Application note for LED terminals:

Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

Keywords
- LED
- LED control
- Illumination
- Lighting control
- Lighting technology
- Dimming
- EL2564, EL2564-0010
- EL2574
- EL2595, EL2596
- Voltage control
- Current control
- PWM
- DMX
- EtherCAT Terminal
- Bus Terminal

LED control with EtherCAT and Bus Terminals

This application note describes various options for controlling different LED types with EtherCAT and Bus Terminals.
An introduction to LED basics is followed by a description of LED control options using products from the Beckhoff I/O system.

An LED (light-emitting diode) converts electrical energy into light. An LED consists of a semiconductor PN junction.
Like a conventional semiconductor diode, an LED is forward-biased and reverse-biased. When it is forward-biased, the excess electrons in the semiconductor recombine with the electron holes and release energy in the form of photons. The energy of the emitted photons determines the wavelength, which in turn determines the color of the light. The energy, and thus the light color, depends on the semiconducting material used.

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The following important parameters must be considered when selecting the LED and the control system:

1.) Forward current I_F [mA]]

The forward current of an LED is the current flowing through the LED in forward direction from the anode (+) to the cathode (–). For the maximum forward current, a distinction can be made between the maximum current in continuous light mode and in pulse mode. The maximum forward current is usually higher in pulse mode than in continuous light mode.

2.) Nominal current I_N [mA]

If the LED is operated with a forward current that corresponds to the nominal current, the LED will have the properties specified in the data sheet, including the nominal brightness. Operation with I_F greater than I_N reduces the service life of the LED due to increased heat generation. Common nominal currents for LEDs are 20 mA, 350 mA, and 1000 mA.

3.) Conducting voltage U_D [V]

The conducting voltage indicates the level of electrical voltage required for the LED to become conductive. When the conducting voltage is applied between the anode (+) and the cathode (-), a current flows through the LED in forward direction. The conducting voltage level of an LED depends on the semiconducting material. Typical conducting voltage values for different LEDs are 1.6 V for red and 2.6 V for blue emitting LEDs (see Table 1).

4.) Forward voltage U_F [V]

The forward voltage of an LED is the voltage applied in the forward direction between the anode (+) and the cathode (–). The forward voltage is a function of the forward current $U_F = f(I_F)$. This dependence is strongly non-linear. As an example, a relationship between U_F and I_F is shown in Figure 1.

5.) Reverse voltage U_R [V]

The reverse voltage is the electrical voltage applied to the LED in reverse direction. Data sheets usually indicate the maximum reverse voltage. This maximum reverse voltage must not be exceeded, otherwise the LED can be irreversibly damaged. A typical value for the reverse voltage of an LED is 5 V.

6.) Typical wavelength λ [nm]

The typical wavelength is the wavelength of the emitted light at the nominal point.

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The characteristic curve of an LED is strongly non-linear. An LED is non-conductive if no external voltage is applied. The LED starts to conduct when the applied forward voltage UF is higher than the conducting voltage U_D and the band gap is overcome by the electrons. The increase of the forward current is not proportional to the applied forward voltage. A small change in voltage can cause a large change in current. A small change in voltage can lead to a strong change in light emission due to the proportionality of luminous flux and current intensity. This means that LEDs must generally be operated with a current limiter of some form or other, otherwise even slight fluctuations in the applied voltage can destroy the LED.

Figure 1: Example characteristic curve of an LED

There are four common types of control for LEDs:

- Voltage mode (p. 4)
- Current mode (p. 9)
- Pulse width modulation (p. 11)
- Communication protocol (p. 15)
- Pulse train (p. 16)

Each control mode has advantages and disadvantages for certain applications, so the user must decide which mode to use depending on the application.

Fields of application of LED lighting include buildings, stage applications, machine illumination, machine status visualization, and machine vision. The following table shows examples of the four control options for different fields of application.
This table is not exhaustive and should be verified for each application.

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	Application		
	Building/stage technology	General Machine illumination	Machine vision
Dimming	Communication protocol, PWM	Communication protocol, PWM	Current mode
On/Off (non-dimming)/ Pulsing (stroboscope function)	Communication protocol, voltage mode	Communication protocol, voltage mode	Current mode

Table 1: Assignment of the control types to different exemplary applications of LEDs

The different control types of monochrome and multicolored LEDs with digital output I/Os from Beckhoff are described below.

Voltage mode

Voltage mode – e.g., with a battery or a power supply unit, is a simple and cost-effective way of controlling LEDs. All that is needed is an additional R_S series resistor. Due to the linear behavior of an ohmic resistance, R_S makes the overall circuit much less sensitive to voltage changes, resulting in robust LED control.

Formulas for the series resistor:

– 1 LED: $R_S = \frac{U_R}{I_{LED}} = \frac{U - U_{LED}}{I_{LED}}$

– n LEDs connected in series: $R_S = \frac{U_R}{I_{LED}} = \frac{U - U_{LED,1} - U_{LED,2} - U_{LED,n}}{I_{LED}}$

The disadvantage of this type of control is that the luminous intensity cannot be controlled precisely. As described above, a small change in voltage can lead to a large change in current and thus a strong change in luminous intensity. With voltage control, fluctuations in the supply voltage can have a direct influence on the luminous intensity of the LED. It is also important to note that the electrical properties of the resistor are temperature-dependent and subject to aging.

- **Advantages:** Simple design, easy control, LED brightness can be adjusted directly via the voltage, series resistor limits the peak current
- **Disadvantages:** Additional resistance, resulting in waste heat

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The following digital standard outputs from the Beckhoff product portfolio can be used for control in voltage mode (as of August 2023).

EtherCAT Terminals – positive switching

	24 V DC	12 V DC	5 V DC	24…72 V DC
± 20 mA			EL2124	
0.5 A	**EL200x** **EL206x** with diagnostics **EL2809** **EM2042** terminal module, D-sub connection **EL2014** with diagnostics **EL2819** with diagnostics **EL2869** with diagnostics **EL2872** flat-ribbon cable **EL2878-0005** flat-ribbon cable, diagnostics **EL2202** T_{on}/T_{off} 1 µs **EL225x** timestamp **EL2262** oversampling **EL2808** 0 V outputs **EL1259** multi-timestamp inputs/outputs **EL1859** inputs/outputs			
2 A	**EL202x** **EL2828** **EL203x** with diagnostics	EL2024-0010		
2 x 4 A/1 x 8 A	EL2042			
10 A peak				EL2212

EtherCAT Terminals – ground switching

	24 V DC
0.5 A	**EL208x** **EL2889** **EL2872-0010** flat-ribbon cable

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Bus Terminals – positive switching		
	24 V DC	5 V DC
± 20 mA		KL2124
0.5 A	KL2012	
	KL2114	
	KL2408	
	KL2809	
	KL2032 reverse polarity protection	
	KL2212, KL2819 diagnostics	
	KL2404 2-wire connection	
	KL2872 flat-ribbon cable	
	KL2808 0 V outputs	
	KL1859 inputs/outputs	
	KM200x terminal module	
	KM2042 terminal module, D-sub connection	
2 A	KL2022	
	KL2134 reverse polarity protection	
	KL2424 2-wire connection	
	KL2828 0 V outputs	
4 A	KL2442 2-wire connection	

Bus Terminals – ground switching	
	24 V DC
0.5 A	KL2184
	KL2488
	KL2889

The brightness of the LED can be adjusted in voltage mode at Beckhoff I/Os via the series resistor (fixed or via potentiometer). One of the advantages of the fast EtherCAT bus is that PWM can be performed from the central controller. This means a pulse width modulation can be generated from the PLC so that the brightness of the LED can be changed in true color. A maximum convertible PWM frequency must be observed for all the terminals listed above. For details on the maximum achievable frequency, check the Ton and Toff switching times in the technical terminal data in the documentation. Special PWM terminals are recommended for control via PWM, since considerable heat can be generated in the terminal due to transfer losses during fast control.

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DANGER:

The high-frequency light switching may create a stroboscopic effect. If the frequency of the emitted light is in phase with the movement frequency of a rotating machine part, for example, a stroboscopic effect can make it appear as if the machine is stationary despite it moving. This can lead to a misinterpretation by an operator who may intervene due to the apparently stationary machine part, potentially leading to serious injury or death.

1.) Monochrome LEDs

All standard output terminals can be used for monochrome LEDs, regardless of whether they are ground or positive switching. The connection of a monochrome LED is shown in the following diagram as an example on the EL2004 (positive switching) and the EL2084 (ground switching).

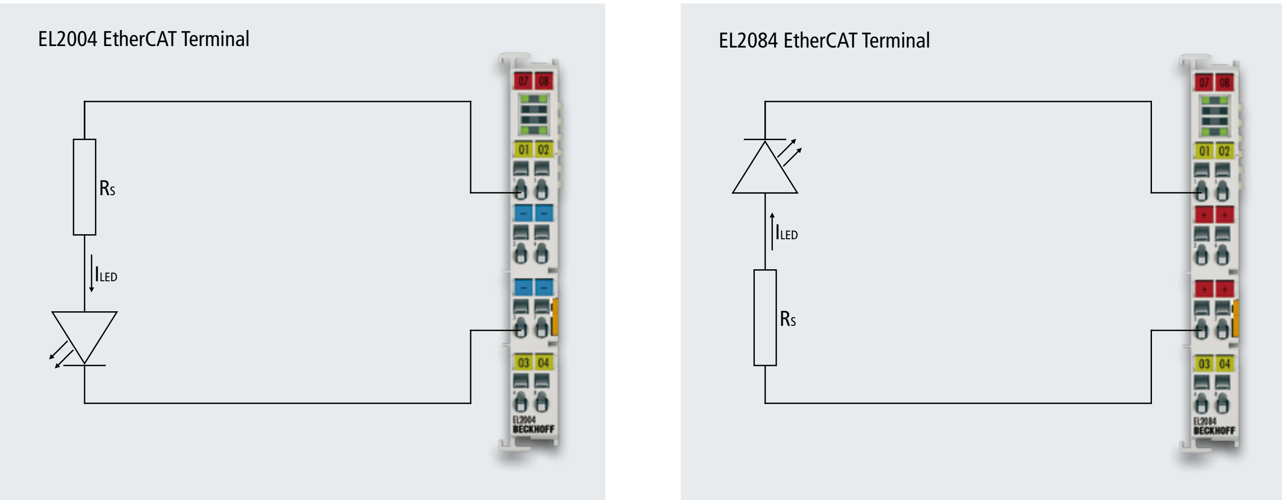

Figure 1: Monochrome LED in voltage mode on standard output

The series resistor must be calculated specifically for the application. A series connection of LEDs on digital output terminals is possible, but must be taken into account in the calculation of the series resistance. It must also be ensured that the output current of the digital terminal is sufficiently high to operate the LED used ($I_{max} = \frac{U}{R_S}$).

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2.) Multicolored LEDs

With multicolored LEDs, the connection type must be taken into account. To save connection lines, the plus connections (anodes) are usually combined on a single line known as a common anode. LEDs with a common anode can only be operated with ground-switching terminals, while the rarer common cathodes can only be operated with positive-switching terminals. Multicolored LEDs with an integrated series resistor can be connected directly to digital output terminals in a voltage-controlled manner. Otherwise, a series resistor must be connected to avoid destroying the LED. The connection of multicolored LEDs is shown in the following diagram as an example on the EL2004 (positive switching) and the EL2084 (ground switching). The series resistances must be calculated for each color, since the different colors have different characteristics (conducting voltage, etc.).

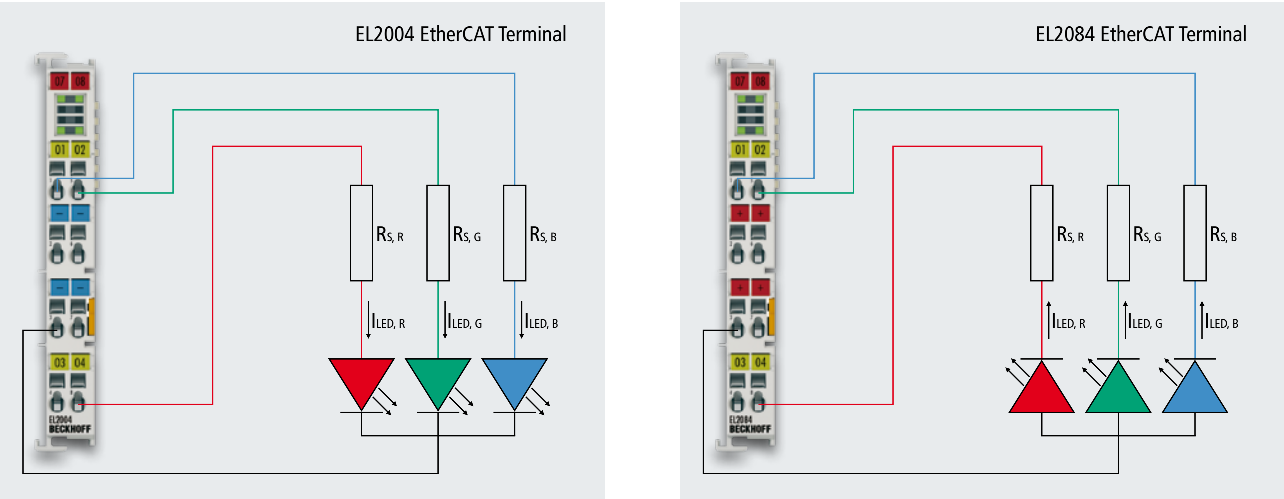

Figure 2: Multicolored LED in voltage mode on standard output

Application note for LED terminals:
Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

Current mode

An LED can be operated directly if a current source (electronic circuit) is used instead of a voltage source (e.g., battery). With current control, the luminous flux of the LED can be adjusted directly via the specified current value without resistance. This means that fluctuations in the supply voltage have no effect on the luminous flux of the LED. The luminous flux is with a current control constant and reproducible. The luminous flux is constant and reproducible with current control. Current control is recommended in machine vision applications, among others.

– **Advantages:** No additional components required; LED brightness is adjusted directly via the current
– **Disadvantages:** A complex power source may be required

Our portfolio also includes products that can be used for current mode. The current control terminals are specifically designed for controlling LEDs, in which case no series resistor is required for the LED. This means that, in addition to the simple operation of an LED, further functionalities such as a trigger input from a camera can be used with the current control or LED terminals. Pulses with pulse lengths of 25 µs and less are possible with the LED terminals. In addition to current-controlled mode, the EL2596-00x0 can be used for both voltage-controlled mode and current/voltage-controlled PWM mode so that the brightness can be changed in true color. In current mode, the brightness can be adjusted directly via the current through the LED.

DANGER:
The high-frequency light switching may create a stroboscopic effect. If the frequency of the emitted light is in phase with the movement frequency of a rotating machine part, for example, a stroboscopic effect can make it appear as if the machine is stationary despite it moving. This can lead to a misinterpretation by an operator who may intervene due to the apparently stationary machine part, potentially leading to serious injury or death.

The following products can be used to operate LEDs in current-controlled mode (as of August 2023).
EtherCAT Terminals:
– EL2595: First-generation LED terminal, 2...48 V output adjustable up/down, max. 700 mA
– EL2596-00x0: Second-generation LED terminal, up to 24 V or 48 V output, max. 3 A
– Further versions in development

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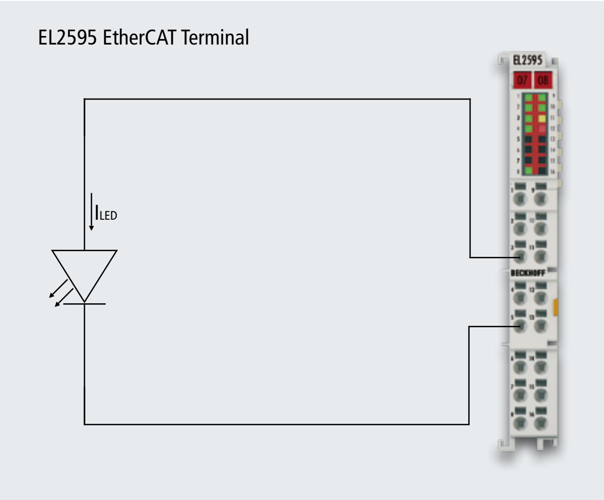
Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

1.) Monochrome LEDs

Monochrome LEDs can be operated at current-controlled LED terminals. A voltage-controlled mode can be selected with the EL2596-00x0. Further information on operating modes, possible setting parameters, and commissioning can be found in the documentation for the respective product on the website.



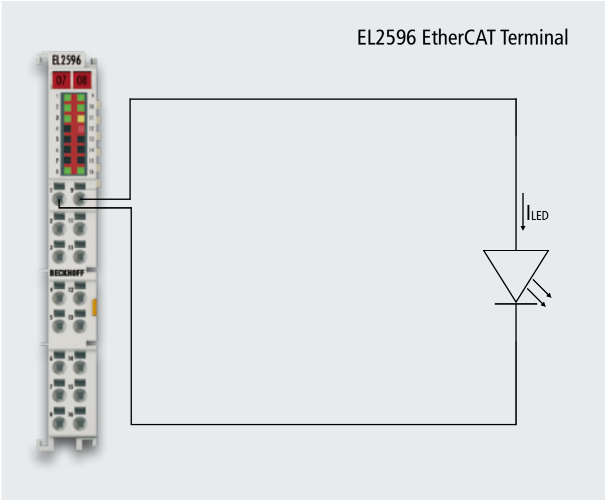


Figure 3: Monochrome LED in current mode at LED output

For more information on the specifications and use of these LED control terminals, please refer to the product-specific documentation and the website.

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Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

2.) Multicolored LEDs

Multicolored LEDs can only be operated on the EL2596-00x0 (with or without PWM). Only common anode LEDs can be used. If the LED is to be used in voltage mode, the use of series resistors is mandatory. In current-controlled mode, operation without series resistors is possible. Further information on operating modes, possible setting parameters, and commissioning can be found in the documentation for the respective product on the website.

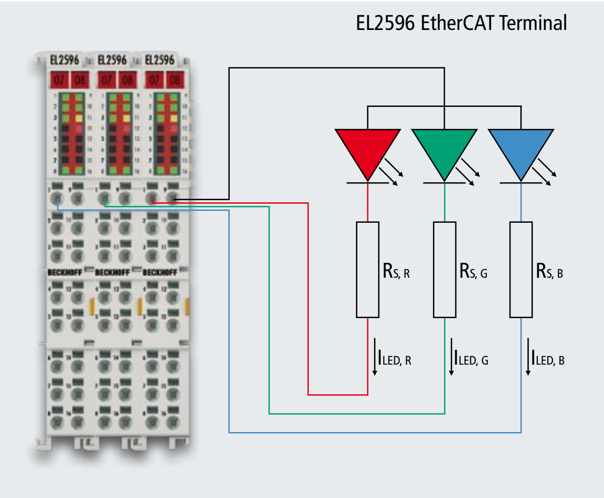

Figure 4: Multicolored LEDs with EL2596 LED control source

Pulse width modulation

If the constant current or constant voltage with series resistor is clocked quickly, this is referred to as a PWM mode.
The brightness can be adjusted in true color via pulse width modulation (PWM). By switching the power supply on and off with a sufficiently high frequency and a preset duty cycle (0...100%), the flashing appears to the human eye like a continuous light. By changing the duty cycle, the current averaged over time is reduced or increased by the LED, thus adjusting the brightness.

- **Advantages:** True-color brightness adjustment
- **Disadvantages:** Supply must be able to provide rapidly increasing currents; complex supply source may be required

PWM can be used in voltage mode from the PLC or in the LED terminals in current mode. The I/O product portfolio includes special PWM terminals to generate pulses at the output (as of May 2020).

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EtherCAT Terminals:

- EL2564-00x0: LED control up to 48 V/16 A, up to 16 kHz
- EL2502-00x0: Voltage output up to 24 V / 1 A, up to 125 kHz
- EL2535-xxxx: Current output on inductive load up to 24 V / 2 A, 30 kHz (default); see note
- EL2545: Current output on inductive load up to 50 V / 3.5 A, 32 kHz (default); see note

Bus Terminals:

- KL2502: Voltage output 24 V / 1 A, up to 20 kHz
- KL2512: Voltage output 24 V / 1.5 A, up to 20 kHz, ground switching
- KL2535: Current output on inductive load up to 24 V / 1 A, 36 kHz; see note
- KL2545: Current output on inductive load up to 50 V / 3.5 A, 36 kHz; see note

NOTE:

The current-controlled PWM outputs (EL2535-xxxx, EL2545, KL2535, KL2545) are not suitable for direct operation of an LED, since the pulse width current terminals require inductive loads at the output.

DANGER:

The high-frequency light switching may create a stroboscopic effect. If the frequency of the emitted light is in phase with the movement frequency of a rotating machine part, for example, a stroboscopic effect can make it appear as if the machine is stationary despite it moving. This can lead to a misinterpretation by an operator who may intervene due to the apparently stationary machine part, potentially leading to serious injury or death.

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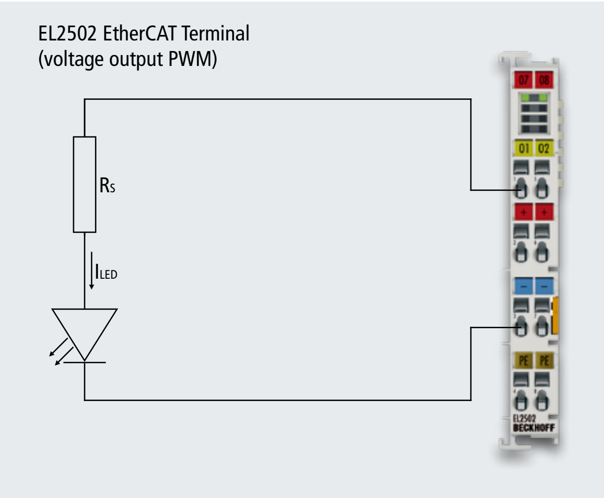
Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

1.) Monochrome LEDs

A series resistor for the LED is mandatory for the PWM terminals since they operate with a voltage output. All LEDs with a series resistor can be operated directly on the EL2564 (ground switching) or EL2564-0010 (positive switching). The corresponding terminal assignment is described both on the website and in the documentation for the respective terminal. The connection of monochrome LEDs to alternative PWM outputs (positive and ground switching) is shown in the following diagram.



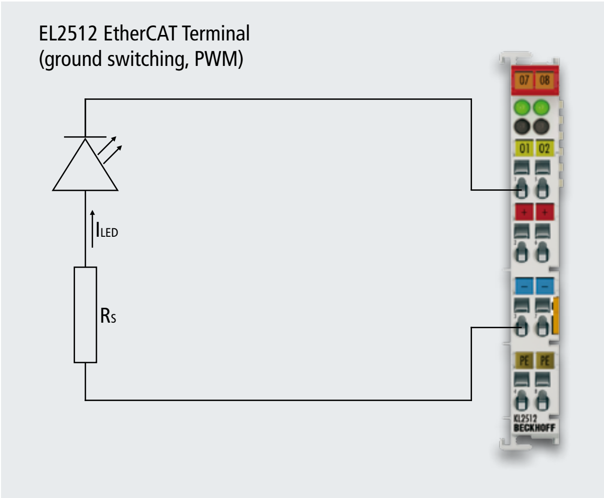


Figure 5: Monochrome LED at a pulsating output

Application note for LED terminals:

Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

2.) Multicolored LEDs

With multicolored LEDs, the connection type must be taken into account. LEDs with a common anode can only be operated on ground-switching terminals. All LEDs with a series resistor can be operated directly on the EL2564 (ground switching) or EL2564-0010 (positive switching). The corresponding terminal assignment is described both on the website and in the documentation for the respective terminal. The 4 channels of the terminals allow the operation of four-colored LEDs (e.g., RGBW) on a single terminal. The connection of multicolored LEDs to alternative PWM outputs (positive and ground switching) is shown in the following diagram.

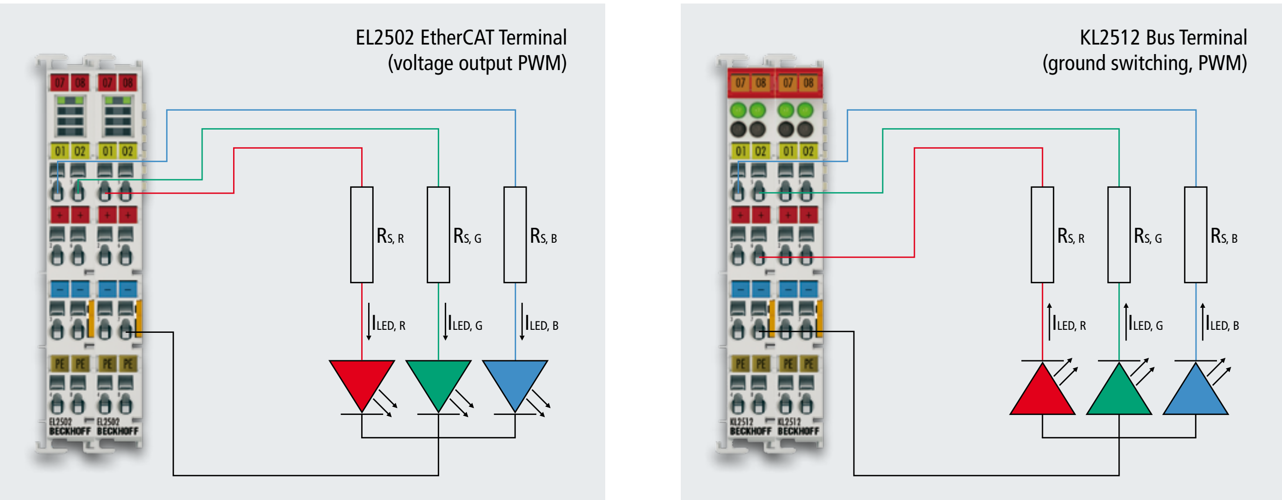


Figure 6: Multicolored LED at a pulsating output

Application note for LED terminals:

Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

Communication protocol

A common application for controlling LEDs using a communication protocol is the use of pixel LEDs. The pixel system is an intelligent method of LED control for several LEDs. Pixel LEDs are LEDs with an integrated circuit (IC). In an LED matrix or LED strip, several LEDs are not conventionally connected in series, but each LED can receive individual signals via bus communication, so that each LED can be controlled individually. These LEDs or LED strips require an LED controller, which serially transmits the communication signals with >100 KHz. The corresponding EL2574 terminal can be used as the controller. With the 4-channel EtherCAT Terminal, up to 2048 pixels can be individually controlled with just one terminal, without needing an additional external LED controller. Various typical pixel LED protocols are supported.

Alternatively, LEDs can be controlled using communication protocols for building and stage technology, such as KNX/EIB (European installation bus), DMX (digital multiplex), and DALI (digital addressable lighting interface), through an external controller. DMX and DALI are communication systems for lighting technology, while KNX/EIB describes a general communication system for building automation. This allows many LEDs to be controlled with minimal cabling effort. Behind the bus receiver mounted on the LED is an LED driver in current or voltage mode for the lighting application. This document is not intended to cover the exact functionality of these communication systems or how they are used for LED control.
This chapter is only provided for the sake of completeness. Separate documents for DMX, EIB, and DALI are available in the Application Notes download area on the Beckhoff Automation website, which describe the functionality of the communication systems. The pixel LEDs described above can also be controlled via DMX. An EL6851 EtherCAT communication terminal must be used as a DMX master to establish communication. A DMX controller must be used as an interface between the DMX master and the LED strip. Compatibility must be verified when selecting the controller and LED strip.

Beckhoff offers various products for the three named bus systems that can be used to control LEDs (as of August 2023).

EtherCAT Terminals:
- EL2574: Pixel LEDs
- EL6851: DMX master
- EL6851-0010: DMX slave

Bus Terminals:
- KL6301: KNX/EIB Bus Terminal
- KL6811: DALI/DSI master and power supply terminal
- KL6821: DALI/DALI-2 master and power supply terminal

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Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

Pulse train

LEDs can also be controlled by means of the pulsating output of the pulse train terminals; however, it is important to consider that this only allows simple control, since only the frequency can be specified with this type of terminal – not the duty cycle. This means that true-color dimming is not possible with this type of control. As a result, the terminals behave like standard voltage-controlled digital output terminals in operation with an LED.

Beckhoff offers various products for solutions with a pulse train that can be used to control LEDs (as of August 2023).

EtherCAT Terminals:

- EL2521-0024: Voltage output 5...24 V / 1 A, up to 500 kHz
- EL2521-0025: Voltage output 5...24 V / 1 A, up to 500 kHz, ground switching

Bus Terminals:

- KL2521-0024: Voltage output 5...24 V / 1 A, up to 500 kHz

DANGER:

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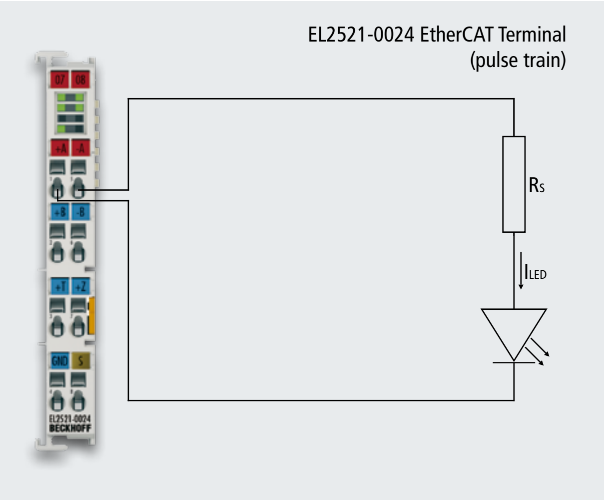
1.) Monochrome LEDs

The connection of monochrome LEDs to the pulse train terminals (positive and ground switching) is shown in the following illustrations



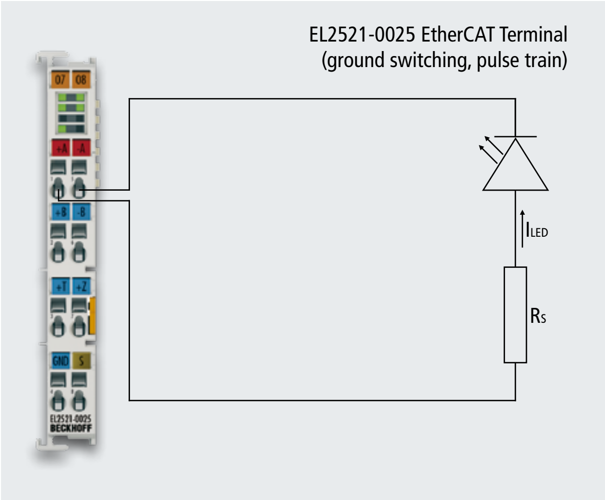


Figure 7: Monochrome LED at a pulsating output

Application note for LED terminals:

Options for controlling LEDs with Beckhoff EtherCAT and Bus Terminals

2.) Multicolored LEDs

Multicolored LEDs can also be controlled with the pulse train terminals. With multicolored LEDs, the connection type must be taken into account. LEDs with a common anode can only be operated on ground-switching terminals. The connection of multicolored LEDs to the pulse train terminals (positive and ground switching) is shown in the following illustrations.

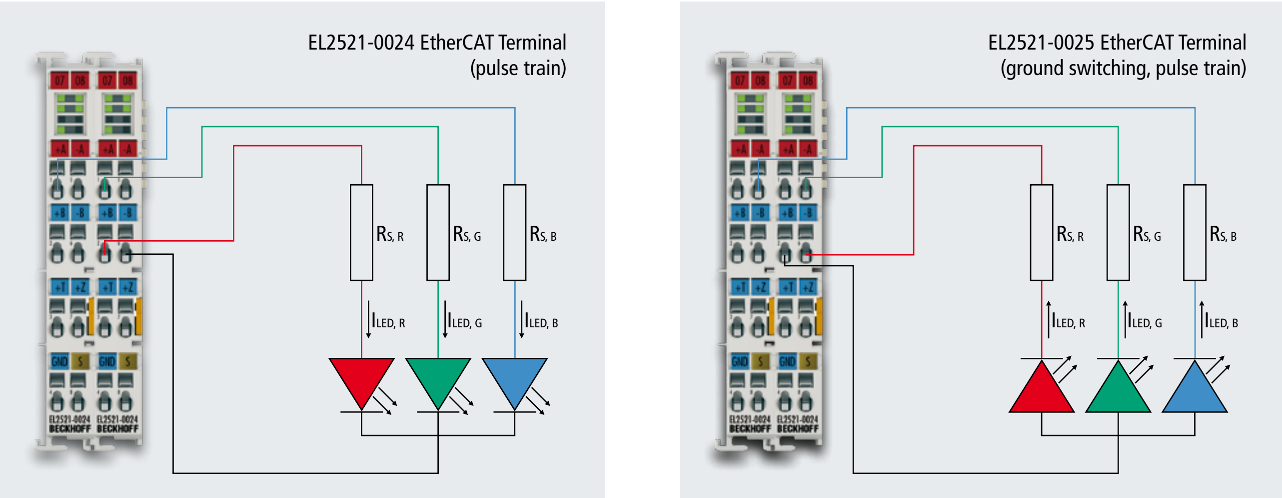


Figure 8: Multicolored LED at a pulsating output