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Integrated Circuit within LED: A comprehensive Guide



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1. IC LEDs

1.1 Full-color LEDs with integrated control

The control of analog LEDs is initially not a trivial task. ICLEDs, on the other hand, allow precise digital control of three LEDs in the basic RGB colors using an integrated control (IC).

In the rapidly evolving landscape of modern technology, smart lighting has emerged as a pivotal innovation, transforming the way we illuminate our spaces. Over the past decade, the lighting industry has witnessed a significant shift towards intelligent LED control, driven by advancements in technology and the growing demand for energy-efficient and sustainable solutions [1, 2, 3, 4]. As devices have become more sophisticated and multifunctional, the demand for high-performance, compact, and efficient components has surged. This trend is particularly evident in the lighting industry, where smart lighting systems have necessitated the development of more advanced and integrated solutions [5, 6].

One of the most notable developments in this arena is the creation of LED packages with integrated controllers [7]. These innovative components are a direct response to the growing need for more efficient and manageable lighting systems. By incorporating the control circuitry directly into the LED package, manufacturers can achieve several key benefits:

- **Size Reduction:** Integrating the controller within the LED package allows for a significant reduction in the overall size of the lighting solution. This is crucial for applications where space is at a premium, such as in modern electronic devices, architectural lighting, and automotive lighting systems.
- **Enhanced Performance:** Integrated controllers enable more precise control over the LED's performance. This includes better management of light output, color temperature, and energy consumption. The result is a more reliable and efficient lighting system that can be finely tuned to meet specific requirements.
- **Simplified Design:** By reducing the number of discrete components needed, integrated LED packages simplify the design and manufacturing processes. This not only lowers production costs but also improves the reliability of the final product by minimizing potential points of failure.
- **Increased Functionality:** With the control electronics embedded in the LED package, it's possible to incorporate additional features such as dimming, color changing, and network connectivity. These features are essential for creating smart lighting systems that can adapt to different environments and user preferences.

Recognizing this trend and the market's demand for innovative lighting solutions, Würth Elektronik has introduced a new family of products to its portfolio: the IC LEDs [7]. This new range of intelligent controlled LEDs is designed to meet the evolving needs of both industrial and consumer markets, offering unparalleled performance, reliability, and flexibility. With features that enable precise control over lighting conditions, the IC LEDs represent the cutting edge of smart lighting technology, setting a new standard for what can be achieved in illumination.

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1.2 Inside IC LEDs

An Integrated Circuit within a Light Emitting Diode (IC LED) is a semiconductor device that combines at least one light-emitting diode (LED) with an integrated circuit (IC) as depicted in Figure 1. The red, green, and blue LED chips are responsible for light emission, while the integrated circuit manages the operational aspects such as: individual LED dimming, color mixing, and communication between the control unit (microcontroller) and the adjacent IC LEDs in the circuit. This combination allows IC LEDs to perform more complex tasks than standard LEDs, making them suitable for a wider range of applications.

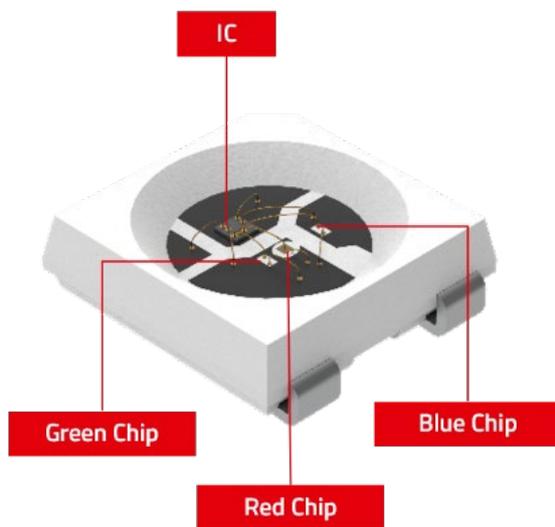


Figure 1: Internal components of an IC LED (PN: 131505093002).

Integrated Circuit role

The main role of the Integrated Controller (IC) in the IC LED is to accept the incoming signal in the Data IN (DIN) pin, translate the information given into the duty cycle to be sent to the LED chips, send the individual PWM signals for the LED chips and, if available, transfer the information of the adjacent LEDs via the Data OUT (DOUT) pin. Because LEDs are semiconductor devices they allow high switching speeds, making the dimming with Pulse Width Modulation (PWM) suitable for any application [6], [8].

This control is accomplished by controlling the average current through the LED (refer to Equation 1).

Calculation of the average current according to the duty cycle of a PWM signal:

$$I_{F_{avg}} = I_{F_{peak}} \cdot D \quad (1)$$

Where D corresponds to the duty cycle of the PWM signal defined by:

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \quad (2)$$

Equation 2 indicates that the duty cycle is equal to the ratio between the switch on time and the period of the signal. In other words, a driver (e.g. MOSFET, bipolar transistor, current sensor, etc.) will act as a “switch” that turns the LED on and off at a fixed frequency [9,10]. As the duty cycle increases, the luminous output of the LED is also expected to be increased. Figure 2 illustrates the expected effect on the brightness of an IC LED, when changing the duty cycle of the PWM signal for the red LED at 25%, 50% and 75%.

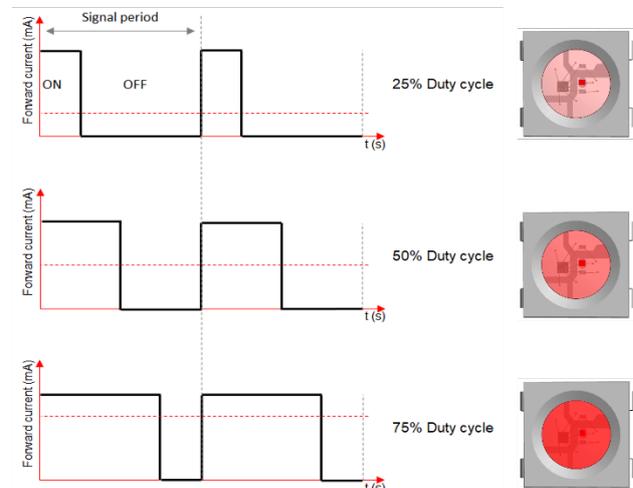


Figure 2: Effect of the PWM control on the brightness of the red chip on the IC LED.

The information of the PWM signal is encoded in “bits” (the most common being 8 and 12 bits per color) defined by the user via a microcontroller (e.g. Arduino, STM32, ESP32, Adafruit Feather). This bit encoding translates into the resolution or available intensity levels that the IC can support. For example, the **1315050930002 IC LED from Würth Elektronik [11]** features an 8-bit color encoder, providing 256 intensity levels per color.

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As there are three LED chips inside the package, this encoding allows over 16 million different color combinations (256^3), enabling a vast array of lighting possibilities.

For more detailed information about IC LEDs, Würth Elektronik provides an application note to help users understand the parameters on IC LED datasheets: [AppNote AN0009](#) "Understanding parameters in ICLED datasheets" [12].

1.3 Differences between analog and digital LEDs

IC LEDs are suited for applications that require sophisticated control and flexibility. They are commonly used in smart home lighting, automotive lighting systems, digital displays, and industrial automation. In smart home systems, for instance, IC LEDs can be programmed to create various lighting scenes and moods, controlled via smartphone apps or voice commands. In automotive lighting, they enable features such as adaptive headlights that adjust the beam pattern based on driving conditions. The precise control and programmability of IC LEDs make them indispensable in modern lighting solutions.

A direct comparison of analog and IC LEDs (depicted in Figure 3) highlights several key areas of difference:

- Analog LEDs are simple and cost-effective, making them suitable for basic applications where budget constraints are a concern. In contrast, IC LEDs are more complex and typically higher in cost due to the integrated control circuitry.

However, this higher cost is justified by the advanced features and greater functionality that IC LEDs offer.

- Control and customization are another area where analog and IC LEDs differ markedly. Analog LEDs have limited control capabilities, primarily through current adjustment. This limits the range of lighting effects and precision that can be achieved. IC LEDs, on the other hand, offer extensive control options, including digital programming for precise light management and customization. This enables a wide array of lighting effects, from smooth dimming to intricate color changes and patterns.
- When it comes to integration and scalability, IC LEDs have a clear advantage. Analog LEDs require additional components for control, leading to more complex circuit designs in large-scale applications. This can be a limitation when scaling up lighting systems. IC LEDs simplify the design process by integrating control electronics, making them more scalable for large and complex lighting systems. This integration reduces the number of components needed, simplifying the design and manufacturing processes.

While analog LEDs are suitable for simple and cost-sensitive projects, IC LEDs offer unparalleled control, functionality, and integration capabilities for advanced lighting systems. As technology continues to evolve, the adoption of IC LEDs is expected to grow, driving innovation and efficiency in the lighting industry.

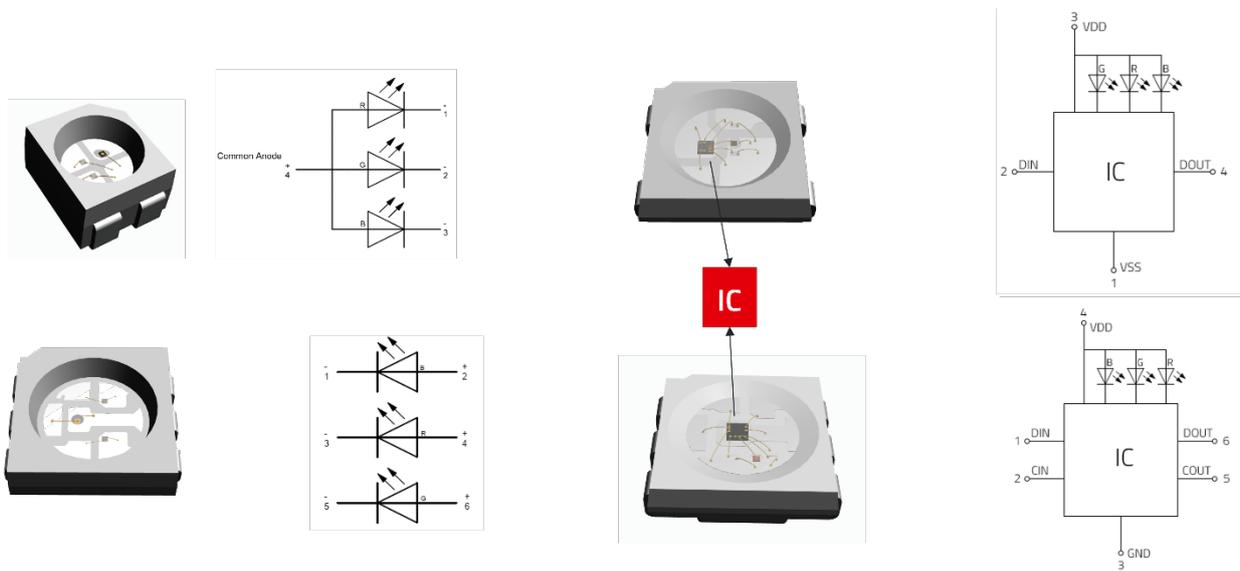


Figure 3: Example of analog LEDs (left) and IC LEDs (right).

1.4 Programming of IC LEDs

Many IC LEDs can be controlled via the SPI (Serial Peripheral Interface) port of most common microcontrollers (e.g. Arduino, Raspberry Pi, and ESP32 ^[13]). These boards provide the necessary interfaces and computing power to handle the communication protocols and drive the LEDs. Regarding the software libraries, there are plenty of open-source resources available online, which makes it easier to create complex lighting effects without needing to write low-level code (one example is the FastLED library on Github ^[13]).

Advanced programming techniques allow for the creation of dynamic lighting patterns or integration with sensors (e.g. distance sensors, motion sensors, temperature sensors or even Time of Flight (ToF) sensors). Dynamic lighting patterns can be achieved by using arrays to store color values and iterating through these arrays to update the LEDs. Whereas the sensor integration requires reading sensor data and using it to adjust the LED parameters in real time, enabling interactive lighting systems.

24-bit Communication Protocol for IC LEDs

The IC LED model [1315050930002](#) from Würth Elektronik ^[11] utilizes a 24-bit communication protocol to control its integrated LEDs. The LED data package is structured in a specific order: green, red, and blue, each taking up 8 bits (a combination of digital "1"s and "0"s). This order must be considered when transmitting data to the LED.

In order for the integrated circuit (IC) to where the length of the pulse determines whether the bit is interpreted as a "0" or a "1". A "0" bit is represented by a shorter high pulse followed by a low pulse, whereas a "1" bit is represented by a longer high pulse followed by a low pulse. The timing parameters for the IC LED [1315050930002](#) include TOH (High Time for "0" bit), TOL (Low Time for "0" bit), T1H (High Time for "1" bit), and T1L (Low Time for "1" bit) are specified in the LED's datasheet and must be strictly adhered to for proper operation. Ensuring precise timing ensures that the LED correctly interprets the transmitted data and functions as intended.

Figure 4 below demonstrates the working principle of IC LEDs. For simplicity, the example provided reduces the 8-bit protocol to just three bits, representing green, red, and blue colors respectively. In the first circuit, the signal sent by the microcontroller indicates that all LEDs should be illuminated in red. The first IC LED in the sequence receives the entire data string, extracts its own information, and then retransmits the remaining data to the next LED in the chain. Even if no further data is sent, the IC LEDs will maintain their selected state until they receive a reset code signal, as specified in the datasheet, followed by a new data command via the DIN pin. Moreover, the circuit below demonstrates how these LEDs can achieve individual pixel control, allowing each LED in the strip to display different colors based on the data received. This feature enables a wide range of creative and dynamic lighting designs, making it possible to create intricate and colorful displays limited only by one's imagination.

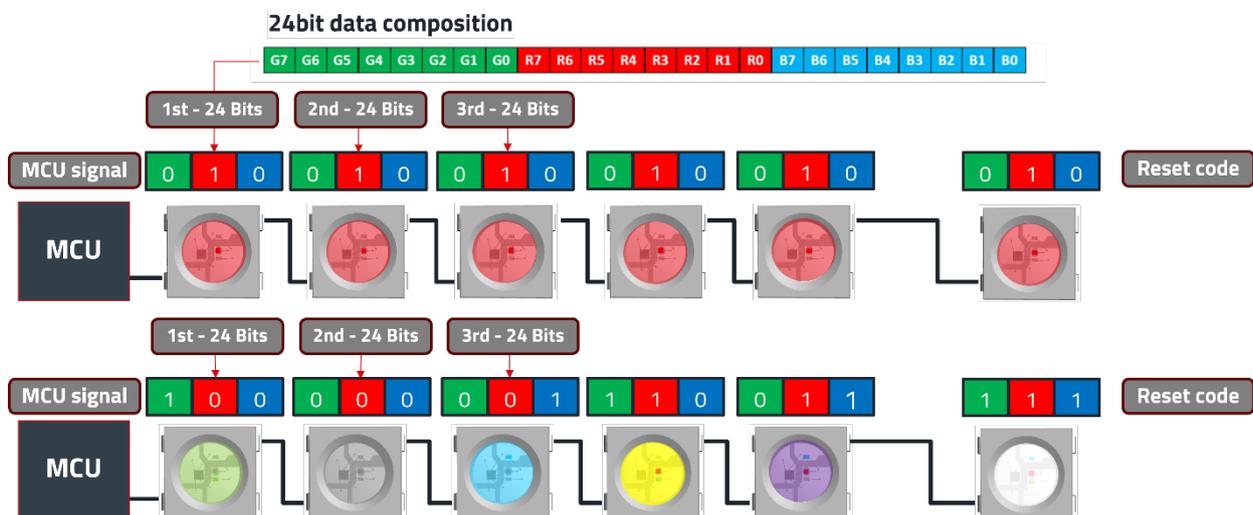


Figure 4: Example of IC LED working principle (individual pixel control).

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1.5 Applications – IC LED Featherwing

The IC LED Featherwing (Figure 5) is a powerful tool for integrating Würth Elektronik's smallest IC LED package ([1312020030000](#)) into microcontroller projects, providing high-density LED displays with individual pixel control.

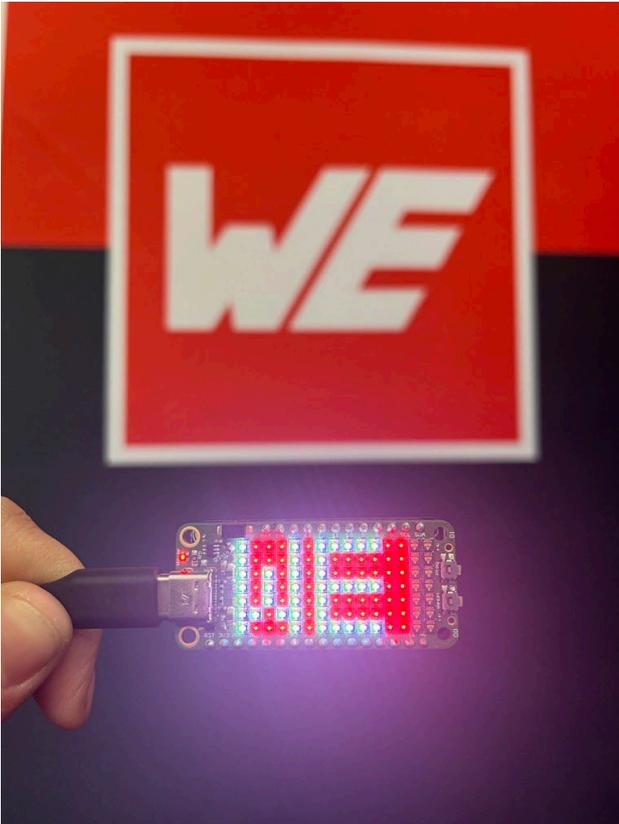


Figure 5: IC LED FeatherWing are easy to program, e.g. with a running text.

These IC LEDs use the 24-bit communication protocol, allowing precise control over each LED's color and brightness. The Featherwing features a 4-layer PCB for EMC compliance, with specific layers for VSS and VDD, and routing on both top and bottom layers. It is powered via a USB-C connector (5V @ 3A) and can be used with 1.8 V logic microcontrollers.

Key characteristics of the IC LEDs on the Featherwing include a supply voltage range of 3.3 V to 5 V, a minimum logic level high of 1.65 V and a maximum power consumption of 8W (reduced to 2.5 W via software). The LEDs provide an emitting power density of up to 16,000 cd/m², with peak wavelengths for red (630 nm), green (520 nm), and blue (465 nm). They support a typical sleep current of 90 mA and a maximum frame rate of 150 Hz.

The Featherwing includes features to optimize the performance of IC LEDs, such as level-shifters for logic levels, EMC filters, resistors for current handling, fuses for overcurrent protection, and a TVS diode for voltage spike protection. What's more, we have even made the control libraries for this product available on our Github page [\[14\]](#), so that the users can create dynamic visual displays, animations, and interactive projects, leveraging the precise control and versatility of Würth Elektronik IC LEDs.

A APPENDIX

A.1 Literature

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