

## LED Drive Methods and Circuit Design

LEDs are current-driven light-emitting devices, the characteristic values of which are specified using forward current values as the parameters. Accordingly, the minimum requirement of circuits that light an LED is that they supply the current necessary for producing the required luminous intensity. However, because of the distribution (variation) in characteristics during the LED manufacturing process, minimum and maximum values are also stipulated for the electrical characteristics. This means that even where the product is the same, the forward voltage and forward voltage characteristics will vary within the specified range. For example, if the same voltage is applied to the same product, the current that flows will not necessarily be exactly the same. Naturally, if the current is different, the product luminous intensity and color can also be expected to demonstrate different characteristics. As will be shown below, various drive methods and circuit configurations are used to light LEDs, and each has its advantages and disadvantages in terms of obtaining the desired characteristics.

This document explains the key points to note with regard to the drive methods and circuit configurations.

### Drive Methods & Circuit Configurations

LED drive methods are either DC (static) drive methods, in which a set current flows continuously, or pulse (dynamic) drive methods in which the LED flashes repeatedly. While their lighting methods differ, the pulse drive and DC drive methods can have the same apparent result if the interval between flashes in the pulse drive method are short enough to be effectively undetectable by the human eye.

The DC drive method is normally used for applications such as indicators, where its ability to provide high levels of luminous intensity and little or no flicker is an advantage. The pulse drive method is mostly used in displays made up of a matrix array and in adjustable light sources. This method has the advantage of lower cost, since fewer drive transistors are used.

## DC (Static) Drive

### Constant voltage drive circuit

This method uses an ordinary load-limiting resistor. The current is determined as shown in Fig.1 and Equ.1 below. Determine the supply voltage and the current, read the LED forward voltage from the product specifications or technical data and use these to determine the limiting resistance R.

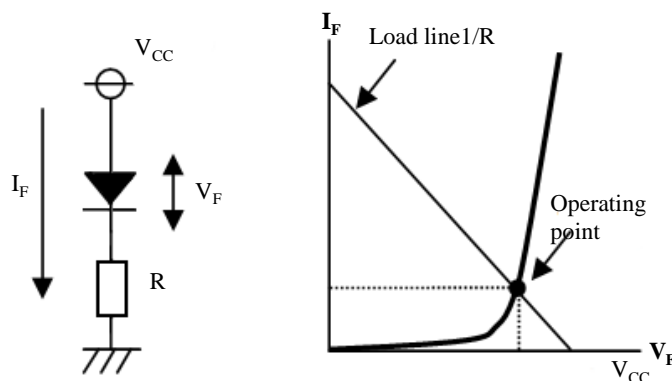


Fig.1 Relationship of the limit resistance

$$V_{CC} = V_F + R \times I_F \quad (\text{Equ.1})$$

This can also be obtained from the  $I_F$ - $V_F$  characteristics. The point set by  $I_F$  on the characteristic curve becomes the operating point, and a line from  $V_{CC}$  extended through the operating point becomes the load line, so the value is obtained by reading the slope of the line  $1/R$ . Working backwards, the same method can be used to calculate the current  $I_F$  from a set resistance R.

We now need to consider ways to suppress variations in the  $V_F$ - $I_F$  characteristics.

If the operating point  $I_F$  is set for the standard characteristics Typ., the actual current will fluctuate between  $I_{Fmax}$  and  $I_{Fmin}$  due to the characteristic variations included in the specifications. As Fig.2 shows, the higher the supply voltage is set at this point or the larger the resistance R, the shallower the slope on the load line, showing that the variation between  $I_{Fmax}$  and  $I_{Fmin}$  is minimized.(Fig.2)

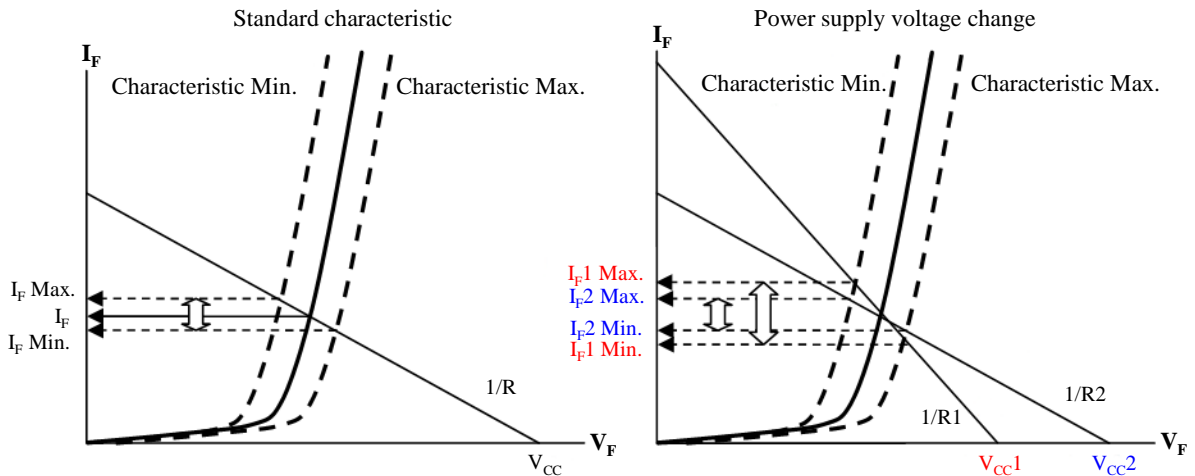


Fig.2 Relationship of the power supply voltage and the current unevenness

The same is true for changes in the current due to temperature (Fig.3).

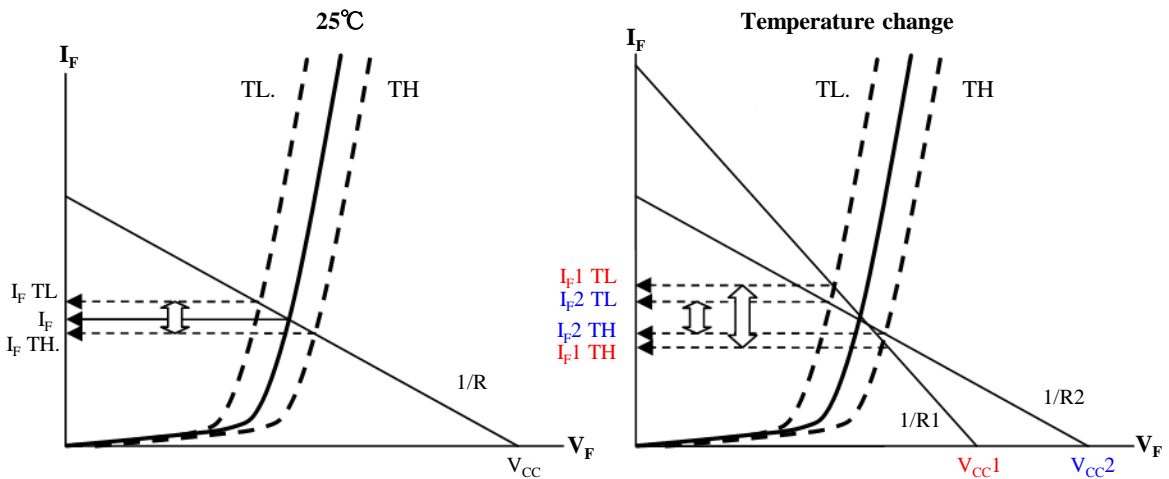


Fig.3 Relationship of temperature and the current unevenness

So in a constant voltage circuit, if the supply voltage cannot be set high and there is a large number of LED serial connections relative to the supply voltage so that a large value cannot be obtained for the resistance R, care is required since the current variations in response to temperature changes and  $V_F$  fluctuations will be larger.

### Constant current drive circuit

To provide a stable supply of current  $I_F$  for the given  $V_F$  fluctuations and changes in temperature, a constant current drive circuit is required. This method has the advantage of being more resistant to changes in the supply voltage. An example is shown below Fig.4.

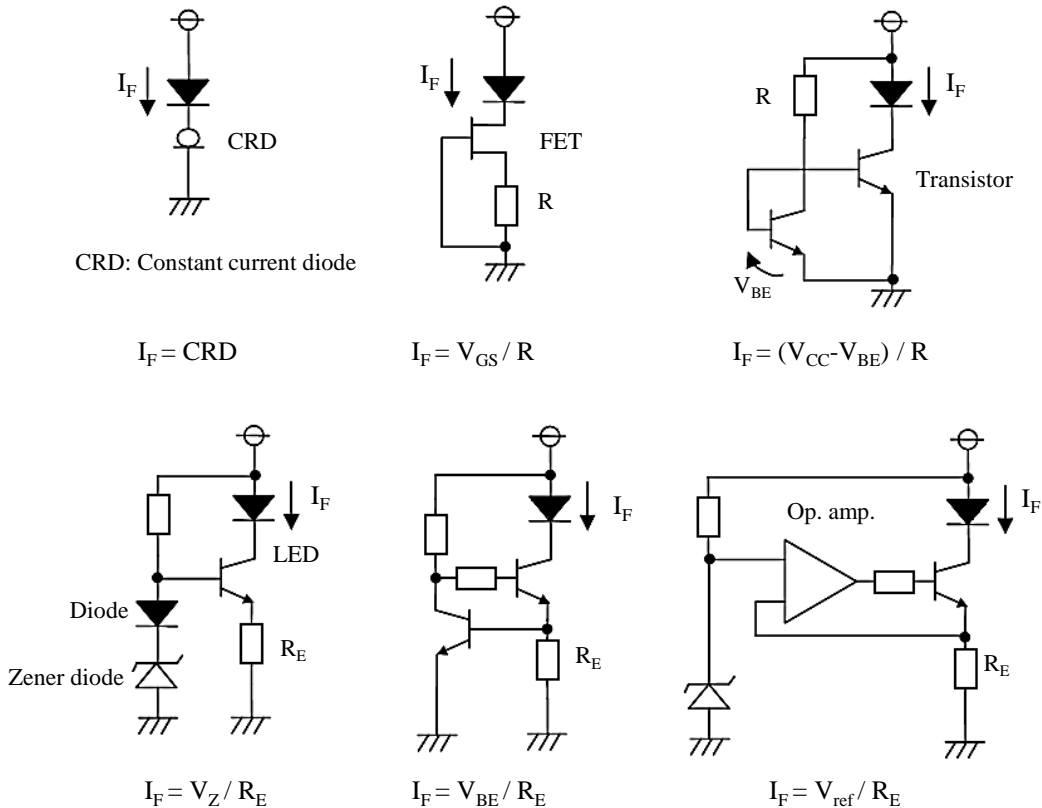


Fig.4 Constant current drive circuit example

While constant current drive circuits are excellent in terms of product quality, they are less desirable when it comes to cost and space. Also,  $V_{CE}$  must be at least 2 to 3 volts to drive the transistors and a voltage drop (1 to 2 volts at  $R_E$ ) is required for the resistance, so the rate of power use is also an issue.

If multiple LEDs are connected, one option is to provide a constant current circuit for each series circuit, as shown in Fig.5 This is also a good option if there is ample space and cost is not a problem

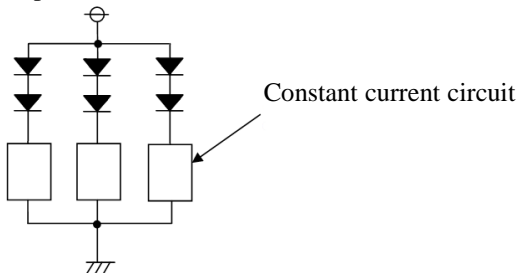


Fig.5 A constant current circuit is set by every series circuit

It is also possible to adjust the variations to almost zero by further modifying the circuit, inserting a variable resistor or multiple resistors and using DIP switches or jumpers to switch and adjust the current for different product luminous intensities or  $V_F$  ranks.

The design measures employed in the constant current drive circuit to deal with  $V_F$  fluctuations and temperature changes should be selected taking into account all factors, such as the pricing and quality of the set used.

Using multiple circuits (series, parallel and matrix)

Fig.6 shows the type of circuit configuration normally used for multiple LEDs.

The equation for a series circuit (circuit a) is as follows:

$$V_{CC} = N \times V_F + R \times I_F \quad (\text{Equ.2})$$

(N: Number of series LEDs)

The equation for a parallel circuit (circuit b) is as follows:

$$V_{CC} = V_F + R \times I_F \quad (\text{Same as Equ.1})$$

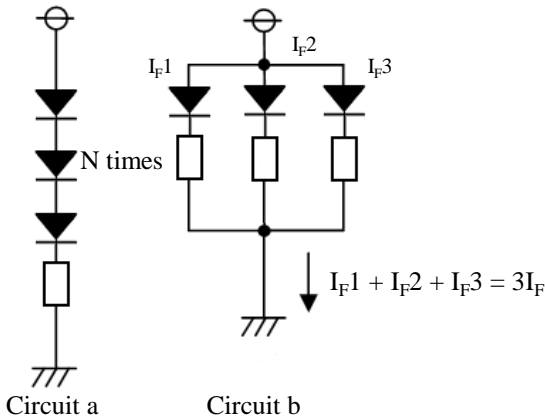


Fig.6 It is plurally the circuit of the errand

The table below shows the circuit characteristics.

	Advantages	Disadvantages
Series circuit	Works even for low currents. (Low currents are better than high voltages for driving transistors.)	Requires a high voltage.
Parallel circuit	Voltage can be low. Provides an effective failsafe in the event of wire breakage.	Requires a large current.

This section discusses a circuit where the LEDs connected in parallel are all the same and a centralized resistance is used rather than load-limiting resistances in the LEDs Fig.7.

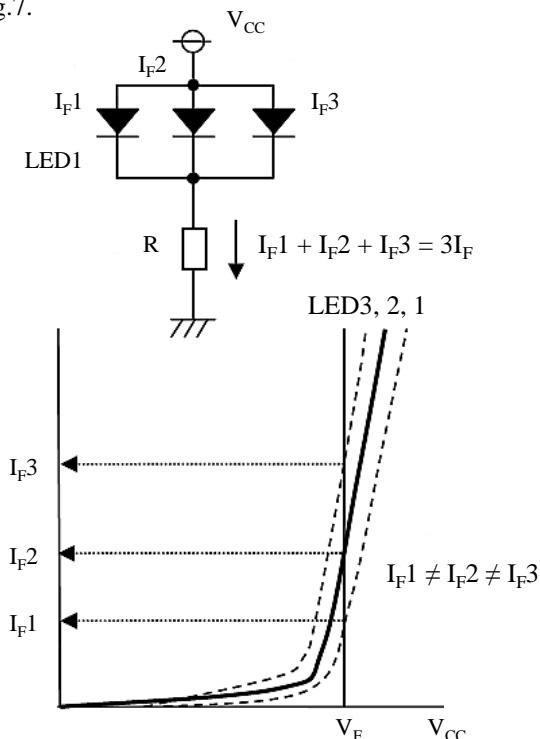


Fig7 Only one resistance is set by a parallel circuit

Setting the current  $I_F$  determines the  $V_F$ , and  $R$  is obtained using  $I_F$  in this case is averaged, and when LEDs with different characteristics are actually connected in parallel, the current values for each of the LEDs differ markedly, as shown by  $I_{F1}$ ,  $I_{F2}$  and  $I_{F3}$ . In this situation, it is possible for a current that exceeds the maximum rating to flow, and still greater differences in the individual currents can occur depending on the temperature characteristics. Such variations in the current not only lower the lighting quality, they also magnify the variations in lifespan, so the circuit design must take this into account.

One countermeasure for the above is to select and use something that tracks the  $V_F$ . Stanley provides a service with particular specifications that splits  $V_F$  values at certain amplitudes. (Whether or not the countermeasure can be used depends on the required specifications.) However, the more restrictive the specifications, the poorer the yield, which can result in high costs. So research that includes circuit design is very important in obtaining the desired characteristics.

The next circuit is a slightly moderated version of circuit b in Fig.6. This circuit is configured with resistors  $R1$  to  $R3$  that balance the current flowing to each LED as well as a resistor  $R4$  that limits the overall current flow Fig.8. While it is preferable that stability be achieved using the individual resistance settings, the resistor ratings can be lowered individually.

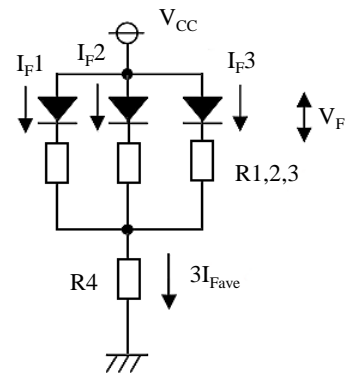


Fig.8 Individual resistance and intensive resistance are set by a parallel circuit

$$V_{CC} = (I_{F1} + I_{F2} + I_{F3}) \times R4 + I_{F1, 2, 3} \times R1, 2, 3 + V_F$$

$$= 3 \times I_{Fave} \times R4 + I_{F1, 2, 3} \times R1, 2, 3 + V_F$$

When there are large numbers of LEDs, it is normal for series and parallel circuits to be combined Fig.9. This is to prevent the supply current and voltage from becoming too large, and is also effective as a failsafe when faults occur.

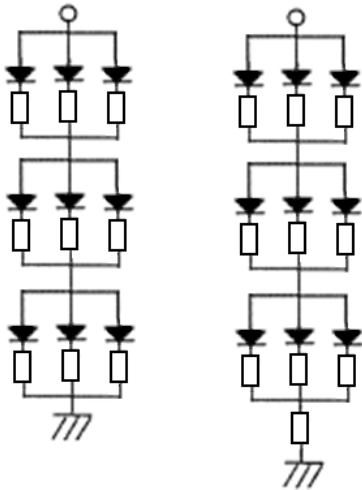


Fig.9 Series and parallel compound circuit

Fig.10 shows an expanded form of the circuit discussed earlier without the individual resistors. This circuit is similarly susceptible to variability and changes. The advantages of this circuit are that it provides an effective failsafe when a wire breakage occurs, has minimal power loss due to resistance, and is thermally resilient. It also uses only a small number of components, which provides advantages such as easier circuit board design, lower costs and greater compactness.

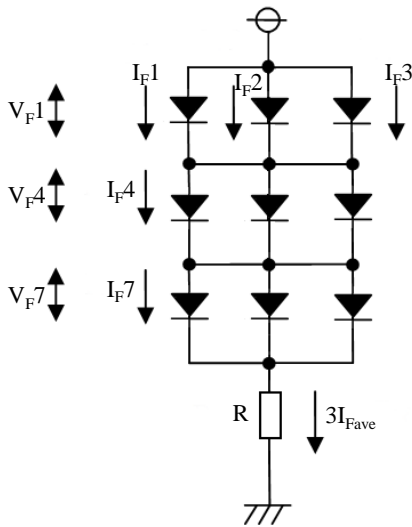


Fig.10 Matrix circuit

$$V_{CC} = (I_{F1} + I_{F2} + I_{F3}) \times R + (V_{F1} + V_{F4} + V_{F7})$$

$$= 3 \times I_{Fave} \times R + 3 \times V_{Fave}$$

$$I_{F1} \neq I_{F2} \neq I_{F3} \quad I_{F1} \neq I_{F4} \neq I_{F7}$$

(If  $V_F$  is selected,

$$I_{F1} \cong I_{F2} \cong I_{F3} \quad I_{F1} \cong I_{F4} \cong I_{F7} )$$

Another option when large numbers of LEDs are used is the type of step-up circuit shown in Fig.11 which is used in the situations listed below.

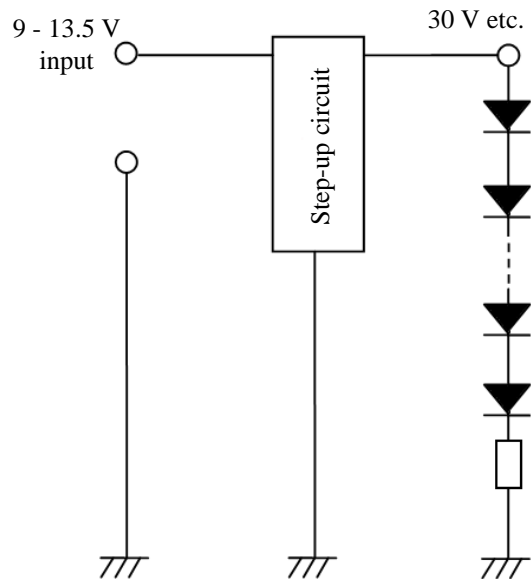


Fig.11 Voltage up circuit method

This type of circuit works well in the following conditions:

- (a) When there is a large number of direct connections (as when the drive current is too high in parallel circuits, etc.)
- (b) When all the connections need to be serial (noting that wire breakage at any point will turn off all the LEDs)
- (c) When the  $V_F$  is high (LEDs equipped with InGaN dies, such as white, blue or green, become extremely vulnerable to voltage variations, temperature changes and overvoltage faults when there is a lot of current)
- (d) When a stable drive current is required (high limiting resistance can be used and current variations can be suppressed)

We have recently begun to see dedicated LED drive ICs that use step-up circuits. This option can be used after researching the costs involved and confirming its suitability using reliability testing that also includes the circuits.

## Pulse (Dynamic) Drive

Normally, pulse drives for LEDs use a bipolar transistor, a simple FET-based switching circuit and a constant current circuit that is compatible with the variations in the LED's forward voltage  $V_F$ . There are now also driver ICs specifically for lighting LEDs.

If the LED flashes at a high frequency so that it looks as though it is DC lit (when the observer is still), pulse drive poses no problems. However, if the flashing frequency drops below a certain level, the LED appears to flicker visibly. Flicker generally becomes discernible at frequencies lower than 50Hz, so a flashing frequency of 100Hz or higher is normally required. However, if the observer is not still, or if the LED is being monitored by a mechanical sensor, flicker may still be observed even at high frequencies. Accordingly, the frequency set must be tailored to the application.

The figure below Fig.12 shows some sample circuits and equations for reference. For more information, refer to a specialist guide to circuits to determine the multipliers and confirm the suitability of the circuit using reliability testing that also includes the circuits.

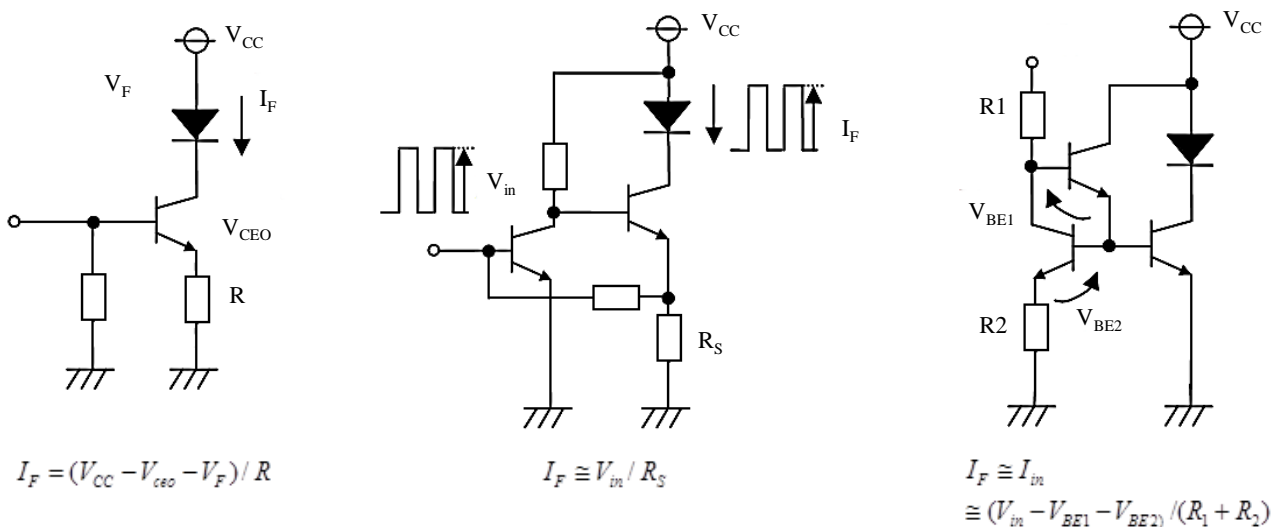


Fig.12 A pulse drive circuit example and calculation type

Each LED features some variability within its specifications. To obtain the desired characteristics, it is vital that the circuit design take into account these characteristic variations. This document has outlined some general examples of the drive methods and circuit configurations. The information provided here should be carefully observed when using LEDs, particularly where there are no design margins.