

FAQ on Digital LEDs

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A. Power, Voltage & Electrical Design

Power consumption, operating voltage, current versions, power distribution, stand by current, and external components.

A-01. WHAT IS THE MAXIMUM POWER CONSUMPTION OF A DIGITAL LED?

The maximum power consumption of a Digital LED is determined by its operating voltage, channel current, and number of active channels.

➤ $\text{Power} = \text{Operating Voltage} \times \text{Total Channel Current}$

For RGB Digital LEDs, the maximum power occurs when all R, G, and B channels are fully turned on at 100% brightness. A typical Digital LED, such as the IN-PI55TAT series, consumes approximately 0.2W–0.3W at maximum brightness.

Actual power consumption depends on the specific product design and operating conditions. Please refer to the product datasheet for detailed specifications.

A-02. WHEN THE LED BRIGHTNESS IS NOT SET TO 100%, IS IT DRIVEN BY DC OR PWM?

When the brightness level is below 100%, Digital LEDs typically use PWM (Pulse Width Modulation) control to adjust the average light output.

The LED chip is still driven by a DC current during the ON period, while the internal PWM controller rapidly switches the LED ON and OFF to control the duty cycle.

For example:

- 100% brightness: LED remains ON continuously.
- 50% brightness: LED is ON for approximately half of each PWM cycle and OFF for the remaining time.

The PWM switching frequency is typically high enough that the human eye perceives the output as a stable brightness level.

A-03. ARE THE 5MA AND 12MA VERSIONS OF A SAME PART USING DIFFERENT LED CHIPS?

Yes. The rated current of a Digital LED is typically determined by its built-in LED chip. The 5mA and 12mA versions represent different current limits, which are likely due to the use of LED chips with different specifications, sizes, or manufacturing processes. The maximum current and luminous efficiency of different chips vary, leading to different versions designed for specific applications, such as low power or high brightness.

A-04. WHY DO SOME DATASHEETS HAVE MAX VF AT 5.5V AND OTHERS AT 7.5V?

The VF here likely refers to the maximum input voltage of the IC driver, not the VF of the LED chip itself. Digital LED drivers are typically designed for either 5V or 12V power systems. Therefore, their maximum input voltage (also called VDD or VCC) specifications will differ:

- Max VDD of 5.5V: This type of IC is usually designed for 5V systems, such as the "IN-PI55TAT." The 5.5V maximum provides a safe tolerance range for a 5V supply.
- Max VDD of 7.5V: This might be designed for 12V LED strips or have a special internal voltage regulation circuit. Higher voltage versions often have internal resistors in series with each LED, allowing them to be powered directly by a higher voltage.

Also, ICs from different manufacturers have different operating voltage ranges. Max VDD of 7.5V sometimes means the LEDs would not burn out at 7.5V, not the operating voltage.

A-05. CAN DIGITAL LEDS RUN AT 3.3V VCC?

Most Digital LEDs require a supply voltage higher than 3.3V. The internal driver IC must operate within its specified voltage range to ensure stable communication and LED performance. For example, our current products typically require approximately 3.7V–5.5V operation. A 3.3V supply may cause unstable operation or improper LED control. For 3.3V applications, a dedicated low-voltage solution or customized design may be required.

A-06. HOW SHOULD 24V DIGITAL LEDS BE DESIGNED?

24V Digital LED systems use a higher supply voltage to reduce drive current and power loss in long LED chains. The 24V value refers to the system supply voltage and is not directly applied across each LED chip. Internal circuits regulate the voltage and current delivered to each LED channel.

A-07. WHAT IS THE LOWEST VOLTAGE REQUIRED FOR A DIGITAL LED TO OPERATE?

The minimum operating voltage of a Digital LED is determined by the internal driver IC operating voltage, not only by the LED chip forward voltage (VF). The LED chip VF is the voltage required to emit light and varies depending on: LED color, driving current, and junction temperature. For example, a red LED chip may have a VF of approximately 1.8–2.2V. However, a Digital LED also includes an internal control IC that requires a higher supply voltage to operate correctly.

For most Digital LED products, the required VDD operating voltage is typically around 3.7V–5.5V (depending on the specific device). Operating below the specified voltage range may result in unstable communication, incorrect LED control, or failure to illuminate.

Please refer to the product datasheet for the recommended operating voltage range of each Digital LED model.

A-08. WHAT / HOW MANY CAPS AND RESISTORS ARE NECESSARY TO SUPPORT THE DIGITAL LEDS?

The 5V resistor is only added to the DIN terminal of the headlight and the DOUT terminal of the taillight. Two resistors are sufficient for one light string. Capacitors are typically added to each light, but to reduce costs, 5- 10 pieces can be added together.

A-09. HOW MANY LEDS ARE RECOMMENDED TO BE PUT ON A SAME POWER TRACE?

Under proper power distribution and signal integrity conditions, the number of cascaded LEDs can be extended to several hundred or more. The specific conditions should be based on the actual test data.

There is no single answer to this question; it depends on the current capacity of your power supply and the thickness and length of your power traces.

Generally, each LED consumes about 60mA at full brightness. If your power supply provides 5A, you could theoretically power $5000\text{mA} / 60\text{mA} \approx 83$ LEDs. (This calculation only considers current consumption and does not account for voltage drop or signal integrity.)

However, this is an ideal scenario. In reality, as the number of LEDs increases, the voltage drop on the power trace becomes significant. Longer and thinner wires lead to a larger voltage drop, which can cause the LEDs at the end of the chain to be dimmer or not work at all.

Recommended practices:

- a) Periodically inject power (e.g., every 50 or 100 LEDs) from your power supply, rather than running all LEDs on a single trace.
- b) Use thicker power wires to reduce resistance.
- c) Estimate the total current draw during the design phase and leave at least a 20% margin.

A-10. WHY DO SOME DATASHEETS HAVE $V_{DD} > V_{IN}$ AND SOME OTHERS HAVE $V_{IN} > V_{DD}$?

This sometimes depends on the IC's internal design.

- V_{DD} : Typically refers to the IC's supply voltage.
- V_{IN} : Typically refers to the input signal voltage.

In most LED ICs, V_{DD} and V_{IN} is the same pin, the power input. Therefore, they are the same voltage. However, in certain IC designs, a level shifter may be used, causing the input signal voltage (V_{IN}) to differ from the IC's supply voltage (V_{DD}). For example, you might use a 3.3V microcontroller to control a 5V-powered LED string, resulting in a situation where $V_{DD} > V_{IN}$.

A-11. WHAT IS THE SLEEP MODE POWER CONSUMPTION?

The sleep mode power consumption (or standby power) of a Digital LED is very low, typically in the microampere (μA) range. When no data signal is being sent and all LEDs are off, the driver IC enters a low-power mode. This consumption is the minimal current needed for the IC's internal circuitry to remain active and can be considered negligible for most applications.

B. Thermal, Reliability & Handling

Thermal limits, ESD handling, moisture sensitivity, EMI considerations, and expected lifetime.

B-01. WHAT IS THE MAXIMUM OPERATING TEMPERATURE OF LEDS? AND HOW SHOULD THERMAL DESIGN BE CONSIDERED?

The maximum operating temperature of an LED refers to the maximum allowable junction temperature (T_j) of the LED chip. T_j is one of the most important parameters affecting LED reliability and lifetime.

For most IC-integrated LEDs, the maximum junction temperature is typically in the range of 85°C to 125°C, depending on the device structure and package design. Operating beyond the recommended T_j limit may accelerate lumen degradation, reduce lifetime, affect color stability, and potentially cause permanent device damage.

Therefore, proper thermal management should be considered during circuit and mechanical design to ensure that heat generated from the LED can be effectively dissipated and that the junction temperature remains within the safe operating range.

In practical system design, the recommended PCB pin temperature should be maintained below 60°C. By measuring the temperature at the VDD and GND pins during operation, the LED reliability can be verified when the measured pin temperature remains $\leq 60^\circ\text{C}$, ensuring that the product operates within the designed thermal conditions.

B-02. WHAT HANDLING PRECAUTIONS SHOULD BE CONSIDERED WHEN USING A DIGITAL LED DEMO BOARD?

Digital LED demo boards contain sensitive semiconductor components that require proper ESD protection during handling and testing. Electrostatic discharge may cause immediate failure or latent damage that gradually affects electrical performance and reliability.

To ensure accurate evaluation results:

- a) Use ESD-safe handling procedures.
- b) Properly ground operators and test equipment.
- c) Avoid touching exposed pins and LED components directly.
- d) Follow recommended operating conditions during evaluation.

Proper handling ensures the demo board maintains its designed performance throughout the evaluation process.

B-03. WHY IS THE MSL LEVEL RELATIVELY HIGH? CAN IT BE REDUCED?

The MSL (Moisture Sensitivity Level) rating is determined by the moisture absorption characteristics of the package materials and product structure.

The current MSL level is mainly related to the material properties of the existing package, including: Encapsulation material (e.g., epoxy or silicone), package structure, and internal material interfaces.

Reducing the MSL level would require material or package design changes, followed by reliability validation to confirm product performance. Any improvement would require a dedicated evaluation of materials, process conditions, and reliability performance.

B-04. WHAT EMI EFFECTS SHOULD BE CONSIDERED WITH 800KHZ COMMUNICATION AND INTERNAL PWM SWITCHING?

Digital LEDs use high-speed communication protocols (typically around 800kHz) and internal PWM control to regulate LED output. These switching activities may generate electromagnetic noise, which should be considered during system design.

The 800kHz communication frequency itself generally has limited EMI impact. However, the fast signal transitions and high-frequency harmonics generated by the data switching can contribute to electromagnetic radiation, especially when signal traces are long or improperly routed.

The internal PWM operation of each LED IC also involves high-speed switching, which may introduce noise through:

- Signal lines:
Fast edge transitions on the data line may generate RF noise and cause radiation effects, especially with longer traces.
- Power lines:
PWM switching currents may introduce ripple or noise into the power supply network, potentially affecting other sensitive components sharing the same power source.

Recommendations for EMI Reduction

To minimize potential EMI issues, the following design practices are recommended:

- a) Add proper decoupling capacitors
Place a suitable decoupling capacitor (typically 0.1μF to 1μF) close to each LED IC power pin to reduce high-frequency power noise.
- b) Optimize signal routing
Keep data traces as short as possible and avoid unnecessary routing loops. For longer communication distances, consider differential signaling or signal conditioning solutions if supported.
- c) Ensure good ground design
Maintain a solid and low-impedance ground connection between the LED modules, controller, and power supply to reduce noise coupling.
- d) Consider shielding in EMI-sensitive applications
For applications with strict EMC requirements, shielded cables or additional filtering components may be considered.

With proper PCB layout and power design, Digital LED systems can achieve reliable communication performance while maintaining good EMI/EMC performance.

B-05. WHAT IS THE LIFE EXPECTANCY OF THE DIGITAL LEDS?

The lifespan of a Digital LED is usually measured by the time it takes for its light output to degrade to a certain percentage, for example, "L70" (the time required for brightness to drop to 70% of its initial value).

- Under normal conditions:
The expected lifespan of a Digital LED can be 50,000 to 100,000 hours.
- Factors affecting lifespan:
Operating temperature, drive current, and environmental humidity are the main factors. Excessive temperature and current will accelerate light degradation, significantly shortening the lifespan.

C. Communication Protocol & Data Timing

Signal rate, data latching, serial transfer, backup input, protocol timing, clock IC applications, and code compatibility.

C-01. FREQUENCY / SWITCHING SPEEDS OF LEDs - HOW QUICKLY CAN THEY GET A NEW SIGNAL?

This depends on the Digital LED's communication protocol. Most Digital LEDs, like the "IN-PI55TAT", use a single-wire Non-Return-to-Zero (NRZ) protocol with a data transmission rate of 800kHz.

This means the LED can receive data at a rate of 800,000 bits per second. Specifically, refreshing the data for a single full-color RGB LED takes approximately 30μs. This allows the Digital LEDs to update colors and brightness very quickly.

C-02. DOES THE LED KEEP THE SAME STATE UNTIL THERE IS A REFRESH / NEW SIGNAL?

Yes, it will. The internal driver IC of the LED stores the received RGB data in its built-in register. Once the data is written, the LED will maintain that brightness state until a new signal is received, which refreshes the content of its register.

This is known as the latching function, which allows the microcontroller to perform other tasks without needing to continuously send signals to maintain the LED's state.

C-03. HOW DOES EACH LED IC CAPTURE ITS OWN 24-BIT DATA BEFORE PASSING THE REMAINING DATA TO THE NEXT LED?

Digital LEDs use a serial data transmission architecture, where multiple LED devices can be connected in a daisy-chain configuration. When an LED IC receives a continuous data stream, it processes the data as follows:

- a) Data capture
The first 24 bits of data are captured and stored into the internal register of the LED IC.
Typically, these 24 bits contain 8-bit data for Red, Green, and Blue channels (RGB).
- b) Data forwarding
After capturing its own data, the LED IC regenerates and forwards the remaining data stream through its DOUT (Data Out) pin to the next LED IC.
- c) Chain processing
The next LED IC repeats the same process by capturing its assigned 24-bit data and forwarding the remaining data downstream until all LEDs in the chain have received their corresponding data.

This operation is similar to a shift register, where each LED IC sequentially extracts its own data segment while continuously passing the remaining data to the next device.

C-04. WHAT IS THE ADVANTAGE OF THE LED WITH BACKUP PIN VERSION? AND HOW DOES IT MAINTAIN DATA TRANSMISSION?

Digital LEDs with a backup data input pin (e.g., DIN2) provide improved system reliability by enabling signal redundancy in a daisy-chain configuration.

Advantages of backup pin design:

- Improved system reliability
If one LED IC fails or the primary data path (DIN1) is interrupted, downstream LEDs can continue receiving data through the backup signal path. This prevents a single failed LED from affecting all LEDs connected after it.
- Reduced maintenance risk
For large LED displays, long strips, or applications requiring high availability, the backup function reduces the impact of a single-point failure and minimizes the need for system repair.

How the backup signal works:

LED ICs with a backup pin typically include internal signal detection and switching mechanism.

- a) Under normal operation, the LED receives data through the primary input (DIN1).
- b) If the DIN1 signal is detected as interrupted or invalid, the IC automatically switches to the backup input (DIN2).
- c) The backup input receives the data signal from the previous LED's backup output path, allowing the data stream to continue through the chain.

How does the LED still process the first 24 bits?

The backup function only changes the signal receiving path; it does not change the data processing method. Regardless of whether the data is received through DIN1 or DIN2, the LED IC follows the same operation:

- a) Capture and store the first 24 bits of data (typically 8 bits each for R, G, and B channels).
- b) Display the assigned color information.
- c) Forward the remaining data stream through the DOUT pin to the next LED IC.

Therefore, the backup pin maintains the integrity of the serial data chain while providing additional protection against signal interruption.

C-05. WHAT IS THE COMMUNICATIONS PROTOCOL?

Most Digital LEDs, such as the IN-PI55TAT series, use a single-wire Non-Return-to-Zero (NRZ) communication protocol for serial data transmission. This protocol allows multiple LED devices to be connected in a daisy-chain configuration, where each LED receives, processes, and forwards the remaining data to the next device.

Key characteristics of the NRZ protocol

- Single data line
only one signal line (DIN) is required for communication, which simplifies wiring and reduces system complexity.
- Timing-based data encoding
the protocol uses pulse timing to distinguish between logic "0" and "1".
The data value is determined by the duration of the high-level pulse:
 - Logic "0": Short high-level pulse followed by a longer low-level period.
 - Logic "1": Longer high-level pulse followed by a shorter low-level period.

- Fixed communication speed
the typical communication frequency is approximately 800kHz, with each data bit transmitted within 1.25μs.

Design Considerations

The NRZ protocol provides a simple and efficient communication method with low pin count and easy system integration. However, because data is encoded based on timing characteristics, the controller design and PCB layout should maintain accurate timing control and signal integrity, especially for long data chains or high-density LED applications.

C-06. CAN I SLOW DOWN THE TIMING (OR SPEED IT UP)?

No, generally you cannot. The Digital LED's communication protocol is fixed, and its internal timing circuit is hardwired. It can only work correctly within a very narrow timing window.

- Slowing down the timing:
If the timing is too slow, the IC may misinterpret the signal as a reset signal, leading to data loss.
- Speeding up the timing:
If the timing is too fast, the IC cannot correctly identify the duration of the high and low pulses, which will lead to data decoding errors.

Therefore, when designing your driver program, you must strictly follow the timing specifications provided in the IC's datasheet.

C-07. ARE YOUR DIGITAL LEDS CODE COMPATIBLE WITH WS OR OTHER VENDORS?

This depends on the LED IC used. However, some vendors may have their own proprietary protocols or special features, and these ICs may not be fully compatible with the WS series.

C-08. WHEN SHOULD CLOCK-BASED DIGITAL LEDS BE USED?

Clock-based Digital LEDs are recommended for applications requiring faster response, higher refresh rates, improved timing accuracy, or large-scale synchronization. Compared with single-wire NRZ solutions, the clock signal provides a more stable timing reference.

D. Cascading, Layout & Mixed-LED Systems

Failure behavior in a chain, mixing LED types, last-device termination, 24V LED design, and spacing between devices.

D-01. WHAT HAPPENS IF AN LED STOPS WORKING IN THE MIDDLE OF THE CHAIN? WHAT HAPPENS TO THE LEDS BEYOND IT?

This depends on whether the Digital LED you are using has a backup pin (eg., DIN2).

- If there is no backup pin:
When one LED fails, it cannot pass the signal from its DOUT pin. This means all subsequent LEDs will not receive a signal, and the entire chain will stop working from that point onwards.
- If there is a backup pin (break-point resume feature):
When one LED fails, the next LED will receive the signal from its backup DIN2 pin, effectively bypassing the failed LED and continuing to work normally. Only the single failed LED will be unlit.

D-02. CAN WE MIX RGB, RGBW AND MONO-COLOR DIGITAL LEDS IN THE SAME STRING?

Yes, you can mix them, but it requires careful planning in your software code.

The Challenge: Different Data Requirements

The main challenge is that RGB, RGBW, and single-color LEDs require different amounts of data to function. This is because each type has a different number of individual LED chips (or "channels") to control:

- RGB LED: has three channels (Red, Green, Blue), which requires 24 bits of data (8 bits per channel).
- RGBW LED: has four channels (Red, Green, Blue, White), which requires 32 bits of data (8 bits per channel).
- Mono-color LED: has only one channel (e.g., just White), which requires just 8 bits of data.

The data is sent to the LEDs in a specific order. The first LED in the chain grabs the data it needs, and then passes the rest down the line. If you mix LED types, the total data stream length will be unpredictable and your LEDs will display the wrong colors or flicker.

The Solution: Building a "Data Map"

To make it work, your software needs to know the exact order of every single LED in your string and what type it is. You can do this by creating a simple "data map" or array in your code.

Here's how you'd structure your code:

- Define the LED types:
Create a list or array that specifies the type of each LED in your chain. For example: RGB, RGB, RGBW, RGB, MONO, MONO, RGB.
- Generate a full data stream:
When you want to send a command, your software would read this map and create a single, correctly-sized data.

D-03. HOW DO YOU (OR DO YOU NEED TO) TERMINATE THE LAST LED IN THE CHAIN?

Generally, there is no need to terminate the last LED in the chain. The Digital LED communication protocol is unidirectional, with data flowing only from DIN to DOUT. Therefore, the DOUT pin of the last LED can be left floating without affecting the system.

However, in applications with very long signal chains or a risk of signal reflections, you might consider adding a termination resistor to the DOUT pin of the last LED to absorb signal reflections. This is not a common practice in most applications.

D-04. WHAT IS THE MAX SPACING BETWEEN 2 DIGITAL LEDS?

Theoretically, unlimited cascading is possible, but the output data of the previous cascaded light source must be used as the basis. Only if the data is undistorted can the subsequent cascaded light source decode it!

General Recommendation: To ensure good signal quality, the distance between two Digital LEDs is generally recommended to be no more than 10 cm (approximately 4 inches).

Long-distance Applications: If the distance exceeds this range, the signal line may be susceptible to interference, resulting in timing errors, especially due to signal reflections. If your application requires longer distances, consider the following solutions:

- a) Increase the thickness of the signal line to reduce resistance.
- b) Add a buffer or driver to the signal line to enhance signal strength.
- c) Use a Digital LED with a spare pin (for resumable transmission) to improve link reliability.

E. Demo Boards, Controllers & Software

Demo-board availability, controller platforms, digital interfaces, software libraries, and evaluation tools.

E-01. ARE THE NEW SMALL DEMO BOARDS OPERATING AT MAXIMUM BRIGHTNESS / INTENSITY?

Yes. The new small demo boards are designed to demonstrate the LED performance and visual effects under high brightness conditions.

E-02. WHAT IS THE PART NUMBER AND COST OF THESE SMALL DEMO BOARDS?

These small demo boards are developed for product demonstration and customer evaluation purposes only. They are not standard products for sale. Demo boards can be provided through our Sales / BD team based on customer evaluation requirements.

E-03. WHAT CONTROLLER IS USED FOR THE NEW DEMO BOARD? IS IT STILL BASED ON ARDUINO?

The latest ESP32-C3 development board size is approximately 18mm x 22.5mm, which provides a more compact solution compared with traditional Arduino boards while maintaining sufficient processing capability for Digital LED control.

E-04. WHAT DIGITAL INTERFACES ARE TYPICALLY USED IN OUR HMI SOLUTION DEMOS?

Both Arduino Nano and ESP32-C3 are used, depending on the demo purpose and system requirements..

E-05. IS THERE A DEMO BOARD AVAILABLE FOR TESTING DIGITAL LEDS?

Yes. Demo boards are available for Digital LED evaluation. These boards allow customers to quickly evaluate:

- LED lighting effects
- Color mixing performance
- Brightness and visual appearance
- Overall system integration concept

Digital LED demo boards typically include: a microcontroller, a chain of Digital LEDs, and pre-loaded demonstration programs. Customers can power on the board directly and evaluate the Digital LED functions without developing the communication protocol from scratch.

E-06. DO YOU HAVE ANY SOFTWARE LIBRARIES FOR CUSTOMERS TO USE?

Yes. Digital LEDs are widely supported by open-source software libraries in the industry. For example:

- FastLED
- Adafruit NeoPixel

These libraries simplify Digital LED control by handling the timing protocol and communication details, allowing developers to focus on lighting effects and application development.

For specific Digital LED models, the factory can also provide the corresponding sample code or program examples for customer evaluation.

F. Optical Performance & Product Options

Wavelength/intensity binning and feasibility of brighter or higher-power versions.

F-01. HOW DOES BINNING WORK FOR WAVELENGTH AND INTENSITY IN DIGITAL LEDs?

Binning is a manufacturing classification process used to ensure consistent optical performance among Digital LEDs. During LED production, each device is tested and categorized based on key optical characteristics, including wavelength and luminous intensity.

Wavelength Binning

Due to normal variations in semiconductor manufacturing, LED chips may have slight differences in their emitted wavelength. To maintain color consistency, LED chips are measured using optical testing equipment (such as a spectrometer) and classified into different wavelength bins. For RGB Digital LEDs, the Red, Green, and Blue LED dies are selected within controlled wavelength ranges to ensure consistent color reproduction and stable color mixing performance.

Intensity Binning

The brightness output of an LED can also vary slightly under the same driving current due to manufacturing variations. During production, each LED is measured for luminous intensity and categorized into different intensity bins. LEDs with similar brightness characteristics are grouped together to achieve consistent light output across the product series.

Bin Control in Digital LED Manufacturing

For Digital LEDs, LED chip suppliers typically provide dies with controlled wavelength and intensity bins. During the package assembly process, manufacturers select matched LED dies to maintain optical consistency. This bin control process helps ensure:

- Consistent color appearance between LEDs
- Stable RGB color mixing performance
- Uniform brightness across LED modules and displays

F-02. CAN WE GET A BRIGHTER OR HIGHER POWER VERSION OF THE DIGITAL LED?

A higher brightness or higher power Digital LED version may be possible, but it cannot be achieved by simply increasing the current of the existing product. A higher power design requires re-evaluation of key components, including:

- LED chip for higher optical output
- Package structure and substrate for better heat dissipation
- IC, bonding wire, and encapsulation materials for higher current and reliability requirements

Therefore, a higher power version requires a complete product design review and reliability validation to ensure stable performance. For applications requiring higher brightness, system-level optical design optimization (such as lens, light guide, diffuser, or PCB layout improvement) should also be considered before increasing LED power.