SCR (Silicon-Controlled Rectifier) Dimming Technology in LED Lighting

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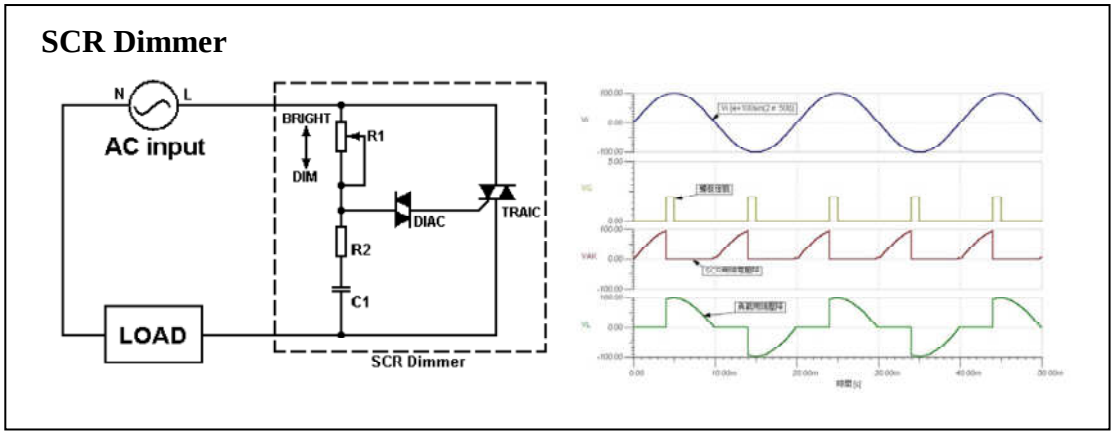
Introduction

A dimming function in lighting has a growing demand in the market in terms of efficient use, lifestyle and comfort. More importantly, it is all about energy saving.

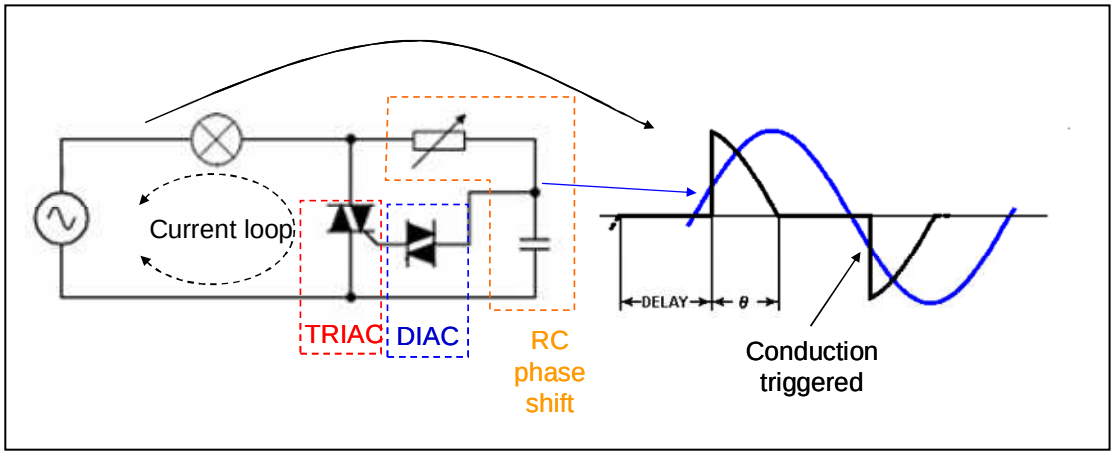
There are different dimming technologies to control the brightness of a light source. They include AC/DC dimmer, amplitude/phase dimmer, active/passive dimmer, step/stepless dimmer. In addition, there is the rheostat dimmer, autotransformer dimmer or SCR (Silicon-controlled Rectifier) dimmer. Among all these, the SCR dimmer is the most efficient, stable and popular method.



Principle and Characteristics of SCR

A SCR is a four-layer solid state device that controls current. In the normal “off” state, SCR restricts current to the leakage current. When the gate-to-cathode voltage exceeds a certain threshold, SCR turns “on” and conducts current. A SCR will remain in the “on” state even after gate current is removed so long as current through the device remains above the holding current. Once current falls below the holding current for an appropriate period of time, the device will switch “off”. If the gate is pulsed and the current through SCR is below the holding current, SCR will remain in the “off” state.

To achieve the dimming effect using SCR dimming technique, first, a RC phase shift is used to delay triggering the gate-to-cathode voltage. There will be a phase-cutting and the Root Mean Squared Voltage V_{RMS} is modified. The symmetric characteristic of DIAC (DIode for Alternating Current) can be used to trigger TRIAC (TRIode for Alternating Current) symmetrically. Then, the dimming effect can be achieved by varying the R1 value that changes the phase angle for conduction.

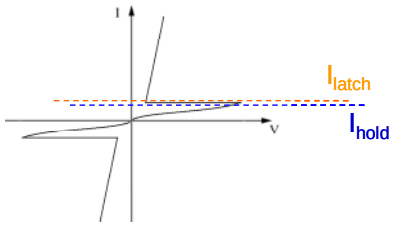


Due to the TRIAC characteristic, a minimal holding current I_{hold} has to be maintained to turn on TRIAC. Otherwise, TRIAC will remain open. Different TRIAC has different I_{hold} with a range of a few to tens of mA, and even up to 50mA for stable conduction.

Commercially available dimmers from different brands have specification of 100W, 200W, 600W to 1000W. Higher wattage then requires higher holding current.

Without enough holding current to maintain TRIAC conduction angle, the output waveform will become uneven, fluctuate or even have spikes, affecting V_{RMS}.

This situation will not affect the incandescent light since incandescent light is a linear load with operating current, usually over 50mA. However, in case of LED lighting, the uneven output waveform will become a flickering issue.



TRIAC I-V Curve

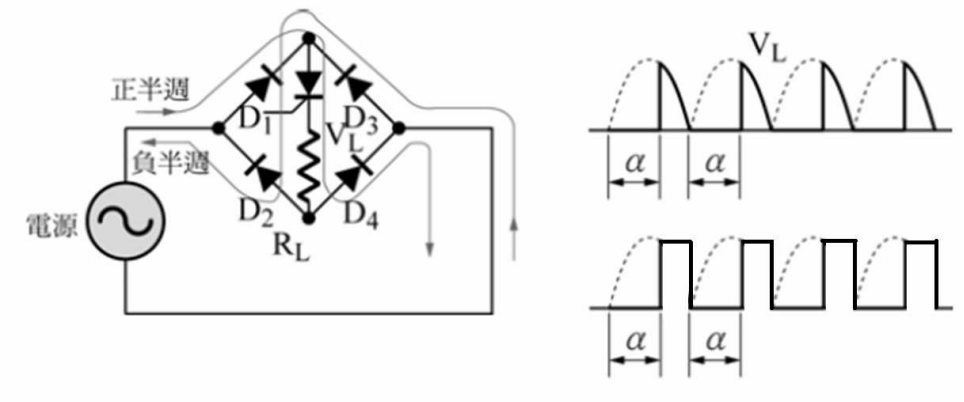
Waveform of SCR dimmer
at 80% level with LED load

Solomon Systech's Dimming Solution for LED Lighting

For LED as a retrofit lighting to replace traditional incandescent lighting in the market, it has to be able to adapt the SCR dimming function without flickering. It also has to solve other different problems in SCR dimming such as loading, over-heating and flickering due to under-loading.

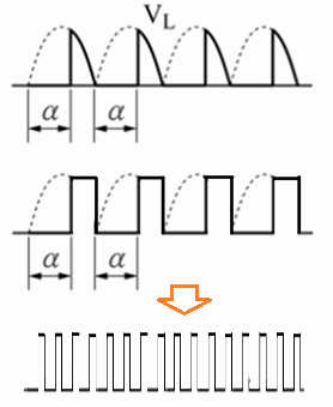
Solomon Systech's LED driver controller ICs offer highly efficient constant current source with wide input voltage range for LED lighting. They have active Power Factor Correction (PFC), various dimming algorithms and sophisticated circuit protection schemes that make end product easily to be accepted by the market as a replacement for traditional lighting.

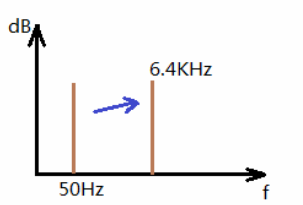
100Hz Flickering with SCR



- The mains frequency is 50/60Hz. After phase-cutting, 100/120Hz pulse signal can be obtained and applied to generate PWM dimming signal.
- In real application, any minor fluctuation in voltage and/or current may affect the PWM duty cycle, resulting in 100/120Hz flickering.
- Incandescent lamp does not have such issue because the decay time of the incandescent filament (the time it takes the filament to cool off and stop emitting energy) is much longer.

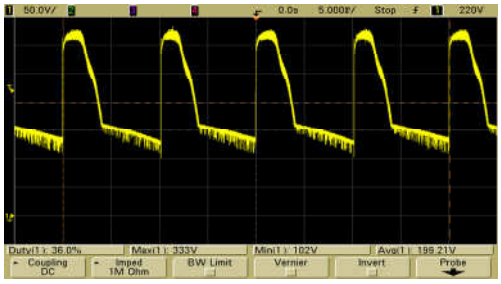
Solution from Solomon Systech





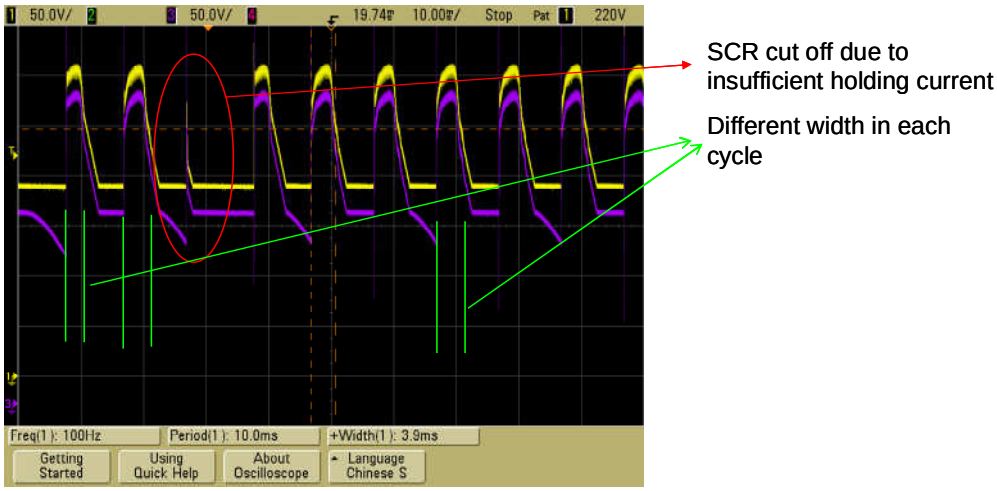
- Migrate the PWM signal from the original phase-cut waveform to a higher frequency band and make the flickering not visible to human.
- SSD1075 LED driver controller migrates the dimming signal to a frequency band at few kHz.

Loading issue of SCR



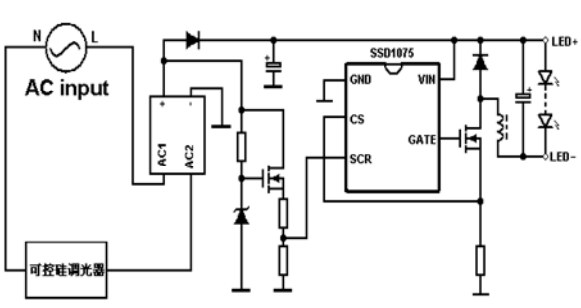
- Stable operation of SCR needs steady holding current I_{Hold}.
- Most of the power supply to LED is non-linear switching power supply, together with the power saving nature of LED, the power required from whole lamp is not that high. Then the operation of SCR becomes unstable.

Triggering SCR requires a minimal current. LED load is non-linear and requires variable input current. Then, the conduction state and the triggering voltage of SCR will vary like the following diagram. (Purple refers to $220V_{AC}$ rectified input to SCR, yellow refers to the capacitor filtered waveform.)



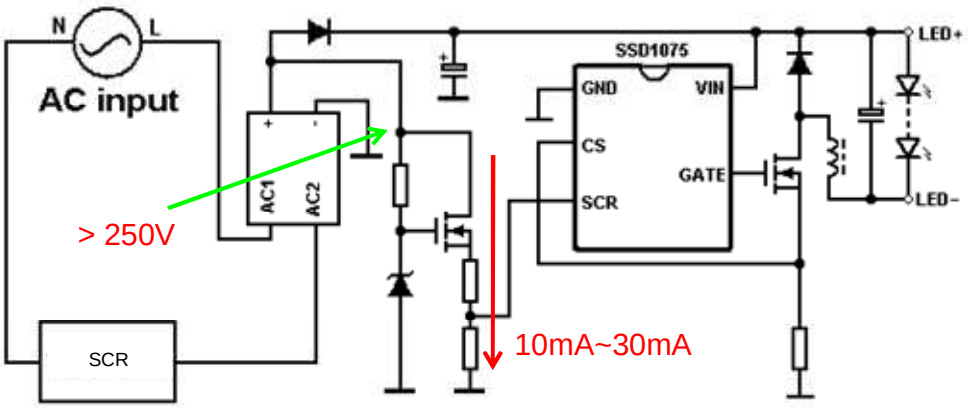
- If the PWM signal is generated directly from the phase-cut power supply, flickering in LED will happen.

Solution from Solomon Systech



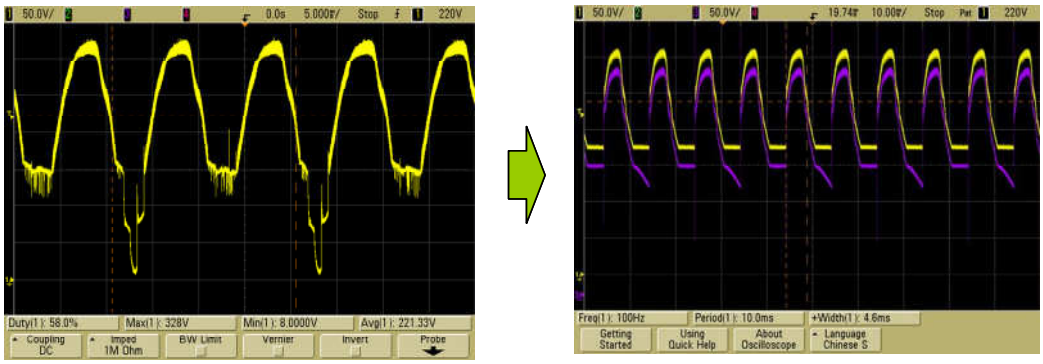
- Before the SCR input signal, a virtual load of steady 10~30mA is added to TRAIC. The waveform of SCR is greatly improved.

Over-heating issue of Virtual Load



- Power consumption in virtual load = 250V x 0.01A = 2.5W ~ 250V x 0.03A = 7.5W
- Putting 7.5W virtual load into E27 bulb is not feasible, also efficiency is low. The virtual load current has to be minimized, e.g. < =10mA

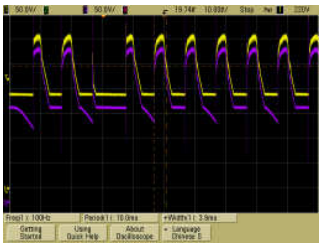
Solution from Solomon Systech



- Challenge: Minimize the virtual load, while maintaining an accurate conduction angle.
- Using DSP technique, the extracted signal from SCR is conditioned, making a more reliable dimming signal.

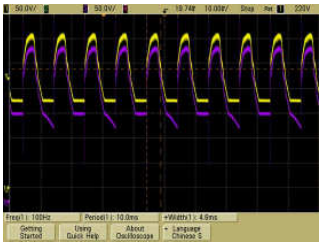
Flickering due to under-loading in SCR

- The signal becomes unstable when under-loading.
- Some missing cycles and uneven width happen.

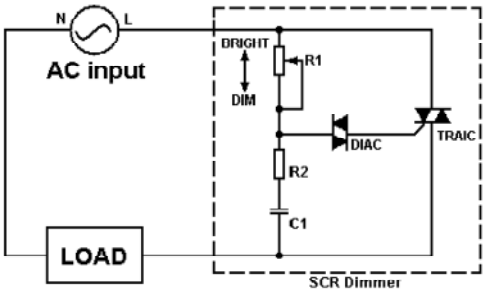


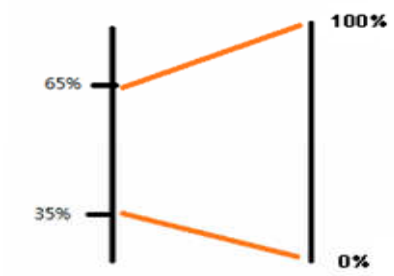
Solution from Solomon Systech

- Signal conditioning and phase locking techniques are applied to two neighboring cycles. The flickering is greatly eliminated.



Variation in operating range of SCR





- R1, R2, C1 are the main components to determine the TRIAC conduction angle and these 3 components affect the conduction position and shut-off position.
- Therefore, SCR dimmers have various operating range. Some may be able to control LED lamps's brightness from 35% to 65%, some may be able to control from 10% to 70%.

Solution from Solomon Systech

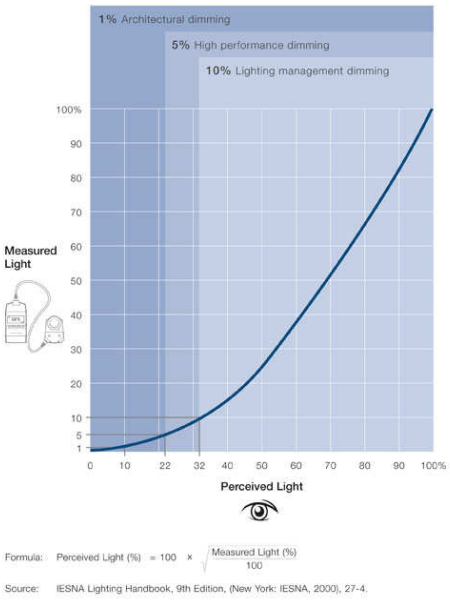
- Our LED driver controller ICs employ DSP technique for the dimming algorithms, which allows a full operating range of LED lamps from 0% to 100% brightness despite any kind of dimmers.
- With the introduction of regional linearity, the dimming performance of LED lamps can be made consistent even with different dimmers.

Brightness adjustment to human eyes

- Dimming control in the market in general has not any specific scheme to take care the comfortability of brightness adjustment to human eyes.

Solution from Solomon Systech

- According to the IESNA Lighting Handbook, Gamma-compensated brightness adjustment fits human eyes better.
- Our LED driver controllers have gamma-compensated brightness control implemented on-chip.



Conclusion

Solomon Systech's LED driver controller ICs have overcome all these SCR dimming issues with LED lighting. They are highly efficient LED driver controller ICs with high voltage input range (450V) to support High Brightness (HB) LED lighting products (e.g. E27/E26 and GU10 light bulbs). They are designed for low BOM cost, low power consumption and low EMI. And they are also optimized for high power factor, high efficiency and long-term reliability.