

Energy Savings Using Series Drive in LED and Laser Diode Burn-in and Stress Systems

Overview

High volume LED (Light Emitting Diode) and Laser Diode applications often employ a parallel circuit configuration in which each device is powered individually using a simple linear regulator and a common low voltage bulk power source. For low power devices where current drive requirements are simple enough to be met with a resistor or monolithic regulator IC, this method is sufficient. Considering higher power devices, the parallel drive scheme suffers from high losses in the regulators and other system components resulting in high costs.

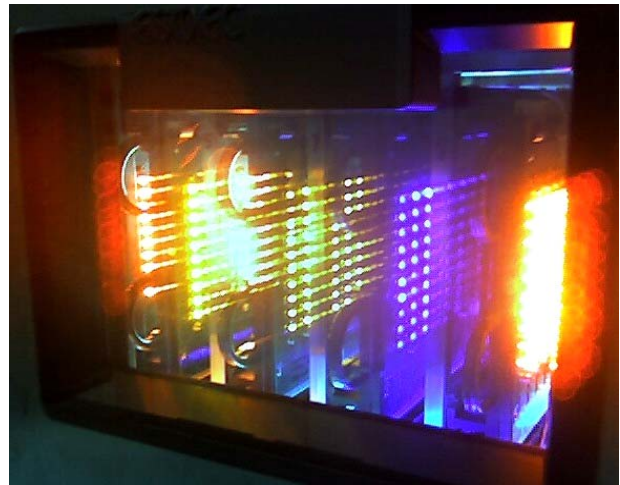


Figure 1: Series Mounted LEDs Undergoing Stress Screening

To reduce energy costs, devices can be arranged in a series circuit and driven with a single high compliance voltage regulator. This arrangement is much more efficient and leads to higher reliability. When properly implemented, series drive systems reduce electricity usage by over 60%. Series systems also allow for sophisticated drive and control, thus providing the ability to meet the complex specifications and test recipes for today and in the future. This white paper describes the benefits and energy savings when using the series method for high power LED and laser diode burn-in and stress test.

Background

In a typical LED environmental stress screening or burn-in system, large numbers of LEDs are powered under room temperature or elevated operating temperature conditions (see Figure 1). The LEDs may be operated in one of many modes:

- Constant current mode such as that used in automobile headlamps;
- Pulsed mode meeting the needs of applications where flashing is important;
- Proprietary recipe where specific operating conditions must be validated.

The drive current is often elevated beyond the device's normal operating current. Current regulation is important as is thermal control. Usually these applications employ temperature chambers or thermal platforms to regulate the LED temperature. Heat removal is a big issue, especially with high power LEDs, as each device dissipates 1W or more. In large-scale operations, tens of kilowatts of power are consumed by hundreds of devices. Adding to this power dissipation is the power overhead, which consists of losses in the drive circuitry and the power needed for air conditioning and thermal control systems. This power overhead often exceeds the power driven to the devices themselves.

Parallel Drive System Requires High Current Supplies and Wiring

Using a parallel drive scheme, each LED is powered from a separate current regulator. At low currents a simple resistor can be used to regulate current. At higher powers a linear regulator is often used to provide a more accurate current. Each regulator is fed from a common bulk power source. Since the regulators are all in parallel, the total current draw from the bulk source is the sum of all the regulator currents. Figure 2 shows a typical design for a single 40 LED load board; note the current draw from the bulk power supply is $40 \times I_f$. In a typical LED burn-in system with ten 40 device load boards and with each device running at 1A current, the bulk power supply would need to supply 400A to the regulators. At 2A, 800A would be required.

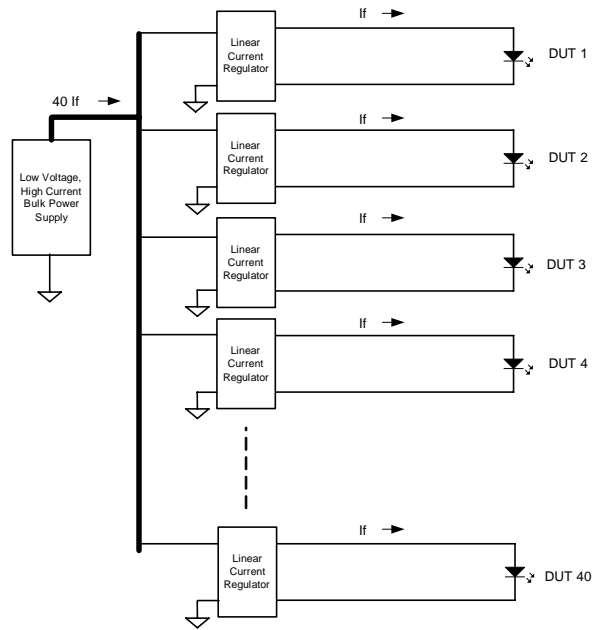


Figure 2: Parallel LED Drive Requires High Current

Losses in Parallel Drive System

There are three main power losses in a parallel drive system: 1) losses in the linear current regulators, 2) losses in the cabling to the regulators, and 3) losses in the bulk power supply.

Regulator Losses Increase with Each Device Added to Parallel Drive System

Current regulators maintain a constant current by regulating a fixed input voltage to the output voltage that will result in the desired current through the LED. Linear regulators do this by dissipating some power as heat; switching regulators convert the power to a lower voltage. In both cases, the regulator requires a few volts of voltage differential between the input and output to operate properly. For the LM317 operating at 1A, this differential is about 4V. Thus the losses in the regulator are $4V \times 1A = 4W$. Since there is one regulator per LED, this loss is multiplied by the number of LEDs in the system. For a 400 LED system, this loss is 1600W.

Cable Losses May Exceed Hundreds of Watts

In the parallel system, the large number of regulators can be located near the LEDs, or they can be placed in external racks. Either way, cabling must connect the bulk power to the regulators. This cabling carries high currents and thus is subject to power loss that goes up with the square of the current. To some extent this can be combated with larger cable, but for high currents, cables become impractical and custom bus bars must be used. For a typical 400A system, these losses can easily be a few hundred watts.

Bulk Power Supply Losses Are Approximately 20%

The bulk power supply converts AC power to the DC voltage necessary to power the regulator banks. Low voltage power supplies in this class typically have losses of about 20% -- 2400W for the 1200A, 10V supply needed in this example.

Series Drive is Efficient

In a series drive system, the LEDs are arranged in a series circuit, and the entire circuit is powered from a single current regulator, usually a switching current regulator. In series drive, the same current flows through each LED, and the current into the regulator is roughly equal to this current. Since the LEDs are in series, the regulator supplies current at a voltage equal to $n \times V_f$, where n is the number of LEDs in the series string. For a typical 40 LED circuit, like the one shown in Figure 3 with 3.75V average V_f , the regulator would need to supply current at $40 \times 3.75V$ or 150V. In practice the regulator would be sized to handle the worst-case forward voltage of $40 \times 4.5V$ or 180V.

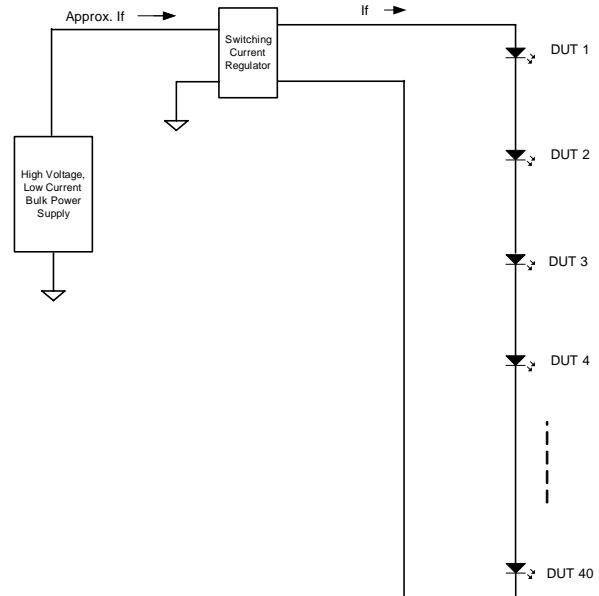


Figure 3: Efficient Series LED Drive System

In a series system, while the overall power delivered to the LEDs is the same as that in the parallel system, this power is delivered at a higher voltage and a lower current than in the parallel approach. This higher voltage distribution provides several benefits. These benefits are similar to those discovered by designers of the first electrical power distribution systems – systems that have uniformly evolved to high voltage, low current distribution.

Minimal Losses Occur in Series Drive System

Losses in the series drive system are much lower than those of the parallel drive system.

Switching Current Regulator Operates with Conversion Efficiency of 90%

The switching current regulator used in the series drive system operates with a conversion efficiency of roughly 90%. For a 400 LED system operating at 1A with 3.75V average V_f LEDs, power losses in the current regulators are roughly $10\% \times 1A \times 3.75V \times 400 = 150W$, which is roughly one tenth the losses of parallel regulators.

Cable Losses Are Negligible

In the example 400 LED system with series drive, the bulk power supply needs to deliver 180V at roughly 10A. Thus, there is no need for high current cabling, and cable losses are negligible.

High Voltage Bulk Power Supplies Operate at Twice the Efficiency of Low Voltage Supplies

Higher voltage bulk power supplies can operate at roughly twice the efficiency of equivalent low voltage supplies. To drive 400 LEDs in ten series strings at 180V, 10A supply is required. This supply would have losses of roughly 10% or 180W – less than one fourth that of the low current supply.

Higher Voltage DUTs Can Be Supported

Since the regulator has high voltage capability, series drive can easily support newer high voltage DUT.

Series Drive – 62% Less Expensive To Operate

Annual and lifetime operating costs in US dollars for the two drive schemes are compared in the tables below. For these calculations, a \$0.1 per kWh electricity cost was used. The energy required to remove heat was estimated.

Efficiency Calculation	Parallel
LEDs in System	400
If, Amps	3
Average Vf, Volts	3.75
Total Power To LEDS, Watts	4,500
Bulk Power Voltage	10
Bulk Power Current, A	1,200
Bulk Power Used, W	12,000
Bulk Power Supply Conversion Losses (20%), W	2,400
Total Power Dissipated, W	14,400
Power Required to Remove Heat	4,800
Total Power Used, W	19,200
Total Delivered Efficiency	23%

Efficiency Calculation	Series
LEDs in System	400
If, Amps	3
Average Vf, Volts	3.75
Total Power To LEDS, Watts	4,500
Bulk Power Voltage	188
Bulk Power Current, A	26
Bulk Power Used, W	4,950
Bulk Power Supply Conversion Losses (10%), W	495
Total Power Dissipated, W	5,445
Power Required to Remove Heat	1,815
Total Power Used, W	7,260
Total Delivered Efficiency	62%

Electricity Cost Calculation	
Power Per Burn-in System, W	19,200
Systems per Facility	10
Power per Facility, W	192,000
Hour/year operation	8,766
Kilowatt Hours/year	1,683,072
Electricity Cost/kWhour, US\$	\$ 0.10
Electricity Cost/year, US\$	\$ 168,307.20
Operating Lifetime, Years	10
Lifetime Operating Cost, US\$	\$ 1,683,072.00

Electricity Cost Calculation	
Power Per Burn-in System, W	7,260
Systems per Facility	10
Power per Facility, W	72,600
Hour/year operation	8,766
Kilowatt Hours/year	636,412
Electricity Cost/kWhour, US\$	\$ 0.10
Electricity Cost/year, US\$	\$ 63,641.16
Operating Lifetime, Years	10
Lifetime Operating Cost, US\$	\$ 636,411.60

As the tables show, the operating costs for series drive are 62% less than the costs of parallel drive when operating at 1A.

Other Considerations

In addition to electricity costs, there are other factors to consider when choosing between parallel and series drive.

LED Failures Must Be Handled

Series drive places multiple LEDs in the same circuit. When an LED in the series circuit fails, it can impact the others in the same circuit. There are two main LED failure modes that must be handled: short and open.

When an LED fails short, its V_f drops to near zero and the total string V_f is reduced. This sudden change can cause the current in the series circuit to spike up unless the regulator is designed to handle this. Vektrex's SpikeSafe current sources have built-in protection to prevent excess current. When LEDs fail in an open circuit condition, current flow stops in the circuit. For series systems this would mean that all of the LEDs in that circuit stopped operating--an undesirable result. To combat this, failed LEDs can be bypassed, either manually or with an automatic shunting circuit. For example, Vektrex's Shunt/Expander modules automatically sense an LED open failure and shunt current around the failed device.

Series Drive Simplifies System Wiring

Parallel drive systems require fairly elaborate power distribution schemes. Fusing must be provided at various levels to ensure safety, and often there are many high current connection points in a system. This design tends to increase the number of connections in the system and decrease its reliability. Series drive has fewer, lower current connection points and is more reliable and easier to maintain.

Series Drive is More Accurate

Current accuracy in the parallel drive system depends on the accuracy of the regulator IC and a power resistor. Typically these are in the range of 2-5%. For series drive, more expensive accurate components can be used. Typical accuracy for these components is in the range of 0.2-0.5%, roughly 10X better. It is also much easier to verify and calibrate a few series regulators rather than a few hundred parallel regulators.

Series Drive Enables More Sophisticated Current Control

Parallel drive systems typically provide current adjustment by replacing fixed resistors. This scheme is time consuming and limited by gradations in standard resistor values. With series drive, a more sophisticated current regulator can be employed that allows for computer control of the current set point, current and voltage readback, and even pulsed current operation.

Summary

Series topology allows more efficient burn-in and stress systems to be constructed that use far less power. In addition, series drive simplifies system wiring and reduces cable losses. Together these savings dramatically reduce electricity consumption – a key consideration for system designers in today's energy conscious world. Series drive also enables more accurate, precise current control. Finally, it simplifies system design reducing operating and maintenance costs.