National Semiconductor
2900 Semiconductor Dr.
Santa Clara, CA 95052

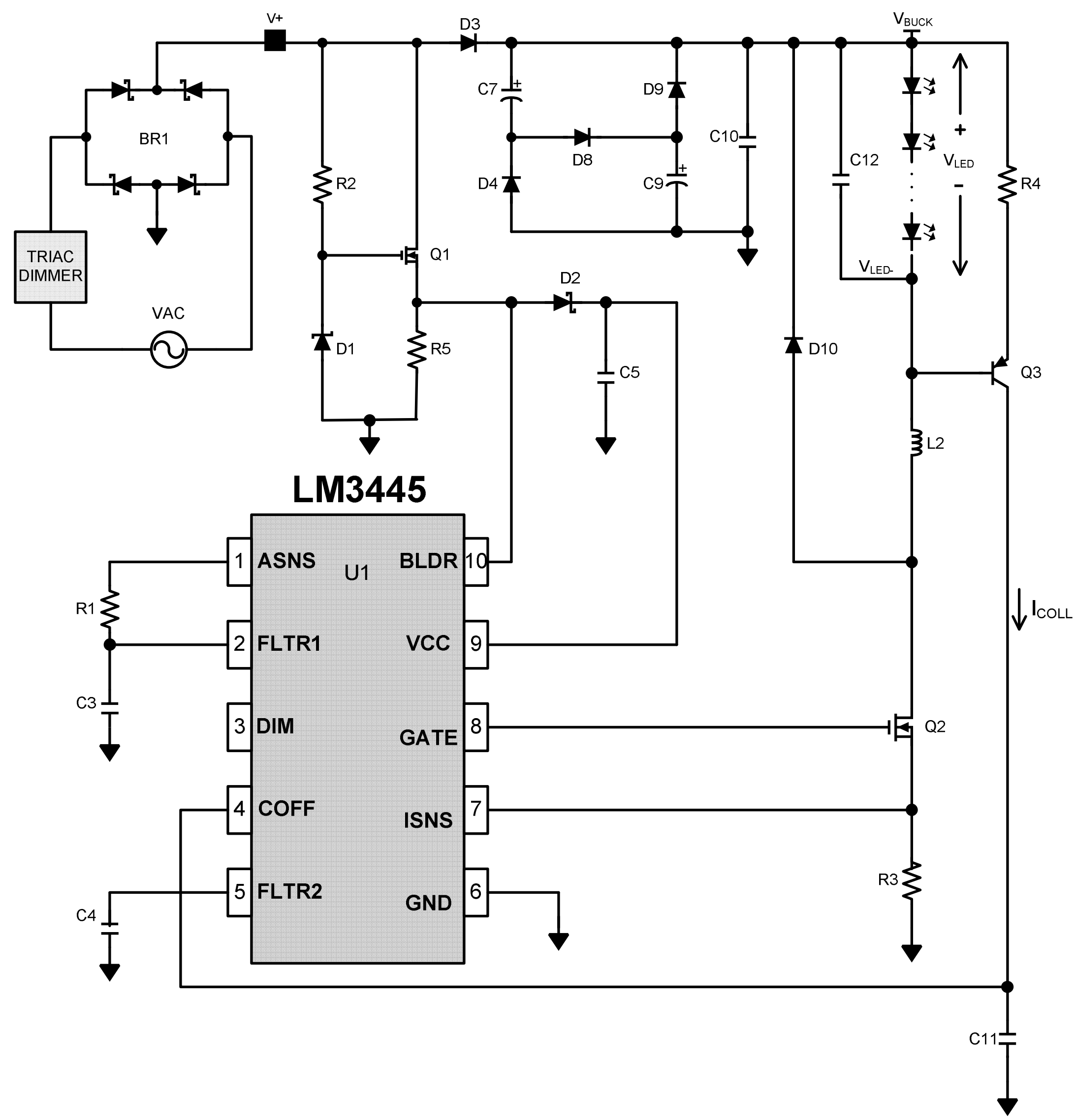
Matt Reynolds
Principal Apps
SSL Division

National Semiconductor
The Sight & Sound of Information

LM3445 Work Book (Tips and Tricks, and troubleshooting)

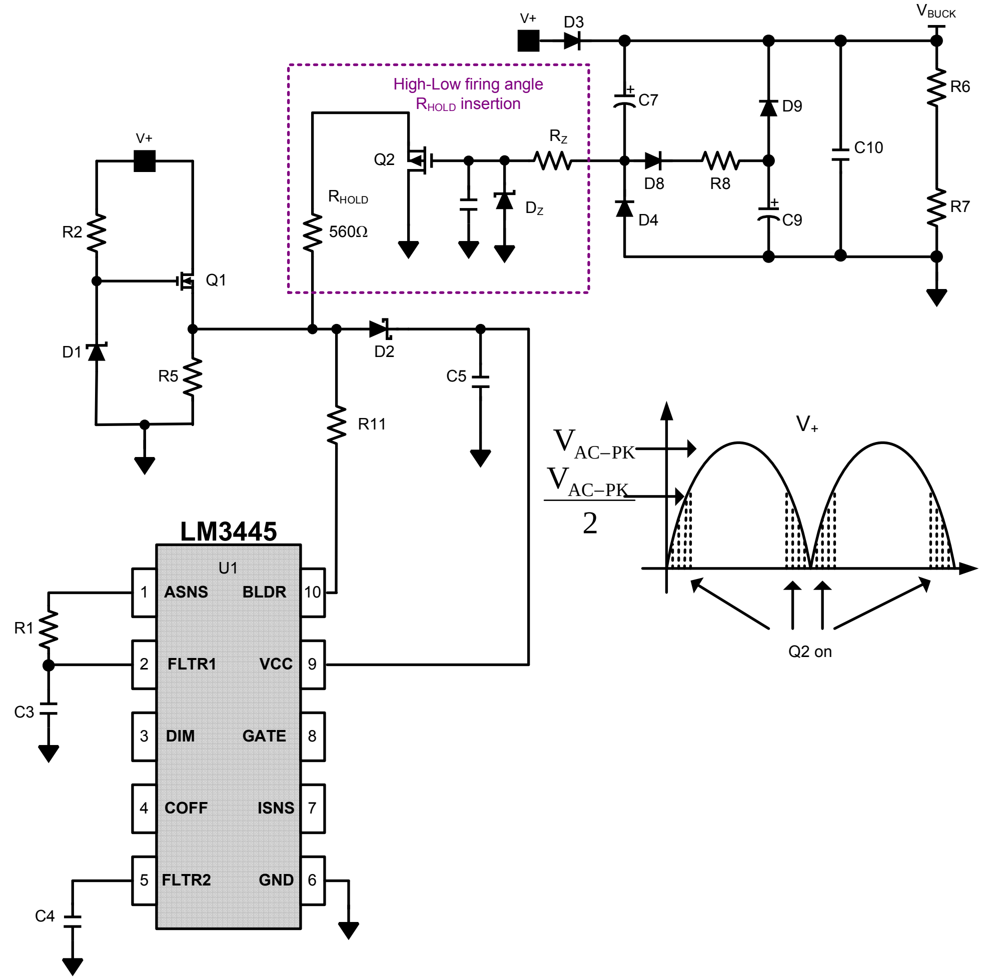
Reducing the power consumption of the holding current circuit:

Triac Dimmers require a minimum amount of current to "hold them on". Our current LM3445 circuits pulls this minimum current from the AC line by first dropping most of the AC line voltage across Q1, and placing a resistor from Q1 source (BLDR) to ground.



The modification to the standard LM3445 triac hold circuit is shown below

CIRCUIT #1



V_{CC} divided by resistor R_{HOLD} sets the triac holding current. A small value of R_{HOLD} creates a greater holding current. This current times the standoff voltage of Q1 (nearly the full line average voltage) is the power consumed by the circuit.

Depending on the triac used, a large amount of holding current maybe required (I_{HOLD} > 40mA), or a very small amount of holding current is may be required for ELV type dimmers (I_{HOLD}< 5mA).

Holding current is needed when the LEDs are dimmed very low, and there isn't much input current holding the triac on, and during the last few degrees of the AC line voltage as it drops to zero. When the valley fill circuit is drawing current from the line (bulk capacitors charging in series) there is plenty of input line current holding the triac on. When the valley fill circuit changes from series connected to parallel connected bulk capacitors the output power (LED current) is being delivered by the bulk capacitors, and the line current is very small. At this time it would be nice to apply an external resistor to the line to keep the triac on. A simple circuit is to add holding current when valley fill diode D4 is conducting.

This simple circuit will reduce the power consumption of the holding circuit (Q1) by 885%.

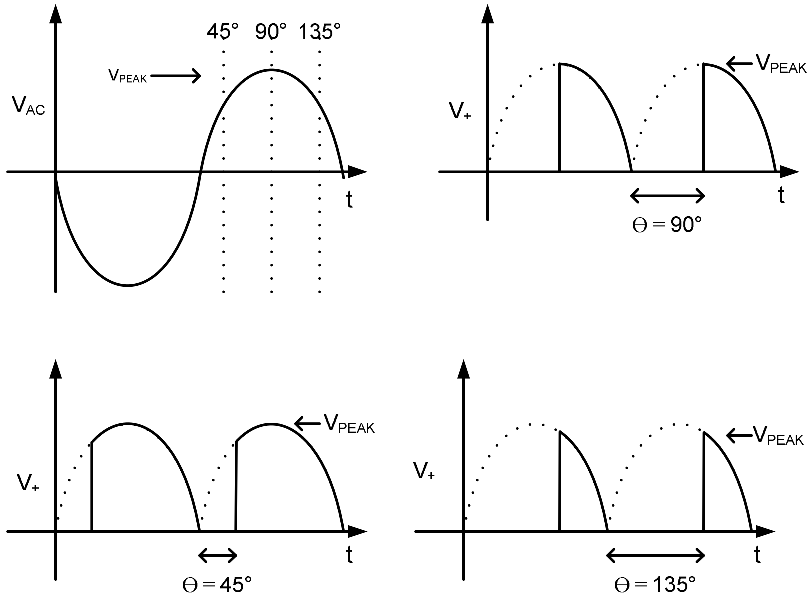
Detecting a Triac Dimmer, and Reverse Phase and Forward Phase Detection:

The reduced power consumption circuit described above should apply the R_{HOLD} resistor for forward and reverse phase dimmers at both the first part of the AC cycle, and the last part of the AC cycle.

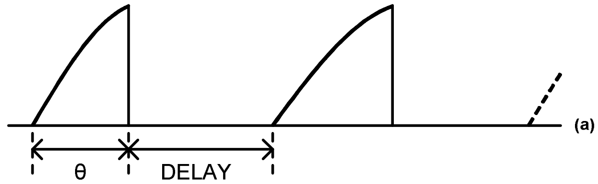
A comparison between the conventional method of applying the holding resistor (100% of the time on), vs the above circuit (about 33% on, but only during low ac line voltages) results in approximately a 85% power savings.

Although this is fairly significant, Energy Star requirements may require even lower power loss. Energy Star requirements and measurements are only applicable when the triac is completely off, or better yet not present. Therefore the obvious next step in power savings is to detect when the triac is not present or present.

The Triac needs to be held on with some current during the last part (Θ > 135°) and on. For a reverse phase dimmer, this is at the same time that the triac angle fires.



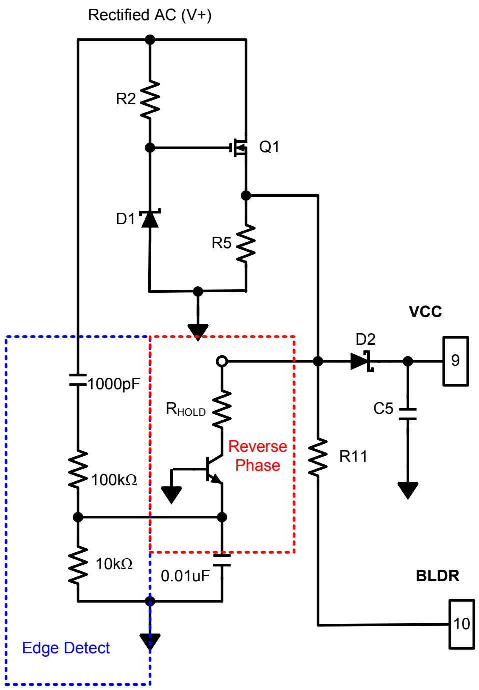
Reverse phase Triac Dimming AC waveform



Knowing that the triac requires its holding current during the last portion of the AC cycle, and that with a reverse phase dimmer there is a sharp voltage transition from high to low allows the below circuit to be used for reverse phase dimmers.

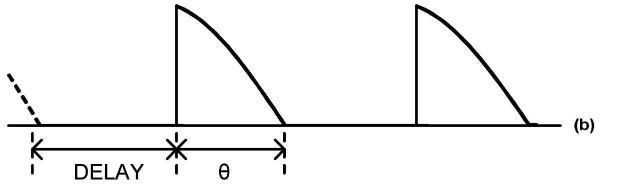
Reverse phase detection, and insertion of R_{HOLD} resistor circuit is shown below:

CIRCUIT #2



The series connected resistors and capacitor from the rectified AC line will detect the high -dv/dt transition and bias the transistor, applying R_{HOLD} resistor.

Forward Phase Triac Dimming AC waveform



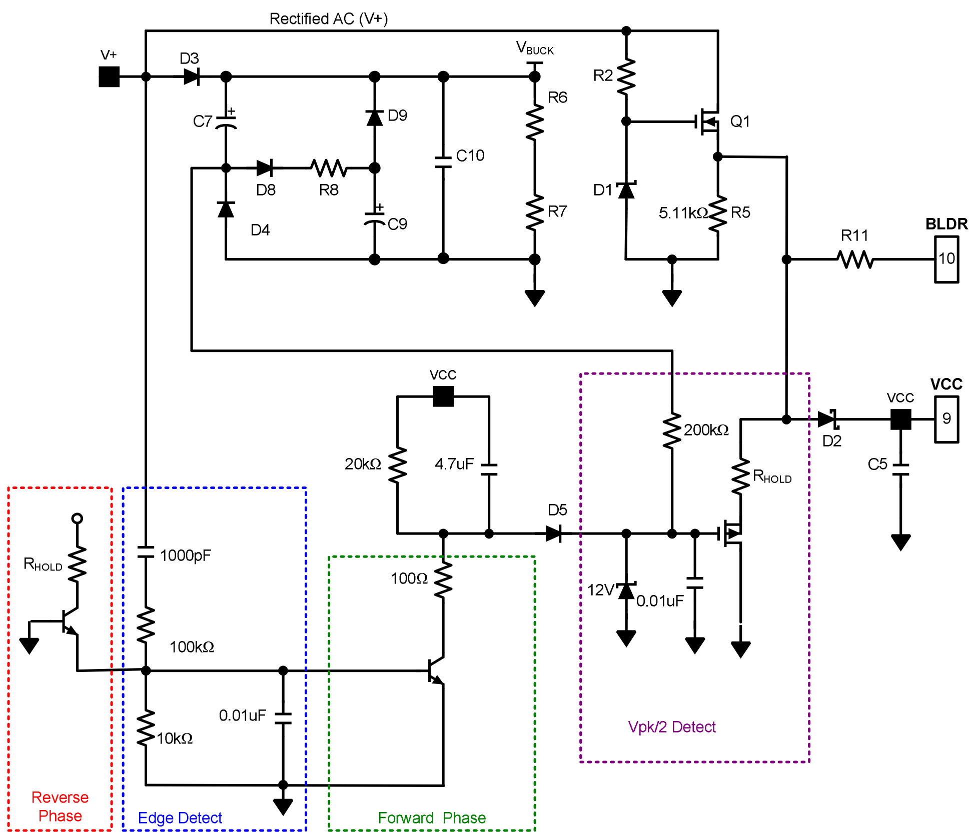
Forward Phase detection circuit:

The forward phase triac dimmer (which is more common) still needs requires the holding current at the last portion of the AC cycle. The fast transition, or high +dv/dt happens earlier in the cycle although. Remember, it is the last few degrees of the AC cycle where the triac holding current needs to be applied, not the first portion of the AC cycle.

Circuit #1 applies the holding current of the first and last portion of the AC cycle. By using the same edge detection circuit as the reverse phase dimmer (circuit #2), we can add circuitry to disable the circuit when no high dv/dt is detected (not present).

Therefore a combination of circuit #1 and circuit #2 that disables the RHOLD resistor when the triac isn't present, and applies the RHOLD resistor only when needed. This circuit works with reverse and forward phase dimmers, and is illustrated below:

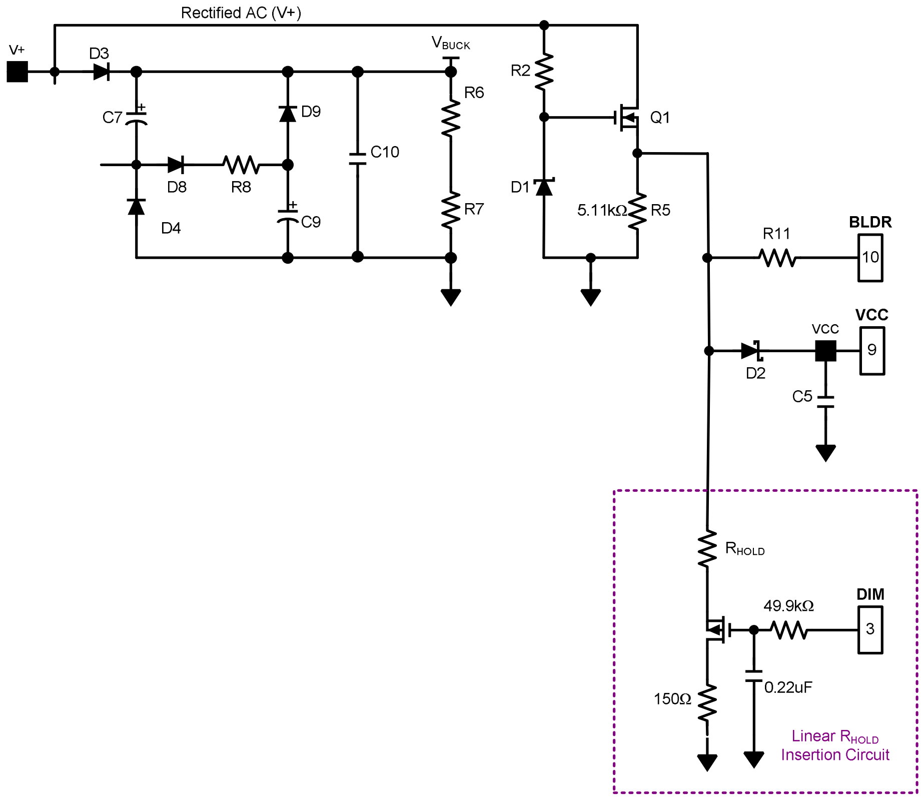
Forward and Reverse Phase detect with Triac absence detect circuitry
CIRCUIT #3



Linear R_{HOLD} Circuit

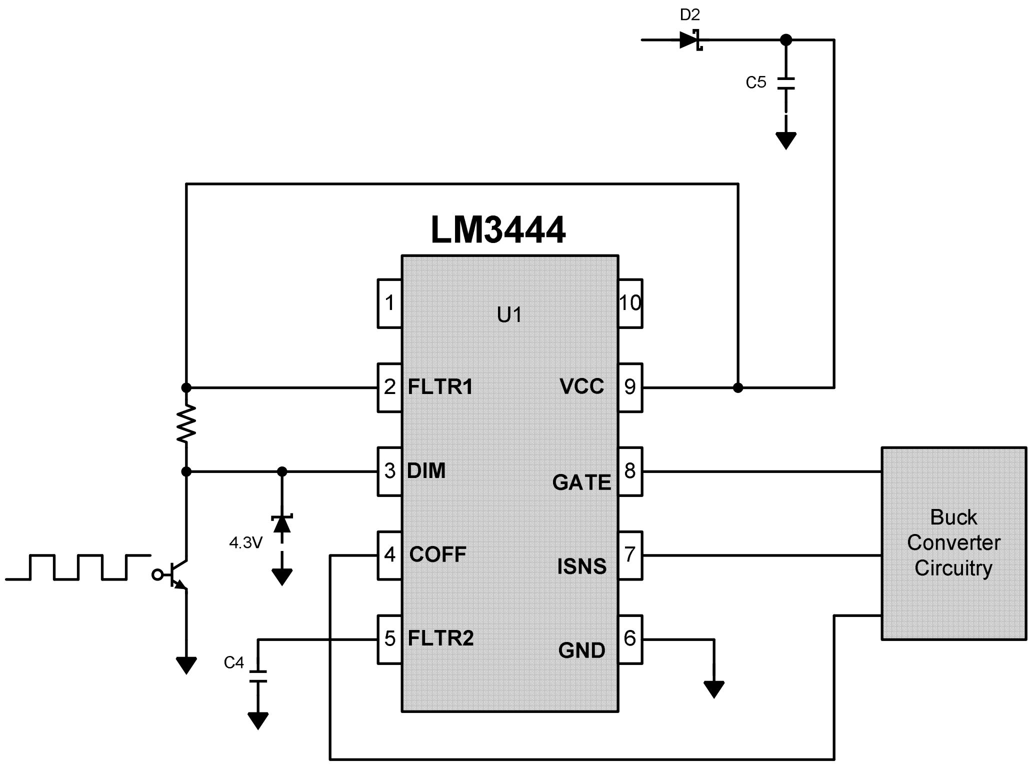
The previous circuits satisfy the triac dimmer when the input line voltage is decreasing. Another problem with a common triac and LED lighting is when the LEDs are dimmed to a very low level. Now the input line current is low for the whole cycle, not just when the AC line is low. The circuit below will draw more current from the R_{HOLD} resistor as the LED current is decreased (as the triac firing angle is increased). This stops the LEDs from fluttering which is common to some applications. There really isn't any need for extra triac hold current until the LEDs are drawing less than 50% of their rated forward current. From the table you can see that this circuit only adds triac holding current from duty cycles of 50% on. Remember, the input to the DIM pin, or output is inverse to a normal PWM dimm signal 100% DC equals off, and 0% is fully on.

Linear R_{HOLD} circuit:

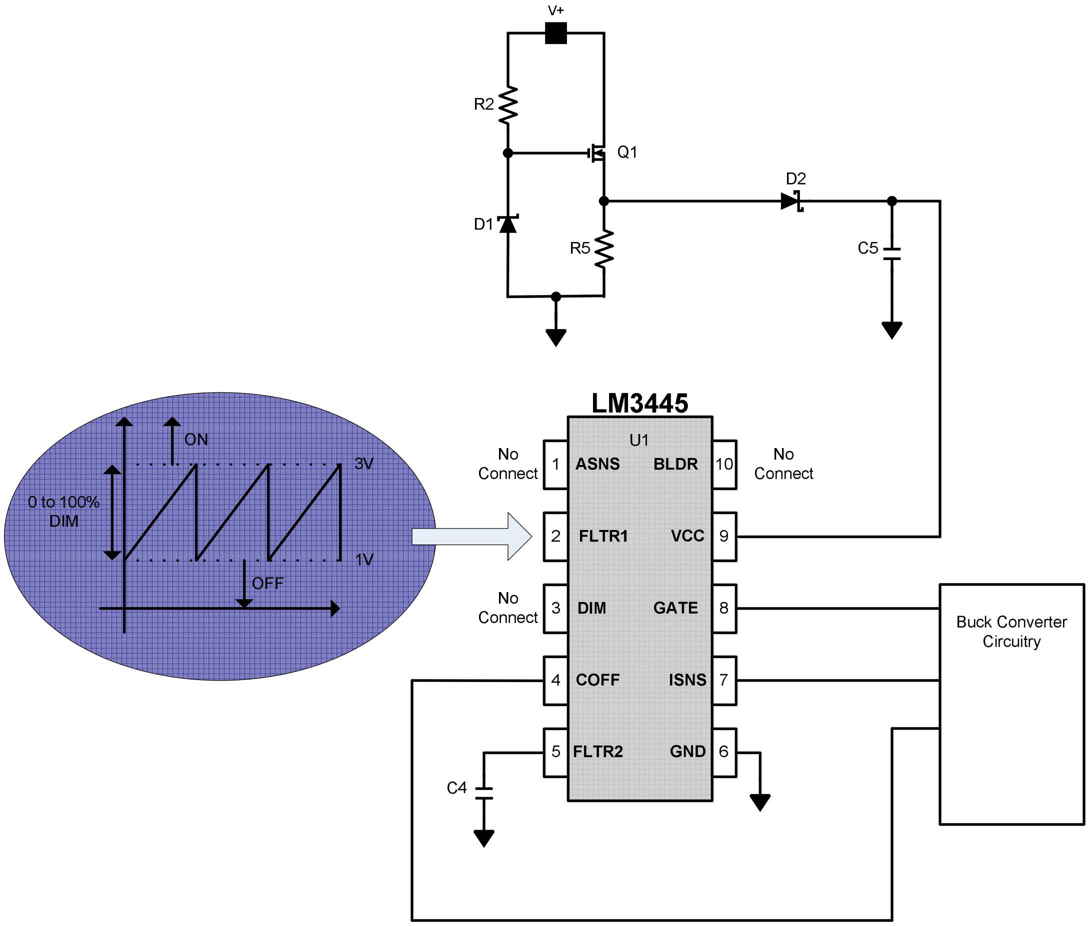


Duty Cycle	I_{HOLD}
10%	1uA
20%	1uA
30%	1.3mA
40%	4.25mA
50%	7.25mA
60%	10.5mA
70%	13.5mA
80%	16.5mA
90%	16.5mA

External PWM Dimming Circuit/Connection:



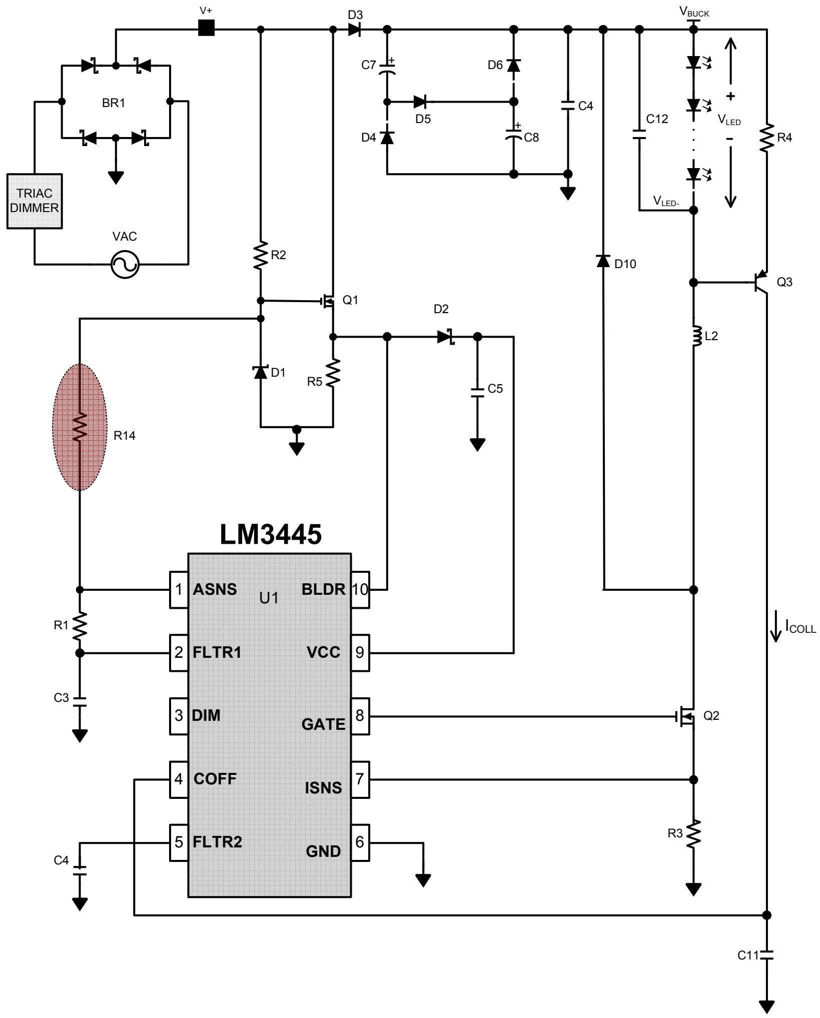
Analog Dimming Circuit/Connection:



Adjusting the LM3445 Angle sense / Filter circuit to match the triac firing angle.

After analyzing dozens of different triacs in our laboratory it was observed that most triacs when considered 100% on, are actually firing between 20° and 45°. There are also differences between triacs when they would be consider off as well (anywhere from 135° to 180°). The ASNS converts the triac firing angle into a 0V to 4V (off to 100% on respectively) this is compared to a 1V offset to a 3V peak triangular 5kHz waveform. Any signal out of the ASNS that is below 1V is considered off, and any signal above 3V is considered 100% on. Depending on what type of triac used, you my not be able to achieve the full range of the triac dimmer. As an example, you set you maximum forward LED current to 500mA, but you only observe 400mA when the triac is fully on. Another sign of issues is if the LEDs seem to be on at 100% when the triac is only at 50%.

You can correct the first issue by placing a very large resistor (2.2MΩ to 10MΩ) from cathode of the zener diode D1 to ASNS. This resistor offsets/pulls up the 0V to 4V signal so full range can be achieved. If R14 is too small, you will then notice the second issue where you reach 100% LED current with plenty of room left on the triac dimmer. Increase the value of R14 until both issues are satisfied.

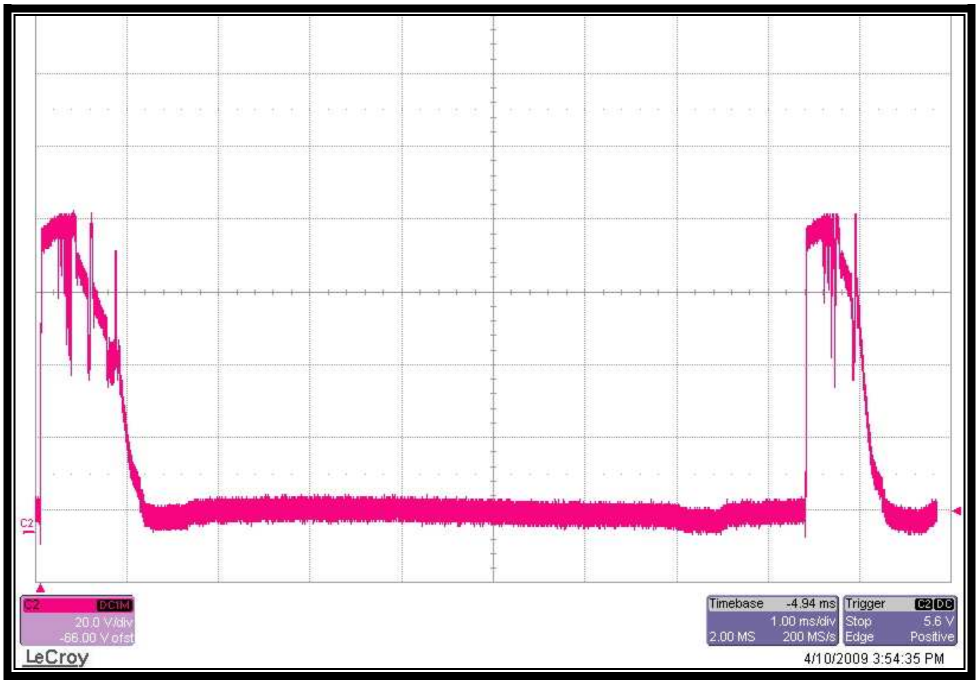


Troubleshooting LED fluttering, or LED flickering.

The two common LED flickering, or fluttering issues are traic misfire, and too littler triac holding current.

Too littler triac holding current:
As mentioned in the LM3445 datasheet, triacs and incandescent light bulbs work very well together. The incandescent light bulb is very inefficient, and behaves like a resistor. The beauty with LEDs is that they are so efficient, but this can cause issues when they are used in conjunction with a triac. A triac needs a minimal holding current of a couple of milliamps for very good triacs, and up to 40mA for a poor quality triac. If the triac is loosing its holding current it will turn off to soon during some ac cycles and stay on for the proper time for other cycles. This will give the LEDs its fluttering look. This fluttering usually happens at low forward currents, or when the triac is firing at high angles. The easiest method to determine if triac is losing its holding current is to decrease the value of R5. This resistor sets the holding current in the basic LM3445 circuitry. The previous circuits add in a R_{HOLD} resistor only when it is required. This resistor may be lowered to verify the issue.

Triac misfire:
The second most common issue with LED flickering, or fluttering is noise shutting off the triac itself. See the picture below for a noise issue affecting the triac firing.



We dissected dozens of triac in our laboratories, and there were many triacs that had a basic firing circuitry that was similar, but here were many types that had unique circuits. Therefore differences in design, components, and values created no two triacs the same. This and the fact that the input EMI filter of the LM3445 and the current through the input filter causes interesting interactions with the triac firing.

Any triac, EMI filter and loading condition can be made to work with each other, but you may need to modify circuitry to ensure proper operation. Typically the end user will see flickering in the LEDs when the LEDs are not at their lowest dimming. Somewhere around 30% to 50%of full load is a spot commonly favorable to triac misfires. The easiest method to prove or disprove the triac is misfiring is to take off the differential mode inductors, and X-capacitors one at a time. You should quickly see the circuit start to perform properly once a single differential inductor or X-capacitor is removed. To fix this issue reconfigure your EMI filter, or add series R-C snubbers across the line.

Noise

Depending on the evaluation board being analyzed, we have heard (and seen) issues with the input inductors humming, the input RC snubber capacitors (ceramic) buzzing, and sometimes the V_{CC} capacitors buzzing. You can usually determine what external capacitor is making noise by taking a pencil, and poking around. To solve the issue, you can use different components (inductors), or I have used hot-melt glue to stop the noise.