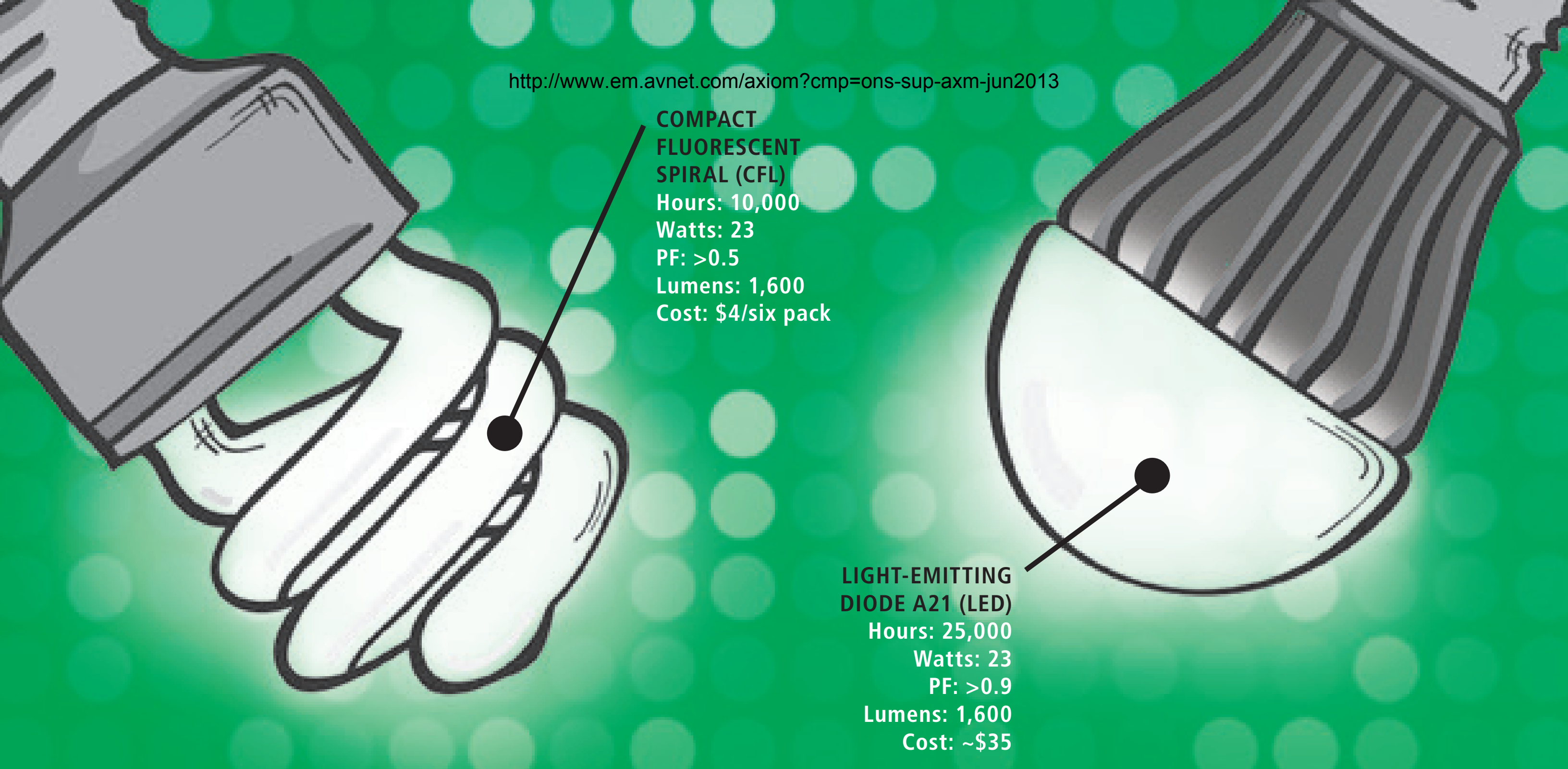

ON Semiconductor®

DRIVING THE LED REVOLUTION FOR LIGHT AND FOR ART

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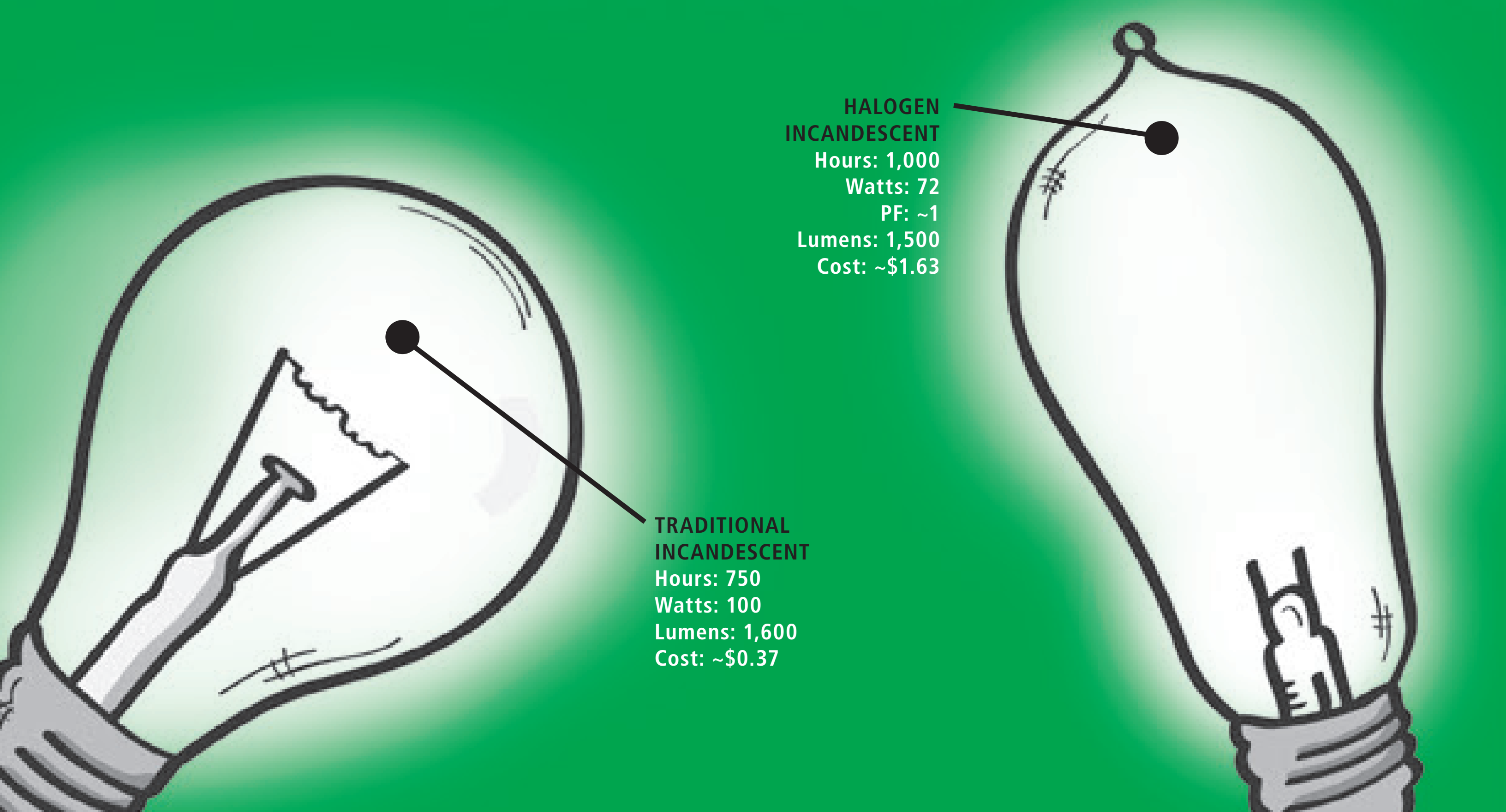

Figure 1: San Francisco's Bay Bridge

LEDs for Light and Even Art!

The emergence of LEDs as a usable and hugely beneficial light source has created a massive impact in the global lighting market. Old incandescent technology – if an approach that sees light created as a consequence of a conductor glowing and where 90% of energy is released as heat rather than light can be called technology – has truly had its day. Driven by its energy saving abilities, reliability, long life and design flexibility, LED lighting is continuing to make major inroads into sectors of the lighting industry such as domestic halogen replacements, public buildings, street lighting and automotive. The versatility and controllability of LED lighting has also attracted attention from artists and public projects that involve different forms of light displays using often many thousands of interconnected and individually controlled LEDs.

The Bay Lights project in San Francisco is a perfect example of how all the virtues of LED lighting can be utilized to create a visual spectacle that attracts publicity, tourist dollars and puts a location in the spotlight for all the right reasons. The Bay Lights project is the world's largest LED 'sculpture'. Comprising 25,000 individually programmable and controllable white LEDs, the continually changing display across the 1.8 mile Bay Bridge West Span in the iconic west coast city is up to 500 feet high at certain points.

This type of attraction could only be designed and implemented using LEDs for many reasons. In addition to the aforementioned control made possible by an array of digital and analog components that have spawned to support the LED lighting revolution, their robustness also makes them more than suitable for challenging outdoor environments plus their reliability and longevity; LEDs have a life expectancy tens of times longer than incandescent lighting technologies. Additionally, when illuminating 25,000 light points, energy consumption and maintenance cost have to be considerations. Even high-power white LEDs are typically sub 5 W devices – compare that with > 50 W for traditional lighting. To illustrate this point, the Bay Lights Project uses just 150 to 175 kilowatt hours (kWh) of energy while operating for approximately seven hours each night. This equates to an energy cost of $11,000 per year or $30 per day at $4.25 per hour – quite remarkable given the scale of the light sculpture.

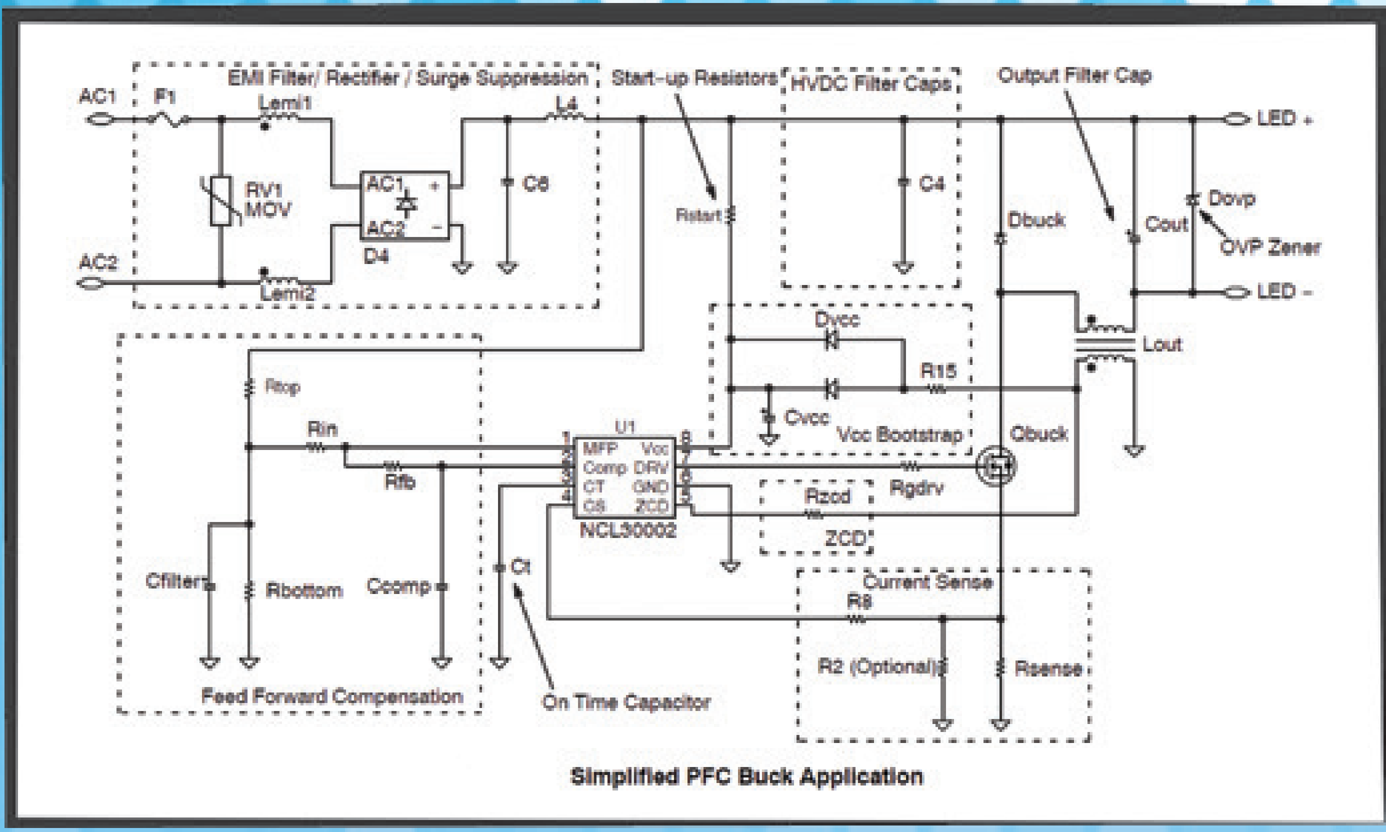

Figure 2: Power Factor Buck Application Schematic

Taking a more global viewpoint, as its popularity grows, LED lighting is making a large and valuable contribution to the essential need to cut energy consumption and in so doing allowing greater dependence on more sustainable sources of energy. In like-for-like light output halogen replacement applications for example, LEDs can achieve a remarkable 80% energy consumption reduction. Along with energy cost savings, their long life expectancy can allow a 'fit and forget' approach – this is especially useful in installations that are difficult to access such as high ceiling buildings or where public access is required 24 hours a day making the scheduling of maintenance difficult.

Driving the LED Revolution

Whether for the Bay Bridge project or LED replacements for incandescant or CFL lighting, it is important not to forget the electronics technology 'behind the bright lights.' Numerous drive and control components are needed to ensure LEDs are powered correctly to achieve efficient performance, reliability and the correct light output.

White LEDs were the most recent color to be introduced. They presented the greatest technical challenges that had to be overcome. But now that they are here they have proven to be the catalyst for the LED revolution as the most commonly required light source. White LED technology is still advancing rapidly with higher lumens per packaged LED as well as increased efficacy. White LEDs can now offer lifetimes at least 25 times that of a standard incandescent bulb with efficacy already exceeding the performance level of CFL bulbs. What may not be understood is that while incandescent bulbs appear like resistive loads to the AC mains and have near perfect (~1) power factor (PF), the electronic ballast inside the most common CFL bulbs is capacitive and has a typical power factor of just 0.5-0.6. This means that while the user only pays for delivered watts, the electric utility must actually generate the proportional volt-amps; so a 13 W CFL bulb with a PF of 0.5 represents a 26 volt-amp load, which is slightly less than 50% of the volt-amps of 60 W incandescent. As a result, in the U.S.,the Energy Star™ program has established a minimum power factor of 0.7 for > 5 W LED lamps and 0.9 for commercial LED luminaires such as downlights and spotlights. Globally, the U.S. does not have the toughest PF requirements for LED bulbs; this accolade goes to Korea where the minimum PF requirement is 0.9 for bulbs with input power over 5 W. This requirement presents challenges in designing the drive electronics where efficiency, available space, and bill-of-material cost must all be evaluated to achieve an optimal solution.

Incandescent bulbs are designed for one specific line voltage and applying this principle for LED bulbs introduces a new degree of freedom for designers as they no longer need to consider a single universal design that must work globally. In addition, the power supply within the bulb does not need to be electrically isolated from the load as it is integrated inside a single housing. Care must of course still be taken in the mechanical design to meet the safety requirements through physical means. Taking that into account, it is no longer necessary to use an isolated fly back topology as the only power conversion architecture option.

A buck topology can be optimized for good power factor under specific boundaries. Recall for high power factor the input current is coincident with the line and increases proportionally as the rectified line voltage increases. The drawback of the buck is that no current flows until V_{in} is greater than V_{out}, this is why it is important

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that compared to the line voltage the LED string voltage must be relatively low. This is not a problem as in most cases the number of LEDs in series is relatively low compared to the line voltage. For example, 8 LEDs in series is ~ 25 V which is < 15% of the peak voltage of a rectified 120 V AC input.

One control scheme for high PF boost converters is a fixed on time control where the switching cycle restarts when the inductor current reaches zero. To control the power, feedback is used to adjust the on time. The same concept can be adapted to implement a buck topology and can be improved with a twist. With fixed on time, the current through the inductor/switch rises in proportion to the line, this results in near perfect power factor with the tradeoff that the peak current can be very high at the top of the switching cycle. In the bulb case, ideal power factor is not required so if the peak current is limited during a portion of the switching cycle, losses in the switch and inductor can be reduced which achieving higher conversion efficiency and limiting the inductor size. This creates a typical line current waveform which doesn't look very sinusoidal. However this waveform easily achieves a PF > 0.9 with the tradeoff of increased distortion.

To implement this hybrid fixed on time/peak current scheme the NCL30002 controller from ON Semiconductor has been developed and Figure 2 illustrates the complete application schematic.

The first point in reviewing the schematic is that the LEDs are referenced to the high voltage rail while the power switch is referenced to ground. This is referred to as a reverse buck and simplifies the architecture since the peak LED current can be sensed directly and a level shifter is not required to drive the FET. After the controller starts switching, the driver is biased from an auxiliary winding on the inductor, this has an added function to sense when the current through the inductor drops to zero indicating a new switching cycle should start. A precise 485 mV (± 2% typical) is used to regulate the peak current through the switch. After V_{in} exceeds the LED V_f, fixed on time control is used to regulate the power to the LEDs until the peak current limit is reached which is detected by Rsense. To control the delivered power if the AC line varies from nominal, line feedforward compensation is used to modulate the on time.

Summary

With an optimized architecture, it is possible to solve the challenge of achieving high efficiency in a compact form factor while meeting the most stringent PF requirements for lighting arrangements that use LEDs. The basic design can be scaled for lower power by changing the MOSFET and reducing the size of the inductor. This is critical since LED efficacy will continue to advance as manufacturers increase lumen output per LED, requiring few LEDs for the same lumen output and thus pushing down the energy consumption while at the same time reducing the cost of integral bulbs and increasing their market acceptance.

Projects and temporary artistic installations such as The Bay Lights do not always need to comply with PF requirements and other performance stipulations that apply to permanent functional LED lighting installations. However they do provide an important proof point for the technology, its controllability, reliability and energy/cost efficiency. As well as providing an inspiring spectacle, The Bay Lights act as a showcase for how far LEDs and their supporting drive and control technology have come. This in turn can only help to speed the penetration of LEDs into many sectors of lighting.