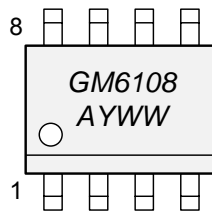
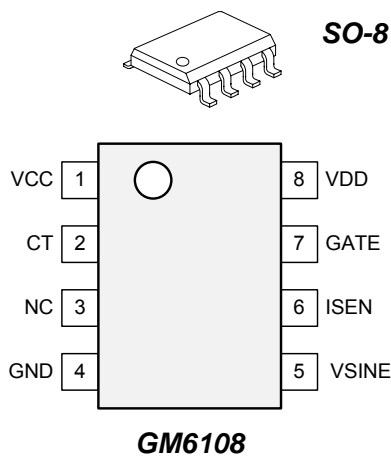


ABSOLUTE MAXIMUM RATINGS

Supply Voltage
 VDD, GATE to GND.....-0.3V to 22V

Operating Temperature Range.....-40°C to 125°C
 Storage Temperature Range.....-65°C to 150°C
 Lead Temperature (Soldering, 10 sec.).....300°C

Power Outputs and Control
 VCC, ISEN to GND..... -0.3V to 6.0V
 CT, VSINE, FBK to GND-0.3V to 6.0V

PACKAGE / ORDER INFORMATION


A = Assembly location
 Y = Year code
 WW = Week code

* All GreenMark products are Pb-Free

PIN DESCRIPTION

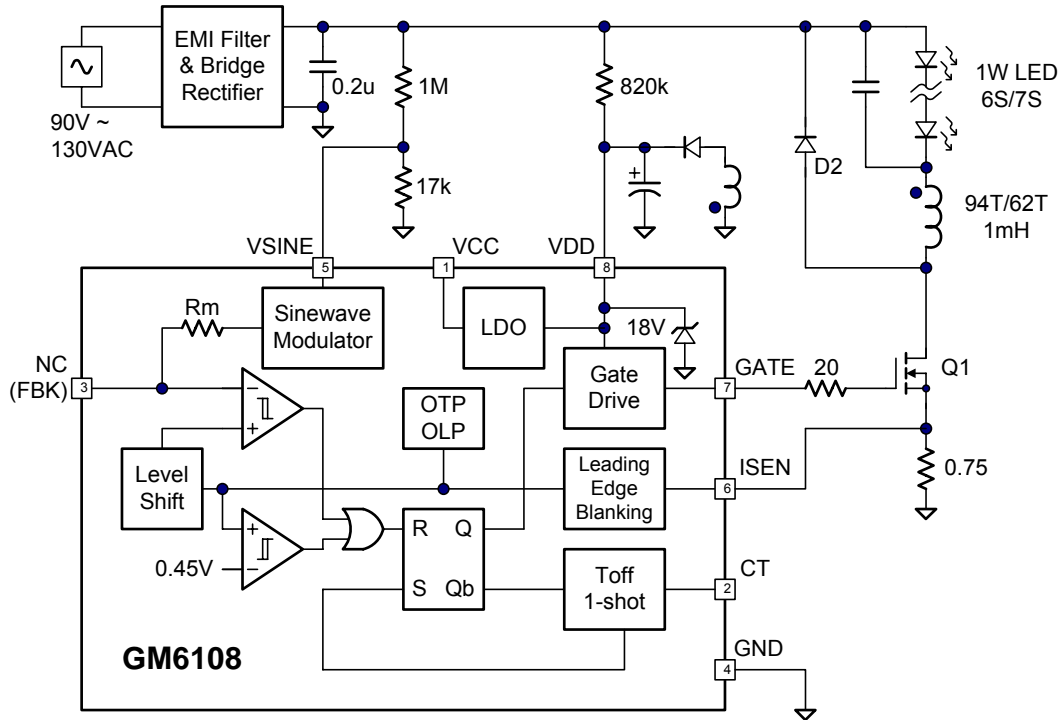
PIN	NAME	FUNCTION
1	VCC	5V LDO output
2	CT	Sets the Toff length and the nominal switching frequency
3	NC	No connection (this pin is bonded as FBK in GM6186).
4	GND	Ground
5	VSINE	Divided sinusoidal ac input waveform
6	ISEN	Current sense voltage input
7	GATE	Gate drive output for external MOSFET
8	VDD	Chip supply voltage

ELECTRICAL CHARACTERISTICS

(VDD = 12.0V. Typical values are at T_A = +25°C)

Parameter	Conditions	Min	Typ	Max	Units
Supply Power Section					
VDD supply voltage range		8.0	12.0	16.0	V
Operating current	Switching at 100kHz, Ciss = 1nF		2.5	4.0	mA
Start-up current	VDD = 10V		60	80	μA
OVP trip point		17.5	18.0	18.5	V
UVLO Section					
Turn-on threshold voltage		10.0	12.5	14	V
Turn-off threshold voltage			7.0		V
Hysteresis			5.0		V
Bandgap and LDO Section					
Bandgap accuracy	-40°C to 120°C	1.22	1.23	1.24	V
VCC output voltage	Vin from 8V to 16V	4.5	5.0	5.5	V
VCC output current limit			2		mA
Protection Section					
Internal OTP shutdown threshold	Switching is turned off		150		°C
Internal OTP shutdown reset	Switching is resumed		100		°C
Gate Drive Section					
Source current	VDD = 12V		2		A
Sink current			4		A
Current Sense Section					
Current limit reference voltage			450		mV
Leading edge blanking time			350		nsec
Propagation delay	From OCP to MOSFET turn-off		200		nsec
PFC Section					
Clamp voltage	Measured on Vsine		2.50		V
Oscillator Section					
Toff length	Ct = 470pF		8.5		μsec
PWM frequency adjustable range		50	150	200	kHz

FUNCTIONAL BLOCK DIAGRAM



11-09-09

Fig. 1 Functional Block Diagram

APPLICATION INFORMATION

The GM6108 is a high power-factor, constant current driver IC for offline LED lighting. It can accept input range of 90V to 130VAC, or 200V to 270VAC. It is based on a proprietary sinusoidal buck topology to achieve a very high power factor, typically 0.95 or better.

It supports both non-isolated (buck topology) and isolated (forward topology) designs. The GM6108 has a start-up current of less than 80uA. A bias winding on the buck converter's inductor or the forward converter's transformer provides the VDD power to sustain circuit operation after start up.

Setting the Switching Frequency

The GM6108 is basically a constant Toff switching regulator. Its nominal switching frequency, Fsw, can be adjusted via connecting a capacitor on the CT pin, according to the following equation:

$RT * CT = T_{off} = (1-D) / F_{sw}$, where RT is a 18kΩ internal timing resistance. For a 6W LED lighting for 120Vac such as shown in Fig. 3, Fsw is selected to be 100kHz. At Vpeak = 165V, D is about 12%, we find Toff is about 8.8u

To set Toff = 8.8 usec, we need CT to be 488pF. Using a 470pF capacitor will yield a Toff of about 8.5 usec.

Natural Frequency Jittering

The switching frequency of a GM6108 converter is naturally modulated as Vin varies and follows the AC line's sinusoidal waveform. This natural frequency jittering helps the LED lighting fixture to meet the EM compatibility test.

For 110VAC input, Vin varies from 0V to 150V peak. Since the switching frequency is typically near 100kHz, the duty cycle D basically obeys the following equation:

$V_{in} * D = V_o = V_f$ where Vf is the combined forward voltage of the series-connected LEDs.

$$T_{off} = (1-D) * T_{sw} = (1-D) / F_{sw}$$

That is, $F_{sw} = (1-D) / T_{off} = (1 - V_f/V_{in}) / T_{off}$

So if we keep Toff constant, the switching frequency Fsw will be higher when Vin is high.

For 110VAC input, most of input power happens when Vin is above 60V. If Vf = 20V, and Toff = 8.5us, Fsw will be 80kHz at Vin = 60V. Fsw increases to 102kHz at Vin = 150V.

Setting up Sinusoidal LED Current Waveform

LED current waveform follows the rectified sinusoidal waveform of the AC input voltage. Use a voltage divider R1, R2 to provide a proper amplitude at the VSINE pin. The required VSINE amplitude is 2.5V.

For a typical 120VAC system, we recommend a voltage divider of R1 = 1M, R2 = 17K.

Also, due to the Buck converter topology, a GM6108 application circuit can not drive current through the LEDs when Vin drops below Vf (the combined LED forward drop voltage). To reduce the switching loss, GM6108 cuts off switching when VSINE falls below 0.6V. In general, this corresponds to a cut-off angle of about 15°. In other word, GM6108 delivers a truncated sinusoidal current to the LED lamp during the conduction angle [15°, 165°].

High Power Factor

Because of the in-phase sinusoidal LED current waveform, a GM6108 application circuit achieves excellent power factor, typically better than 0.95.

An important advantage of the GM6108 LED lighting driver is there is no need for a large electrolytic or tantalum filter capacitor after the input bridge rectifier. Most conventional LED driver designs require an input filter capacitor in the order of 1uF per watt.

In contrast, GM6108 requires only a very small input filter capacitor, C1, of about 0.22uF to filter out high-frequency switching noise from feeding back to the AC lines.

No Electrolytic Capacitors

A large electrolytic capacitor not only takes up significant space and volume, its limited life, usually less than several thousand hours, may seriously downgrade the usable life of an LED lighting fixture

The operating life of an electrolytic capacitor can be expressed as

$$Lop = Mv * Lb * 2^{[(Tm-Ta)/10]}$$

where Lop is the expected operating life in hours.

Mv is a voltage multiplier for voltage de-rating.

Lb is the expected operating life in hours at full rated voltage and temperature

Tm is the maximum permitted capacitor internal temperature in °C

Ta is the actual capacitor internal temperature in °C.

In other words, an electrolytic capacitor's life will be cut in half for every 10°C temperature rise.

In fact, a major challenge in designing an LED lighting fixture confirming to the conventional incandescent light bulb form factor such as MR16, A19, PAR30, or PAR38 is the thermal management. The LED driver circuit is enclosed inside of a completely sealed chamber with elevated temperature. It is common to measure an internal chamber temperature of 100°C or even higher. This harsh operating condition often takes a toll on the electrolytic capacitors. Therefore, a top priority in designing a long-life LED lighting is, eliminating the need for any electrolytic capacitors, which takes up significant amount of space and has only several thousand hours of operating life in many LED light bulb designs.

Non-isolated, 110VAC Buck Topology Design

Fig. 3 shows a reference design for a 6W LED A19 light bulb. It uses six 1-W LEDs connected in series. The combined Vf is about 20V at room temperature.

The voltage on the current sense pin, ISEN, will follow a truncated sinusoidal waveform of peak value of 450mV. Also, there is a cycle-by-cycle over-current limit that terminates a switching cycle when the ISEN pin exceeds 450mV.

In Fig. 3 circuit, the target average LED current is 350mA. Since GM6108 modulates the LED current to follow a sinusoidal waveform, therefore, Ipk is 500mA. To have 450mV*Sin θ, a 0.75Ω current sense resistor is used.

For the power MOSFET, we recommend a 250V NFET with Rds(on) of about 1.2Ω, and Coss of 50pF. Its conduction loss is about 27mW. Switching loss at 100kHz is about 42mW.

The inductor uses an EE10 ferrite core. The primary winding has 94 turns with an inductance of 1mH. The bias winding has 62 turns.

The free-wheeling diode, D2, will see a full Vin when the MOSFET, Q1, turns on. We recommend a 1.0A, 200V schottky diode. A 300V ultra-fast recovery diode can be used, but the efficiency of the driver circuit may drop by 1.5% to 2%.

The bias winding voltage is in proportion to Vf at MOSFET off time. For Vf = 20V, the bias winding voltage is 20V * 62/94 = 13.2V. Notice the reverse voltage on D3 is (Vin+Vf) * 62/94 (when Q1 is on). We recommend a 200V ultra-fast recovery diode. Two 1N4148 in series can be used as well.

Fig. 4 shows the Fig. 3 circuit waveforms over a half cycle of 60Hz line frequency. The conduction angle is 6.5° to 173.5°. Power factor is over 97.5%. Fig. 5 shows the zoom-in waveforms at θ of 10°, 30°, 60°, and 90°.

Thermal Design

Notice the safety isolation in Fig. 3 circuit is provided by the insulation layer between the LED devices and their aluminum substrate. The insulation layer structure relative to the LED devices and the heat-sink substrate is shown in Fig. 6.

An adequate heat-sink design for an LED light bulb can keep its outside surface temperature below 60°C. This in general will keep the junction temperature of the LED devices below 85°C.

However, the air sealed within the air-tight light bulb chamber will be heated up by the power dissipation from the inductor, the free-wheeling diode, and the power MOSFET. In many un-suspecting designs, the air trapped inside may get as hot as 150°C whereas the

GM6108

heat sink outside surface is only 60°C. This trapped hot air often leads to components and circuit failure, especially in those LED drivers using electrolytic capacitors.

This circuit board hot spot situation is due to the lack of heat conduction path from the converter circuit board to the inside wall of the heat-sink. Uncirculated air around the circuit board has very little heat transfer capability. The heat dissipated from the circuit board simply accumulates within the chamber, elevating the circuit board and components temperature to ever higher level.

In certain light bulb design, convection holes are added to provide a tiny amount of air flow in order to cool off the internal chamber's air temperature. Although effective, adding convection holes will incur the drawbacks of condensed moisture and trapped dust inside of the lamp fixture.

We recommend to apply heat conducting, but electrically insulating glue between the power dissipating devices, (the transformer, the MOSFET, and the free-wheeling diode) and the inside wall of the heat sink.

Using 20mA LED Arrays

Due to their huge volume production and use in backlight applications for cellular phones, portable computers, and LCD TVs, the 20mA LEDs are very cost effective. Their efficiency is in general higher than that of 1W power LEDs.

In addition, using a large amount of 20mA LEDs to form a distributed light emitting surface on top of a heat-sink substrate can help to resolve both the glare and the hot-spot issues. With all these advantages, there appears a trend to adopt 20mA LEDs for general lighting applications.

Non-isolated, 220VAC Buck Topology Design

Fig. 7 shows a reference design for a 7.5W LED A19 or PAR30 light bulb. It uses 92 pieces of 20mA LEDs (operating at 25mA) connected in a 23-series, 4-parallel configuration. The combined Vf is 74V at room temperature with 3.2V nominal Vf per LED. The total power output is 7.36W. Using high-grade 20mA LEDs, it can generate near 700 lumens of light output.

The circuit design is similar to the 110VAC buck circuit. However, the duty cycle at 300V is about 75% due to the combined Vf is raised to 74V. The conduction angle is from 15° to 165°. Power factor is measured at over 96%. In Fig. 7, R3 is doubled to 1.6M. Its power dissipation is about 30mW at 220Vac input.

Notice the inductor design for this 220V buck converter is more challenging than in the case of the 110V buck converter. We have the need to increase the winding number of turns, N1, to reduce the core flux density and thus the core loss. But increasing N1 has the ill effect of increasing the magnetizing field intensity, since $H = N1 \cdot I1$. High NI level, in turn, will drive an undersized core into saturation.

Therefore, the inductor design generally requires a small air-gap to counter the NI level on the core.

In this 220V buck converter, we choose an EE13 ferrite core. N1 is 150 turns of AWG32. N2 is 28 turns of AWG34..

The maximum flux density Bmax is calculated to be

$$B_{max} = 74V \cdot 6.0\mu\text{sec} \cdot 10^7 / (150T \cdot 0.17\text{cm}^2) = 174 \text{ mT}$$

At Vin = 300Vdc, Vout = 74V, the duty cycle is about 25%. With Toff set at 6.0μsec, the switching frequency is found to be 125kHz.

To achieve a current ripple of 40mA out of 100mA RMS current, we need about 10mH of primary inductance. An EE13 core without air gap has 1.13μH per turn. At 150 turns, its inductance is 25.4mH.

A small air-gap is inserted to reduce the primary inductance to about 10mH. This help to prevent the core from saturation. However, a larger core with fewer turns may be able to increase the overall circuit efficiency by 1% to 2%.

The bias winding voltage is in proportion to Vf at Q1 off time. For 23 LEDs in series with a combined Vf of 74V, we need only 28 turns for N2 to supply a bias voltage of 14V.

Notice in this 220V buck design, the conduction loss of the power MOSFET is nearly negligible, whereas the switching loss can be several times higher than the conduction loss. A key to improve the circuit efficiency is

to select a power MOSFET with a fair $R_{ds(on)}$ but a very low C_{oss} .

95% High Efficiency

With proper selection of power MOSFET and free-wheeling diode, and fine-tuning of the inductor design, a GM6108 buck converter can expect an efficiency of as high as 95%. In comparison, many flyback converter based LED drivers can only achieve efficiency of around 80%.

High efficiency not only simplifies the heat sink design, it also improves the overall efficacy and the reliability of the lighting fixture.

Isolated Forward Topology Design

In certain applications, such as LED ceiling light tubes and LED street lights, where an LED driver board is used to drive and regulate several lighting fixtures separately, an isolated design (forward topology) is preferred. Although a forward topology requires several additional parts, it does simplify the thermal design, and it is easier to pass safety regulations. However, there is generally a size and cost premium due to the addition of two diodes and a power transformer. The efficiency of a GM6108 forward converter design will be expected to be about 85% to 90%.

A major benefit of using a forward topology is its transformer allows flexible turn-ratio design, and it can extend the duty cycle to 25% at high V_{in} . The extended duty cycle reduces the RMS value of the current flowing through the primary winding and the power MOSFET. It will also help to prevent a jittery T_{on} issue.

Fig. 8 shows a reference design for a 220VAC, 48W, LED lighting driver circuit using a GM6186 as a single

stage PFC converter, and a GM6133 driving four 12W LED light tubes on the secondary side.

Each LED light tube consists of 12 1-W LEDs connected in series. Alternatively, each light tube can be implemented using 144 pieces of 20mA LEDs connected in a 12-series, 12-parallel configuration.

For the transformer design, we select an LP2308 ferrite core for its low-profile and long winding window. The primary winding is 90 turns of AWG30. The secondary winding is 60 turns of AWG26. The N_1/N_2 turns-ratio is 3:2. The bias winding is 10 turns of AWG34.

We set T_{off} to be 6 μ sec. The maximum flux density is calculated to be

$$B_{max} = 52V * 1.5 * 6.0 \mu\text{sec} * 10^7 / (90T * 0.31\text{cm}^2) = 168\text{mT}$$

The maximum switching frequency at 220VAC input is 125kHz.

RCD Snubber Design

In a forward transformer, it is necessary to reset the flux after each turn-on cycle. The minimum reset voltage required is according to the following equation,

$$V_{rst} = V_{in} * D / (1 - D)$$

However, the voltage across C_3 is typically higher than the minimum reset voltage. The reset voltage level and the RCD snubber design are related to several factors. Heuristically, we found a transformer with a good coupling (lower leakage inductance) between the windings will reduce the RCD snubber loss and the reset voltage level. In Fig. 8 circuit, C_3 is 10n, R_3 is 300K. Higher R_3 will reduce the snubber loss, but the reset voltage will increase too. It is important to keep the reset voltage to less than 120V if a 600V MOSFET is used.

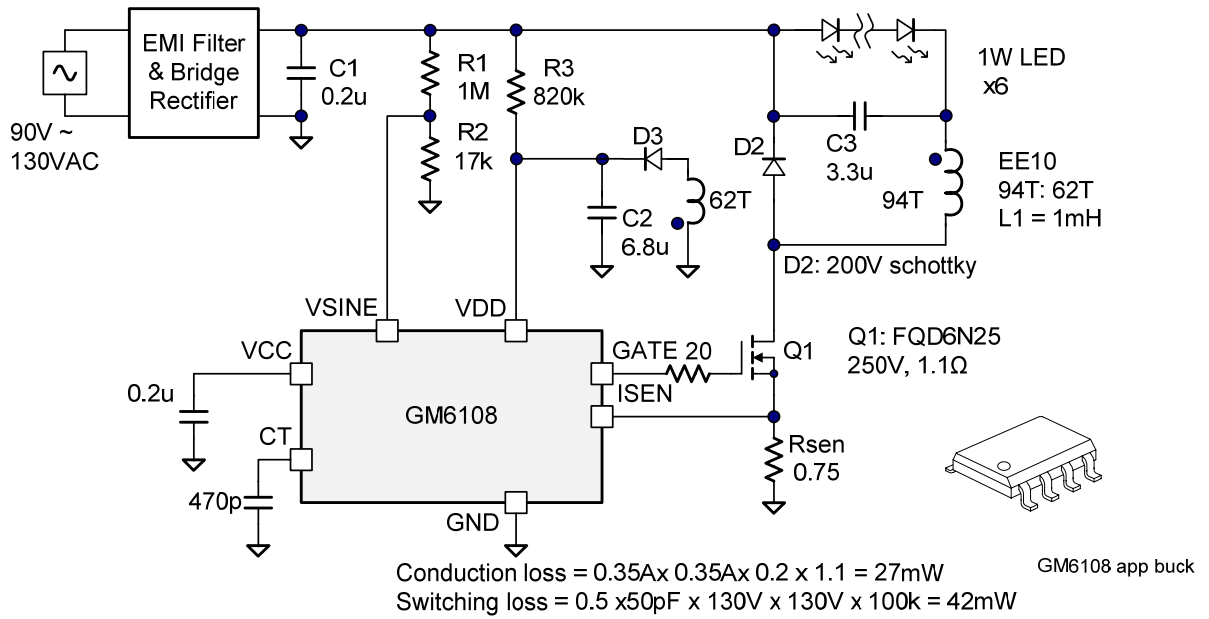
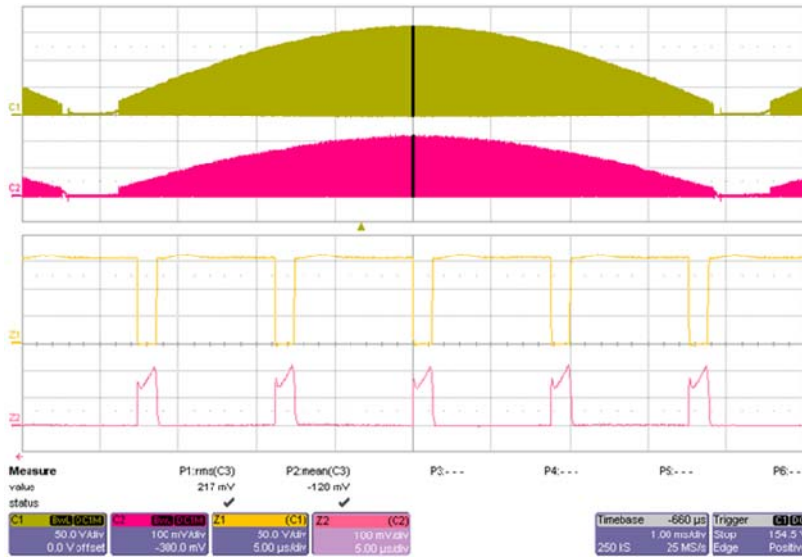
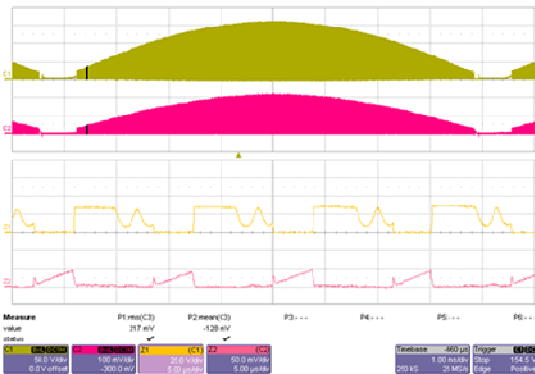


Fig. 3 110VAC 6W Non-Isolated LED Light Bulb

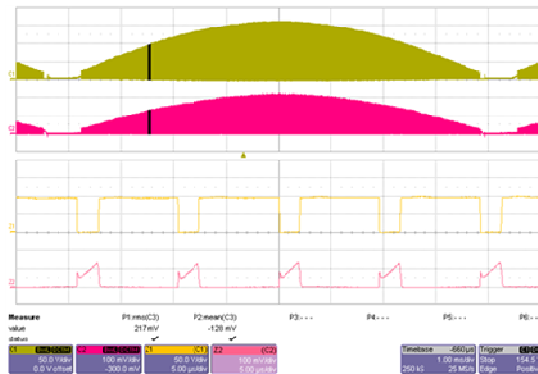


110V Buck Waveforms
 Top Trace: Vds (50V/Div.). Bottom Trace: Vsen (0.2V/Div.)

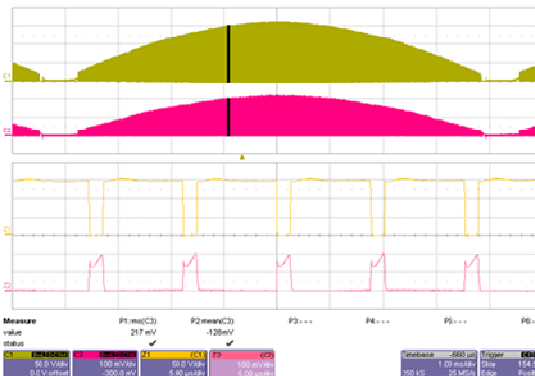
Fig. 4 120VAC 6W Buck Waveforms



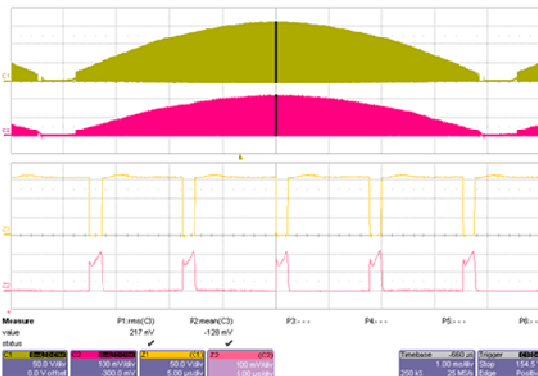
110V Buck Waveforms at $\Theta = 10^\circ$
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)



110V Buck Waveforms at $\Theta = 30^\circ$
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)

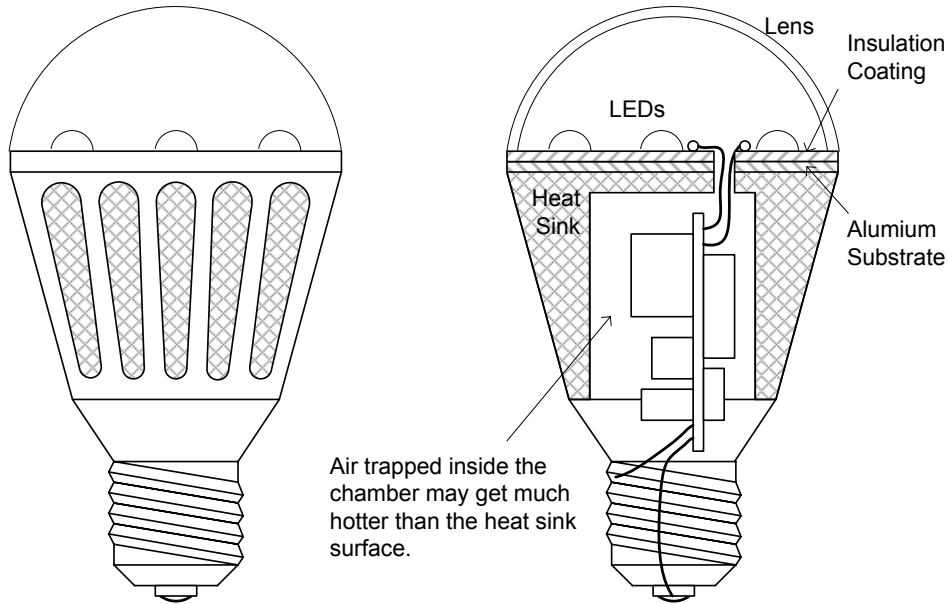


110V Buck Waveforms at $\Theta = 60^\circ$
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)



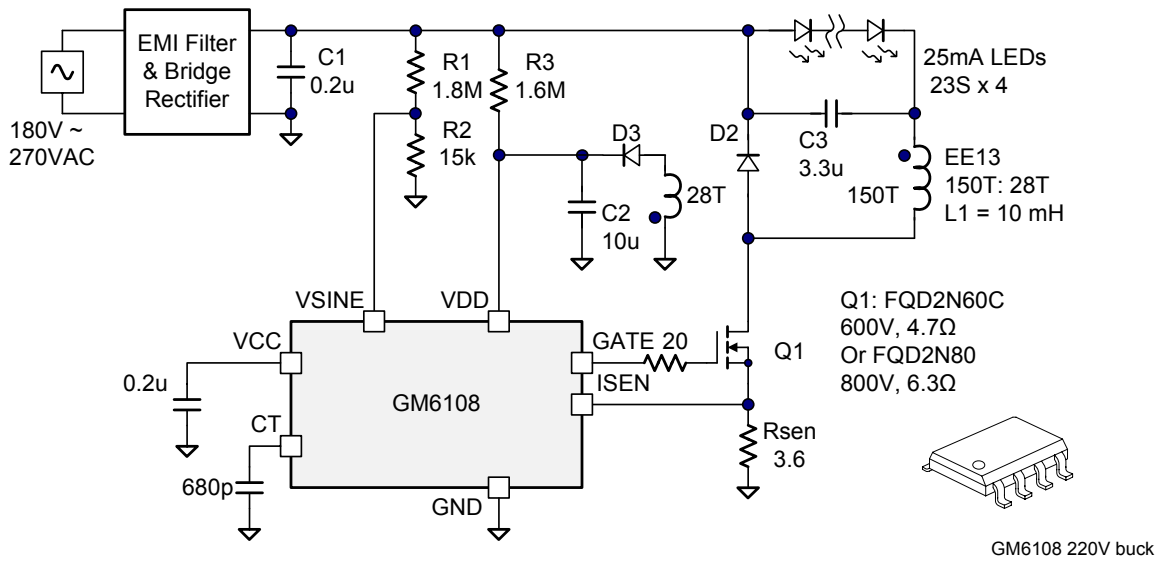
110V Buck Waveforms at $\Theta = 90^\circ$
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)

Fig. 5 110VAC 6W Buck Waveforms at $\Theta = 0^\circ, 30^\circ, 60^\circ$ and 90°



Nov. 2, 2009

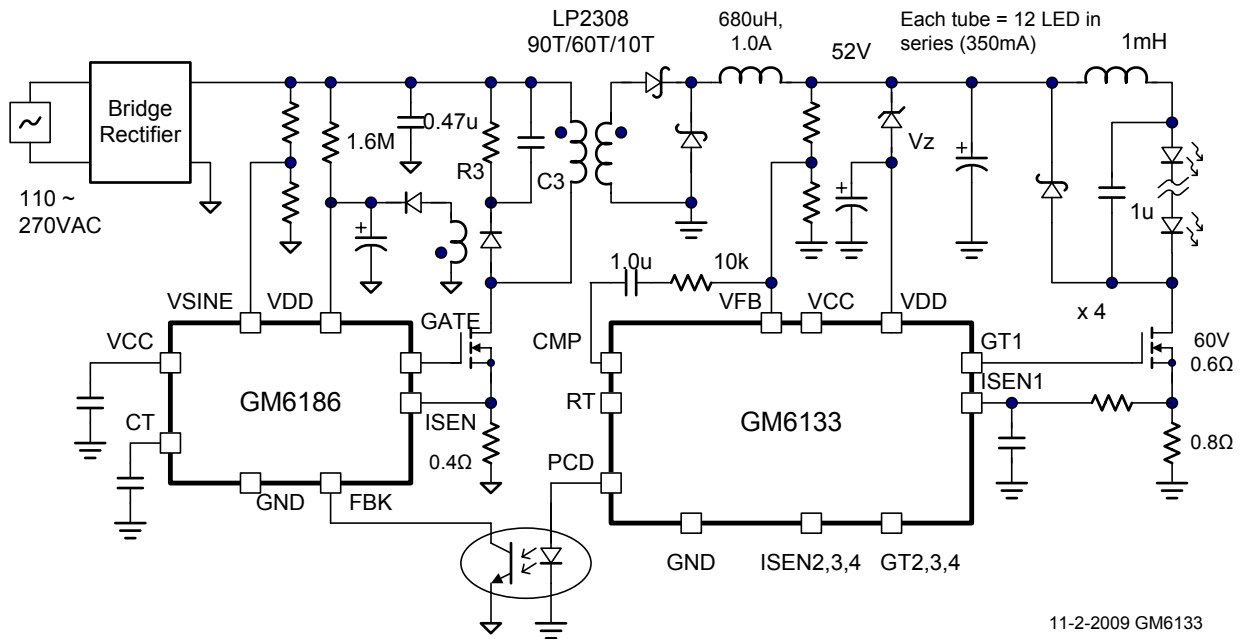
Fig. 6 Non-Isolated A19 LED Light Bulb Design



Conduction loss = $0.1A \times 0.1A \times 0.3 \times 5 = 15mW$
 Switching loss = $0.5 \times 30pF \times 270V \times 270V \times 124k = 135mW$

220V Buck 7.5W

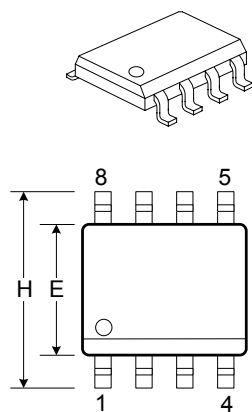
Fig. 7 220VAC 7.5W Non-Isolated LED Light Bulb



11-2-2009 GM6133

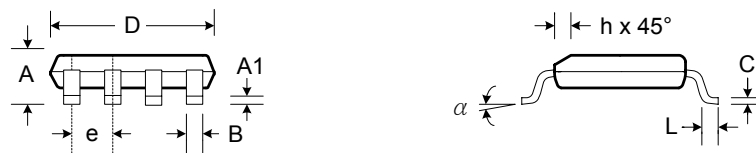
Fig. 8 220VAC 48W (12W x 4) LED Ceiling Light

PACKAGE DIMENSIONS



DIMENSIONS

Symbol	Millimeters	
	Min.	Max.
A	1.35	1.75
A1	0.10	0.25
B	0.33	0.50
C	0.19	0.20
D	4.80	5.00
E	3.81	4.00
e	1.25BSC	
H	5.80	6.00
h	0.25	0.50
L	0.40	0.50
α	0°	8°



SO-8 Package Drawing