![ST logo]

AN2711
Application note

15 W offline TRIAC dimmable LED driver

Introduction

The cost of power LEDs is rapidly coming down, while performance is improving. Their efficacy (light out per watt in) is now competitive with compact fluorescent lamps, while their life is significantly longer at 100,000 full-power hours (11+ years) to half brightness. Dimming of LEDs can extend the lifetime further and also reduces power drain. By far the most common dimming method is the TRIAC phase-control dimmer, which replaces the AC on-off switch directly, but can be used only on incandescent lamps and specially designed fluorescent ballasts.

This application note presents a low-cost driver for LEDs that is compatible with TRIAC phase-control dimmers. The design gives luminaire manufacturers a low-cost, commonly available dimming option for home fixtures. A side benefit is that, when not wired to a dimmer, the unit's power factor is over 0.9. The design is based on the L6562A transition-mode PFC controller driving a single stage PFC-flyback power converter. An STMicroelectronics Patent Application is pending for the method for dimming an offline LED driver by means of a TRIAC based dimmer as described in this document.

Figure 1. 15 W offline TRIAC dimmable block diagram (STEVAL-ILL016V1)

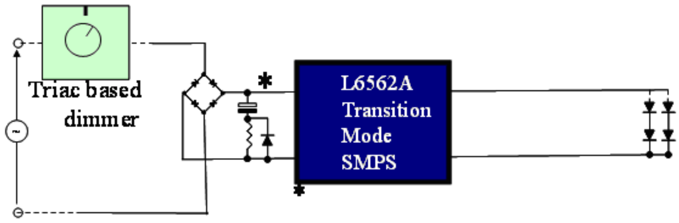


Figure 2. 15 W evaluation board top side

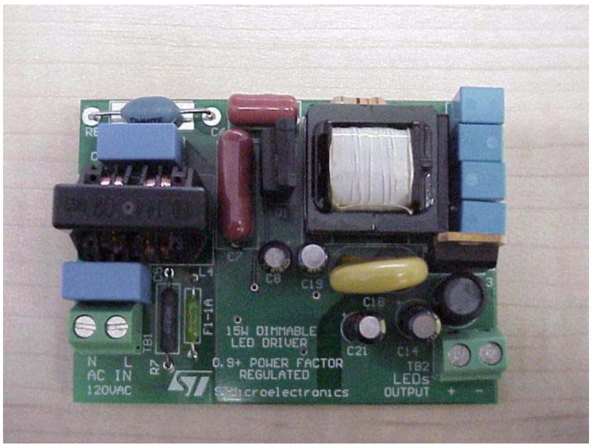
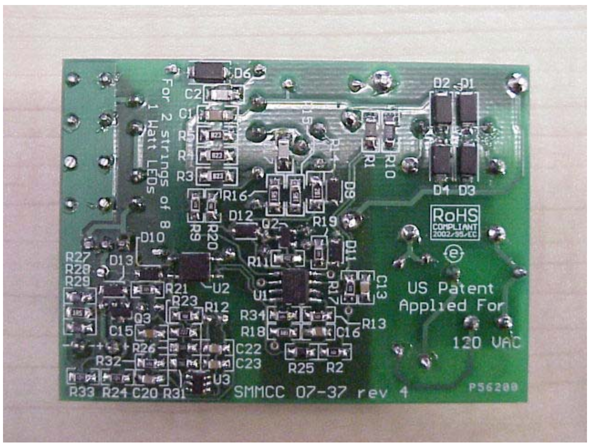


Figure 3. 15 W evaluation board bottom side



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1 Main characteristics and brief circuit description

The main characteristics of the design are listed below:

- 120 V line (96 V to 132 Vrms)
- Vout is set at 40 V max
- Iout is set at 0.7 A maximum average current
- 0.7 minimum power factor, required for residential use
- 0.9 or greater power factor, required for commercial use
- Capable of FCC Class B conducted EMI
- Emitted acoustic noise less than 24 dBA
- Isolated output, "safe" voltage
- Dimmable with low-cost TRIAC based dimmer, average current down to less than 10% of maximum LED current
- Smallest size possible
- Lowest cost possible (currently less important due to high cost of LEDs)
- LED lifetime of 25,000 hours (residential) or 35,000 hours (commercial) to 70% light output
- Meets requirements of US DOE ENERGY STAR® program requirements for SSL luminaires - version 1.0.

It was decided to use a single-stage PFC-flyback converter to save space, cost, and components. The PFC-flyback converter does away with the large input capacitor (usually an electrolytic) and replaces it with a small film capacitor. The input current waveform is then shaped to match the input voltage, and the input current level is adjusted to give the required output. Power factors above the commercial application required 0.9 are easy to meet. Residential-required 0.7 power factors are, of course met, and the 0.9 undimmed performance of the device is a strong competitive advantage.

Dimming is accomplished by the TRIAC dimmer, powering the converter only during the later portion of each half cycle. Since there is virtually no energy storage in the converter, current flows to the LEDs only when the converter is powered. The flyback converter is easy to isolate for safety, and the output voltage and current can be selected by simply choosing transformer turns ratios.

The design regulates peak FET current on the primary side and average LED current on the secondary side. The secondary side current regulation acts only if the unit is undimmed, and at the brightest dimmed setting. A voltage clamp is included to keep unloaded output at safe levels.

2 Background

2.1 LED characteristics

The driver electronics design is strongly influenced by the nature of the light source.

2.1.1 Heat

Contrary to a very popular belief, LEDs produce heat. While they have efficacy in the same range as compact fluorescents, the heat from the fluorescent is spread out over a large surface. The LED concentrates all its heat in one place.

Newer LEDs use silicone rubber as lens material rather than low-temperature plastics. This allows an increase in chip temperature, easing heatsink requirements.

The electronics can be very close to the heat source. Environment temperatures over 80 °C are common.

2.1.2 Speed

LEDs, unlike incandescent lamps, have virtually no turnoff time. The incandescent, when dimmed, continues to glow when power is not present during a dimming half cycle, due to its thermal mass.

The human eye is pretty much insensitive to variations in light level if the variations have a period less than about 10 milliseconds (100 Hz). However, at 60 Hz, variations between half cycles are quite visible.

The LED is therefore more susceptible to unsymmetrical firing of the TRIAC at low dimming levels, where the TRIAC conduction time may be polarity sensitive.

2.1.3 Safety

There is a perception in the general public that LEDs operate from safe low-voltage sources. "Safe" voltages are defined by the regulatory agencies as being below 60 Vdc. However, even this level can cause "startle" if it is coupled to a human through metal tools.

The safe operating level chosen for this design is 32 V. In addition, the output is fully isolated from both the line and ground, so that two incidental connections to the human must occur to result in startle.

2.1.4 Color shift with current reduction

White LEDs are made from blue emitters covered with a phosphor that emits longer wavelengths of light when excited by blue light. The phosphor is non-linear - it is most efficient when excited by strong blue light. LED color balance is specified at a particular current. If the current is reduced, the glow from the phosphor is overwhelmed by the blue glow from the LED. Simply reducing the current from an LED therefore causes a shift in color toward blue, unlike the incandescent lamp with its shift toward red. The blue shift can be avoided by exciting the LED with a constant current, using pulse width modulation at 100 Hz or more to reduce the average light output. The eye perceives an illusion of continuous light of even color as the current is reduced, but there are problems to be solved.

2.1.5 Effects on flicker

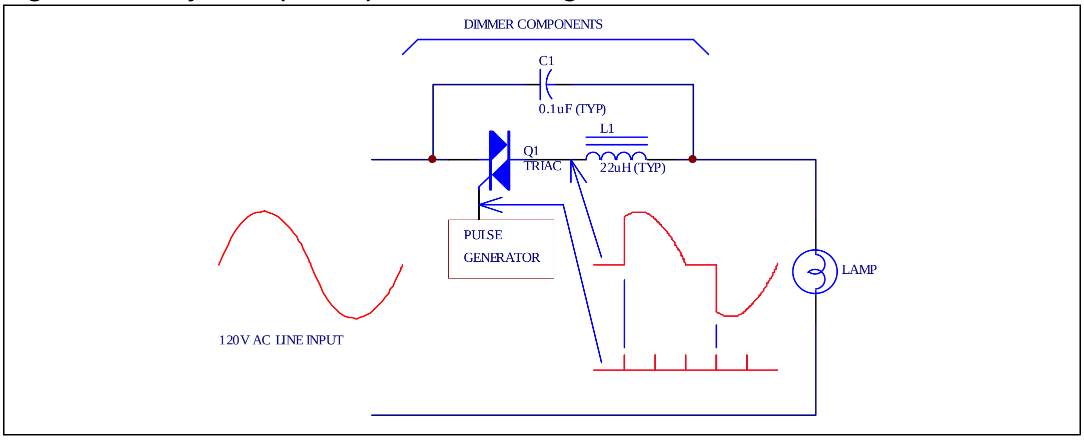
Any variation in average current shows up very visibly with LED lighting. Major sources of variations are:

- Last-cycle instability at extremely low dimming levels, where the power converter may or may not output the last cycle before the AC zero-crossing.
- Variations in line voltage, which cause the dimmer's delay to vary significantly, again most noticeable at very low dimming levels.

2.2 TRIAC based dimmers

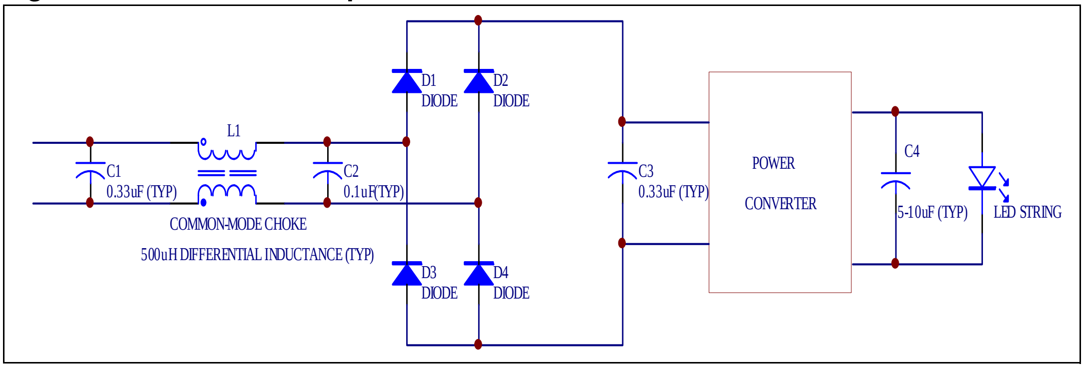
Conventional "2-wire" dimmers replace wall switches in some applications. It is highly desirable to have the LED driver accept power from a TRIAC-dimmed source. The TRIAC dimmer reduces load power by delaying the application of load voltage during each half-cycle. The scheme works very well for resistive loads such as incandescent lamps, but it breaks down for other types of loads.

Figure 4. Thyristor (TRIAC) dimmer with light bulb



The common thyristor dimmer circuit shown above works well with incandescent lamps. The thyristor turns on abruptly when the pulse generator fires, and it turns off near the voltage zero-crossing when current falls below its holding current. The inductor and capacitor filter the sharp voltage edge to reduce conducted EMI. The lamp provides resistive damping to the L-C filter, and its resistance provides holding current to the thyristor.

Figure 5. Non-dimmable power converter LED driver



When the thyristor feeds an electronic load, such as a power converter, the damping and holding current effects of the lamp load are not present. Typically, the electronic load has an input EMI filter and a small DC filter capacitor (as shown in *Figure 5* above) to provide steady voltage for the power converter. No damping is present. Many fluorescent, compact fluorescent, and LED drivers have stickers stating "not for use with dimmers" because they are unable to cope with the sudden rise of voltage late in the half cycle, or the reduced average voltage. Many low-cost drivers directly rectify the incoming AC and apply the resulting pulsed DC to capacitive filters. Current is drawn from the source during a very short period at the peak of the incoming voltage waveform, and no current is drawn during the remainder of each half cycle.

The dimmer presented in this note has characteristics compatible with the triac dimmer. *Figure 6* below shows the (approximately) sinusoidal line current when the driver is not dimmed, and *Figure 7* shows the line current when the triac dimmer (set near maximum) is in the circuit. Note that the undimmed power factor is an excellent 0.95.

Figure 6. Line current without dimming

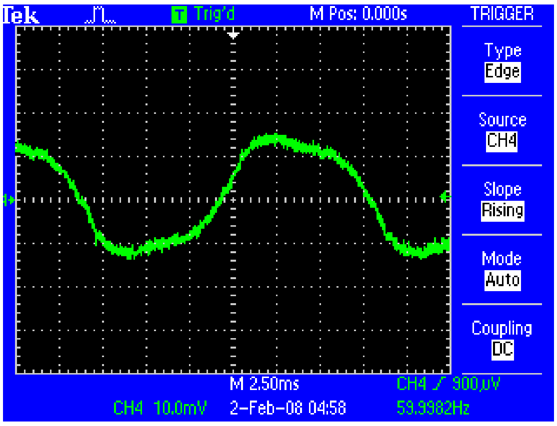
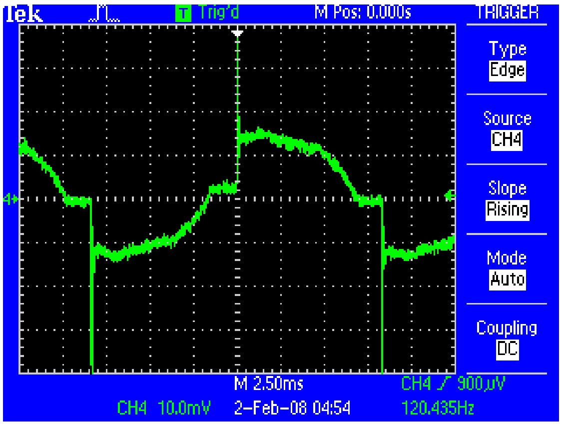


Figure 7. Line current with dimming



3 Circut description

3.1 Deviations from normal PFC-flyback design

Excellent descriptions of the PFC-flyback design are presented in ST Application notes AN1059 and AN1060. Detailed data on the L656X family are available on the ST website. Operation of the L6561, L6562, L6562A, and L6563 are quite similar and are not discussed in detail here.

In a normal PFC-flyback converter very high value electrolytics must be used at the output to hold voltage in the required range, because the converter looks like a current source having substantial 120 Hz ripple. Fortunately, being forward-biased diodes, the LEDs are quite good at maintaining voltage while acting as current sinks, and relatively small capacitors can be used to reduce the high-frequency ripple from the converter. The 120 Hz current ripple component is sent to the LEDs, which, at full conduction (no dimming, sinewave input), provide a light waveshape similar to that of a ballasted fluorescent lamp.

Figure 8. Line current near minimum conduction angle

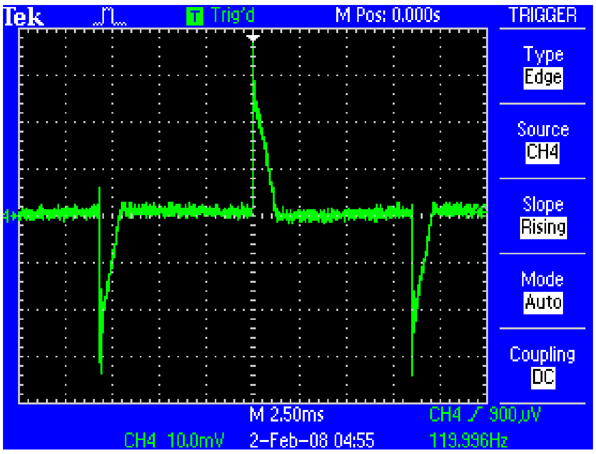


Figure 9. LED current near minimum conduction angle

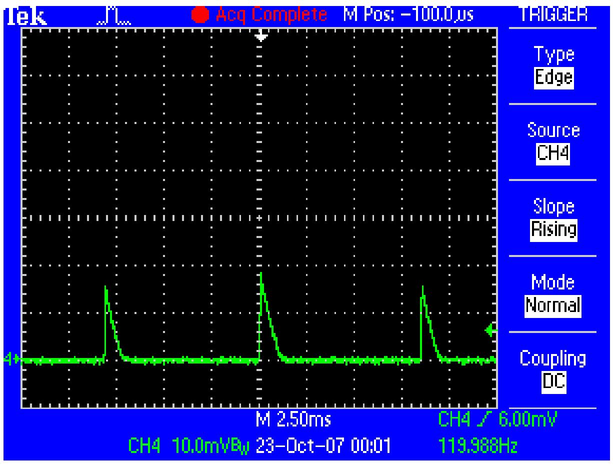


Figure 10. Line current at 90° cond. angle

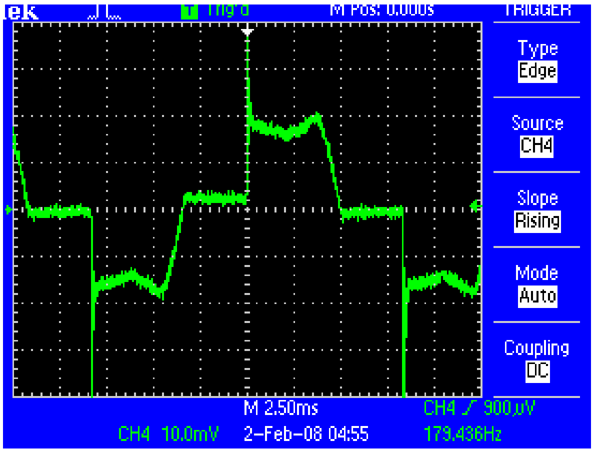


Figure 11. LED current at 90° cond. angle

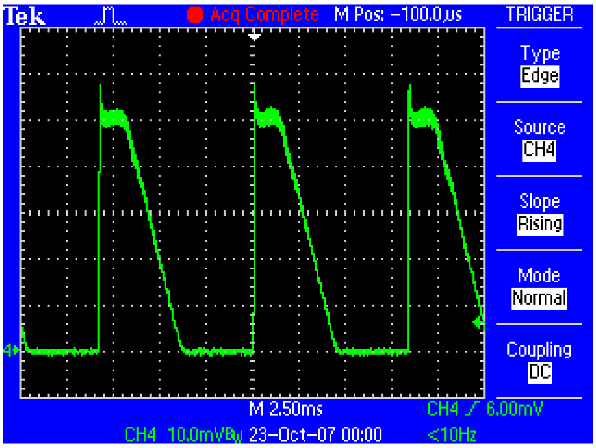


Figure 12. Line current at max conduction angle

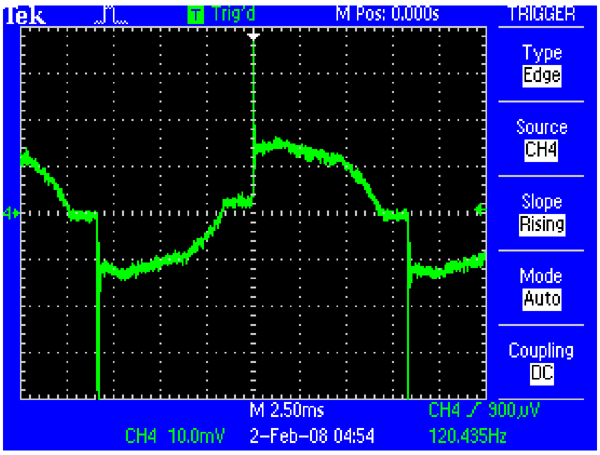
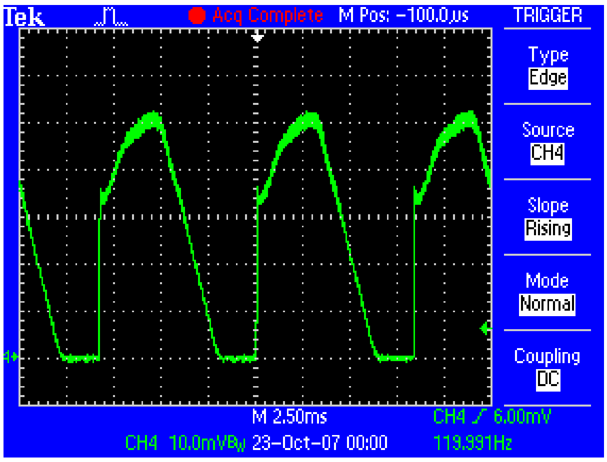


Figure 13. LED current at max conduction angle



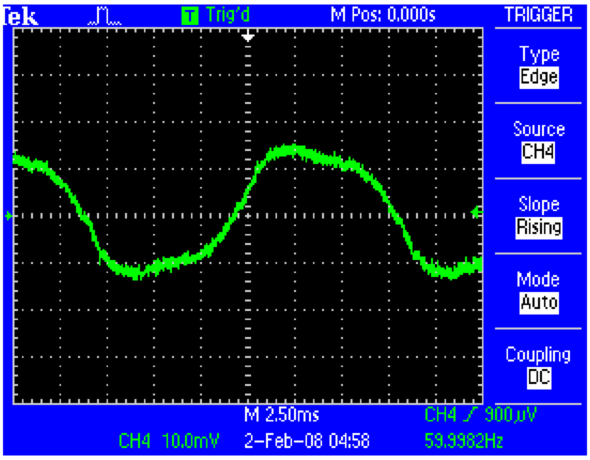


Figure 14. Line current with no dimmer

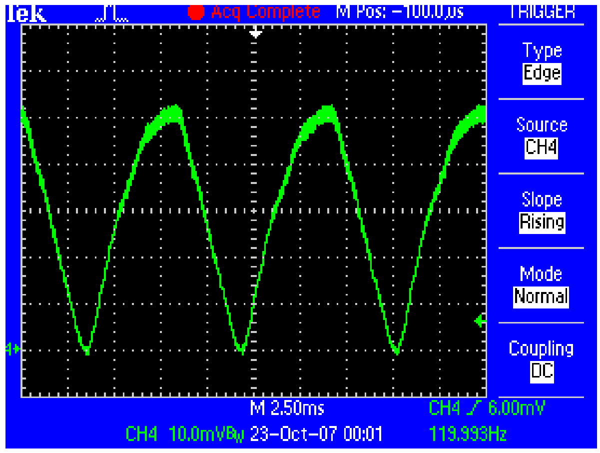


Figure 15. LED current with no dimmer

With virtually no energy storage, phase control dimming is now practical. The LEDs emit light only when power is available through the dimmer.

The figures above show the input current and the corresponding LED current with and without the dimmer.

3.2 Electrolytic capacitors eliminated

Electrolytic capacitors are unsuitable for the filters for two reasons:

- The phase-control dimming technique requires low-value capacitors to allow pulse-width modulation to take place. The ESR of low-value electrolytics is quite high - filtering will not be effective, and losses in the ESR will be high. This makes electrolytics unsuitable for the output filters.
- Dielectric losses in low-value electrolytics, which are proportional to ripple voltage, are also quite high. This makes electrolytics totally unsuitable as input filters.

Film capacitors, such as metallized mylar or polypropylene, are very well suited for high-frequency filters. Their ESR is low, and the dielectric losses are quite low for the 120 Hz ripple waveform, even for the steep TRIAC wavefronts.

Eliminating the power-handling electrolytics has other advantages. These are the main life-limiting components in normal solid-state ballasts.

The main input filter capacitor, C7 in the schematic (*Figure 16*), should be as small as possible consistent with the high-frequency ripple voltage (which generates conducted EMI). The value 0.1 µF was used for the 15 W dimmable LED driver board.

3.3 Damper

The damper capacitor C6 has to be 3 to 5 times the size of the main filter capacitor. Any smaller values will not damp ringing, while larger values waste power in the damping resistor. The value 0.33 µF was selected for this capacitor. R8 was manually tuned to minimize ringing.

3.4 Housekeeping power

When line power is present (triac in conduction), the converter must operate on each cycle up to the point near the zero crossing when the voltage is too low to sustain operation. If housekeeping power (Vcc for the L6562A chip) disappears with energy remaining in the input filter, the converter could restart due to the trickle current from R1. In this 15 W version, to prevent that from happening, a bleeder resistor, (R19, 18 k) is added to the regulator circuit. This shunts the trickle current from R1 at low instantaneous line voltage, allowing the converter to turn off if the conduction angle is too small to sustain output, and it prevents the restart (flashing) after turnoff. See the *Appendix A* for a detailed description of the problem and the solution.

3.5 LED current and voltage regulation

At the output side of the LED driver, C14 provides the voltage to keep the regulator, Q3, powered when the dimmer is operating at very narrow conduction angles.

U3, TSM1052, has two feedback loops, one to limit the output voltage and another to limit the output current. The voltage feedback loop acts only if LEDs are disconnected at the output. It is present strictly for safety purposes.

The current feedback loop is wired differently from normal applications (as outlined in the TSM1052 datasheet). GND and ICTRL pins of TSM1052 are connected to the input negative, raising the setpoint to +0.172 V to allow filtering of the 120 Hz output pulses. C23 and R33 perform this filtering function. The current feedback loop is purposely quite slow (nearly a second to respond to application of undimmed line voltage) to prevent the appearance of a flash when the unit is first turned on. This loop acts slower than the response time of the eye, allowing the eye to adjust to the slow dimming as the loop settles to the final light level. The current feedback loop acts only for the highest settings of the dimmer. Peak current is controlled directly by the L6562A from the voltage on current sense resistors R15 and R16 on the primary side.

Figure 16. 15 W LED driver schematic

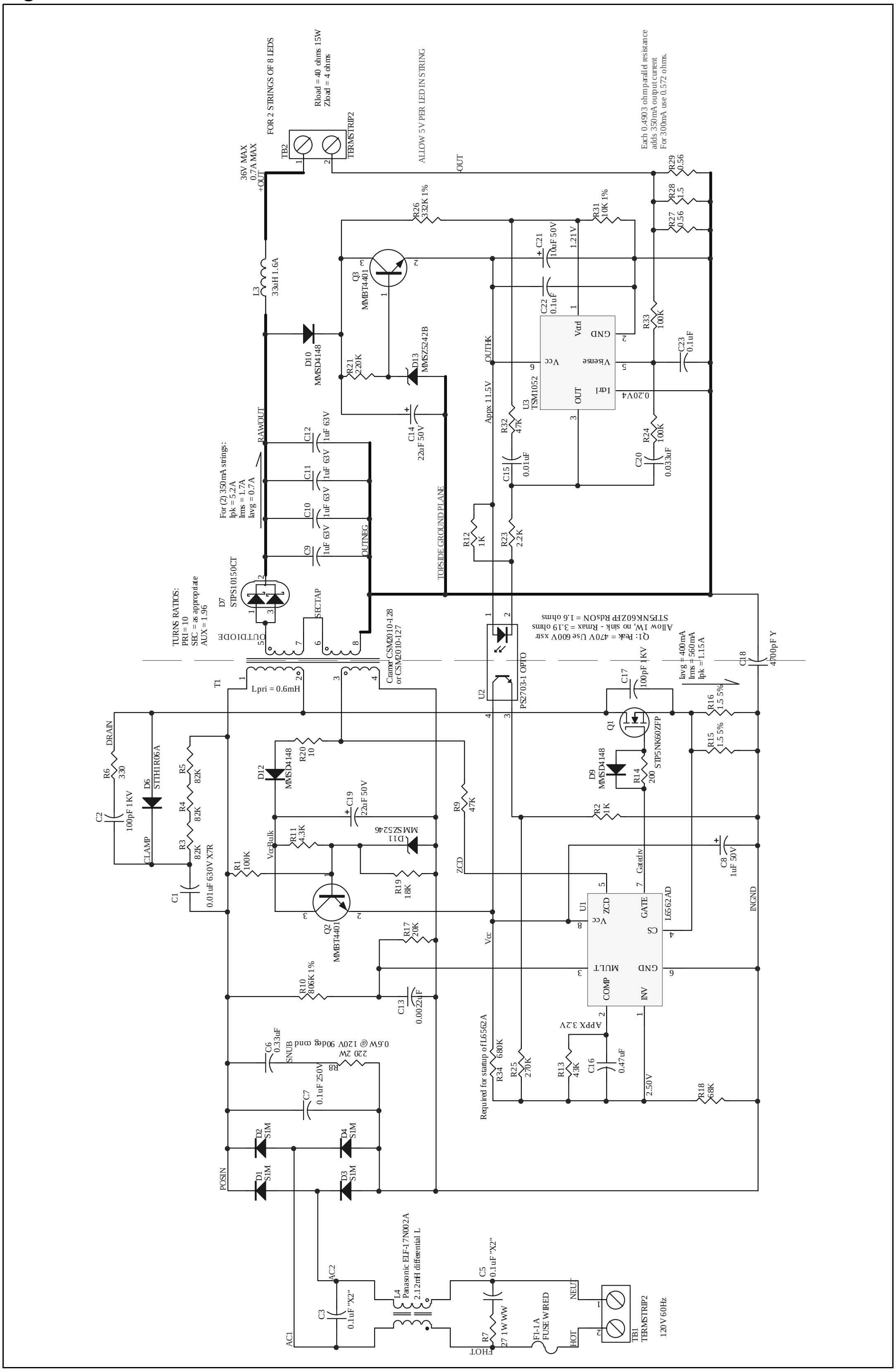


Table 1. 15 W LED driver bill of materials

Part type	Designator	Footprint	Description	Qty	Manufacturer, #	Vendor, #
0.01 µF 630 V X7R	C1	1206	Capacitor	1	Panasonic ECJ-3FB2J103K	Digikey PCC2292CT-ND
2200 pF	C13	805	Capacitor	1	10% X7R	*
22 µF 50 V	C14	CEV6.3MMP	Capacitor	1	Panasonic EEU-FC1V101	Digikey P10294-ND
0.01µF	C15	805	Capacitor	1	X7R 20% 0805	*
0.47 µF	C16	805	Capacitor	1	0805 X7R	*
4700 pF Y	C18	RAD0.4Y	Capacitor	1	Panasonic ECK-ANA472ME	Digikey P9529-ND
22 µF 50 V	C19	CEV5MMP	Capacitor	1	Panasonic EEU-FC1H220	Digikey P10318-ND
100 pF 1 kV	C2,17	1206	Capacitor	2	AVX 1206AC101KAT1	Digikey 476-2951-1-ND
0.033 µF	C20	805	Capacitor	1	5% X7R 0805	*
10 µF 50 V	C21	CEV5MMP	Capacitor	1	Panasonic EEU-FC1H100L	Digikey P10316-ND
0.1 µF	C22; C23	805	Capacitor	2	X7R 20% 0805	*
0.1 µF "X"	C3	BoxHWLSD12-6-12.5-10-0.6	Capacitor	1	Vishay 2222 338 20104	Digikey BC-1601-ND
0.1 µF "X"	C5	BOXHWLSD15-10-17.5-15-0.8	Capacitor	1	Lab stock fits existing holes	Use same part as C3
0.33 µF 250 V	C6	BOXHWLSD13.5-6-18.5-15-0.8	Capacitor	1	Panasonic ECQ-E2334KF	Digikey EF2334-ND
0.1 µF 250 V	C7	BOXHWLSD14-7-18-15-0.8	Capacitor	1	Panasonic ECW-F2104JB	Digikey PF2104-ND
1 µF 50 V	C8	CEV5MMP	Capacitor	1	Panasonic EEU-FC1H220	Digikey P10318-ND
1 µF 63 V	C9-12	33.3209	Capacitor	4	BC Components 2222 370 11105	Digikey BC1622-ND
MMSZ5246	D11	SOD-123	Zener diode	1	Diodes Inc. MMSZ5246B-7	Digikey MMSZ5246BDICT-ND
MMSZ5242B	D13	SOD-123	Zener diode	1	ON Semi MMSZ5242BT1G	Digikey MMSZ5242BT1GOSCT-ND
S1M	D1-4	SMA	Diode	4	Diodes Inc. S1M-13-F	Diigikey S1M-FDICT-ND
STTH1R06A	D6	SMA	Diode	1	ST STTH110A	*

Table 1. 15 W LED driver bill of materials (continued)

Part type	Desig nator	Footprint	Description	Qty	Manufacturer, #	Vendor, #
STPS10150CT	D7	TO-220VERT3P	Dual Schottky diode	1	ST STPS10150CT	*
MMSD4148	D9,10, 12	SOD-123	Diode	3	Digikey MMSD4148-ND	Fairchild MMSD4148
FUSE WIRED	F1	RES0.5	Fuse	1	Littelfuse 0251.500MXL	Digikey F2311-ND
33 µH 1.6 A	L3	INDUC8MMVERT		1	J.W.Miller RL622-330K-RC	Digikey M9987-ND
Panasonic ELF-17N002A	L4	CM_CHOKE-PANA_ELF17	Choke common-mode PANA ELF17	1	Panasonic ELF-17N002A	Digikey PLK1168-ND
STP5NK60ZFP	Q1	TO-220VERT3P HV1		1	ST STP5NK60ZFP	*
MMBT4401	Q2,3	SOT-23C	NPN transistor SOT-23C	2	ON Semi MMBT4401LT1G	Digikey MMBT4401LT1GOSCT-ND
100 kΩ	R1	1206		1	5% 1206	*
806 kΩ 1%	R10	1206		1	1% 1206	*
4.3 kΩ	R11	805	Resistor	1	5% 0805	*
43 kΩ	R13	805		1	5% 0805	*
200	R14	1206		1	5% 0805	*
1.5 5%	R15,16	1206		2	5% 1206	*
20 kΩ	R17	805		1	5% 0805	*
68 kΩ	R18	805		1	5% 1206	*
18 kΩ	R19	805		1	5% 0805	*
10	R20	805		1	5% 0805	*
220 kΩ	R21	805	Resistor	1	5% 0805	*
1.5	R28	805	Resistor	2	5% 0805	*
2.2 kΩ	R23	805	Resistor	1	5% 0805	*
100 kΩ	R24, 33	805	Resistor	2	5% 0805	*
270 kΩ	R25	805		1	5% 0805	*
330 kΩ 1%	R26	805	Resistor	1	1% 0805	*
0.56	R27,29	805	Resistor	2	5% 0805	*
10 kΩ 1%	R31	805	Resistor	1	5% 0805	*
680 kΩ	R34	805	Resistor	1	5% 0805	*

Table 1. 15 W LED driver bill of materials (continued)

Part type	Desig nator	Footprint	Description	Qty	Manufacturer, #	Vendor, #
82 kΩ	R3-5	1206		3	5% 1206	*
330	R6	RES0.5		1	RES 0.5 W 5%	*
27 1 W WW	R7	RES0.6		1	Vishay CW001-27	Digikey CWA-27-CT-ND
220 2 W	R8	RES0.8		1	Vishay CW02B-150	Digikey CWB-150-CT-ND
47 kΩ	R9,32	805	Resistor	2	5% 0805	*
1 kΩ	R2; R12	805	Resistor	2	5% 0805	*
Cramer CSM2010-128	T1	Cramer CSM2010	Cramer CSM2010 S-P dual sec	1	Cramer CSM2010-125 rev B	*
TERMSTRIP2	TB1,2	SCTERM2	2 screw terminals strip	2	Phoenix 1729018	Digikey 277-1236-ND
L6562AD	U1	SO-8	Transition mode PFC controller	1	ST L6562AD	*
PS2703-1 OPTO	U2	PS2703_NEC_OPTO	Optoisolator SMT	1	NEC PS2703-1-K-A	Digikey PS2703-1-K-A-ND
TSM1052	U3	SOT-23-6L	Voltage & current limit controller	1	ST TSM1052	*

Figure 17. Top view of PCB layout

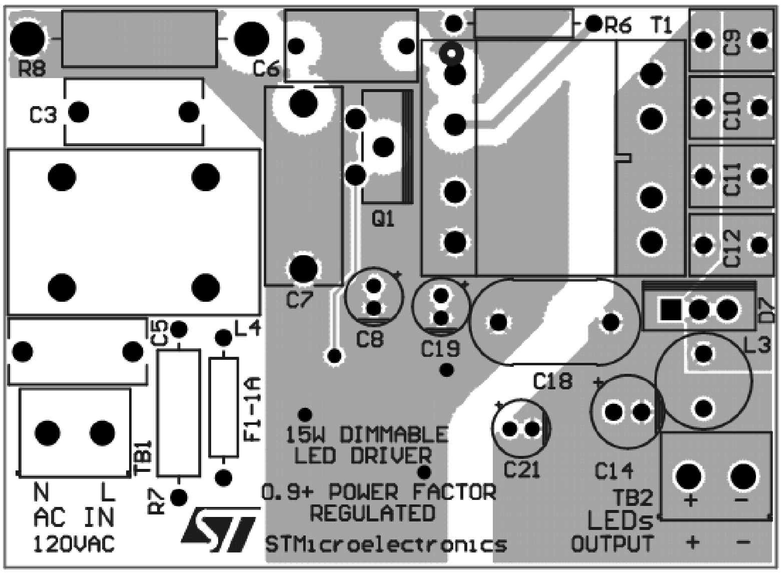
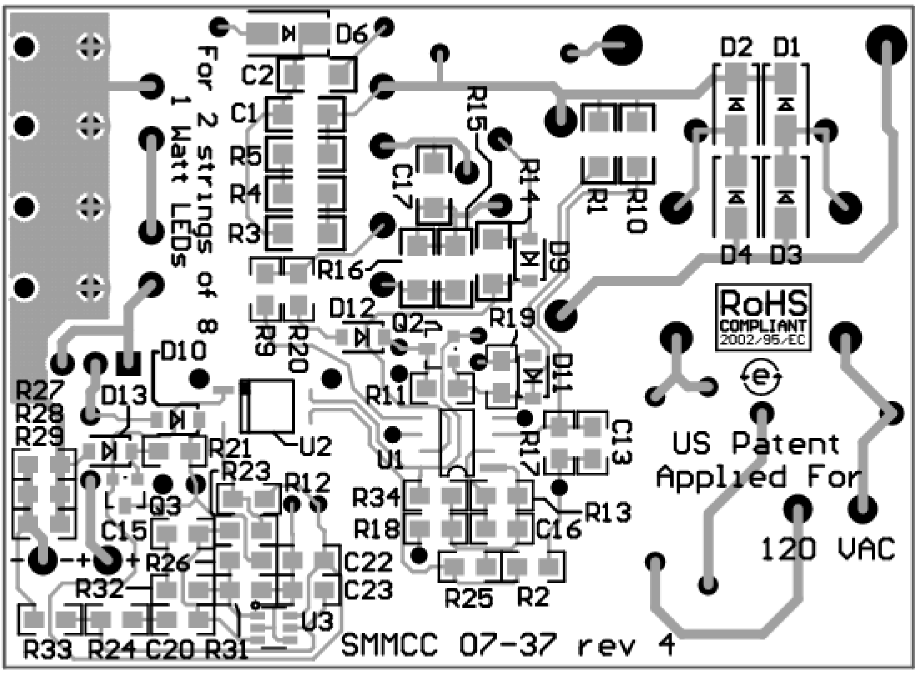


Figure 18. Bottom view of PC layout



Actual size of board is 2.00 inches long by 2.75 inches wide.

4 Test results

4.1 Efficiency measurements

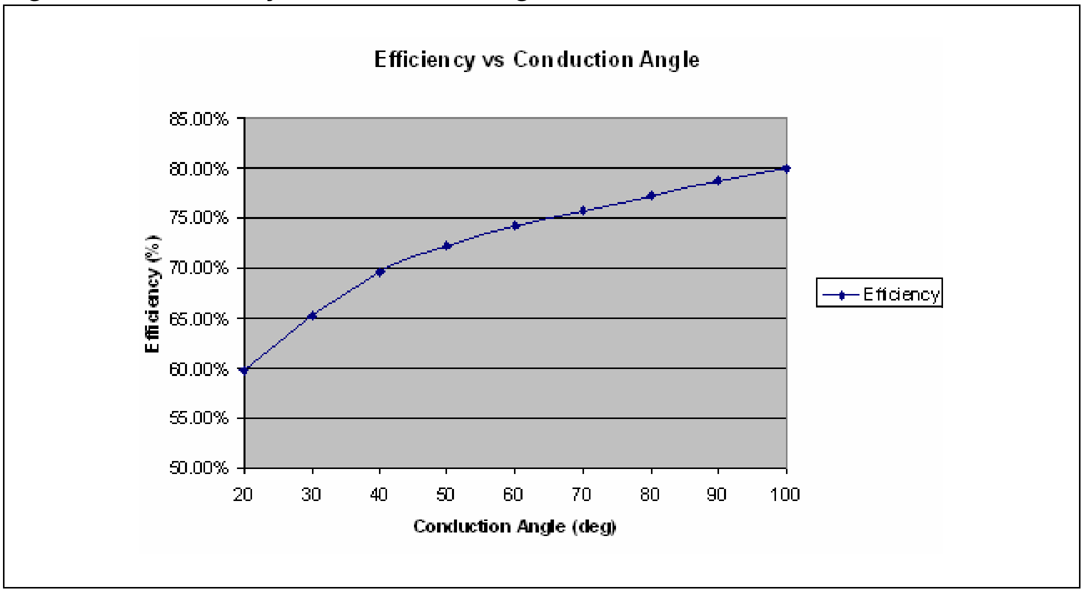
Table 2 shows the input power and output power measurements at nominal mains with the dimmer set at different conduction angles. Efficiency is then calculated from the measurements. These measurements are taken at full load at all times which is 2 strings of 8 LEDs in parallel.

Table 2. Efficiency measurements - Vin = 120 Vac

Conduction angle	Pin (W)	Pout (W)	Efficiency (%)
20 °	3.18	1.9	59.75
30 °	5.7	3.72	65.26
40 °	9.02	6.28	69.62
50 °	14.9	10.76	72.21
60 °	18.86	13.99	74.18
70 °	21.6	16.36	75.74
80 °	25.74	19.89	77.27
90 °	25.05	19.72	78.72
Full	24.44	19.53	79.91

Efficiency of the board at full load with no dimmer attached is measured to be 82.47%.

Figure 19. Efficiency vs. conduction angle



4.2 Output overvoltage protection

Figure 20. Vout with no load at output

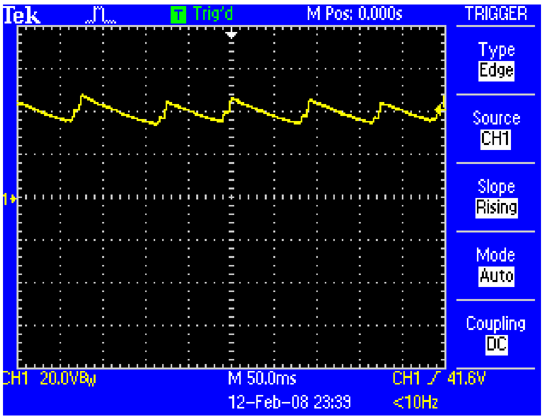


Figure 20 above shows the output voltage when there is no load at the output. The voltage feedback loop of TSM1052 clamps the output voltage to 40 V when no LEDs are connected at the output.

4.3 Thermal tests

Thermal measurements of the board, components side, were taken at nominal input voltage are shown in *Table 3* below.

Table 3. Temperature of measured points at 115 Vac - full load, 25 °C ambient

Points – ref.	Temperature
L4	61.4 °C
Q1	56.3 °C
C7	50.6 °C
Transformer, T1 core	61.5 °C
Transformer, T1 windings	64 °C
D7	36 °C
L3	45.9 °C
R8	57.8 °C
C9/C10/C11/C12	41.3 °C

5 Transformer specifications

5.1 Electrical characteristics

- Core type: EE20-10-6 power ferrite material
- Primary inductance: 608 µH ± 10%
- Leakage inductance: 10.4 µH typical
- Max operating ambient temperature: 130 °C insulation system
- Mains Insulation: Compliant with UL1310

Figure 21. Electrical diagram

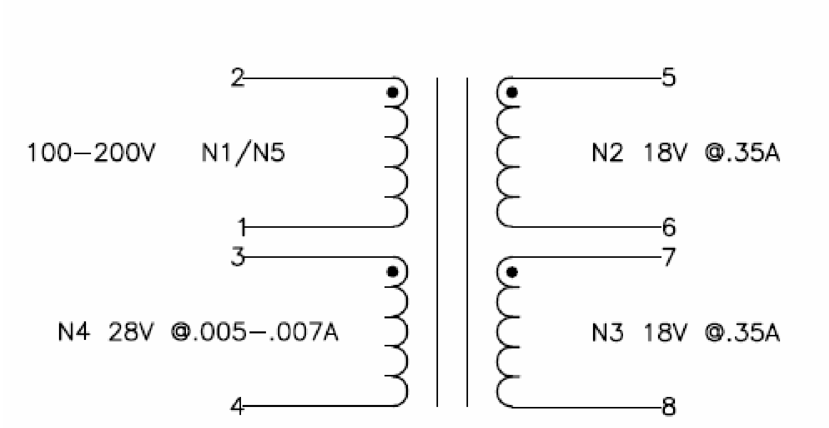


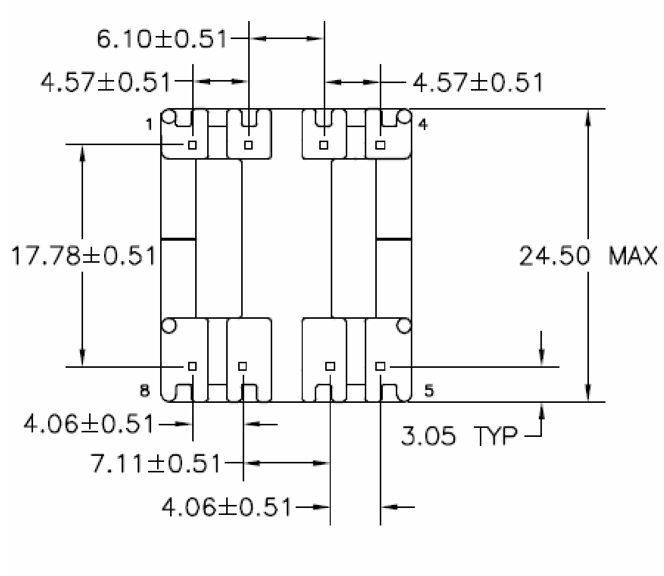
Table 4. Winding characteristics

Pins	Winding	Number of turns
1 – 2	Primary	90
3 – 4	Auxiliary	15
5 – 6	Secondary	10
7 – 8	Secondary	10

5.2 Mechanical aspect and pin numbering

- Maximum height from PCB: 18 mm
- Coil former type: horizontal, 4 + 4 pins
- Manufacturer: Cramer coil and transformer
- Part number: CSM 2010-128

Figure 22. Pin layout



Appendix A Appendix

5.3 Using a TRIAC dimmer with a PFC-flyback converter

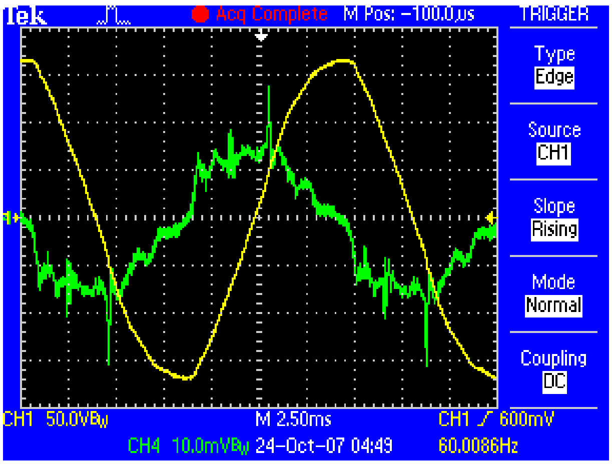
The TRIAC requires a minimum holding current, typically 30 to 50 mA, during the entire half cycle. If current falls below that level, or if it reverses, the TRIAC turns off. It may or may not fire again during that half cycle, and an unknown voltage is left on the dimmer's timing capacitor for the next half cycle. Chaotic operation results if holding current is not maintained.

5.3.1 Capacitive loading from EMI filter

Current drawn by a capacitive EMI filter varies considerably, even without the TRIAC dimmer. The incoming AC voltage waveform is distorted by other loads - its slope varies from the smooth sine wave one would expect. Typically, there is a notch at the top of the waveform, caused by rectifiers on other equipment drawing current, followed by a flat top caused by capacitive loads drawing current through rectifiers, followed by a step downward as the rectifiers go through reverse recovery (abruptly ceasing to draw reverse current). The rapid downward slope can cause a capacitive load such as the EMI filter input to supply reverse current through the TRIAC to the source. Input current (TRIAC holding current) is sharply reduced or reverses.

This effect prevents the driver from starting if the dimmer is set below the 90 degree conduction angle. Once the dimmer is past this point the TRIAC can supply enough power to allow the converter to start. When the converter is started and drawing current, the dimmer setting can be reduced to less than 5% of maximum light output.

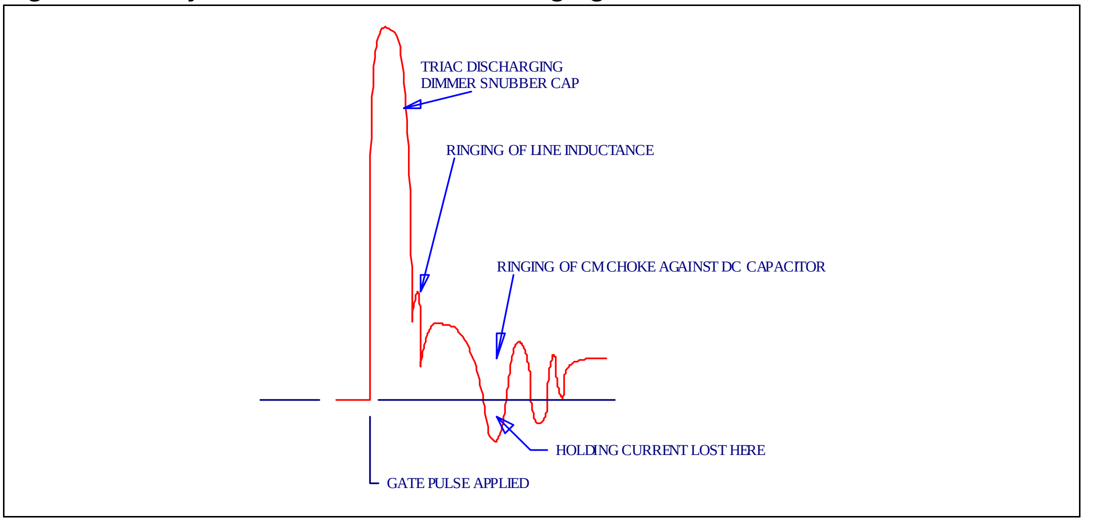
Figure 23. Line voltage and capacitive line current into the input capacitance



5.3.2 Ringing of input current at TRIAC firing

Switchmode lamp drivers of any kind must include EMI filters at their AC inputs. In addition, the TRIAC dimmer may contain its own L-C filter, and the AC line is slightly inductive. All the filters typically contain only inductive and capacitive components - the sharply increasing input voltage when the TRIAC fires each half cycle causes current ringing that reverses several times during the half cycle. The TRIAC may continue to conduct during brief reversals (microseconds to tens of microseconds), or it may turn off. The variable voltage step and variable timing cause the TRIAC gating circuit to apply voltage at random times, leading to flicker in the lamp.

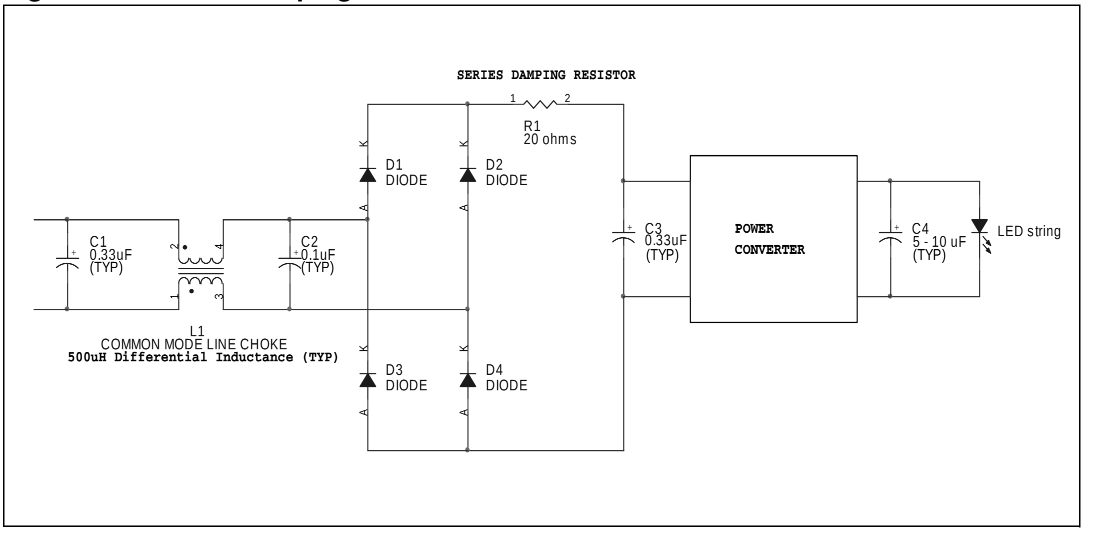
Figure 24. Thyristor current due to L-C ringing



5.3.3 Damping the ringing

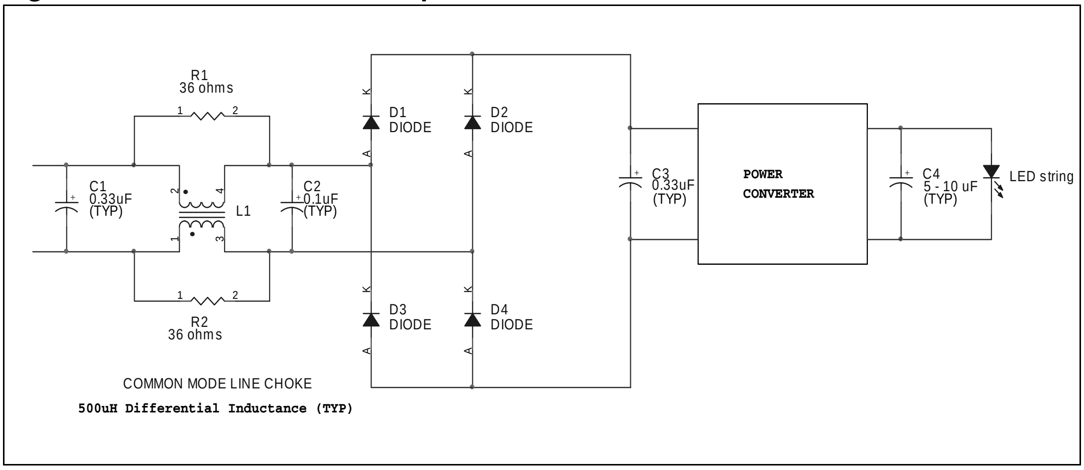
Several attemps were made to damp the ringing.

Figure 25. Series damping resistor



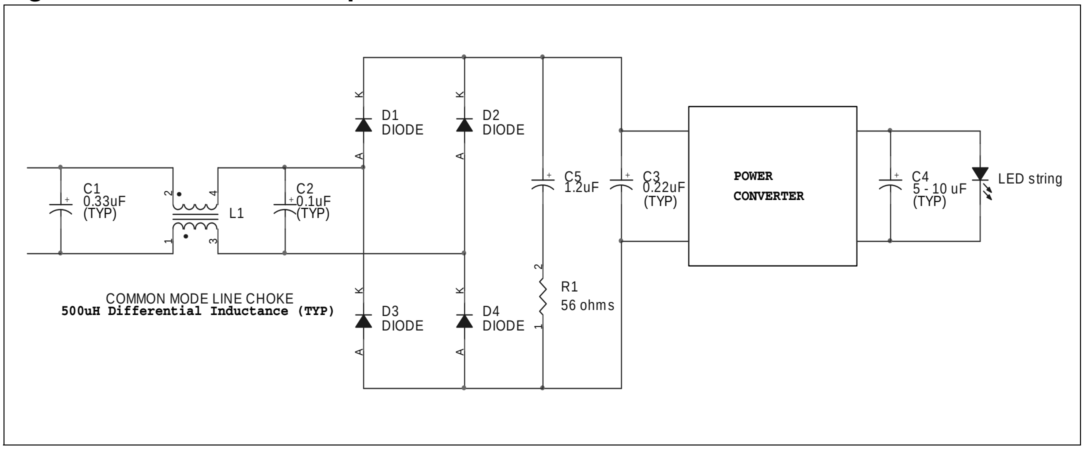
The first attempt was to add a series resistor after the rectifier so that the DC capacitor (C3 in *Figure 25*) would not instantaneously charge and its voltage overshoot. The circuit worked well, but the new resistor dissipated power after the thyristor turn-on as long as current was flowing. Efficiency was prohibitively low. Power loss was present even in non-dimming applications.

Figure 26. Shunt resistors on input inductor



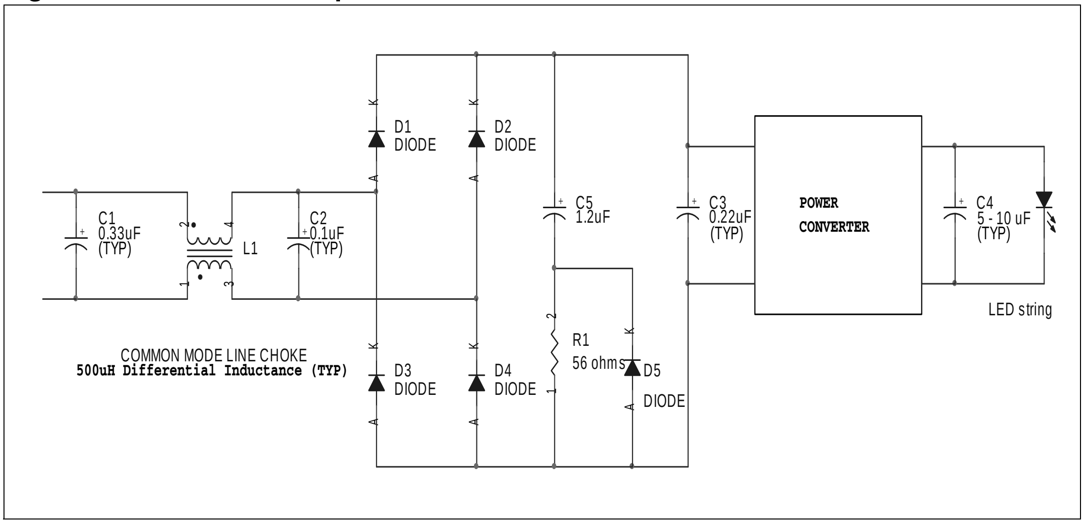
The second attempt added resistors around both windings of the common-mode inductor. While successful at damping the ringing, the resistors shunt electrical noise around the inductor, defeating its purpose.

Figure 27. Shunt R-C damper



The third attempt was very successful. An R-C snubber was added across the DC capacitor. Ringing could be eliminated by proper choice of resistor. The thyristor remained on until slightly after the zero crossing - dimmer operation was very smooth. Dissipation in the damping resistor is high-ish at about 5 W at 90 degrees conduction angle for a 60 W design, but there is almost no dissipation when the circuit is operated without a dimmer.

Figure 28. Polarized damper



Since damping is only needed on thyristor turn-on, a diode was added to eliminate resistor dissipation when the snubber capacitor was discharging into the load. Overall dissipation was reduced to about 2 W at 90 degrees conduction angle. Again, there is almost no dissipation when the circuit is operated without a dimmer. However, this solution doesn't work at low power levels. Therefore, this diode has to be removed for this 15 W design. A patent application on this damper has been filed by STMicroelectronics.

5.4 Eliminating flashing at turnoff

The TRIAC-dimmable LED drivers exhibited flashing on extreme dimming. This is more noticeable with cheaper dimmers, because they may reduce the conduction angle to zero over some part of the line voltage range.

There is an interaction between the TRIAC dimmer and the LED driver as the dimmer's conduction angle is reduced to zero. It should be possible to have the driver simply drop out when a minimum conduction angle is reached. Turn-on would then require the dimmer to be turned up significantly to re-start the driver.

5.4.1 Analysis of the flashing problem

Housekeeping power for the driver is derived from two sources, the startup trickle current from the rectified AC line, and the converter bootstrap winding (the same transformer provides output to the LEDs and the "bootstrap" section of the power supply). The PFC controller (L6562A) turns on when the housekeeping power rises above 12 V, and turns off when it drops below 10.5 V.

The problem occurs when the dimmer conduction angle is reduced to near zero. The housekeeping voltage drops below the 10.5 V threshold, and the driver shuts off, removing the load from the TRIAC. However, there is still energy stored in the DC snubber on the driver, and this trickles current into the startup circuit.

Eventually, the housekeeping voltage reaches the 12 V startup threshold, the converter starts, and the energy in the snubber is dumped into the LEDs, resulting in a flash. The cycle can repeat, or it may stop after one or two flashes.

A second flashing mechanism was discovered during simulation. If the housekeeping power supply has a large amount of ripple voltage, it is possible for the driver to turn on and off during a half cycle. If there is any voltage left on the EMI filter capacitors the dimmer sees that charge and "miscalculates" the delay before firing the TRIAC.

5.4.2 Solving the flashing problem

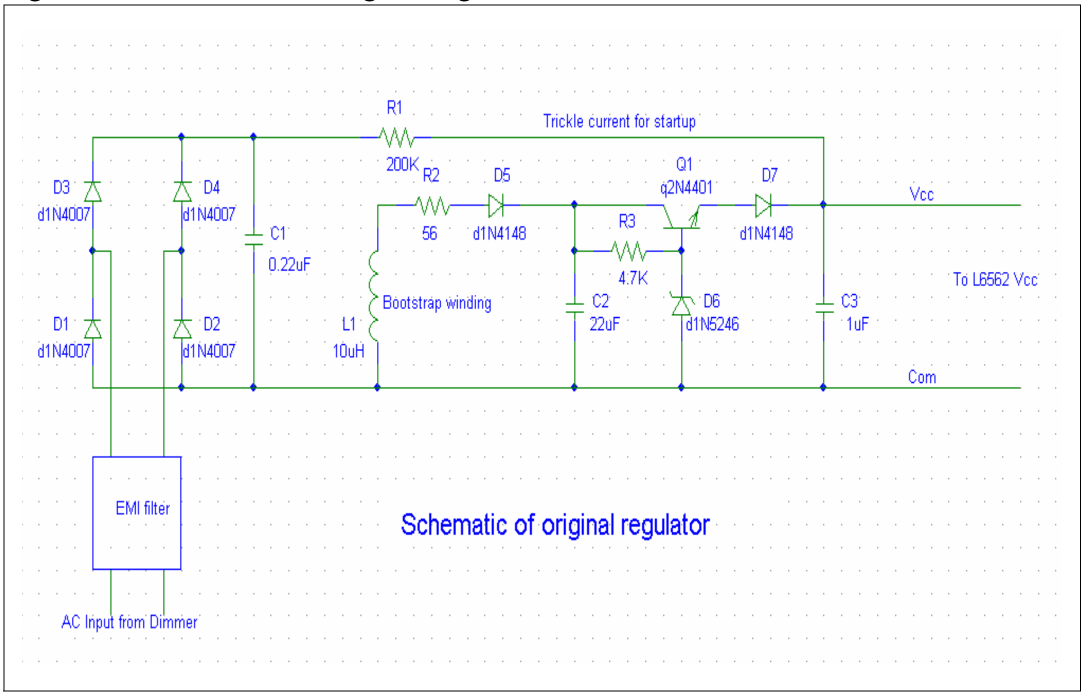
The description below was applied successfully to a 60 W version of the dimmable driver, and later adapted to the 15 W version. The development process shown applies to both designs, though the implementations differ slightly.

Initial attempts to have the LED voltage regulate the housekeeping voltage failed for the following reasons:

1. The LED voltage varies significantly with current. As the current must vary during the half cycle to implement power factor correction, less voltage is available at low conduction angles. This is transformed directly into lower housekeeping voltage.
2. At high conduction angles the bootstrap power is available for a larger amount of the time. Ringing on the transformer's bootstrap output near the AC line's peak voltage causes the housekeeping voltage to rise significantly.

A 2:1 range of housekeeping voltage was observed. This ratio exceeds the 12 to 18 V operating range of the L6562A controller chip.

Figure 29. Schematic of original regulator

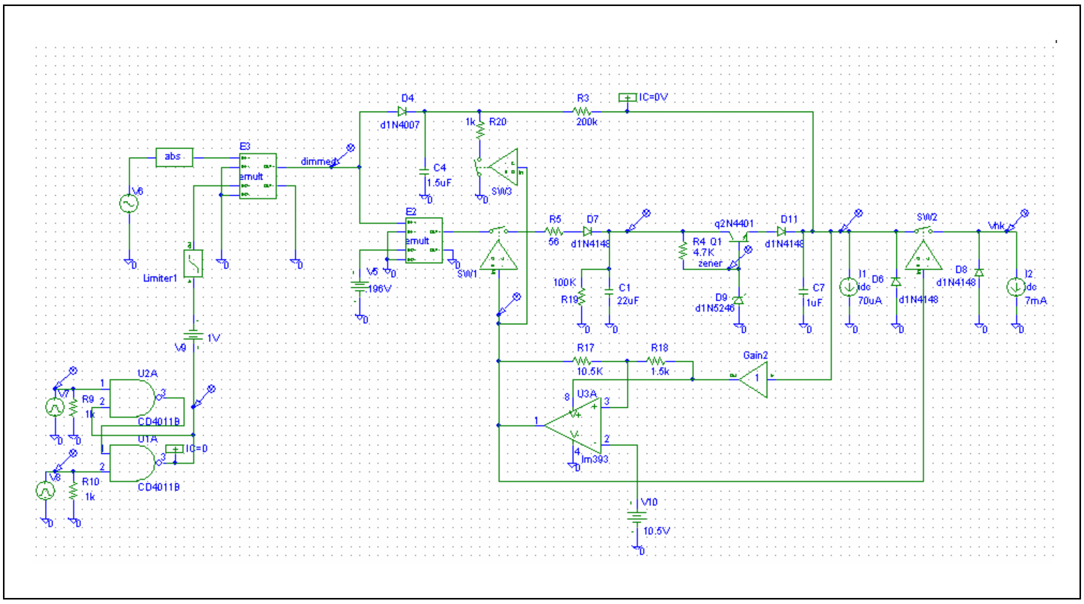


A simple regulator was designed to provide 10.5 to 15 V for Vcc. The schematic is shown in *Figure 29* above.

This supply gave rapid startup because the trickle current only had to charge a 1 µF capacitor. However, random flashing occurred on turnoff, sometimes sustained indefinitely.

A spice model of the housekeeping supply was constructed, complete with a phase-controlled source and simulated loads.

Figure 30. SPICE model of the housekeeping supply, with phase-controlled power source

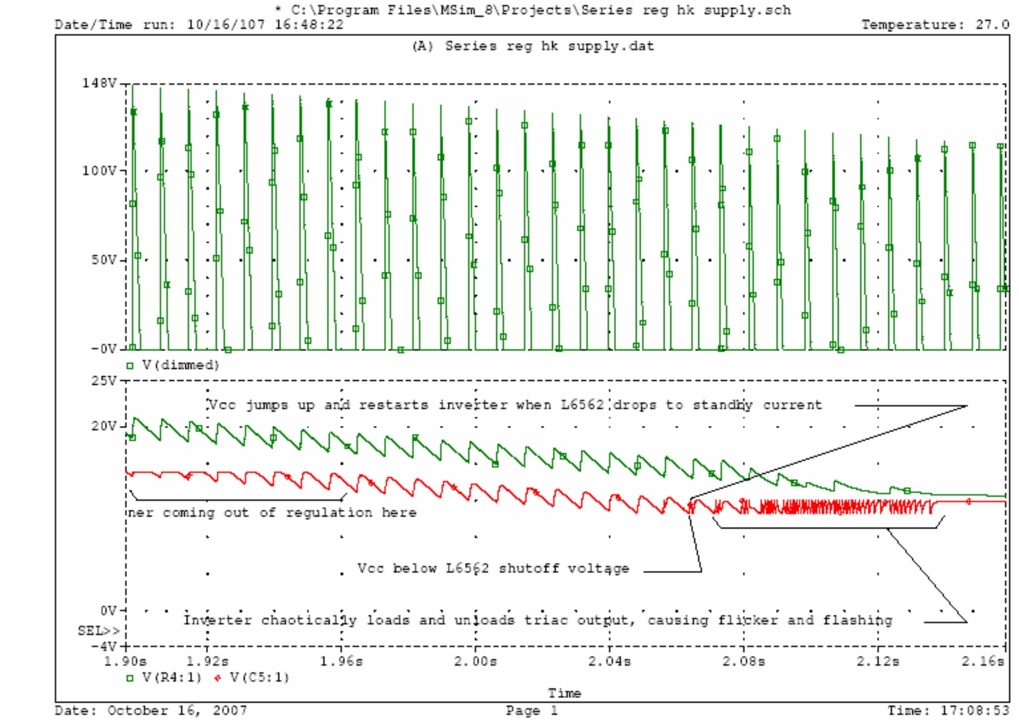


Above is a rough model of the unit. Components to the left of D4 simulate a rectified dimmed AC line. This source simulation is set up to slowly reduce the conduction angle, with dimming proceeding from 1ms per half cycle to full off and back on again at full conduction.

The housekeeping supply is to the right of D4. C1 is the bulk storage capacitor. The voltage at the top of I1 represents Vcc applied to the L6562, which must reach ~12 V for the unit to start. Q1 and D9 regulate the maximum Vcc, to keep it inside the range allowed by the L6562. SW1 and SW2 turn on when the Vcc exceeds 12 V, SW1 simulating bootstrapping from the transformer, SW2 connecting the additional load after the L6562 starts. The comparator at the bottom sets the turn-on and turnoff voltages at 12 and 10.5 V, respectively.

One of the simulation runs is shown below. The flashing and flickering begin as the housekeeping voltage reaches the lower threshold of 10.5 V, when the conduction angle is very small.

Figure 31. Simulation results of model

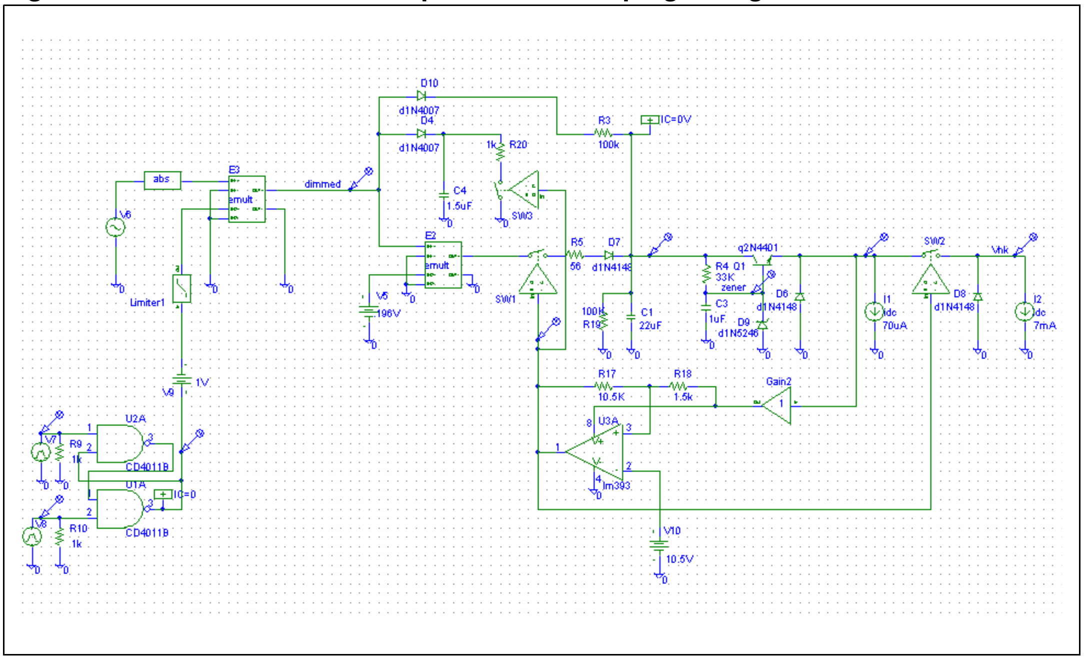


Simulation discoveries:

1. Ripple on the Vcc supply is a serious problem. Ripple exceeding the L6562's Vcc hysteresis causes oscillation, resulting in flashing and flicker. Moving C7 from the emitter of Q1 to the base allows Q1 to multiply C7's effective value by Q1's current gain, making the combination a very effective ripple filter.
2. R4's value is important, but not critical. If it is too small, ripple filtering is less effective. If too large, the output voltage begins to climb after the L6562 turns off at 10.5 V. A good compromise is 33 kΩ.
3. D10 was added to reduce the startup trickle current at low conduction angles. If it is not present, the snubber and "bulk" capacitor (C4 in the model) would supply higher peak-rectified voltage during the time the L6562 is not running (when Vcc has been below 10.5 V and has not yet gone above 12 V). This will require adding 2 diodes to the unit wired from the AC inputs to the bridge to the startup resistor.
4. R19 was added to reduce the amount of startup leakage from the rectified line.

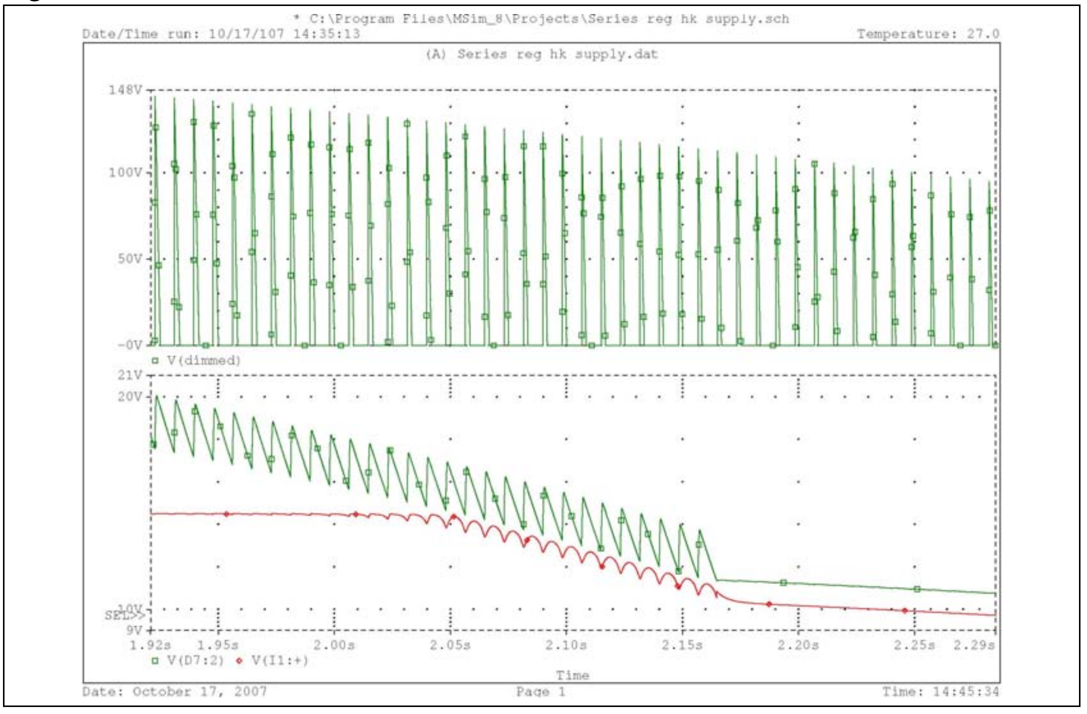
The modified model is shown in *Figure 32 on page 29*.

Figure 32. Modified model to improve housekeeping voltage at turnoff



Improved housekeeping voltage at turnoff is shown below:

Figure 33. Simulation results of model

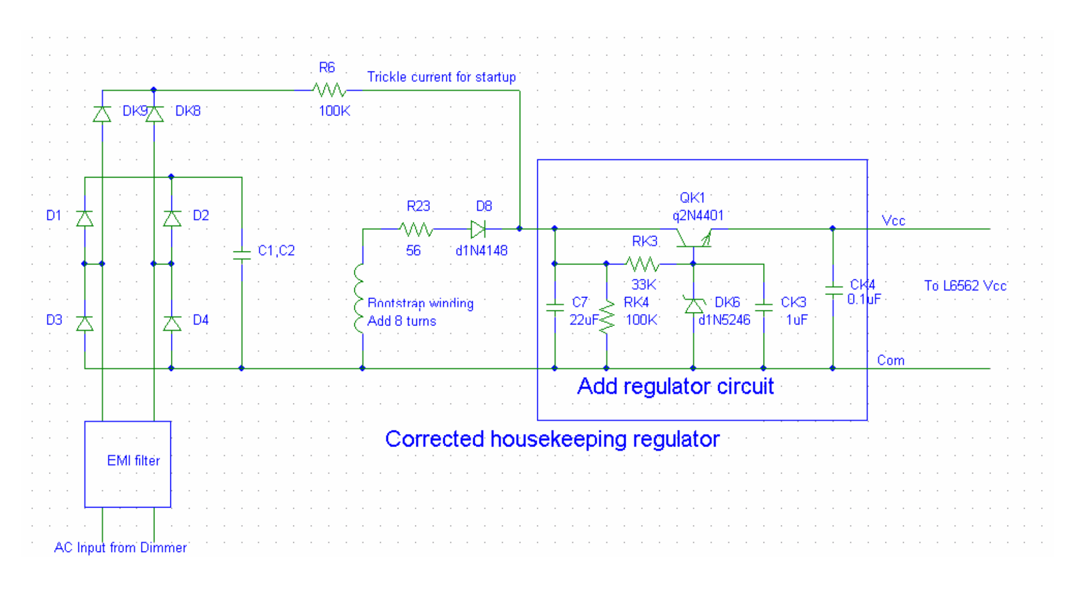


Note that the housekeeping voltage (red) does not rise after it reaches 10.5 V.

Changes required for one of the methods that will work to solve this problem:

1. Add turns to the housekeeping winding of the transformer.
2. Delete R6.
3. Add 2 diodes, S1M or equal, from AC inputs to the top of R7.
4. Add 100 kΩ resistor across C7.
5. DK7 becomes 1N5259 or equal, 39 volts (not shown)
6. Move the top of DK7, the open-load overvoltage protection diode, to the top of C7.
7. Break the connection at pin 8 of U1 and insert the regulator circuit below between C7 and pin 8.
8. Add a 0.1 µF ceramic capacitor between U1 pins 6 and 8, close to the chip.

Figure 34. Corrected housekeeping regulator



5.5 Acoustic noise and solution

Acoustic noise must be less than 24 dBA to meet industry standards. The wire in magnetic components in the EMI filter moves due to the sharp the transformer current edges of the dimming waveform, creating a buzzing sound. The EMI choke and transformer may have to be varnished or potted to eliminate wire and core movement.

6 Revision history

Table 5. Document revision history

Date	Revision	Changes
20-Mar-2008	1	Initial release