

A typical LED lamp consists of many 1 to 2W LEDs operating together. There are a variety of configurations for powering these LEDs. This application note discusses a variety of these configurations. For each configuration a diagram is presented along with a description of basic operation and a discussion of the various advantages and disadvantages. In addition, there is a brief description of what happens if a single LED fails either open or short. For reference, the most common failure mode for LEDs is to fail short.

Series Configuration

The simplest of the various configurations is the series configuration. The LEDs are all simply connected in series. The cathode of the first LED connected to the anode of the second and so on. This configuration is illustrated in Figure 1.

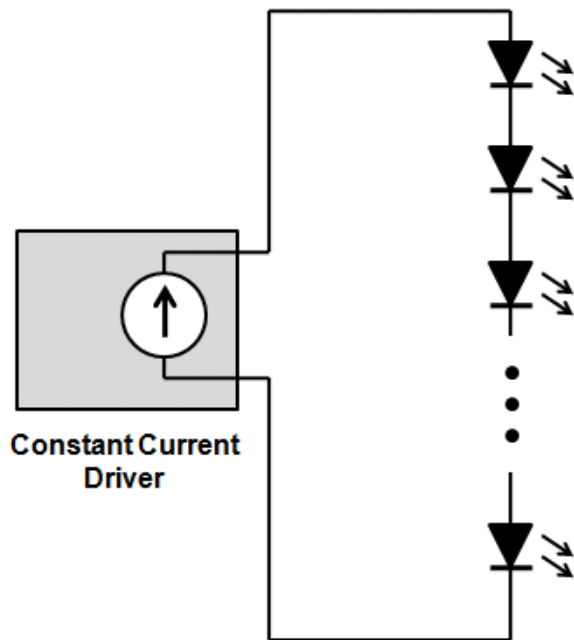


Figure 1. Series Configuration

Basic Operation: The string voltage is a function of the number of LEDs in the string and the typical forward voltage (V_f) of each LED. For example, 24 LEDs with a V_f of 3.5V would operate at a string voltage of 84V. A single current source provides power to each of the LEDs which, by design, all receive exactly the same current.

Advantages: The implementation is very simple with only a single circuit. There are no current imbalance issues as all LEDs receive identical current. System efficiencies tend to be high as it is easier to optimize efficiency with high voltage and low current. No ballast resistors are required which tend to reduce efficiency. The most common LED failure mode has negligible impact on the system.

Disadvantages: Output voltage can become very high which may translate into a safety issue. An open anywhere in the string whether it is a mechanical failure or a failed LED can cause the entire lamp to cease operation.

Failure Modes: In this configuration if a single LED fails short there is virtually no impact on the other LEDs. Each continues to be powered with the same current as it was in normal operation. Overall less power is consumed and the lamp decreases in brightness by $1/n$ where n is the number of LEDs in the lamp. If single LED fails open then the current path is broken, all LEDs are turned off and the lamp ceases to operate.

Design Options: For an application where system reliability is of primary concern, an OVP device can be connected in parallel with a certain number of adjacent LEDs (failure group). The OVP device normally consists of an SCR and some voltage detection circuitry. The SCR is open normally and activates short if any of the LEDs in the failure group fails open. In this case, all other failure groups remain functional. Brightness of the lamp is then reduced by $1/f$ where f is the number of failure groups.

Parallel Strings Configuration

In order to reduce the maximum string voltage and/or to introduce a little more fault tolerance, a common configuration is to utilize multiple paralleled strings of LEDs. Taking the example where 24 LEDs were used to construct a lamp, these LEDs could be arranged in 4 paralleled strings of 6 LEDs each. This configuration is illustrated below in Figure 2.

Basic Operation: Total string voltage is reduced from the Series Configuration by a factor equal to the number of paralleled strings. Current is divided between the various strings based on how well each of the strings are matched. Small differences in the V_f of the various LEDs can cause significant imbalances in current. A resistor in each leg is typically employed to help balance the current. While in theory a constant voltage source could be used to drive the system, the total current can change significantly at the boundaries of the voltage regulation band or when the forward voltage drop of the LEDs varies. Therefore it is highly desirable to employ a constant current driver in this configuration.

Advantages: This configuration requires the use of only a single driver and output voltage can be kept rather low. By properly selecting the value of the resistance, reasonable current sharing can be achieved among the paralleled LED strings.

Disadvantages: The improved accuracy of current sharing is achieved at the expense of increased power dissipation in the resistors. Any failure of an LED open or short can cause significant stress on the remaining LEDs.

Failure Modes: If a single LED fails short, the string in which the failed LED resides will take significantly greater than its share of the current. The stress on the LEDs in this string will increase significantly thus increasing the likelihood that a second LED will fail. The LEDs in each of the other strings will dim considerably as the total current is fixed by the rating of the driver. If any LED fails open, then the LEDs in that string will cease to operate but the current in each of the other strings will increase by a factor of $1/(s-1)$ where s is the total number of strings.

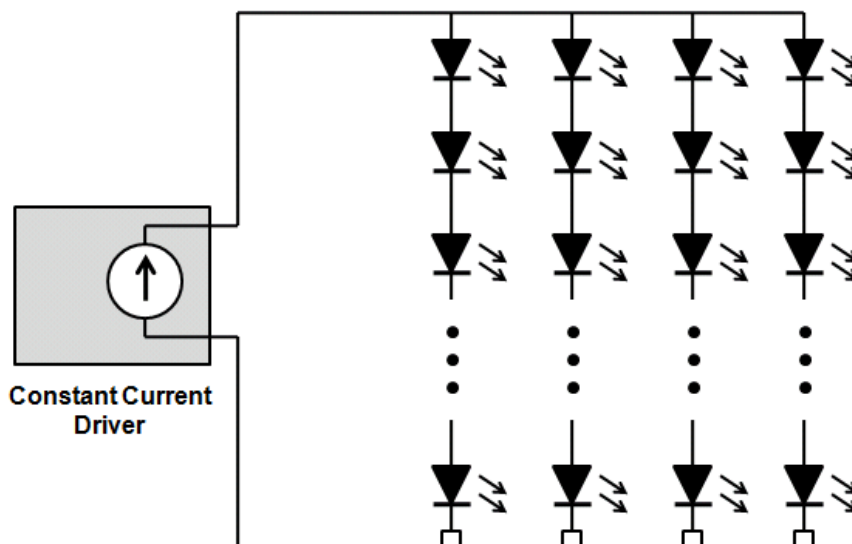


Figure 2: Parallel Strings Configuration

Matrix Configuration

The Matrix configuration seeks to eliminate some of the problems with Parallel Strings configuration by adding more connections between the LEDs. A diagram of this configuration can be found below in Figure 3.

Basic Operation: The basic layout of this configuration looks similar to the Parallel Strings configuration except that now connections have been added between each of the strings. In effect, each of the first LEDs in each string are now operated in parallel as are the second LEDs in each string. The LEDs are now arranged into a matrix of rows and columns.

Advantages: This configuration still only requires the use a single output driver, and the output voltage remains comparable to that of the Parallel Strings configuration shown in Figure 2. In general, this configuration is

more fault-tolerant and should produce better current balance.

Disadvantages: Current sharing remains an issue and it is not as straightforward to add ballast resistors to improve sharing. Non-uniform current sharing leads to non-uniform light and thermal distribution in the lamp. Pre-screening or binning of LEDs is helpful to reducing such an imbalance but is not without its problems.

Failure Modes: If any LED fails short, all of the LEDs in that row will cease to operate. All other rows will operate as normal and brightness of the lamp will be reduced by a factor of $1/r$ where r is the number of rows. If any LED fails open, the other LEDs in that row will have their current increased by a factor of $1/(1-c)$ where c is the number of columns in the matrix. All other LEDs will operate normally.

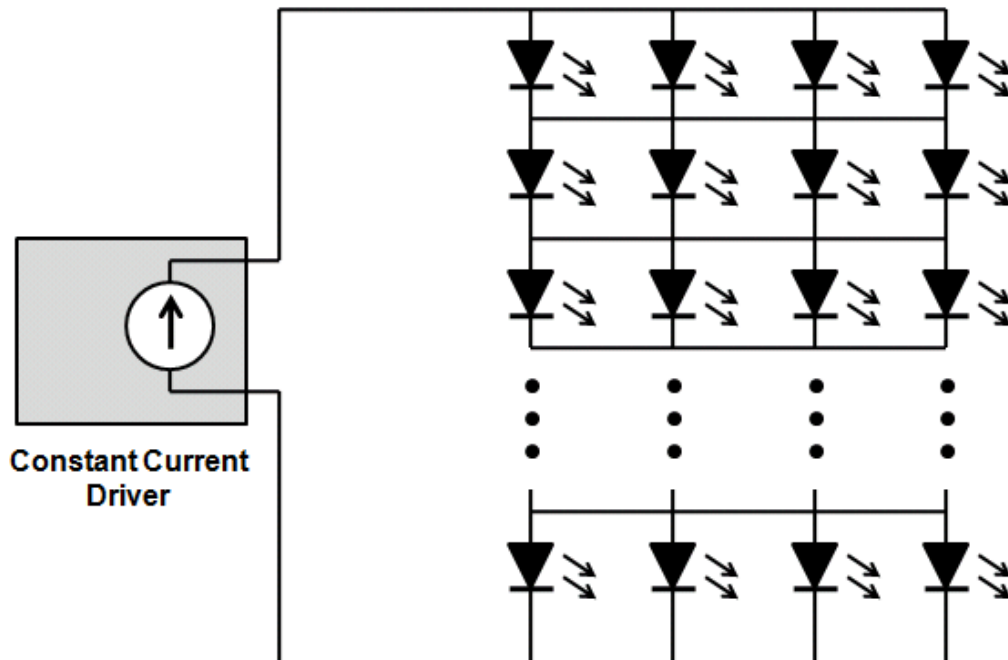


Figure 3: Matrix Configuration

Multi-Channel Configuration

In the Multi-Channel configuration, complexity is added to the driver but the system overall becomes much more robust. This configuration is illustrated below in Figure 4.

Basic Operation:

Assuming again a lamp using 24 LEDs, the LEDs can be broken down, as before, into 4 strings of 6 LEDs each. However, instead of connecting these strings together, they remain independent. The driver is designed to maintain four separate constant current outputs and each of the outputs is connected to one string. This has the advantages of the Series connection in terms of robustness and precision of current regulation in each diode; however it keeps the string voltage as low as the other basic configurations.

Advantages: High accuracy of current regulation can be achieved with minimum string voltages to ease safety considerations. Failures in any one string do not affect the other strings.

Disadvantages: The cost and complexity of the driver is increased somewhat although not nearly as much as four independent drivers.

Failure Modes: If any LED fails short, the other LEDs in that string continue to operate normally and total lamp brightness is impacted only by a factor of $1/n$ where n is the total number of LEDs in the lamp. If any LED fails open then all of the LEDs in that string cease to operate while the other strings operate normally. In this case, total brightness is impacted by a factor of $1/s$ where s is the total number of strings in the lamp.

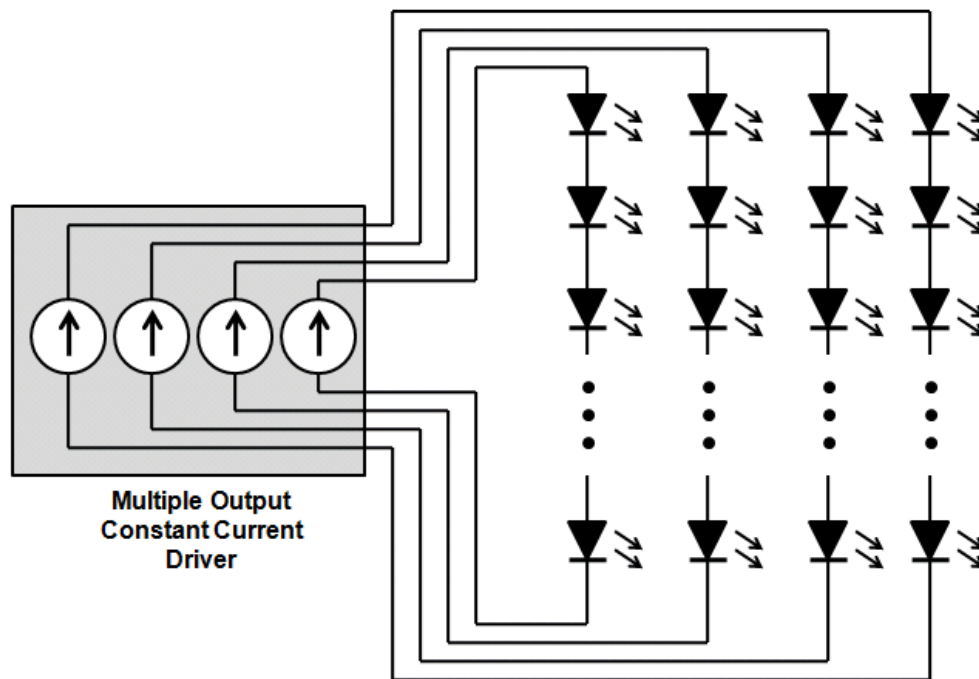


Figure 4: Multi-Channel Configuration