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Dimmable LED based lamps

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Document information

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Abstract	This article discusses the changes in lighting technology, with specific reference to developments in dimmable LEDs. It also explains these different issues and provides examples of the possible compromises to be considered.

Revision history

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1. Introduction

In recent years, the lighting world has witnessed a new revolution with the appearance of LED based lighting. In retail outlets, incandescent lamps now appear to belong to another age, and the Compact Fluorescent Lamp (CFL) must compete with the new player in the retrofit market. There are numerous reasons for the emergence of LED lighting technology. LED technology is constantly developing and rapidly improving with time, and LEDs are becoming far brighter and much more powerful. Added to their efficiency, these features make them ideal for use in lighting. An incandescent lamp produces approximately 10 lumens per Watt, but LEDs can now reach values of up to 100 lumens per Watt. LEDs are already more efficient than the currently available CFL lamps seen in the market today.

Ecological issues are also becoming increasingly relevant to the public. With a heightened awareness of global warming and climate change, the idea of saving resources and energy is becoming a major feature in many marketing strategies.

The concerted effort of manufacturers to decrease the fuel consumption of motor cars over the last 10 years, and the end of the production and retailing of 100 W incandescent lamps, perfectly illustrates this trend. Governments are also steering in this direction by relaxing taxation and providing financial encouragement for ecologically friendly products, generally referred to as “eco” products.

LEDs offer many other advantages including high dimmability, excellent lifetime and a small form factor. They provide access to a world of new perspectives for lighting applications in terms of form, color, and the creation of atmosphere.

However, the consumer LED market is presently made up of retrofit lamps, dictating the need to address the following issues:

- Special measures have to be taken to ensure compatibility with the existing housing constraints, especially when dimmers are used
- The form factor must be equivalent to an Edison type lamp
- The heat created by the LEDs must be dissipated

2. Dimmer compatibility

Until now, control equipment for home lighting has been based on the incandescent lamp. The most economical way to provide dimming functionality was to use AC mains phase-cut dimmers. These dimmers were developed to be used with an incandescent lamp that can be regarded as a resistive load.

The equivalent load of new electronic light sources such as CFL or LED lamps, is no longer purely resistive. This makes a considerable difference in the way the dimmer works. Using an unsuitable load can lead to unsatisfactory functioning of the system. It can create some very unpleasant flickering of the light, or even damage the lamp or dimmer. This can be a disappointment to customers, and after such an experience, a negative opinion about the product can prevail. Moreover, dimmers are still quite expensive, and customers cannot be expected to change their dimmers in order to suit their new lamps. Consequently, dimmer compatibility is a very important feature of the next generation of LED based products.

There are various types of phase-cut dimmers, but they all use the same principle i.e. cutting a part of the mains sine wave during each period. This is achieved using a switch. When the switch is conducting, a supply is delivered to the load (the lamp). When it is off, no supply is delivered. The total energy delivered is modulated by adjusting the conduction time.

There are two types of dimmers: leading edge and trailing edge types.

- **Leading edge dimmers** - the phase is cut at the beginning of the mains half period. After a time corresponding to the dimming position, the switch is set to “on” and the supply is delivered until the end of the half period. After crossing zero, the operation is repeated, see Figure 1 and Figure 2.
- **Trailing edge dimmers** - the switch is set to “on” at the beginning of the half period,” and closed after a time corresponding to the dimming position. It stays off until the end of the half period. After crossing zero, the operation is repeated, see Figure 3.and Figure 4.

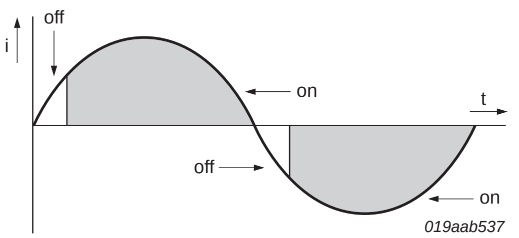

Fig 1. Leading edge - dimmer maximum on

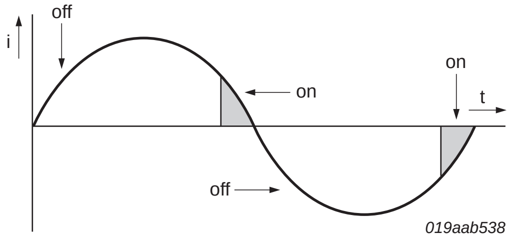

Fig 2. Leading edge - dimmer minimum on

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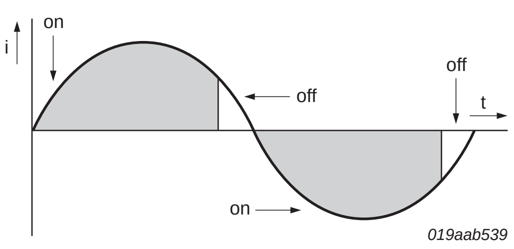

Fig 3. Trailing edge - dimmer maximum on

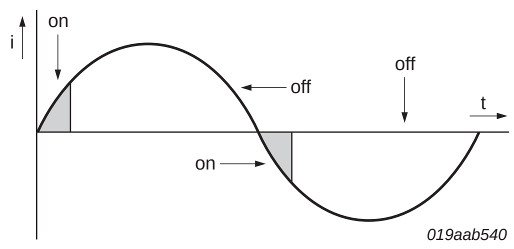

Fig 4. Trailing edge - dimmer minimum on

There are two technologies mainly used to achieve phase cutting:- triac switches and transistor switches. Triac dimmers are always leading edge dimmers whereas transistor dimmers can be either “leading” or “trailing” edge dimmers. The issue with triac dimmers is that they require special conditions to work correctly. A triac is opened by triggering its gate. Once the gate is triggered, the triac enters the conductive mode and it requires a minimum current to maintain it. This current is referred to as the “latch current” and it must be applied for some time for the triac to settle into the conductive mode.

Once the device is latched, a continuous “holding current” flows through the device. If this current is removed or decreased, the triac switches off.

A LED based lamp has to sink the hold current needed for the dimmer to be dimmer compatible. For example, if a 6 W LED lamp (approximately equivalent to 40 W incandescent lamp) is used with a dimmer designed for a minimum load of 10 W, extra circuitry is needed to provide sufficient hold current. In this situation, the efficiency of the lamp decreases, but the energy savings will still be significant when compared with a 40 W incandescent lamp. Moreover, a LED lamp without this circuitry does not operate correctly. There are variations in the hold currents of all dimmers.

To conclude, more additional losses will increase dimmer compatibility. The difficulty in designing a dimmable application, is to find a compromise between efficiency and dimmer compatibility.

The NXP SSL2101 (and derivative SSL2102) has two integrated bleeder switches controlled by the IC. Two different bleeding currents can be set by connecting external resistors. The IC offers good flexibility in the choice of current and this helps to optimize dimmer compatibility. In the SSL2103 (the controller-only version of the SSL2101 and SSL2102), the integrated switches are removed. They are replaced by low cost external bipolar switches (still driven by the IC) for higher bleeding current levels. The internal MOSFET, used to operate the converter, is also removed, and it is corrected externally to enable a specific tuned solution.

3. Form factor versus topologies

LEDs are fundamentally current driven and the quantity of light they emit is approximately proportional to the current flowing. Based on this, different topologies can be used to drive them from a mains supply. One of the key targets in the choice of topology, is the form factor of the final application. Small power lamp LEDs (<15 W) mainly address retrofit markets. Consequently, the shape of the lamp must be equivalent to the classic form of existing lamps.

Section 3.1, Section 3.2 and Section 3.3 provide three topologies that are representative of currently available products.

3.1 LEDs in series with a resistor

The LEDs are in series with a resistor and connected directly to the mains. This topology is the simplest. As soon as the mains voltage is higher than the sum of the forward voltages of the diodes, the LEDs start conducting. The maximum LED current I_{peak} is determined by the value of the resistor as shown in Equation 1.

$$I_{peak} = \frac{V_{mains\_max} - n \times V_f}{R} \quad (1)$$

where n is the number of LEDs and V_f is the forward voltage of the LEDs.

This solution is simple but very inefficient. As an example, consider a 12 W application with a maximum current of 500 mA through the LEDs. The global forward voltage is 24 V. For 220 V (AC) mains, the resistor value needed is 574 Ω. This resistor has a peak dissipation of 143 W at a current of 500 mA. An alternative is to use a series of low current diodes. Although the current flowing is lower, the total forward voltage (V_f) is much higher for the same power of a single LED. As a direct consequence, the open time is much shorter and strobing occurs.

3.2 Buck topology

Buck topology is one of the most efficient topologies and a basic schematic is shown in Figure 5.

When the switch is on, current flows through the coil and the LEDs, and light is emitted. A sense resistor is placed in series with the ground to control the value of the current. The voltage across this resistor is sensed, and when it reaches the OverCurrent Protection (OCP) value, the switch is closed. The energy stored in the coil is then discharged in the free-wheel diode and the LEDs and light is emitted again.

This topology has two main advantages:

- It is very efficient, especially for low power applications (below 10 W). General lighting LED lamps using this kind of topology often claim efficiency values higher than 90 %.
- Advantageous form factor. The global form factor of the application is very important to the retrofit market because the final shape of the product must be comparable to classic incandescent or halogen products. Buck topology does not use transformers or optocouplers, and so the coil can be relatively small, especially if the switching frequency is set relatively high.

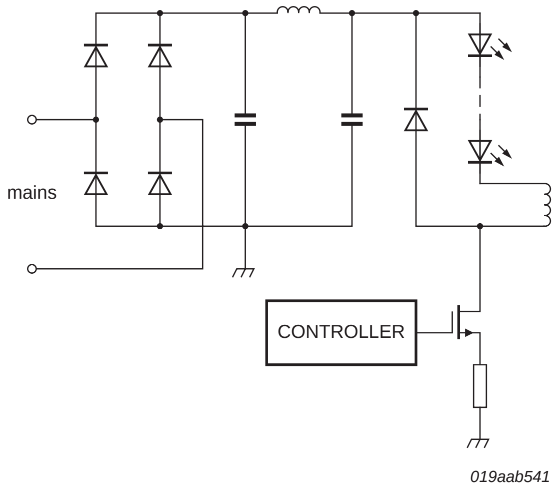

Fig 5. Buck topology schematic

The topology has two disadvantages:

- The main disadvantage of this topology is that it does not provide galvanic isolation. The LEDs are often placed on a metallic heat-sink to dissipate the heat generated. In such cases, galvanic isolation not positioned within the electronics, may be mandatory to provide the necessary safety aspects.
- The second disadvantage is that the LEDs are connected in series with the coil. There is a compromise between the global forward voltage of the diodes and the maximum losses in the converter. If there is a big difference between input voltage and output voltage, efficiency will suffer.

3.3 Flyback topology

In the flyback topology, the coil is replaced by a transformer and LEDs are connected to the secondary side as shown in Figure 6.

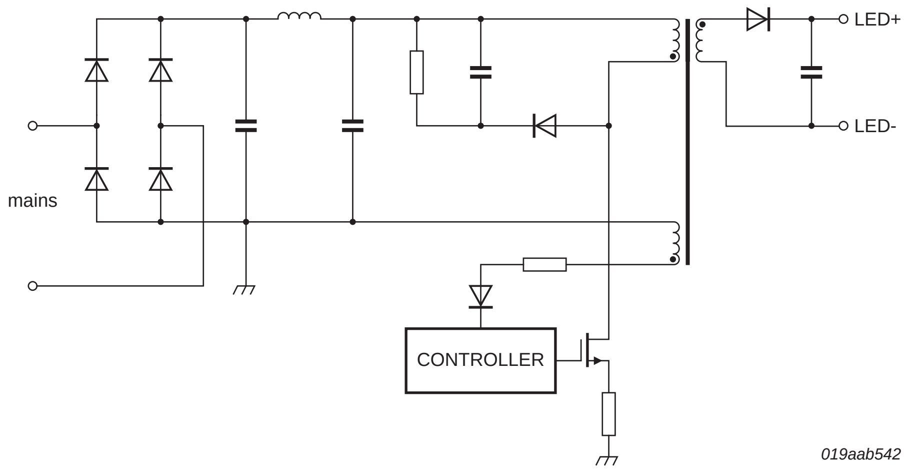

Fig 6. Flyback topology schematic

When the switch is on, current flows through the transformer and the diode on the secondary side is blocked. When the switch is off, the secondary diode conducts and light is emitted.

The main advantage of the flyback topology is that LEDs are connected to the secondary side of the transformer. A compromise between the number of LEDs and the efficiency of the dimmer is no longer necessary because a suitable winding ratio can be selected. Galvanic isolation is now possible, the safety of the unit is improved and V_{CC} generation is simpler. An auxiliary winding can be added to the transformer that generates the supply to the controller.

The main disadvantage of this topology for the retrofit market, is the physical size of the application. The transformer (and potential optocoupler in the case of feedback) occupies a large amount of space.

Some controllers, such as the SSL210x family, are compatible with both buck and flyback topologies. A very compact buck application can be produced to accommodate product requirements. Alternatively, when good thermal dissipation and safety are priorities, a flyback topology can be used for high power LEDs and provide galvanic isolation. To obtain a smaller form factor, both the SSL2101 and SSL2102 have integrated power switches.

4. Dimming

LEDs are relatively easy to dim as the light emitted is almost proportional to the supplied current. The light output is decreased by reducing the average current. However, having a dimmable topology is more complex and different techniques must be used, such as Pulse Width Modulation (PWM) dimming, frequency modulation and I_{peak} modulation.

- **PWM dimming** - the momentary current sent to the LEDs has only 2 values: 0 or I_{max}
  - When the PWM signal is inactive over the complete cycle, $I_{leds} = 0$ A
  - When the PWM signal is active over the complete cycle, $I_{leds} = I_{max}$

  The average LED current can be changed by adjusting the duty cycle of the PWM signal. This technique requires the converter to act as a fast switchable current source. The aim of this technique is to accommodate high currents and have accurate control. Switching losses can be high, especially for deep dimming. The relationship between the duty cycle of the PWM signal and the light output is proportional. The switching time for deep dimming (<0.1 %), has to become very fast which causes high switching losses.
- **Frequency modulation** - the maximum LED current is not changed, but the frequency of the converter is adapted. In other words, the amount of energy sent to the LED during each cycle of the converter is the same, but the number of cycles per second is modulated. The problem with frequency modulation is the audible noise generated if the minimum frequency becomes too low. It also gives considerable switching losses if the maximum frequency becomes too high. These factors can make deep dimming difficult.
- **I_{peak} modulation** - the frequency of the controller is constant but the time that the power switch is open, is modulated. As a result, the maximum current I_{peak} in the LEDs is changed. This means that the number of cycles per second is constant but the quantity of energy sent to the LEDs at each cycle is reduced. To achieve deep dimming using this technique, very small pulses are needed. This is not advisable because of the switching losses.

Some controllers, such as the SSL2101 and its derivatives (SSL2102 and SSL2103), combine frequency and I_{peak} modulation. The drawbacks of each method are minimal. At full power, the switching frequency can be optimized to limit switching losses. To avoid open times being too small and frequencies being too low during dimming, the I_{peak} and frequency are reduced simultaneously. As a consequence, dimming below 1 % can be achieved.

5. Life time

The major advantage of LEDs is their extended lifetime. They can have life expectancies exceeding 50,000 hours. This value is much higher than the equivalent CFL lifetime, and far exceeds that of a conventional incandescent lamp. LEDs, however, cannot be used alone as they need other components to drive them. In the semiconductor industry, the standard for a lifetime test is 1000 hours. Depending on the working temperature of the final application, some coefficients are applied to estimate the lifetime of components. The 1000 hours test is certainly not sufficient to guarantee an estimated lifetime. An extended lifetime test must be done to guarantee that the controller has a lifetime compatible with the lifetime of the LEDs.

All of the SSL210x family have passed the 8000 hours lifetime test at 150 °C junction temperature. The estimated lifetime of the controller depends on the final application temperature and it can be equal to the LED lifetime. At a junction temperature of 115 °C, the SSL210x lifetime is 45,000 hours.

6. Conclusion

LED based lamps are currently still in the minority in terms of numbers in the general lighting market. Nevertheless, the ramp-up in the market has started, and LED solutions will certainly become more and more dominant in the coming years. This application note discusses several aspects of dimmable LED lighting applications with the two mainly used topologies being buck and flyback. The buck topology offers a very compact and efficient solution for low power applications. The flyback alternative, with its intrinsic galvanic isolation, is still the best way to provide a safe and versatile system.

Dimmer compatibility and dimming ranges are two challenging features. Balancing the issues surrounding these choices will determine the difference between having successful or unsuccessful products.

NXP currently provides the SSL210x family to cover all possible dimmable applications for the retrofit market and provide an optimum solution for each design.

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8. Contents

1 **Introduction** 3
2 **Dimmer compatibility** 4
3 **Form factor versus topologies** 6
3.1 LEDs in series with a resistor 6
3.2 Buck topology 6
3.3 Flyback topology. 7
4 **Dimming** 9
5 **Life time** 10
6 **Conclusion** 11
7 **Legal information**. 12
7.1 Definitions. 12
7.2 Disclaimers 12
7.3 Trademarks. 12
8 **Contents** 13

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