Lighting World Reinvented with Ever Improving HBLED Technology

Design optimization of High Brightness LED drivers

Within the range of different light sources, high brightness LEDs (HBLEDs) are currently the fastest growing and beginning to replace other types of lighting, such as incandescent, halogen, fluorescent and even HID. In the past, LEDs have been suitable only for instrumentation lighting, constrained by their limited light output.

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In recent years, the development of high brightness LEDs (HBLEDs) has enabled their use for architectural and decorative lighting as well as signage. HBLEDs have also become an attractive alternative to CCFL (cold cathode fluorescent lamp) light sources as backlighting for LCD TVs and monitors. As HBLED technology continues to improve, the luminous efficacies possible have reached 35 to 50 lm/W (lumens per Watt), which surpasses incandescent and halogen lamps and matches fluorescent lamps. Improvements will produce devices with luminous efficacy >100 lm/W, exceeding fluorescent lamps and eventually matching HID lamps.

It should be noted that dimming, while difficult and expensive to accomplish with fluorescent lighting - and impossible below 50percent light output for HID lamps - is very easy to achieve over the entire range with HBLEDs.

HBLEDs are produced in a range of different colors, sizes and power ratings. Their electrical characteristics, particularly the forward voltage drop will vary substantially between the different types. In addition, there are significant variations between different production lots resulting in wide tolerances. The forward voltage drop also possesses a negative temperature coefficient, which further adds to the problem of defining a suitable power supply for the application. At the present time many power supplies are being sold on the market for the purpose of driving clusters of HBLEDs, which simply provide a constant voltage. This method, although simple to understand for the non-technical user, is counter-intuitive and introduces limitations to the system as well as reduced efficiency.

HBLEDs are rated by their current and not their voltage. For example, a family of HBLEDs will contain several members, all of which have different colors

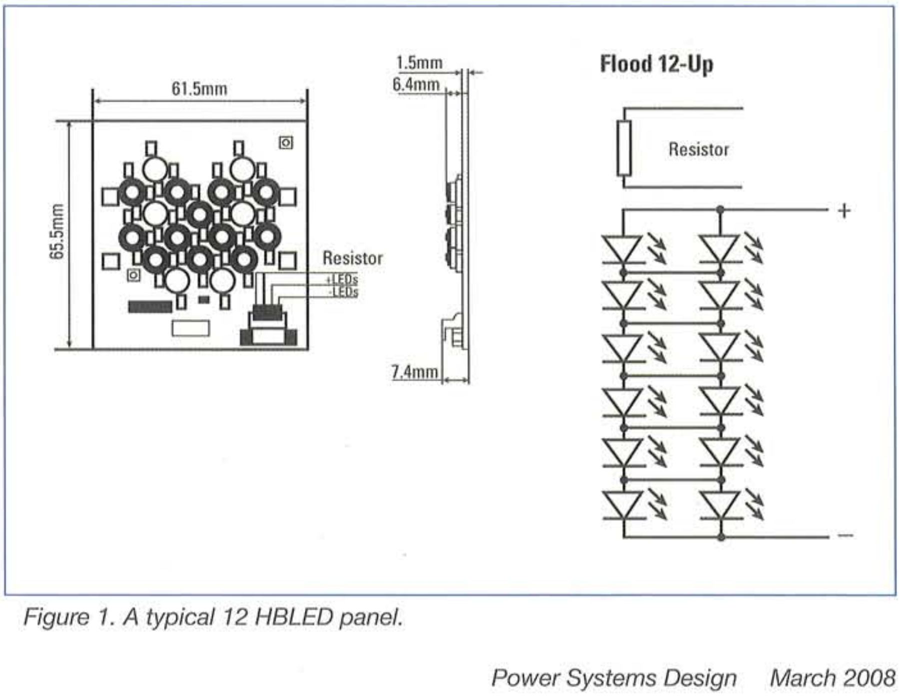

Figure 1. A typical 12 HBLED panel.

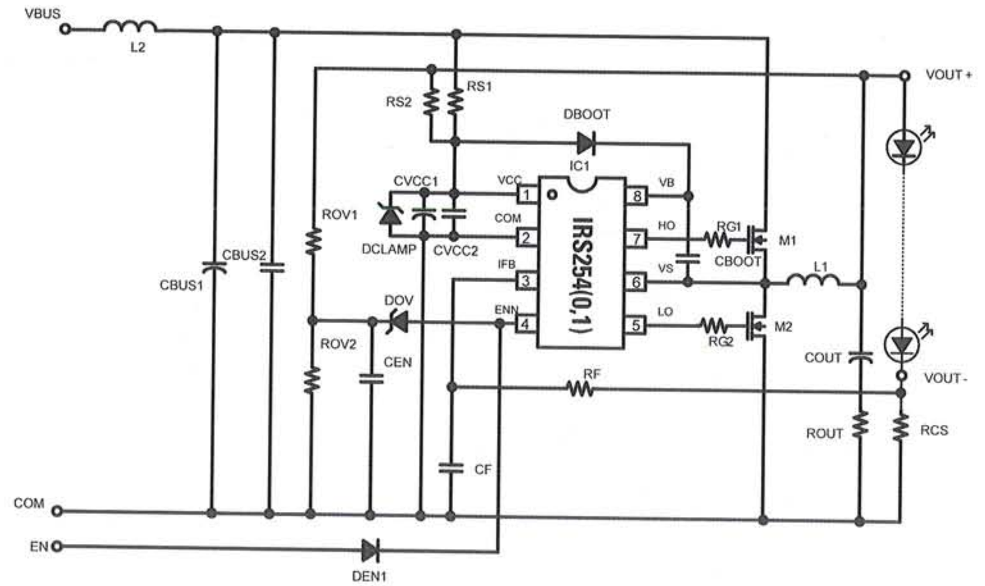

Figure 2. The IRS2540 LED converter.

and forward voltage drops but all have the same current rating, for example, 350mA or 700mA.

As well as being sold individually, HBLEDs are also widely sold in panels, which contain several connected together.

HBLEDs connected in series will inherently supply the same current in each individual LED. However, since the forward voltage drop of each one is something in the region of 4V it can be seen that the cumulative voltage of a series of HBLEDs will rapidly add up. To prevent the panel supply voltage from being higher than is desirable the panels are generally comprised of series and parallel LED networks. For example, a Lumileds Flood panel consists of 12 LEDs which are connected as 6 series pairs of parallel LEDs as shown in Figure 1.

In this example the manufacturer has connected the HBLEDs in parallel pairs. Since they possess a negative temperature coefficient of forward voltage drop, in order to prevent one LED in the pair from drawing more current than the other they must be carefully matched in production. Unfortunately, even a small mismatch will tend to be amplified in operation because if one LED draws slightly more current than the other due to the fact that it has a lower forward voltage drop, it will heat up more rapidly and, therefore, its forward voltage drop will be further reduced and at a greater rate than the other, further amplifying the imbalance. Assuming that the manufacturer is successful in selecting matched pairs, it can be seen that six pairs are connected in series so that the individual pairs can have different forward voltage drops. The total voltage for the whole panel in this case is six times the forward voltage drop of one single HBLED. This panel is available in six different colors and the forward voltage drop varies from 17 to 21V between these. To add to this the tolerance is also large, for example, for a white panel it is from 16 to 24V. The temperature coefficient of this voltage is rated at -12mV / °C meaning that if a panel at room temperature of 25 °C has a voltage of 17V then at 50 °C it will be 16.7V. The important point here is that in all cases the panel current rating remains at 700mA.

Although HBLED power supplies are currently being sold on the market, it is clear that these are not able to supply an LED array as described above, without the addition of a series current limiting resistor. The addition of such a resistor may allow, for example, a 17V rated panel to be supplied from a fixed 24V power supply at 700mA but would introduce an unnecessary power loss of (24 – 17) x 0.7 = 0.49W of energy dissipated as heat. This goes against the entire ethos of energy saving in lighting. In addition, it is not very accurate. A resistor can be calculated to provide 700mA from a 24V supply to a 17V panel, (24-17) / 0.7 = 10 Ohms. However if the panel voltage is only 16V the current supplied will be (24-16) / 10 = 800mA which is substantially higher than the rated current and would overdrive the LEDs in the panel, reducing their working life. On the other hand if the panel voltage were 18V then the current would be (24-18) / 10 = 600mA which would produce a significantly reduced light output. It is unnecessary to add in the effects of forward voltage variations over temperature to illustrate the obvious drawbacks of the constant voltage approach and it becomes increasingly clear that a constant current supply is needed to drive HBLEDs.

The IRS2540 control IC recently launched by International Rectifier is utilized in a Buck converter topology designed to provide a stable, regulated current source over a wide variation in input voltage and output load conditions, making it ideal for many applications where isolation is not required, i.e. where the supply source is already iso-

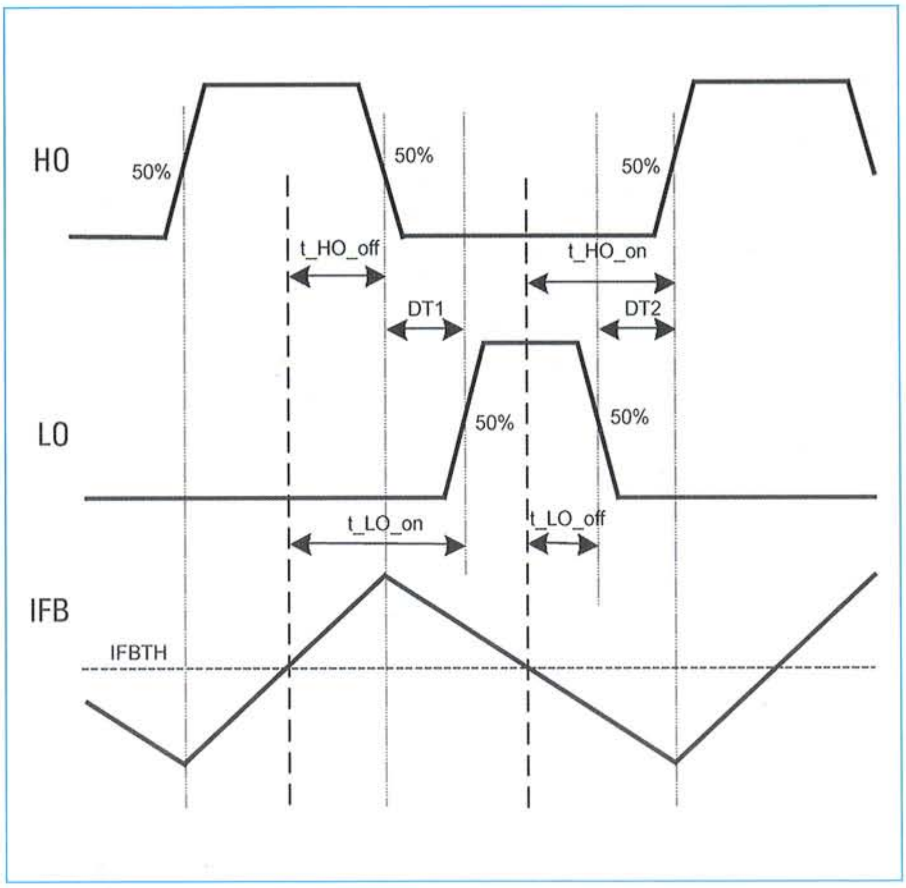

Figure 3. IRS2540 Average current control.

lated or where the HBLEDs are enclosed within a class 2 fixture and are not accessible, such as traffic lights. It should be noted in architectural lighting that electronic ballasts for fluorescent or HID lamps are also generally not galvanically isolated from the AC line.

The Buck circuit topology is suitable only in applications where the input voltage is higher than the output voltage, which covers most signage, decorative and architectural situations. Since the most common HBLED failure mode is by short circuit, it is worth noting that in a series run when one LED fails the others will all continue to operate normally. However, in a parallel arrangement, a short circuit would prevent all of the other LEDs in the array from operating. In the example of Figure 1, if one HBLED in the array fails short circuit, it's partner in the pair will no longer operate but the others will continue to function normally.

The IRS2540 based Buck converter with its unique high side driver allows the continuous monitoring of the load current, which is accurately regulated by means of its patented time delayed hysteretic control method.

The overall system is also very simple and flexible, enabling LEDs to be powered from a DC bus or directly from the rectified AC line. The floating high side driver enables the IRS2540 to sense the LED load current both while the Buck regulator switch is in its on and off phases, providing a significant advantage enabling average current control to be realized as opposed to alternative systems where the current is only detectable during the on phase that must utilize peak current control. Average current control provides inherently stable regulation that is able to operate over a wider line and load range without running into design limitations, since it is able to regulate the on and off times rather than just the on time.

The advantage is that a very accurate current control can be achieved using a very straightforward design concept, which is inherently stable and requires no complex circuit analysis.

Since the LED load requires a DC current with minimal ripple, constant current drivers operate in continuous conduction mode regardless of whether peak or average current mode control is used.

In the case of the IRS2540, care has to be taken to limit stress during hard-switching by the inclusion of defined delays between the time the load current exceeds or falls below the reference level and the time the Buck switch changes state. These delays in conjunction with the dI / dT of the load current (IFB) also determine the frequency and duty cycle of operation, which are further determined by the value of the Buck inductor and output capacitor as well as the input and output voltages of the converter.

Overload and short-circuit protection are inherently provided in this configuration since the output current is constant and open load protection can easily be implemented.

It is well known and documented that switching power supply designs that operate in continuous mode using peak current control run the risk of unstable operation due to sub-harmonic oscillation.

Although this can be eliminated by slope compensation, certain LED con-

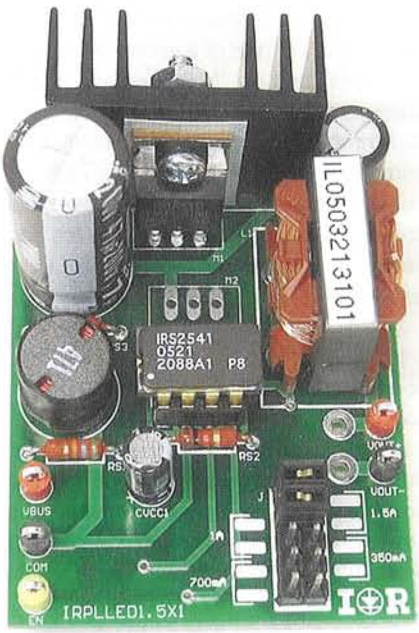

Figure 4. The IRS2540 LED converter demo board.

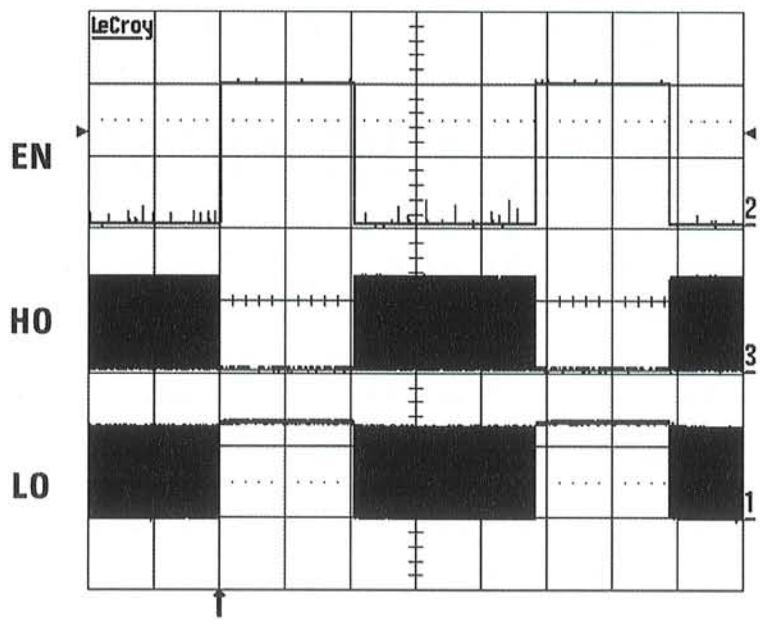

Figure 5. Dimming operation.

trollers currently on the market do not provide access to the oscillator capacitor, which makes such a scheme more difficult to implement. In addition, the slope compensation would also introduce an error between the sensed current and the actual LED load current.

Instead they attempt to get around the problem by operating with a fixed off time rather than a fixed frequency. This does alleviate the sub-harmonic oscillation and allows operation at duty cycles above 50%, however in order for the duty cycle to increase the frequency must drop resulting in a wide frequency variation over the duty cycle range.

In a fixed off time system where the frequency is 100kHz at 50% duty cycle the frequency must be 20kHz at 90% duty cycle and 180kHz at 10% duty cycle.

The IRS2540 does not have this limitation as the on and off times can both vary independently so that the duty cycle can change with little effect on the frequency.

Large frequency variation has the disadvantage of requiring that the inductor value must also be comparatively large.

Changing from a fixed to a variable frequency approach now makes redundant any argument that fixed frequency operation may possess some EMC advantage over the variable frequency operation of the IRS2540 based system in terms of filter simplicity.

This point, however, may well be a misconception based on the assumption that the filter design for a fixed frequency circuit is simpler than that for a variable frequency system, which is not necessarily the case. However, it is clear that in a system where the frequency can vary by an order of magnitude the filtering requirements must be greater.

The IRS2540 method has been demonstrated using the demo board shown in Figure 4, which is capable of driving a string of LEDs with a 17V forward voltage at 1.2A, directly off a rectified 110VAC supply with efficiency above 85% at a frequency of 175kHz.

In many applications dimming is also required. In addition, where there is a combination of LEDs of separate primary colors it is possible by adjusting the intensities of each color, to create any color of the spectrum allowing many possibilities for display lighting, signage and mood lighting. The Buck regulator system based around the IRS2540 is capable of dimming over the full range from logic level a PWM control signal. The PWM signal being at a relatively low frequency is used to switch the drive current to the LEDs on and off and by altering the duty cycle change the light output intensity, without changing the color.

The PWM dimming control signal is shown in Figure 5. The high frequency Buck converter oscillator is being operated in "Burst mode" to adjust the average current in the LEDs. The frequency of the signal is not low enough for flickering to be visible. This allows simple interfacing with microcontroller based dimming control circuitry.

High brightness LEDs are enabling architects, designers, specifiers and manufacturers to create lighting effects and design luminaries not previously possible for theaters, studios, nightclubs, restaurants and other high visibility venues. Using digital control, for example, through the DMX512 protocol, vibrant and changing light can appear to come from a variety of places. Whether embedded in a countertop, ceiling, or wall, lamp size no longer dictates where light can originate from. The lighting world is being reinvented with the introduction of ever improving HBLED technology.

Landscape lighting and outdoor lighting also naturally lends itself to HBLED light sources, which offer advantages over incandescent and fluorescent lamps such as longer life and consequently reduced maintenance costs, as well as less vulnerability to moisture ingression. Unlike conventional light bulbs, LEDs have no fragile internal components such as filaments to break, even when handled roughly. The IRS2540 based converter is ideally suited for many of these applications.

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