot office building. Highlighting the power of the Bluetooth mesh interoperable standard, at the building manager's request, additional components were seamlessly added to the network lighting control system and worked inter-operably with the luminaire lighting controllers. Now, the installation has expanded to 3,923 Bluetooth mesh devices over 17 floors.

Enabled by the network lighting control features, EMC deployed vacancy and occupancy scenarios for most of the project zones and, in addition, configured the high-end trim to as low as 60 percent. This combination of scenarios and settings provided expected energy savings in excess of 75 percent over and above that gained by LEDs alone. As space needs change, the new system can be wirelessly re-zoned as needed to accommodate future reconfigurations of floor layouts.

Read the full case study.

Energy and Cost Savings at Pioneer Markets

Pioneer Markets, a family-owned grocery business operating in Mariposa and Waterford, California, turned to LED GreenLight International LLC, a manufacturer of advanced LED lighting products, for their lighting-control expertise. LED GreenLight International LLC helped retrofit Pioneer Markets' existing T8 lamps with a Type C LED retrofit kit consisting of 95+ CRI LED tubes and LED driver with integrated Bluetooth® Mesh for advanced lighting control features.

According to the case study [4], the LED Drivers, integrated with wireless Bluetooth mesh, provide the granular control capabilities needed to implement advanced network lighting control strategies. These lighting scheduling control strategies increased energy efficiency and lowered electrical lighting costs while meeting California Title 24 code requirements.

Read the full case study.

STEINEL Uses Bluetooth Mesh to Optimize Building Automation

Using Bluetooth® technology to support building automation, STEINEL Solutions AG helped achieve significant energy savings with smart lighting sensors and Bluetooth mesh. In this paper [5], STEINEL outlines several use cases and shows how Bluetooth enabled sensors provide building operators with a range of optimization options, including:

- **Energy-Efficient Facility Management:** Energy data and consumption can be measured with pinpoint accuracy. This directly reveals unnecessary power consumption and saves costs. Some customers achieve more than 90 percent energy savings and thus operate their buildings more efficiently and more environmentally friendly.
- **Optimizing Space Utilization:** Heat maps provide accurate information about the actual volume of people in commercial properties. They show where there are opportunities to optimize space utilization. For example, data for the utilization of flexible office workstations can be collected and evaluated from the information provided by Bluetooth mesh sensor networks. This allows a reliable overview of actual demand and more efficient building utilization.
- **Streamlining Process Flows:** Data from sensor technology can be used to redesign operational processes. For example, in a hotel, cleaning staff can receive information via Bluetooth mesh as to whether a guest has already left their room. Accordingly, cleaning procedures can be planned automatically. The staff does not have to search for free rooms, allowing them to work faster and more efficiently.

"In addition to its high reliability, the great advantage of the Bluetooth standard is its widespread use and connectivity via smartphones," said Manuel Siegrist, sales and product manager SENSOTEC at STEINEL Solutions AG. "This allows us to offer a control app for our sensors that any facility manager can use without complications."

Read the full paper.

A Brighter Future at the Palazzo Sturm

This article [6] highlights how WiSilica used new advancements in Bluetooth® technology to develop a wide range of applications. These applications support iGuzzini's lighting solutions, and the partnership between WiSilica and iGuzzini has led to many lighting projects that created smarter intelligent spaces.

The addition of DALI into the system provides an added leverage of creating interoperable ecosystems with smooth dimming and zero flickers. The article highlights some of the duos most meaningful achievements across various deployments. The most prominent among them is the

smart lighting deployment at the Palazzo Sturm in Italy which is well-known for consistent and high-quality lighting.

Read the full article.

Espressif Uses Bluetooth Mesh to Help Unlock the Full Potential of the IoT

In a recent Q&A article [7], Teo Swee Ann, the founder and CEO of Espressif, discussed why Espressif uses Bluetooth® mesh for its open-source protocol stack and how it is used across smart home, smart lighting, and smart industry environments.

Thanks to its adoption in smartphones, gateways, and endpoints, Bluetooth technology is one of the most ubiquitous wireless communication protocols. "Its ability to work in a congested 2.4 GHz frequency band through adaptive frequency hopping (AFH), secure design, and a high degree of interoperability has made Bluetooth mesh a robust, safe, and important local-area-network protocol," said Swee Ann. "Also, the design of the Bluetooth mesh protocol can easily be extended to existing Bluetooth devices through OTA (over-the-air) upgrades if hardware resources allow."

Since Bluetooth mesh is defined on top of the existing Bluetooth specification, it can easily be supported on current hardware platforms using the Bluetooth radio.

"The most common use case for our Bluetooth® mesh solution in the smart lighting market is connecting the lighting equipment using the Bluetooth mesh topology," said Swee Ann. "This can be implemented effectively in home, enterprise, industrial, or public environments. Our Bluetooth mesh solution reduces the complexity of deploying and managing the networking infrastructure."

Read the full Q&A article.

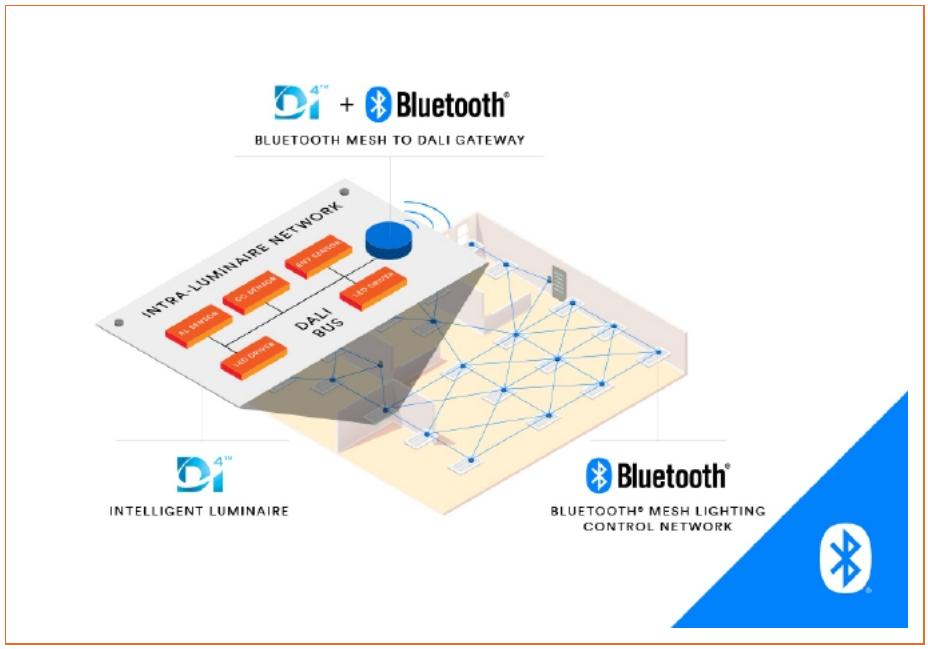

Figure 1: Bluetooth Mesh to DALI Gateway

Silvair Lighting Control Deployment Maximizes Energy Savings

A popular bottled water provider in the U.S. needed to maximize energy savings by installing a lighting control system at its production facilities. At the same time, the facility needed to be able to take advantage of the future connected lighting and building intelligence benefits. To fulfill these needs, a combination of Bluetooth® mesh standard components from different vendors and the Silvair lighting control solution was used.

According to the case study [8], the installation supports 550 lighting fixtures across the facility, including high bay and office lighting. The baseload reduction (just from LED fixtures) was projecting about $85,000 in energy savings annually, and the installation achieved 30 percent in additional energy savings by incorporating Silvair lighting control with the LED luminaires.

Read the full case study.

Why Lighting Professionals Prefer Bluetooth Commercial Connected Lighting

This Q&A article [9] with Sog Yang, software and platform manager at Delta Electronics, looks at how Delta Electronics used Bluetooth® mesh to develop a lighting control solution that helps professionals easily deploy commercial connected lighting systems.

"In the construction and lighting industry, designers and architects do not like to see their work occupied with drilling holes for wiring," said Yang. "Bluetooth mesh uses wireless technology to minimize the need for control wires or a central controller."

Built on Bluetooth mesh's unique, decentralized architecture, the system supports group control, scene recall, schedule settings, and sensor triggers all without needing a central controller. The system offers convenient lighting environment design and deployment for architects, interior designers, and building automation solution providers.

"For designers, Bluetooth mesh uses decentralized, wireless technology to minimize the need for control wires or a central controller," said Yang. "This helps maintain the original design concept and aesthetics. In addition, compatibility with the Bluetooth mesh profile lets us use third-party parts, such as wall switches and occupancy sensors, to produce lighting solutions quickly."

For information technology providers, the commercial connected lighting system could be an IoT backbone for a building's control and sensing applications. Bluetooth mesh lighting control systems provide greater convenience to designers and users and can be flexibly used in various sectors, such as offices, hospitals, retail, and industry.

Read the full Q&A article.

Why Bluetooth Technology is Lighting the Way

In light of the aforementioned use cases and case studies, it is clear we are seeing a realization of Bluetooth® networked lighting control in large-scale commercial environments. But what is driving this trend?

There are four key reasons Bluetooth® mesh networking has emerged as the technology of choice for wireless lighting control in commercial settings.

First, it supports a cost-effective decentralized architecture. The cost of deploying, or even piloting, legacy networked lighting control systems has limited their adoption. Bluetooth® mesh removes the need for centralized controllers, lowering the cost of componentry and reducing upfront labor and installation expenses, allowing designers and specifiers to quickly deliver value to building owners and end users.

Second, Bluetooth technology is ubiquitous and creates the foundation for direct mobile device provisioning. With Bluetooth technology native in 100 percent of smartphones and tablets, system integrators and installers can use simple, user-friendly, commissioning apps that communicate directly with nodes on the network, eliminating the need for specialized engineering expertise as well as internet access and cloud platforms to support installation and operation of the system.

Third, Bluetooth® mesh networking was specifically designed with large-scale networked lighting control implementations in mind. Three key features help separate the scale, performance, and reliability of Bluetooth mesh from other wireless lighting control technologies and provide the resiliency needed by installers, building managers, and end users in commercial installations.

- A decentralized control architecture distributes intelligence to all end devices, eliminating single points of failure to prevent system-level outages
- A unique publish/subscribe message addressing approach significantly lowers messaging traffic on the network, leading to greater network scale and performance
- A managed flood message relay approach enables lighting networks to scale to thousands of nodes while maintaining high performance and reliability

Finally, Bluetooth networked lighting control systems offer a range of benefits beyond simple illumination. The same Bluetooth radio embedded in lighting control devices can also be used to implement advanced building services, such as indoor navigation and asset tracking, enabling networked lighting control systems to shift from a single-function solution to a platform for data-driven smart building services that bring benefits far beyond illumination.

Want to learn more about why Bluetooth wireless lighting control networks are well-positioned to take over commercial lighting? ■

Check out more Bluetooth networked lighting control resources.

AUTHOR: Jason MARCEL
Jason is a marketing program manager with the Bluetooth SIG who specializes in translating technical information into easy-to-read content. He enjoys sharing stories that show how people are using Bluetooth® technology to shape our wireless way of life.

About Bluetooth Technology
With over 4 billion products shipping per year, Bluetooth® technology is the global standard for simple, secure wireless connections. Since its formation in 1998, the Bluetooth community has continued to expand the capabilities of Bluetooth — powering innovation, creating new markets, and redefining communication worldwide. Learn more at www.bluetooth.com.

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Selecting a LiFi Standard when Building your LiFi Product

by Musa UNMEHOPA, Signify, The Netherlands

In this article we discuss design considerations when building a commercial LiFi product. LiFi is gaining traction as a means for fast, reliable, and secure communication in a world where our hunger for data and connectivity seems unsatiable. We define LiFi as an optical wireless communication technology that provides broadband wireless connectivity using modulated light. While today Radio Frequency (RF) based wireless systems (like Wi-Fi and 4G/5G) are dominant, there are use cases and application domains where RF communication poses challenges.

In a previous article in this magazine ["A Closer Look at LiFi Standardization", LpR #84, pp.42-45] [1] we introduced two potential standards for LiFi. These were IEEE 802.11bb [2] and ITU-T G.vlc [3]. We explained that each has its merits, and both may co-exist and address different, complementary use cases and application domains. In this article we dive a little deeper and focus on how specific features of the communication protocol relate to the unique properties of light. We hope these considerations may aid you in your design decisions when developing a LiFi product or system.

Challenges with Radio Frequency Wireless

Before we discuss the technical aspects, let's first recall why LiFi is gaining so much interest as a wireless communications technology that can complement Wi-Fi local area networking and 4G/5G indoor mobile systems. We generally recognize three categories of challenges where RF communication is struggling, and we will briefly introduce each one.

Congestion

The radio frequency part of the electromagnetic spectrum is finite, yet this scarce resource is in high demand due to the growing number of consumer devices and IoT sensors that need to be connected. The resulting spectral congestion and crowding of the radio channels causes performance degradation on the network. The light frequency part of the electromagnetic spectrum (both visible as well as invisible), while also finite, is orders of magnitude larger. And therefore, light communication can offer a welcome solution to the spectrum crunch available in the RF domain.

Electromagnetic Interference

Another key aspect is electromagnetic interference (EMI). While a potential issue in any environment, especially for the use of wireless communications in industrial use cases, EMI can be a showstopper for RF-based networks. Tools and components typically used in industrial environments, like switching mode power supplies, arc welders, and motor brushes, can generate a significant amount of electrical noise in the RF spectrum range. Sometimes to the point where Wi-Fi cannot be used at all. The light frequency part of the electromagnetic spectrum is much less susceptible to electromagnetic interference, making LiFi communication systems much more suitable in these harsh industrial environments.

Physical Security

As radio signals propagate in all directions and pass through structural elements like walls and ceilings, you can never be sure who is eavesdropping on your conversation. Light, on the other hand, does not penetrate walls, ceilings, or coated windowpanes. You can direct your communication signal at the intended recipient and can be sure that your conversation literally does not leave the room. This directional, line of sight property of light adds an additional layer of physical security, on top of which you can run your regular link encryption.

We see that there are some challenges with RF-based wireless communication, i.e., congestion of the RF spectrum, electromagnetic interference, and physical security. LiFi can successfully address these challenges, but the choice of communication standards is important. In the next section, we will outline how key features of the communication standards relate to some of the particular properties of light.

How do Both LiFi Standards Cope with Light?

Neither IEEE 802.11bb nor ITU-T G.vlc were especially created from the ground up as a dedicated LiFi standard. IEEE 802.11 is of course the protocol suite for the popular Wi-Fi systems, while ITU-T G.vlc has its origins in wired home networking for coaxial cables, twisted pair, and power lines. The benefit of re-purposing an existing standard is that many tried and tested communication features can be reused and applied in the optical wireless domain. This applies equally to both IEEE 802.11bb as well as ITU-T G.vlc. But as neither standard was originally designed with LiFi in mind, some features of these standards fit better with the unique properties of light than others. In this section we will explore some of these features.

How does the Signal Carry Data?

An important feature in communication systems is modulation, which is the process of encoding information such that it can be transmitted over a physical medium (such as an RF or Optical channel). Orthogonal Frequency Division Multiplexing (OFDM) is a popular modulation method for LiFi, because it divides the bandwidth of the channel into smaller subcarriers and subsequently modulates the data on each of these subcarriers separately. This opens the possibility for LiFi systems to make optimal use of a specific property of light channels, namely that frequency response is predictable. For example, LED performance decreases at higher frequencies. Because of this low-pass frequency response of LEDs, using the same modulation scheme across the entire LED channel may result in suboptimal data throughput. That is because subcarriers with high Signal-to-Noise (SNR) ratio may be underutilized, while subcarriers with low Signal-to-Noise ratio may be entirely unusable. With OFDM, a mechanism known as adaptive bitloading is possible, whereby subcarrier modulation across the low-pass response of the LED allows the LiFi system to load more data towards the high-quality (high SNR) subcarriers in the LED channel and restrict data loading towards the lower quality (low SNR) subcarriers that fall in the roll-off region. Depending on channel quality, anywhere from 2 to 10 bits of data can be coded in a single OFDM subchannel.

"Neither IEEE 802.11bb nor ITU-T G.vlc were especially created from the ground up as a dedicated LiFi standard."

MUSA UNMEHOPA

Because the ITU-T standard was originally designed for wired home networking systems, the protocol had to be able to deal with uneven conditions on different frequencies across these different wired networks. As a result, adaptively loading the different subcarriers based on their diverging performance characteristics is an integral feature of ITU-T G.vlc.

In contrast, RF channels do not have a predictable frequency response, so a structured profile for bit loading is impractical. Because of many random reflections, called multipath, the received SNR varies wildly with frequency. Using adaptive bitloading is not supported by Wi-Fi standards, because it would create a huge overhead in RF: the negotiation for how many bits to load per frequency bin would be excessive and would need to be repeated very frequently.

Since IEEE 802.11bb reuses Wi-Fi capabilities, LiFi systems based on IEEE 802.11bb are unable to use any bitloading mechanism to optimally exploit the specific performance properties of optical communication channels, which may result in sub-optimal data throughput.

IEEE 802.11bb is a particularly poor match for LED-based LiFi, where large portions of spectrum are strongly attenuated but are still good enough to contribute significantly to the system throughput.

How is the Signal Generated and Transmitted?

In its most basic form, any digital communication system architecture consists of a baseband (which generates the digital waveform that encodes the data) and an analogue front end (which transmits the signal on a particular medium in the analogue domain). The resulting carrier wave is higher in frequency than the baseband signal, so the data can propagate over longer distances. For example in Wi-Fi devices, we have an IEEE 802.11 baseband unit and an RF Front End, and carrier modulation shifts the baseband signal up to the RF frequency range.

A LiFi device would ideally have a baseband unit and an Optical Front End (instead of an RF Front End), where the baseband signal is used to drive an optical emitter such as an LED or laser. LiFi devices based on ITU-T G.vlc work exactly this way, where a commercially available G.hn baseband chip is combined with an Optical Front End for wireless data communication over an optical channel. LiFi devices based on IEEE 802.11bb could in theory use the same basic architecture, comprised of an IEEE 802.11 baseband and an Optical Front End. The challenge however is the lack of stand-alone IEEE 802.11 baseband solutions available on the market. The reason is that the Wi-Fi market is highly cost competitive. As a result, all major Wi-Fi chip manufacturers provide System-on-Chip (SoC) solutions, where the Baseband and the RF Front End are integrated in a single monolithic solution and realized as a single silicon chip. This implies that no access is provided to internal signals between individual components of the overall system. Specifically for a Wi-Fi SoC, the IEEE 802.11 digital baseband waveform is not separately accessible. Instead, the SoC only outputs the RF signal. In other words, the baseband signal is already shifted to the RF frequency range. And in order to be transmitted over an optical channel, the RF output would have to be shifted back down to baseband in order to drive an optical emitter. The reverse is true at the receiver: baseband output of the optical receiver would have to be shifted up to the RF band expected by the SoC. This extra frequency shifting is inefficient (with a penalty in terms of power consumption, heat dissipation, processing time, and performance) and it adds components (with a penalty in terms of bill of material and size). The additional components you would need for the additional frequency up and down conversion include an RF mixer, phase-locked loop, local oscillator, filters, amplifiers, etc. And as ASIC solutions for this mixing step are not yet commercially available, you would have to use discrete components. All this adds to the challenge of industrializing a commercially viable IEEE 802.11bb LiFi device.

One possible alternative to a Wi-Fi SoC could be to use an FPGA (Field-Programmable Gate Array) which is programmable and reconfigurable after manufacturing. Designers can program or configure the FPGA to perform baseband functionality and provide the baseband signal as directly accessible output. Such an approach would obviate the need for the additional mixing step required with Wi-Fi SoC solutions in order to build a LiFi device. However, because an FPGA is essentially a multi-purpose solution which can be configured to perform a wide variety of functions, it is not optimized for cost, low power, and performance. And therefore, the challenge of industrializing a commercially viable IEEE 802.11bb LiFi device remains.

How can Multiple Devices Send Data on the Same Network?

Another key part of every multi-user communication protocol is the mechanism by which devices gain access to the network for their data transmissions. When multiple devices wish to transmit data over a shared medium, collisions may occur. To avoid such collisions, a mechanism called carrier sensing can be used, which means that the device monitors (i.e., senses) the shared medium (i.e., the carrier) to check if the medium is available before it decides to transmit its data. If the device senses that the network is in use, the device backs off and waits for a randomly distributed amount of time. Once the back-off timer

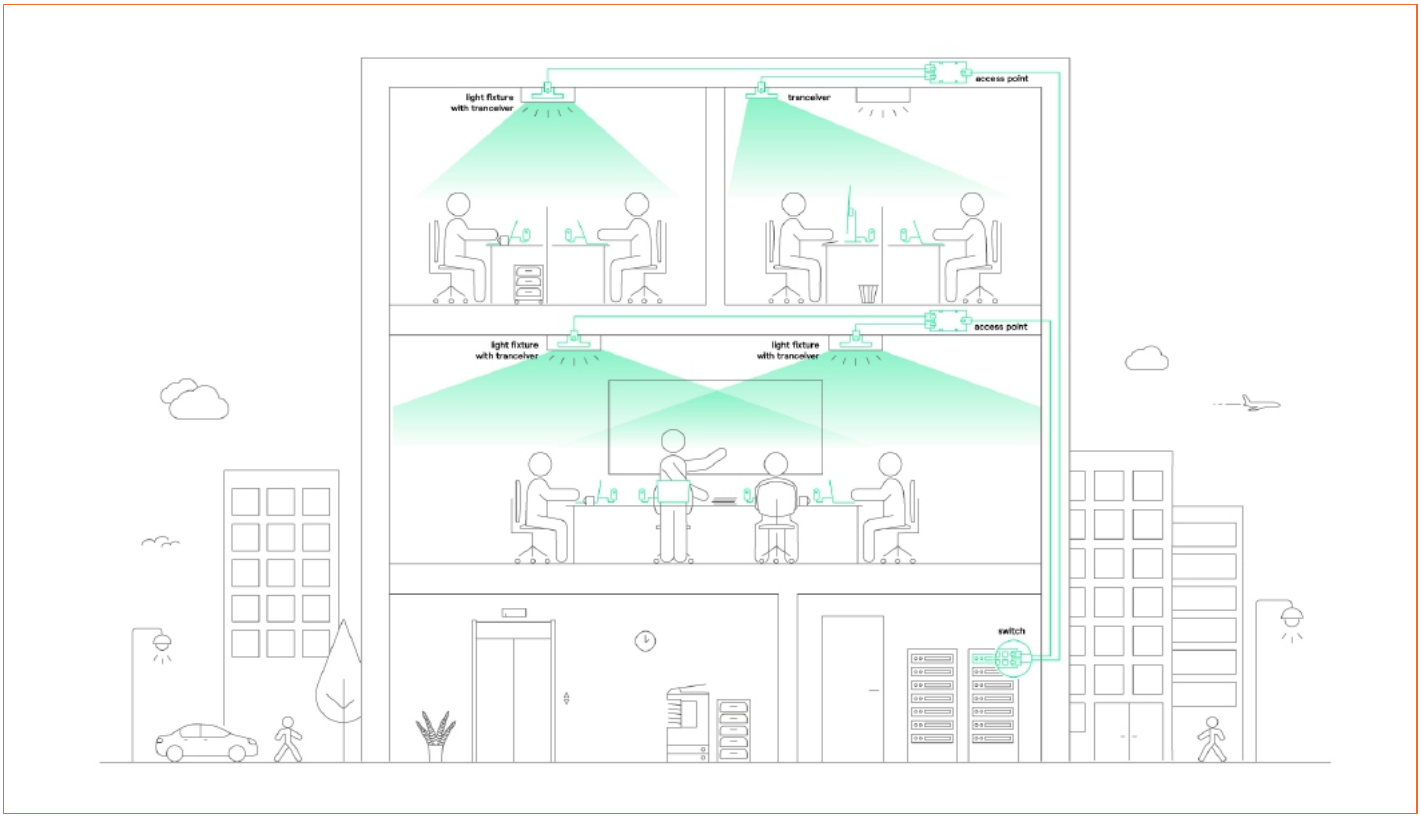

Figure 1: Typical LiFi installation in an office environment.

Figure 2: LiFi makes sure your data stays in the room.

expires, the device then checks again if the network is free and repeats the process. As RF signals propagate in all directions, each device is able to detect the transmissions of all other devices, and therefore carrier sensing is an effective method to avoid collisions.

Like Wi-Fi, the IEEE 802.11bb protocol uses carrier sensing (in particular CSMA – Carrier Sense Multiple Access) as the mechanism to gain access to the shared medium. In Wi-Fi, this works because a device can hear traffic from neighboring devices. Because of the directional, line-of-sight property of optical wireless communication, LiFi end user devices typically cannot sense (i.e., see) each other, and hence an end user device cannot detect if an access point is already receiving a transmission from a neighboring end user device which is outside of its field of view. This is known as the hidden node problem. As more devices connect to and share the same network, collisions become more frequent and performance degrades, eventually to the point that the system becomes unusable. For this reason, carrier sensing, while very appropriate in the RF domain, does not work so well in the optical domain.

Carrier sensing is a distributed medium access mechanism, where devices on the network contend for network access. An alternative, centralized medium access mechanism, is time scheduling whereby the access point allocates non-overlapping time slots to different devices to use for their transmissions on the shared network. The ITU-T G.vlc protocol uses time scheduling (in particular TDMA – Time Division Multiple Access). With time scheduling, devices do not need to contend for access, but rather take turns in accessing the network, so as to avoid collisions. We have seen that, because of the hidden node problem resulting from the line-of-sight property of light, distributed contention-based access mechanisms are prone to collisions and the ensuing network performance degradation.

"At Signify, we have chosen to build our portfolio of LiFi access points and LiFi end devices on the ITU-T G.vlc protocol."

MUSA UNMEHOPA

Even if mechanisms are employed in an IEEE 802.11bb system to help end user devices see each other, the contention-based nature of CSMA may result in individual users experiencing unpredictable delays and variable data throughput. By using a coordinated access mechanism, ITU-T G.vlc based LiFi can ensure reliable access for ongoing sessions. This leads to a guaranteed low latency, making it ideal to use for stable video conferencing or VR sessions.

ITU-T G.vlc based LiFi is therefore better equipped to guarantee Quality of Service (QoS) than IEEE 802.11bb based systems.

Conclusion

We examined the applicability of the IEEE 802.11bb and ITU-T G.vlc standards for LiFi implementations. We explained why adaptive bitloading, baseband access, and medium access are key to the design and implementation of commercial LiFi products. And we have argued that, for each of these considerations, ITU-T G.vlc is the better choice of communication standard.

At Signify, we have chosen to build our Trulifi portfolio [4] of LiFi access points and LiFi end devices on the ITU-T G.vlc protocol, for the reasons outlined in this article. And several other LiFi companies have followed suit. There are of course many dimensions to take into consideration when developing a LiFi product, including commercial, technical, supply chain, etc. Different considerations may be more important or significant for your project, depending on your position in the value chain and where you are coming from. For companies with an RF communications background, it is important to take into account the unique properties of light. And for lighting companies it is necessary to pay attention to the behavior of specific communication protocols. In this article we have aimed to point you to some of the more salient systems design and architecture considerations. We hope it will help you designing a LiFi product that is appropriate for your market and your customer base. ■

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Good Light Guide for Healthy, Daytime-active People

Good Light Group

Preface

The Good Light Group is committed to spreading knowledge and practical advice when it comes to our bodies' need for 'good light'. In years to come, we envision this knowledge reaching all who live and work indoors during the day and becoming a new building block to enable us to live in good spirits and health. We hope that you enjoy this first edition of the Good Light Guide, and that it inspires you to join the movement #goodlightgroup, to sign up for our newsletter at goodlightgroup.com and especially to share the knowledge in this guide with family, friends, neighbors and colleagues. If you are interested in doing more, please write us an email to: info@goodlightgroup.org.

Good Light Group

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This first edition of the Good Light Guide has been made possible thanks to the passion and knowledge of our participants and network of specialists. While we encourage all to spread the word, please contact us prior to distributing this document widely.
Info@goodlightgroup.com

Good Light has the following beneficial effects on the human body and brain:

Good Light revitalizes us

Good Light is essential for a properly synchronized biological clock and that clock is responsible for our day-night rhythm, and how well we sleep.

Good Light energizes us

Good Light makes us feel energetic, alert, and enables us to concentrate.

Good Light comforts us

Good Light makes us feel happy, welcome, cosy, relaxed and safe.

Good Light shows us

Good Light supports our vision, enabling us to see objects, colors, contrast, and motion.

There are four characteristics of Good Light that will be defined in more detail in this guide. Good Light is:

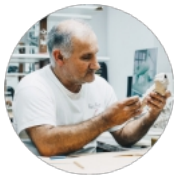
Attractive

Good Light indoors is high quality and comfortable for the eyes.

Dynamic

Good Light indoors, during the day, stimulates with an intensity that is approx. 5× higher than the current standard for vision and relaxes during the evening with an intensity that is approx. 5× lower than the current standard for vision.

Optimized



Good Light indoors has spectral characteristics that vary according to the time of day, personal needs, and specific tasks.

Personal

Good Light indoors can be adjusted by the user to suit their personal needs. A Good Light system safeguards that these personal adjustments are made within the boundaries of an optimal setting.

Introduction

Good Light is the right light at the right time tailored to our activities and personal needs, every day of our life. Good Light is natural light, or electric lighting indoors that mimics the beneficial properties of natural light as much as possible.

The wrong light at the wrong time may result in problems such as mood disturbances, sleep problems, difficulties with learning and memory, problems with vision in the short term, and health problems in the long term.

Limitations

The recommendations in this guide for Good Light are intended to be used by healthy people with a day-active schedule. It is not meant as a treatment for patients; people with eye- or skin diseases or who suffer from mood disorders are advised to seek medical advice. This guide is not intended for people who work shifts. Working in early shifts, late shifts, night shifts, forward or backward rotating shifts impacts your circadian rhythm. Light interventions to support shift workers need to be personalized and may depend on individual differences, shift work schedules and job demands [1].

The Good Light Group developed this practical guideline for Good Light based on scientific knowledge and/or best practices. These guidelines are subject to change and can be updated to incorporate new insights.

Natural Daylight is the Best Light

Being outdoors during the day is very important for people. Daytime light intensities outdoors are always higher than indoors, by a factor of anywhere between ×10 and ×500. And the high light levels outdoors are full spectrum. Sunshine includes infrared (IR) which warms us, and ultraviolet (UV) which, when it reaches the skin, supports Vitamin D production, important for calcium uptake for healthy bone structure, and the immune system [2] [3]. The high light intensities we get when outdoors during the day are also important for well-being, mood, performance, how we sleep at night and for reducing our sensitivity to light in the evening. Exposure to full spectrum, high intensity daylight in the morning prevents our biological clock from getting out of sync with the natural 24h light-dark cycle. It prevents our body from running late, and from fragmented sleep, waking frequently at night [4] [5]. The Good Light Group advises people to enjoy natural daylight as much as possible by being outside during the day. Because we are not able to be outdoors all day, every day, the Good Light Group has come with the following recommendations:

- Unless you would like to fall asleep and wake up later, take measures to get a dose of natural daylight in the morning immediately after waking up for at least 30 minutes, e.g. by taking a walk or bicycle ride outdoors, or walking or biking to work or school. If it is dark when you wake, try to 'see' the first half hour of natural daylight after sunrise [6] [7].
- Take a walk at lunchtime spending at least 30 minutes outside in daylight.
- Play or exercise outside during the day.
- Especially for children, we recommend spending at least two hours outside in daylight every day [8].
- Studies recommend that for periods longer than 20–30 minutes on sunny and/or warm days, you should protect your skin and eyes in an appropriate way against an overdose of UV radiation from the sun [9]. The most common ways to do this is by wearing protective clothes, a cap, sunglasses, by using sunscreen and/or simply moving into the shade. Wearing a cap reduces the light coming into your eyes by ~50%, wearing sunglasses reduces the light coming into your eyes by 5–95% depending on the type of glasses.
- If it is not possible to spend time outdoors, the next best alternative is to spend as much time as you can during the day sitting close to (<1 m) and facing a window.

Photo by Joseph Chan on Unsplash

Indoor Light for Healthy Daytime-active People

People worked and lived outside in natural daylight for many thousands of years. Since the industrial revolution this has changed significantly. Today, people spend 90% of their time indoors. That makes having Good Light indoors essential for our health and wellbeing.

Good Light is Attractive

Photo by Burst from Pexels

Just like in nature, indoor light should be attractive, comfortable and of high quality. This is achieved when indoor lighting shows colors naturally, does not cause too much glare, does not have unwanted artifacts or flicker, provides attractive contrast, lights the space comfortably, does not make noise and feels safe.

Design tips to implement attractive light indoors:

- Let daylight in as much as you can through windows and skylights.
- Increase the overall brightness of the room, don't only light the work surface or task but light the surroundings e.g. the walls and the ceiling.
- Use accents of light to create attractive contrast.
- When you select lighting, choose for a Color Rendering Index (CRI or R_a) of at least 80 [10].
- Avoid Discomfort Glare: design for a Unified Glare Rating (UGR) of 19 or less in long-stay areas (≥30 min) and for UGR ≤22 in short-stay areas (<30 min) [11].
- Avoid Temporal Light Artefacts: Flicker $P_{st}^{LM} \leq 1.0$ and Stroboscopic effects: Stroboscopic Visibility Measure (SVM) ≤1.0 [12] [13] [14] [15].
- Limit audible noise from the lighting installation to ≤24 dBA at 1 m distance [16].

Good Light is Dynamic

Photo by Andrew Neel from Unsplash

The amount of daylight we are exposed to outdoors varies during the day both because daylight itself is ever changing and because we are moving around ourselves, changing what we look at and see, and making changes to the space we are in like sitting in the shade. It might be advantageous to mimic these changes to some extent indoors. People need high light levels during the day, and low light levels during the evening before going to sleep. Good Light indoors is stimulating during daytime with an intensity that preferably exceeds the traditional standards for indoor lighting by a factor 5, while during the evening the preferable light level is dimmed by a factor 5, provided it remains comfortable and safe.

For people 45–50 years and older, higher light intensities and probably spectral changes may be needed to support visual and non-visual (biological and emotional) needs [17] [18]. This is largely due to the normal degrading processes happening in the eye. Many people recognize this as the time when they start needing reading glasses.

Recommended horizontal light levels	<30 years	~50 years	>75 years
Daytime (e.g. 7 am – 7 pm)	≥1000 lux	≥1200 lux	≥1500 lux
Evening (e.g. 7 pm – 11 pm)	≤100 lux	≤120 lux	≤150 lux
Nighttime (e.g. 11 pm – 7 am)	≤10 lux	≤10 lux	≤15 lux

Recommended light levels on the eye in MEDI*	<30 years	~50 years	>75 years
Daytime (e.g. 7 am – 7 pm)	MEDI ≥500 lux	MEDI ≥ 600 lux	MEDI ≥ 700 lux
Evening (e.g. 7 pm – 11 pm)	MEDI ≤10 lux	MEDI ≤10 lux	MEDI ≤ 15 lux
Nighttime (e.g. 11 pm – 7 am)	MEDI ≤1 lux	MEDI ≤2 lux	MEDI ≤5 lux

*Melanopic equivalent daylight illuminance (in the table abbreviated to MEDI) is one of the metrics defined in the international Standard CIE S026:218 [25] recommended to be used in measuring the non-visual effects of light [23].

Design tips to implement dynamic light indoors:

- Use a lighting system that enables you to change the light level;
  dimming ⇒ reducing the light level and/or
  boosting ⇒ increasing the light level.
- Use lighting systems that enable you to change the distribution of light in the room during the day, effectively mimicking daylight.
- Provide horizontal and vertical light levels that ensure adequate visual performance and comfort, while simultaneously providing non-visual (biological and emotional) benefits.
- In the table you will find our recommendations for horizontal light levels. These levels are based on a combination of best practices and scientific arguments [28]. Please note that these light levels must remain comfortable and adequate for the age of the user and the specific task. Timing should be personalized so that it supports personal schedules.

Good Light is Optimized

Photo by João Jesus from Pexels

Just like in nature, the spectral properties (colors) of ideal indoor light vary as a function of the time of day [19]. Light spectrum can be optimized to meet personal needs and preferences and to support specific tasks. During the day, the light spectrum should include a reasonable portion of short wavelengths (cyan light color) to provide the energizing and revitalizing benefits of light. In the evening and at night, the amount of short wavelengths should be minimized to support winding down, enabling a good night's sleep and preventing disruption of the day-night rhythm [6] [20]. With age, from 45–50 years and older, the spectral characteristics required for optimal functioning may change because of changes in the eye, e.g. in the case of the development of cataract [17] [21].

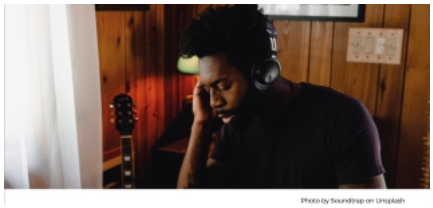
Design tips to implement optimized light indoors:

- Use lighting systems that are 'tuned' or 'tuneable' to support a specific activity. A lighting system is 'tuned' if the spectrum is selected to support a specific activity at a specific time of the day. A

lighting system is considered 'tuneable' if the light spectrum can be changed. 'Tuneable white' systems are most common and can vary in Correlated Color Temperature (CCT). Please note that CCT is only a proxy for spectral content: two light sources with the same CCT can have totally different spectra and therefore a totally different impact on the human non-visual system [22]. The real spectrum is more important than a CCT number. For this reason, you may also choose to use a more advanced 'tuneable color' system. These systems vary not only in CCT, but also in spectral content and in color.

- Although not very common yet, some have reported that it may be beneficial to use a lighting system with additional spectral benefits which can be found in the non-visual part of the spectrum, e.g. supporting Vitamin D production or photo-biomodulation [3].
- Design not only for horizontal light levels as suggested in most lighting application standards, but also for light on the eye. During most daytime activities, this is the vertical light level at sitting or standing height [6] [20] [23].
- The recommended levels in the table are partly based on recent recommendations [20] of a group of scientists, and age corrections [24], and partly based on our own interpretation thereof.

Good Light is Personal



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Good Light indoors can be adapted by the user for personal needs based on suggestions by the system. Individuals may differ in light appreciation with respect to intensities and preference for warm or cool tones of (white) light. In addition, individuals can differ in the timing of their sleep-wake phase, also referred to as being a different chronotype. Early chronotypes have a morning preference and late chronotypes an evening preference [26]. This results in individual needs when it comes to the timing of the dynamic 24h pattern of light, and both its intensity and spectral characteristics. In addition, having personal control over the dynamics and spectral characteristics of light is highly appreciated by individuals.

Design tips to implement personal light indoors:

- Consider using a lighting system with a pre-programmed pattern over the day, and that provides the proper light intensity and spectrum at the proper time [6] [27].
- Consider using a lighting system that offers pre-programmed, task specific light settings to support a range of different activities.
- Many individual users appreciate having personal control over the dynamics and spectral characteristics of the light. The amount of control, or adaption ranges can be selected by the system and made time of day dependent.
- Consider using more advanced lighting systems which include environmental sensors beyond those applied to measure and control the lights. Incorporating sensors like temperature, noise detection, air quality can serve to safeguard and support health and wellbeing of the users. This type of Indoor Environmental Quality sensors should be connected to other building automation systems.

For examples of best practice projects and inspiration see also:
www.valueoflighting.eu
www.katlab.org/public-engagement
lightingforpeople.eu

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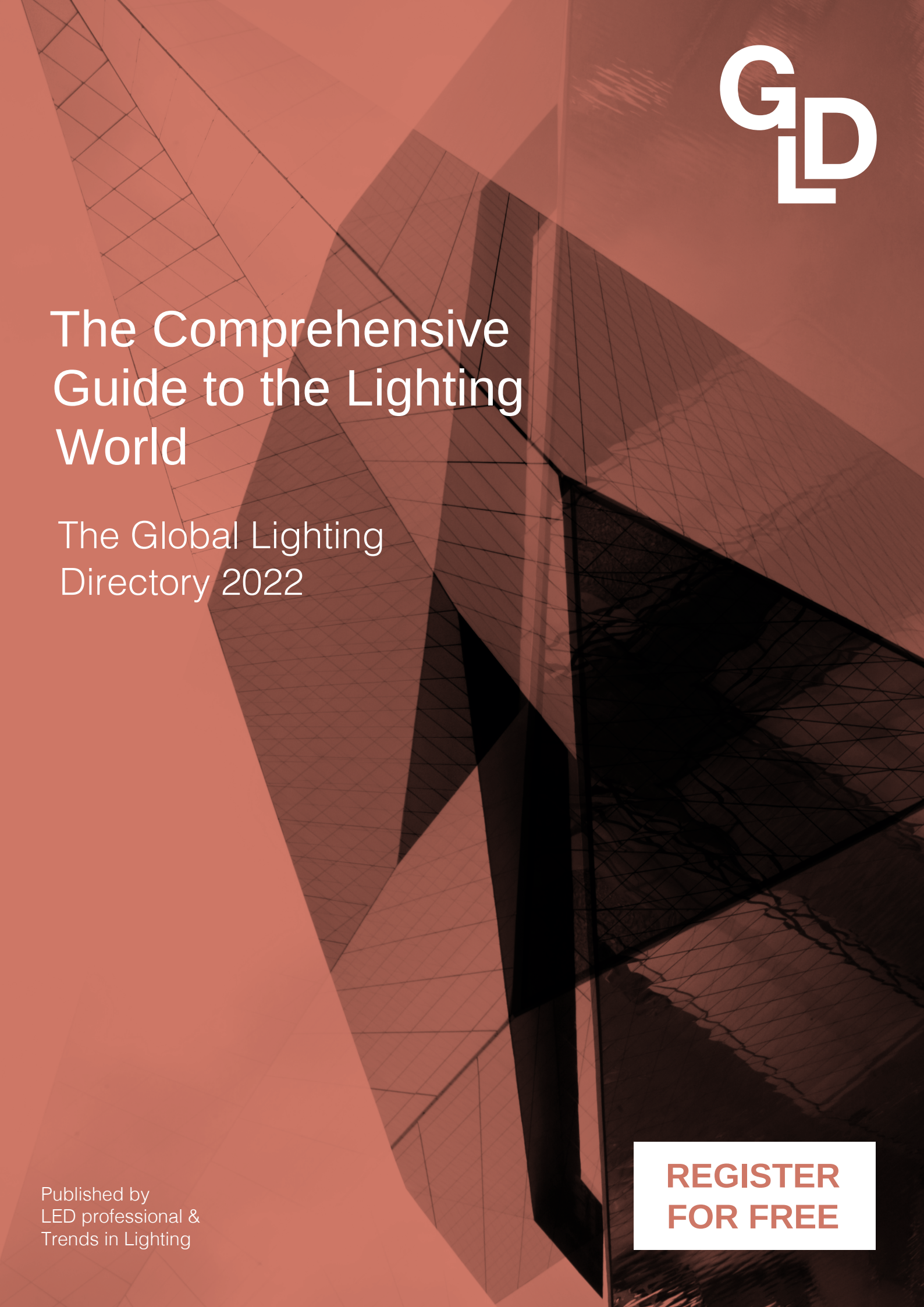

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