

Relio² - A Technical Analysis

Revision 1.05 - December 3, 2018 - info@relio.it

Abstract—Relio² is a professional illuminator that emits white light with very high color rendering.

A series of peculiar characteristics make Relio² suitable for professional, educational and scientific applications:

- Its emitted light represents the current state-of-the-art in terms of spectrum continuity and is certified by dedicated spectrophotometry reports.
- Its interchangeable collimation optics represent the state-of-the-art in terms of chromatic evenness, modulability and collimation efficiency.
- Its advanced mechanical versatility makes for a great addition to a set of professional lighting instruments, with significant savings in medium to long term use.
- Its internal electronics represent the state-of-the-art in terms of energy efficiency, constancy in current control, protection against incorrect use and openness to the most modern wired and wireless communication standards.
- The integration of a re-programmable 32bit processor makes Relio² fully adaptable, thanks to the interaction with its Bluetooth APIs — that are made public — or through a complete customization of its internal firmware.
- The adherence to Open-Source standards and its repairability make Relio² a durable tool, maintainable with components of common availability.
- The availability of a growing series of accessories that can be self-printed in 3D allows for unprecedented versatility of use.

CONTENTS

I	Introduction	1
II	ASPECT: The Light Source	2
III	ASPECT: The Optics	2
IV	ASPECT: Mechanical construction	2
V	ASPECT: Power and Control Electronics	3
	V-A Low operating voltage:	3
	V-B Lack of integrated battery:	3
	V-C Ruggedness:	3
	V-D Very high efficiency:	3
	V-E Ultra-Flicker-free operation:	3
	V-F Pure current-driven brightness control:	3
	V-G Scotopic brightness curve:	3
	V-H Integrated microprocessor:	3
VI	ASPECT: Wired and Wireless Control	4
VII	ASPECT: Adoption of Open-Source and Easy-Maintenance Standards	4
VIII	ASPECT: FDM[®] 3D-Printable accessories	4
IX	Target Audience	4

X	Kits	4
	X-A The Base Kit contains:	4
	X-B The Desk Kit contains:	4
XI	Variants for specific uses	5
XII	Technical Specifications:	5

I. INTRODUCTION

Color rendition is the ability of a white light source to faithfully represent the colors of objects and surfaces illuminated with it.

Natural light emitted by the Sun is considered the light source with maximum chromatic fidelity. This is given by the particular spectrum curve assumed after it originates from an almost ideal black body and passes through a layer of Earth's atmosphere that alters its composition.

Artificial light that comes closest to this spectrum composition is generated by incandescent lamps: because of the same operating principle of incandescent black bodies, incandescent lamps emit light with a very high chromatic fidelity.

Like the Sun, incandescent lamps emit spurious wavelengths (IR, UV), not visible and potentially undesired.

The presence of these spurious wavelengths involves waste of energy in the form of heat and makes incandescent lamps unsuitable for technical uses where low operational temperature, reduced size of lighting fixtures and limited radiated energy to the illuminated surfaces are utmostly required.

Incandescent lamps are being gradually replaced by commercial LED lamps.

However, these LED sources that are available in large-scale distribution benefit energy efficiency at the expense of spectrum continuity: that generally leads to unsatisfactory color rendition.

Relio² emits a better, more continuous spectrum of visible light, inheriting many of the positive features of incandescent

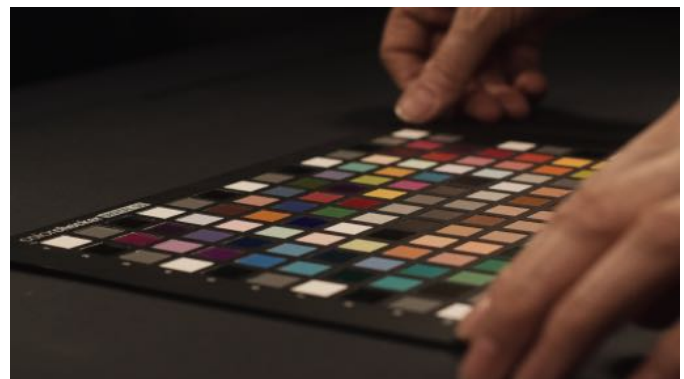


Fig. 1. Colorimetric chart used for calibration.

lamps, minus the excessive energy consumption and without emitting harmful ultraviolet and infrared radiations.

To make Relio² the state of the art of professional lighting, we worked on the following aspects: light source selection and specification, creation of appropriate collimation optics, creation of customized housing mechanics, creation of tailor-made electronics, creation of a custom remote control system, opening to Open-Source and de-facto standards, availability of three-dimensional models of additional accessories to continuously expand its functionality.

II. ASPECT: THE LIGHT SOURCE

The color temperature (CCT) of Relio² LED is 4000K, a neutral white with very high color rendering and certified by CRI, TLCI, CQS, TM-30-15, CIE1931, CIE1976, IEC-SDCM standards.

Upon request, each Relio² is individually calibrated and the emitted light is certified by a spectrophotometry performed on each single product.

For more technical or more critical uses, RAW spectrometry is provided, for example to *mathematically* calculate white-point balance.

Following are the main technical specifications of the 4000K version:

- **CCT:** 4000K
- **CRI (Ra):** 95
- **CRI (Re):** 92
- **TLCI:** 96
- **CQS:** 94
- **TM-30-15:** 91
- **CIE1931:** 98
- **CIE1976:** $x = 0.2235$, $y = 0.5023$
- **IEC-SDCM:** 1 SDCM (1-step MacAdam Ellipse)
- **Lux:** >40000 lux @ 0.25m (with 10° optics installed)
- **PPFD (400-700nm):** 625.44 $\mu\text{mol}/\text{m}^2\text{s}$ (with 10° optics installed)

These values are obtained from a measurement averaged from 10 samples coming from the same production batch.

The instrumentation used consists of a dark chamber (black matte-box) and a professionally-calibrated spectrophotometer (Asensetek Lightning Passport Pro, with the following tolerances: wavelength: ± 0.5 nm, x, y: ± 0.002 @ 1000lux, illuminance: $\pm 3\%$, CCT: $\pm 2\%$).

To the benefit of durability, Relio² light source can be updated: every year the state of the art of LED sources advances and, upon request, every Relio² can be updated to the latest revision of its LED emitter.

III. ASPECT: THE OPTICS

Classical collimation with an open parabola is not suitable where it's required to guarantee constant color rendering throughout the whole lens aperture. This type of lens, in fact, collimates along its axis just the light emitted laterally from the LED (warmer light), without gathering the light rays produced frontally (colder light). This produces a warmer central spot, and an undesirable peripheral crown with colder or deviated tint.

The collimation optics used by Relio² are of TIR (Total Internal Reflection) type. A peculiarity of this family of optics is, as the name implies, the ability to collect and collimate the totality of light emitted by the LED (in its upper 180° arc).

Above the main TIR prism, a second collimation stage is present, formed by a multitude of hexagonal honeycomb-shaped lenses, in order to furtherly homogenize the chromaticity of the emitted beam. This solution eliminates any residual spurious collimation artifact, including any traces of chromatic aberration.

To increase the versatility of use, each Relio² kit includes five TIR lenses with different focal openings, starting from 10° up to 90° nominal apertures. These lenses can be installed as desired by the end-user.

Lens geometry is certified by laboratory analysis performed with the aid of a professional spectrophotometer.

The choice of using interchangeable optics instead of using beam modifiers (e.g. additional Fresnel lenses, flaps, shutters, movable focus lenses) is justified by efficiency requirements (and the resulting heat output): by using additional beam modifier optics, a considerable amount of collimation efficiency would be lost.

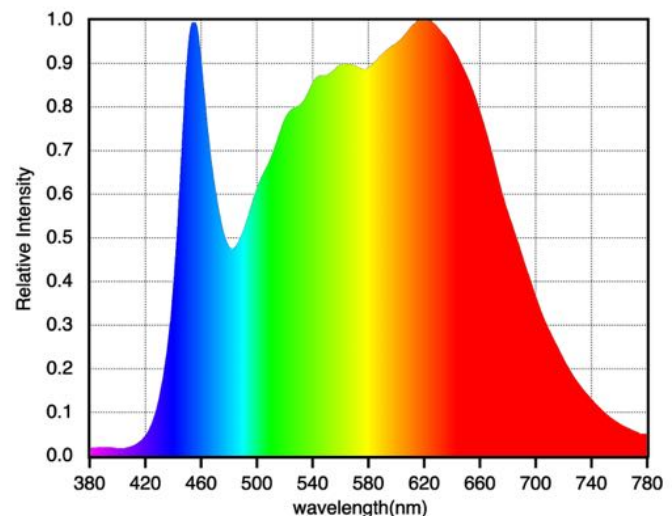
The luminance obtainable with Relio² 10° lens exceeds 40000 lux @ 0.25m.

IV. ASPECT: MECHANICAL CONSTRUCTION

Relio² is based on the concept of modularity: many configurations can be shaped, both in terms of light sources and in terms of anchoring to different surfaces.

The heart of this modularity is constituted by a magnetic anchoring base, used to firmly attach Relio² lamp units to horizontal and vertical planes, without any risk of slippage. Neodymium magnets are placed inside anti-slip rubber mats made of expanded, sealed-cells foam.

While the magnets counteract tensile forces, the expanded foam counteracts cutting forces, allowing both a safe horizontal and vertical assembly and placement.



Graph 1. Spectrometry of Relio² 4000K. Note the wide band around 620-640nm, one of the factors that most influence color rendition.

The overall strength of the magnets of each base is 9.32kgf.

V. ASPECT: POWER AND CONTROL ELECTRONICS

Relio² has fully integrated power supply and driving electronics.

We believe that it represents the current state of the art for the following reasons:

A. Low operating voltage:

It's powered from 5 up to 12 volts, via a micro-USB connector or via a magnetic anti-tear, tangle-free reversible connector.

Its low operating voltage allows safe operation, even in the presence of humidity, public places, places at high risk of fire, or in the vicinity of ancient and valuable objects.

Furthermore, USB standard sockets are present all around the world.

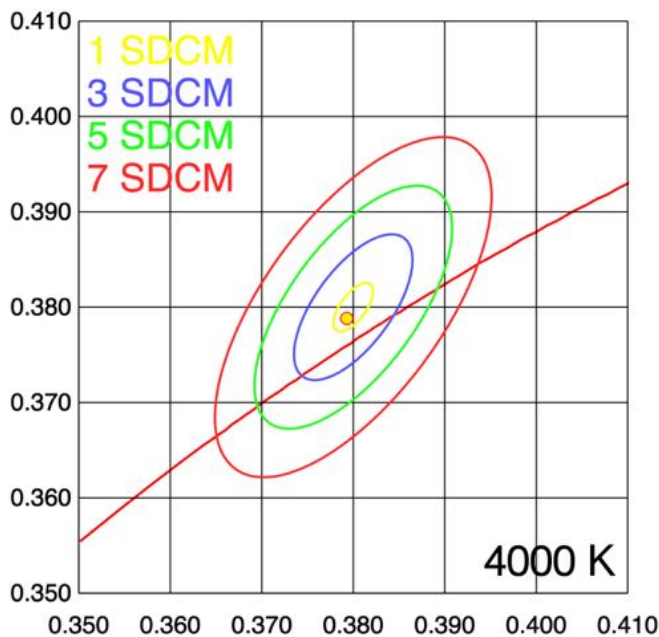
B. Lack of integrated battery:

The presence of an internal power source drastically decreases the useful lifespan of a product.

When power-dense lithium-ion batteries (Li-Co, Li-Mn) are used, the risk of an exothermic, catastrophic reaction must be taken into account.

The absence of an integrated battery allows for safe use, even in the presence of humidity, public places, places at high risk of fire, or in the vicinity of ancient and valuable objects.

When off-grid usage is required, a phone-charging USB power bank can be used as power source; a common 12V DC power supply can be used as-well.



Graph 2. Relio² spectrum falls inside MacAdam first step, exactly on the planckian locus.

The power draw of Relio² at maximum brightness is just 5Wh. Taking into account electronics efficiency losses, optical collimation losses and LED light output conversion loss, total body-radiated heat can be estimated at 2W.

C. Ruggedness:

We designed the state of the art of overload and short-circuit protection circuits. A semiconductor circuit modeled as quasi-ideal diode (<2% inefficiency) protects Relio² from polarity inversions, out-of-range supplies (60V max), involuntary connections, alternating currents, voltage surges, electrostatic discharges and lightning up at 20kV.

Likewise, its 3.3V and 5V logic inputs are also protected.

D. Very high efficiency:

Relio² electronics have a calculated efficiency up to 95%.

E. Ultra-Flicker-free operation:

Traditional control electronics of LEDs generate harmonic ripples. Relio² uses a very high-frequency synchronous buck driver (750kHz) that reduces ripple to less than 2% @ 750.000Hz. Thanks to this, the emitted light is very homogeneous even when performing professional, ultra-slow-motion recordings up to 10,000 frames per second.

F. Pure current-driven brightness control:

Traditional LED brightness control electronics use square wave, pulse-width modulation (PWM) dimming techniques, which make the brightness curve uneven and cause very rapid on-off switching cycles of the emitted light.

In this case too, the oscillations are recorded by video cameras and can generate harmonic beat phenomena. Relio² controls light in a pure variable-current form for the entire range of brightness.

The result is even better than what can be achieved by dimming an incandescent lamp with leading- and trailing-edge dimmers.

G. Scotopic brightness curve:

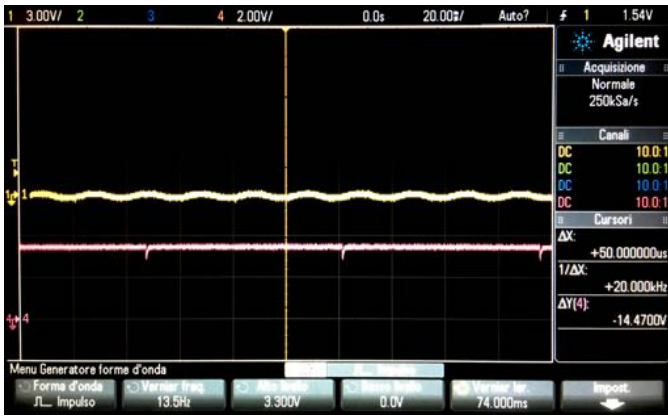
Human eyes do not respond linearly to increases and decreases in brightness levels, due to non-linearity of internal eyes' structures used for the perception of color and brightness. We studied and implemented a linearizing matrix inspired by the CIE-1931 scotopic curves. This matrix uniformes the transition of Relio² light from maximum to minimum brightness. The result is a linear adjustment curve that pleases the human eye, especially in low light conditions.

H. Integrated microprocessor:

Relio² electronics house a tiny (5mm x 5mm x 1mm) ARM[®] Cortex M0 32bit, 40MHz processor, with integrated Bluetooth LE amplifier and integrated patch antennas.

The presence of a microprocessor is what drives all the brightness adjustment functions listed above.

Relio² microprocessor is completely re-programmable.



Graph 3. Light ripple at 98% brightness level.

VI. ASPECT: WIRED AND WIRELESS CONTROL

Relio² allows brightness control in two ways: via wireless Bluetooth®, or via connection to PWM @ 20Khz digital logic outputs (e.g. Arduino, Raspberry PI, Siemens PLC).

Bluetooth LE allows wireless control up to 10 meters away, via a free dedicated App on iOS and Android mobile phones or by writing custom control code on HTML and JavaScript in Google Chrome (through WebBLE public APIs, standard on Chrome v70+).

Among the various special features available, we cite:

- A "Safe Mode" to be used in public places or museums, which deactivates the internal Bluetooth radio after 15 minutes of inactivity;
- A "Fast Stroboscopic" mode for scientific experiments or to carry out analog, real-life animations in prassinoscopic style.

If it is required to control a multitude of Relio² in parallel, sequentially or at greater distances, an USB cable can be cut apart and the Data+ pin can be connected to a low-level digital PWM output (3V~5V), that will be translated by the internal electronics into pure, current-driven brightness control.

VII. ASPECT: ADOPTION OF OPEN-SOURCE AND EASY-MAINTENANCE STANDARDS

All components of Relio² subject to wear and tear (screws, O-rings, USB cables) are standard and available in common parts retailers.

The unique and proprietary components are made of durable materials: aerospace aluminum (AL6082) with hard military anodization (H-A Mil-Spec Type III), and nautical stainless-steel with very low carbon content (AISI316-L).

Integrated mounting threads follow the UNC 1/4-20 photographic standard.

Access to Bluetooth for Relio² wireless control is documented and released to the public (GAP profiles, GATT and related BLE registers).

Power supply parameters and cable interfacing are documented and released publicly.

Spectrometric acquisitions for Relio² light characterization are released in Open-Source exactly as acquired by our laboratory instruments.

VIII. ASPECT: FDM® 3D-PRINTABLE ACCESSORIES

Relio² engineers have developed proprietary accessories, that are distributed in the form of three-dimensional .STL models that can be printed in 3D with domestic-grade FDM® printers.

These models are released in Open-Source under Creative-Commons-CC license, which allows anyone to create, modify and sell new accessories to augment Relio² functionality.

A three-dimensional model of a universal coupling socket is also made available: basing on this socket, it is possible to model and engineer many types of accessories.

The following accessories are provided free of charge: Barn Doors adapter, Bull's Eye adapter, Anti-Glare adapter, Linear diffuser, Rotating polarizing filter holder, Tripod adapters and photographic stands adapters with standard UNC 1/4-20 and UNC 3/8-16 photographic threads.

IX. TARGET AUDIENCE

Relio² is aimed at those who work with light and need a calibrated, certified, reliable, modular light source that is extremely durable over time.

X. KITS

Relio² is based on a "Base Kit" and a single optional accessory called the "Desk Kit".

A. The Base Kit contains:

- A Relio² light unit
- A magnetic and anti-slip base
- A short mounting rod
- A medium mounting rod
- A squared bolt and many O-ring for coupling the lamp units
- Four interchangeable lenses (10°, 25°, 60°, 10x70° nominal)
- A 1.5 meter anti-snap and anti-tangle magnetic nylon cable
- A 3.0 meters anti-tangle gold-plated premium nylon cable
- Two hex keys to assemble and service the Kit
- Information cards with links to the free smartphone official apps
- A chromatic calibration card
- A template correctly to place the wall-mounting holes
- Four ferromagnetic countersunk washers for practical mounting on non-ferrous surfaces
- User manuals
- Shipping box, which also acts as an exhibition and protective carry-box

B. The Desk Kit contains:

- One long rod
- One counterweight made from stainless steel
- One central nut-and-bolt system
- One additional larger-aperture optic (90° nominal)
- User manuals
- External box, which also acts as an exhibition and protective carry-box

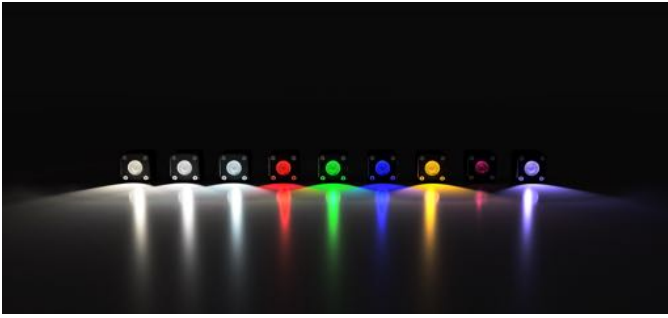


Fig. 2. Some of the wavelengths available.

XI. VARIANTS FOR SPECIFIC USES

On request, it is possible to order Relio² units with custom spectrometry: 4000K (standard equipment), 3500K, 5700K, Deep Red 660nm, Emerald Green 520nm, Phosphor-converted Cyan 470nm, Royal Blue 450nm, Pure Yellow 590nm, IR 850 and 1050nm, Wide-band IR 850 ~ 1050nm, UV 395nm, UV 360nm.

XII. TECHNICAL SPECIFICATIONS:

- CPU: ARM Cortex M0 32bit 40MHz with Bluetooth® BLE 4.2
- Available wavelengths: 3500K, 4000K, 5700K, 660nm, 590nm, 520nm, 470nm, 450nm, 850nm, 1050nm, full-spectrum IR850~1050nm, 360nm, 395nm.
- Certification standards: CE, FCC, RoHS, Bluetooth SIG, CRI, TLCI, CQS, TM-30-15, CIE1931, CIE1976, IEC-SDCM.
- 4000K specs:
 - CCT: 4000K
 - CRI (Ra): 95
 - CRI (Re): 92
 - TLCI: 96
 - CQS: 94
 - TM-30-15: 91
 - CIE1931: 98
 - CIE1976: $x = 0.2235$, $y = 0.5023$
 - IEC-SDCM: 1 SDCM (1-step MacAdam Ellipse)
 - Lux: >40000 lux @ 0.25m (with 10° optic installed)
 - PPFD (400-700nm): 625.44 $\mu\text{mol}/\text{m}^2\text{s}$ (with 10° optic installed)
- Calibrated with Asensetek Lightning Passport Pro:
 - Wavelength: $\pm 0.5\text{nm}$
 - X,Y: ± 0.002 @1000lux
 - Lux: $\pm 3\%$
 - CCT: $\pm 2\%$
- LED is upgradeable in the future: YES
- Optics type: TIR + Honeycomb pattern
- Optics aperture (nominal): 10°, 25°, 60°, 90°, 10x70°
- Magnets attraction force: 9.32kgf (2.33kgf each)
- Magnets are removable: YES
- Power supply:
 - Operational: +4~+15V DC
 - Continuous protection: $\pm 25\text{V}$

- Transient protection (0.1s): $\pm 60\text{V}$
- Overshoot protection (10ms): 20kV
- Logic level input:
 - Operational: +3V3~+5V DC
 - Continuous protection: $\pm 25\text{V}$
 - Transient protection (0.1s): $\pm 60\text{V}$
 - Overshoot protection (10ms): 20kV
- Power consumption: 5Wh (at 100% brightness)
- Body-radiated heat: ~2W (est.)
- Integrated battery: NO
- LED light ripple at full range of brightness: <2% @ 750kHz
- Total electrical efficiency: >90%
- Flicker-free up to: 10000fps
- Light control: Pure current (no PWM modulation)
- External, logic-level brightness control: PWM @ 20kHz
- Bluetooth App: iOS, Android, PC Chrome Web Browser (coming soon)
- Bluetooth range: up to 5m inside, up to 10m outside
- Brightness dimming curve: proprietary, inspired by CIE1931 scotopic curve
- Integrated thread: standard UNC 1/4-20, 7mm length
- Bluetooth API is public: YES
- Published 3D accessories license: Creative-Commons-CC
- Engineering and manufacturing: ITALY



Fig. 3. Some of the modular variations that Relio² can be shaped into.

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