GM6108

Off-line LED Lighting Driver

Preliminary – Feb. 25, 2010

FEATURES

- 90V to 130VAC or 200V to 270VAC input range
- High power factor: better than 0.95
- High efficiency: up to 92% for sinusoidal buck, 88% for sinusoidal forward.
- No need for any electrolytic capacitor
- 450mV current-limit voltage
- Natural current-limited soft start (no inrush current)
- Fast response to over-current condition
- Over-temperature protection
- No-load protection, open feedback loop protection
- **Adjustable switching frequency with natural spread spectrum (up to 10dB EMI reduction)**
- Compatible with triac (SCR) dimming
- 80uA start up current
- Available in SO-8 package

APPLICATIONS

- General ceiling LED lighting
- A19, PAR30, PAR38 LED light bulbs
- LED light tubes
- Outdoor spotlights

DESCRIPTION

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

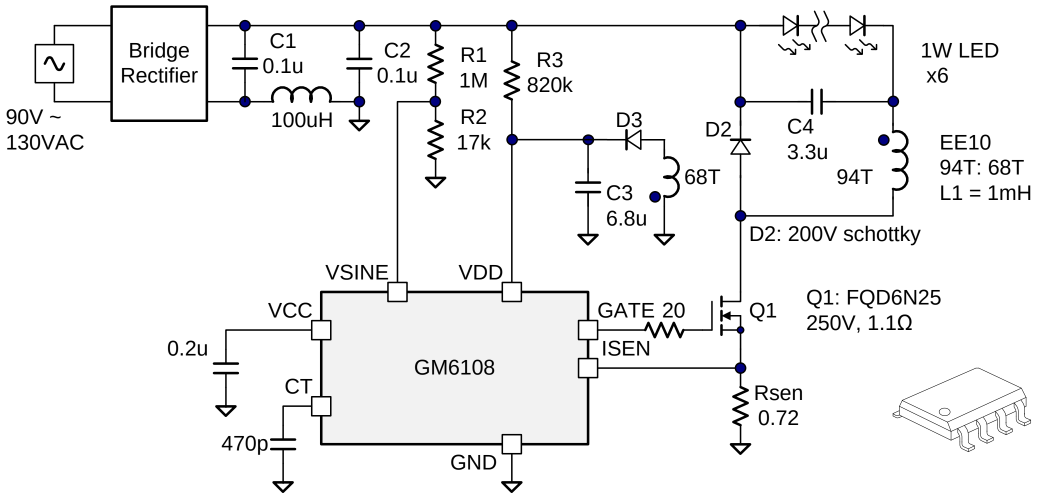
It supports both non-isolated (buck) and isolated (forward) designs. The GM6108 has a start-up current of less than 80uA. A bias winding on the buck converter's inductor or the forward converter's transformer provides the VDD power to sustain the circuit operation after start up.

The GM6108 provides an adjustable switching frequency, up to 200kHz. It has cycle-by-cycle current limit. The GM6108 provides an accurate internal current limit reference of 450mV.

The GM6108 provides an on-chip over-temperature protection. It shuts down the switching when the chip temperature exceeds 150^{o}C. The GM6108 is available in SO-8 package.

Patents pending

TYPICAL APPLICATION



GM6108 app buck

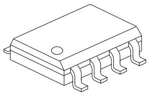
ABSOLUTE MAXIMUM RATINGS

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

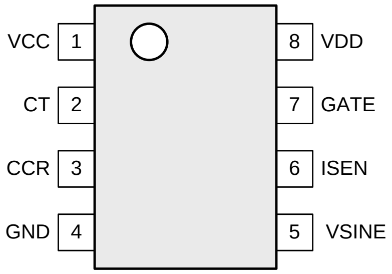
Power Outputs and Control
VCC, ISEN to GND.......................... -0.3V to 6.0V
CT, VSINE, FBK to GND ....-0.3V to 6.0V

Operating Temperature Range...........–40^{o}C to 125^{o}C
Storage Temperature Range.............–65^{o}C to 150^{o}C
Lead Temperature (Soldering, 10 sec.).............300^{o}C

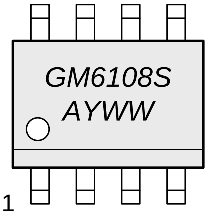
PACKAGE / ORDER INFORMATION



SO-8



GM6108



S suffix = SO-8

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	**CCR**	Constant current regulation
4	**GND**	Ground
5	**VSINE**	Scaled 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		7.0	12.0	17.0	V
Operating current	Switching at 100kHz, Ciss = 1nF		1.5	2.0	mA
Start-up current	VDD = 10V		50	80	uA
OVP trip point		17.0	17.5	18.0	V
UVLO Section					
Turn-on threshold voltage		10.0	12.0	14	V
Turn-off threshold voltage			6.0		V
Hysteresis			6.0		V
Bandgap and LDO Section					
Bandgap accuracy	-40oC to 120oC	1.22	1.23	1.24	V
VCC output voltage	Vin from 8V to 16V	4.75	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					
Internal timing resistor (RT)			18		kΩ
Toff length	Ct = 470pF		8.5		usec
PWM frequency adjustable range		50	100	200	kHz

FUNCTIONAL BLOCK DIAGRAM

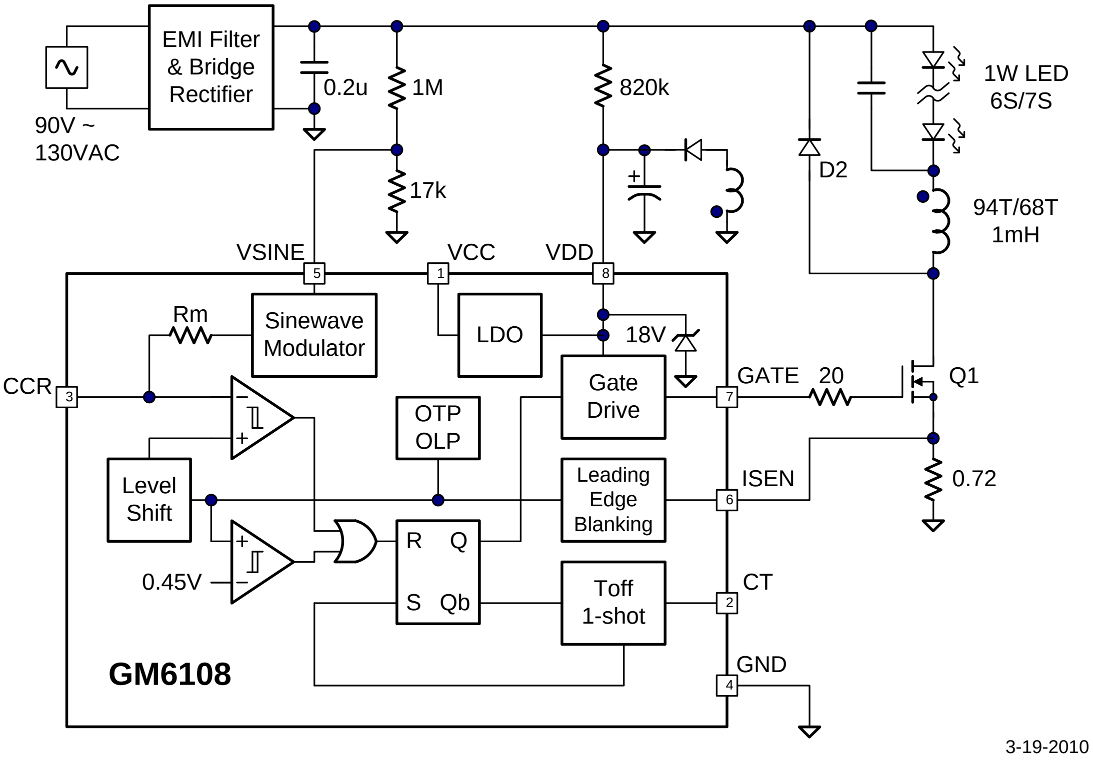


Fig. 1 Functional Block Diagram

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 very high power factor, typically 0.95 or better.

The GM6108 supports both non-isolated (buck topology) and isolated (forward topology) designs. It 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 = Toff = (1-D) / Fsw, where RT is a 18kΩ internal timing resistance. For a 6W LED lighting with 120Vac input 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 EMI 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:

Vin*D = Vo = Vf where Vf is the combined forward voltage of the series-connected LEDs.

Toff = (1-D) *Tsw = (1-D)/Fsw

That is, Fsw = (1-D) / Toff = (1 – Vf/Vin) / Toff

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 78kHz 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 nominal 110VAC input system, we recommend a voltage divider of R1 = 1M, R2 = 17K.

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 of 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 more. 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.

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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 350*3.14/2 = 550mA. With 30% current ripple, we have Rsen = 0.45V/(0.55A*1.15), a 0.72Ω 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 68 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 = 19.2V, the bias winding voltage is 19.2V *68/94 = 14V. Notice the reverse voltage on D3 is (Vin+Vf) * 68/94 (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 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 8W LED A19 or PAR30 light bulb. It uses 96 pieces of 20mA LEDs (operating at 25mA) connected in a 12-series, 8-parallel configuration. The combined Vf is 38V at room temperature with 3.2V nominal Vf per LED. The total power output is 7.68W. Using high-grade 25mA 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 13% due to the combined Vf is 38V. The conduction angle is from 7.5^o to 172.5^o. 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*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 100 turns of AWG32. N2 is 37 turns of AWG34.

The maximum flux density Bmax is calculated to be

$$B_{max} = 38V*8.0usec*10^7 / (100T*0.17cm^2) = 179\ mT$$

At Vin = 300Vdc, Vout = 38V, the duty cycle is about 13%. With Toff set at 8.0usec, the switching frequency is found to be 108kHz.

To achieve a current ripple of 60mA out of 200mA RMS current, we need about 5mH of primary inductance. An EE13 core without air gap has 1.13uH per turn. At 100 turns, its inductance is 11.3mH.

A small air-gap is inserted to reduce the primary inductance to about 5mH. This helps 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 12 LEDs in series with a combined Vf of 38V, we need 37 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 Rds (on) but a very low Coss.

92% 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 92%. 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 Vin. 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 Ton issue.

Fig. 8 shows a reference design for a 110AC, 8W LED light bulb design. It uses an isolated forward topology. Notice the RCD snubber circuit on the primary-side also serves to reset the core flux during Toff.

Notice that Fig. 8 circuit includes a line-regulation enhancement circuit using an AP432 shunt reference. Without this circuit, the output power will varies about +/-10% when then input voltage varies from 100V to 120V (or 110V +/-10%). This line-regulation enhancement circuit acts to keep the reference voltage signal on the CCR pin a constant at 2.5V* Sine Θ. This enhancement circuit can improve the line regulation to +/-5%.

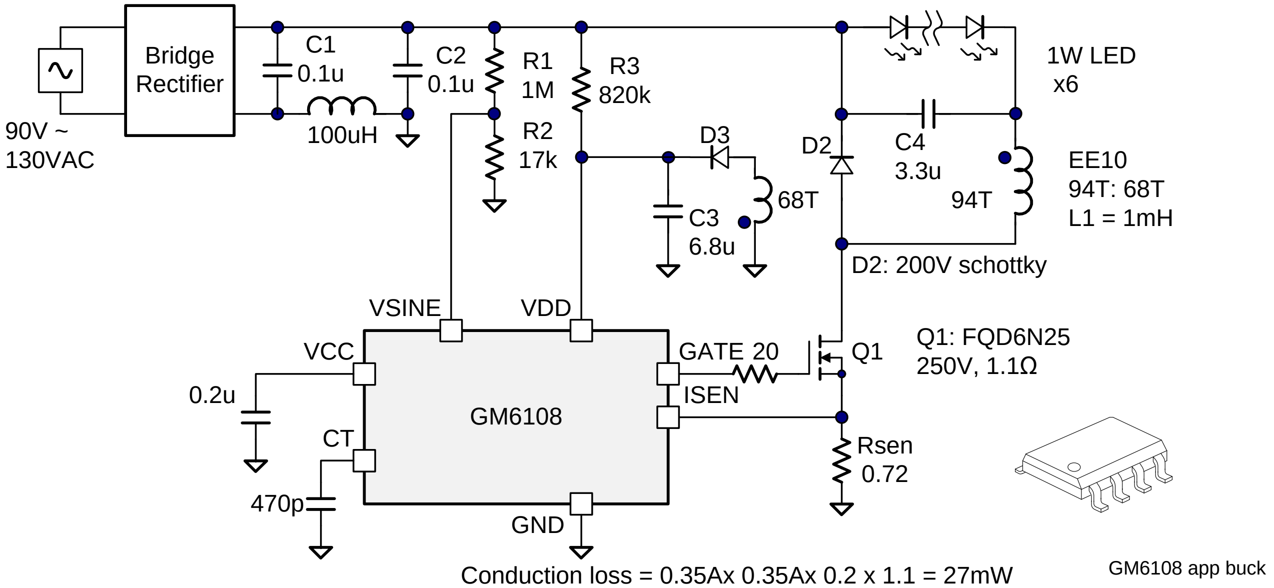
Fig. 9 shows a 220VAC, 20W forward design. Notice the transformer uses an EPC17 core..

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,

Vrst = Vin*D/(1-D)

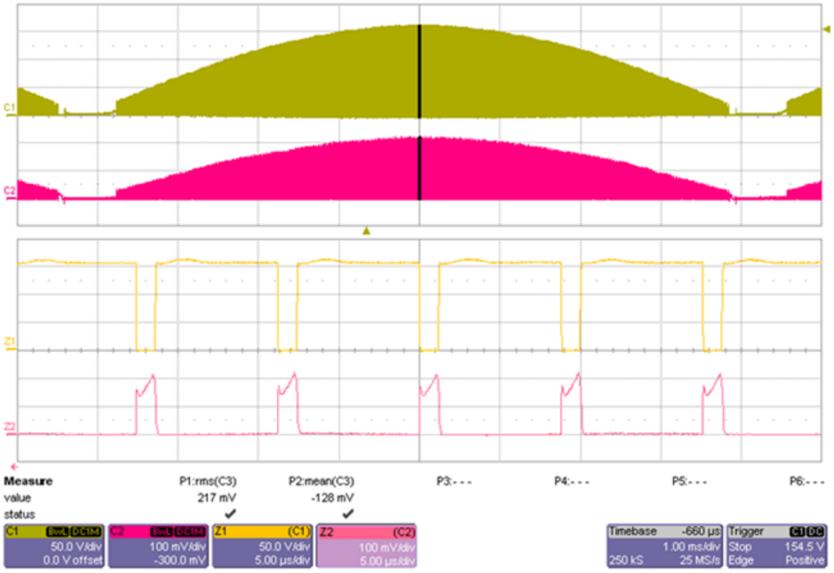
However, the voltage across C3 is typically higher than the minimum reset voltage. The reset voltage level and the RCD snubber design are related to several factors. Heuristically, we found a transformer with a good coupling (lower leakage inductance) between the windings will reduce the RCD snubber loss and the reset voltage level. In Fig. 8 circuit, C3 is 1n, R3 is 120K. Higher R3 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.



Conduction loss = 0.35Ax 0.35Ax 0.2 x 1.1 = 27mW
Switching loss = 0.5 x50pF x 130V x 130V x 100k = 42mW

110V Buck 6W

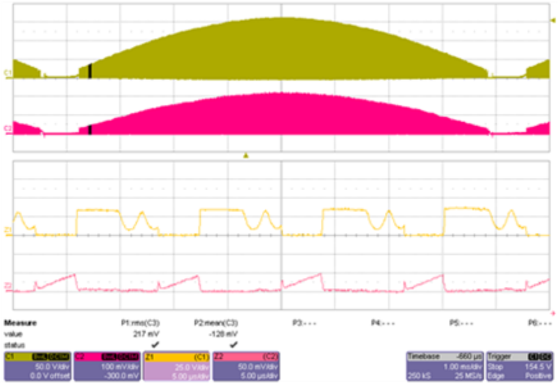
Fig. 3 110VAC 6W Non-Isolated LED Light Bulb



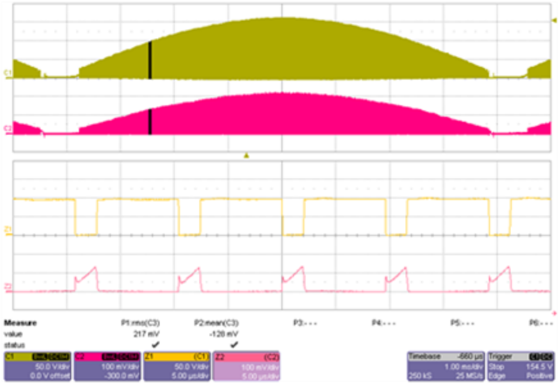
110V Buck Waveforms

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

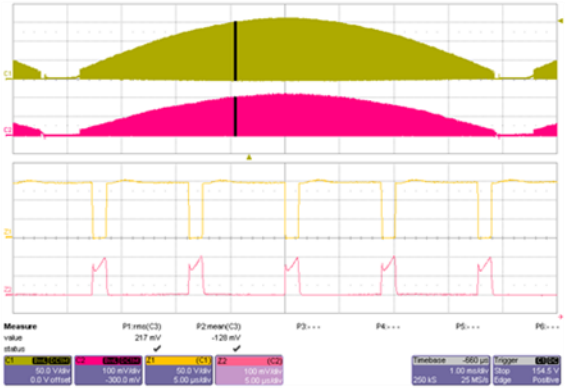
Fig. 4 120VAC 6W Buck Waveforms



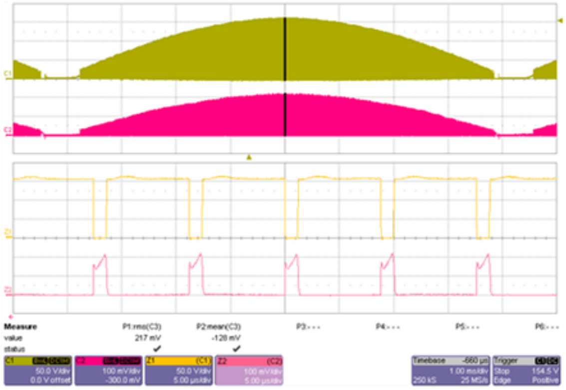
110V Buck Waveforms at Θ = 10°
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)



110V Buck Waveforms at Θ = 30°
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)

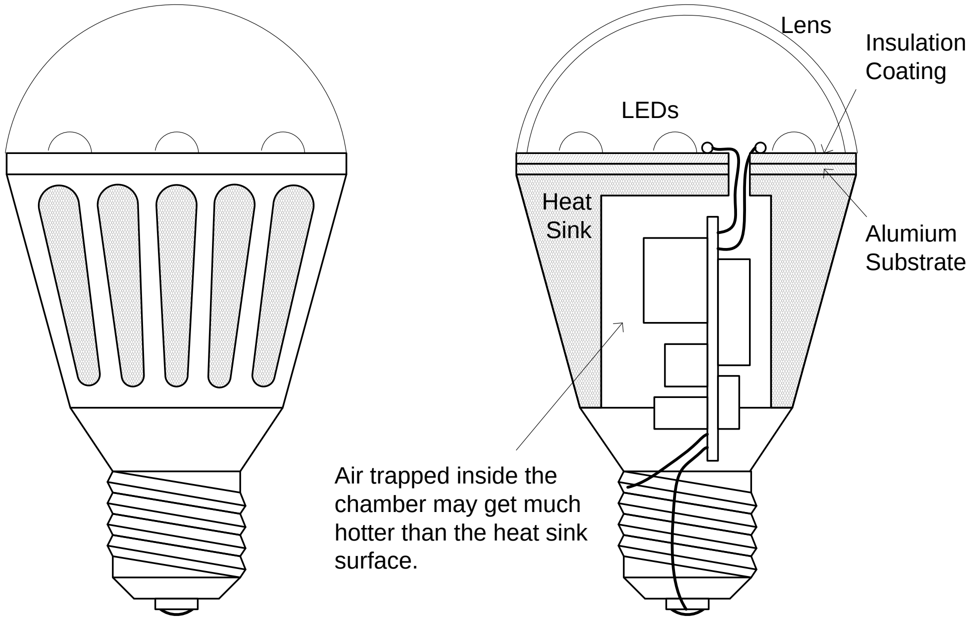


110V Buck Waveforms at Θ = 60°
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)



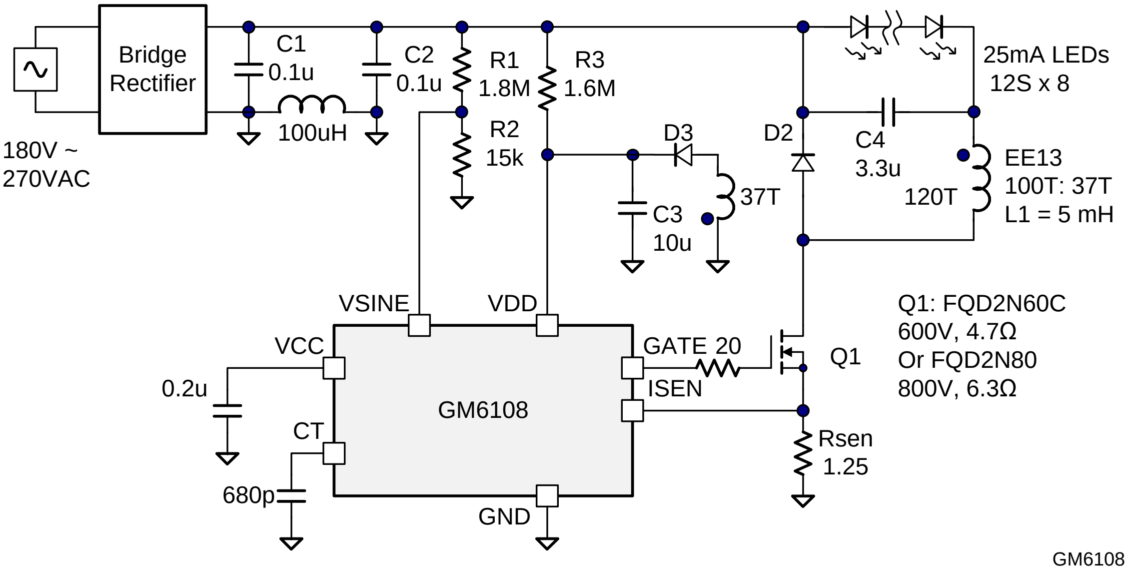
110V Buck Waveforms at Θ = 90°
Top Trace: Vds (50V/Div.)
Bottom Trace: Vsen (0.2V/Div.)

Fig. 5 110VAC 6W Buck Waveforms at Θ= 0°, 30°, 60° and 90°



Nov. 2, 2009

Fig. 6 Non-Isolated A19 LED Light Bulb Design



GM6108 220V buck

Conduction loss = 0.3Ax 0.3Ax 0.13 x 4.7 x 0.5 = 28mW
Switching loss = 0.5 x30pF x 270V x 270V x 124k = 135mW

220V Buck 8W

Fig. 7 220VAC 8W Non-Isolated LED Light Bulb

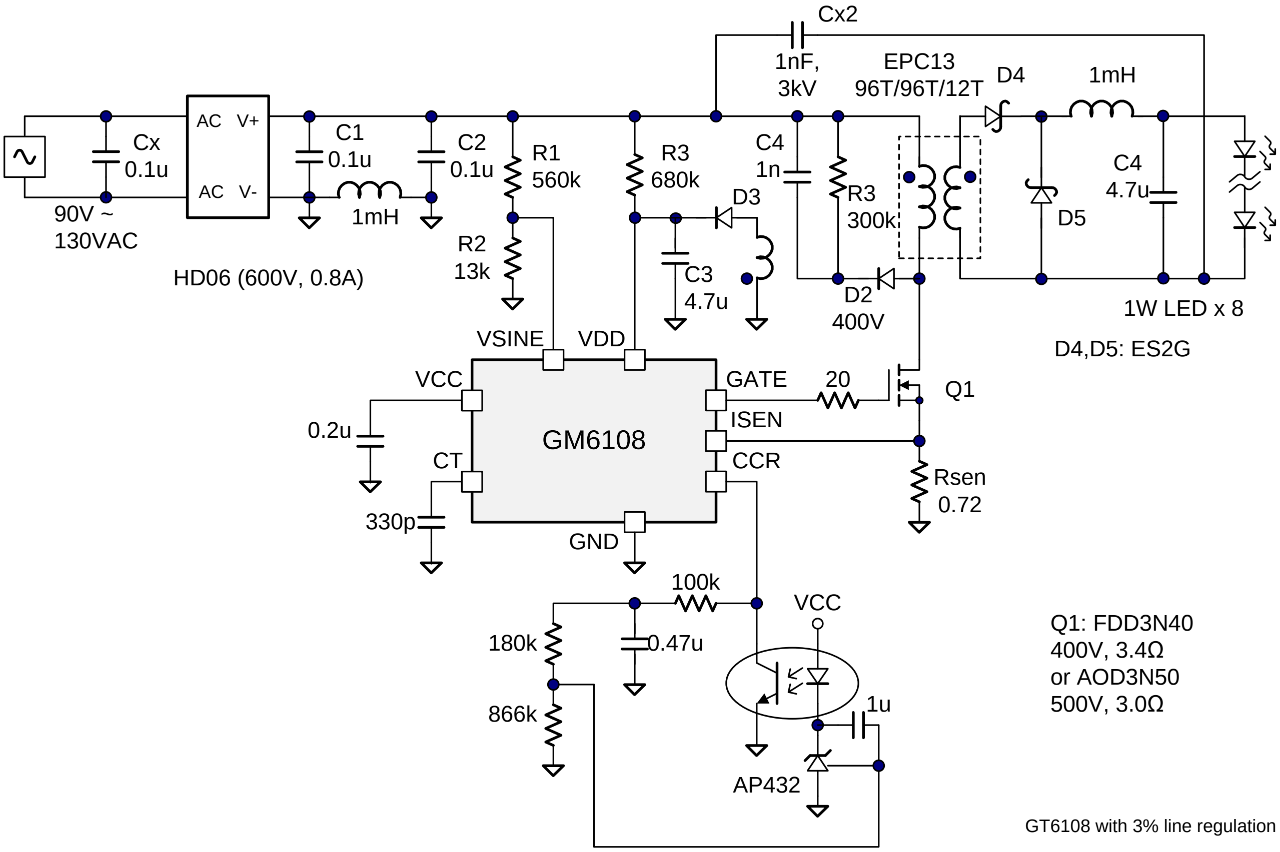


Fig. 8 110VAC 8W (1W x 8) Isolated Forward with Constant Power Control

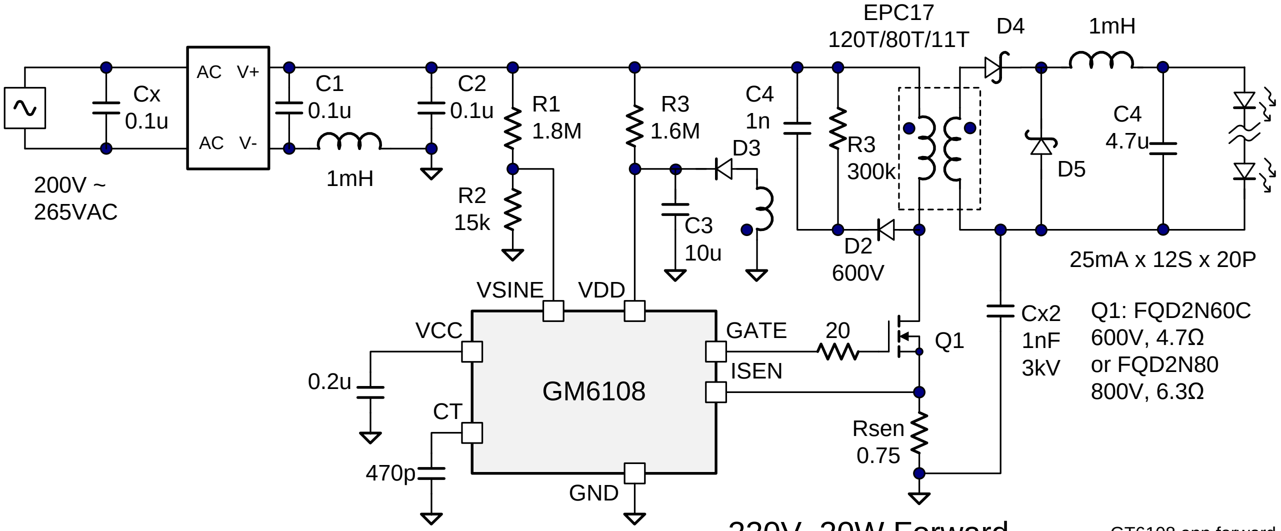
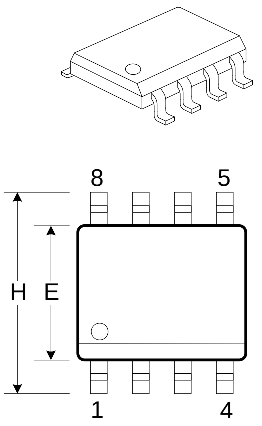


Fig. 9 220VAC 20W (25mAx12Sx20P) Forward LED Light Tube

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