NEXGEN POWER SYSTEMS

NexGen Vertical GaN™ High Frequency T8 LED Driver

Introduction

This paper presents an isolated 20W T8 LED driver with power factor correction with a goal of demonstrating the advantages and challenges associated with the increased switching frequency that NexGen's Vertical GaN transistors offer. The variable frequency Flyback converter operates at the CCM/DCM boarder, forcing unity power factor while regulating the LED output current. A NexGen Vertical GaN transistor and a custom high frequency transformer design (ST750318816) from Würth Electronik are at the heart of the converter.

Description

The converter drives up to 4 paralleled strings of 17 LEDs at 400mA for an output voltage of roughly 50V loaded. The AC input voltage can range from 90Vac to 240Vac while maintain a power factor of 0.98 minimum. In the event of an open load the converter switching from the bandwidth limited current mode loop to a fast voltage loop, limiting the output voltage to safe levels.

T8 LED Driver

The schematic in Figure 11 shows the Flyback converter operating in transition mode at the discontinuous conduction mode (DCM) border with the peak current demand set proportional to the AC input voltage. The current shape of the peak current is programmed to match the shape of the AC input voltage while the magnitude is set by the current error amplifier feedback to meet the LED current demand. The switching frequency is determined by the peak current with the frequency increasing as line increases for a constant load. The switching frequency at the peak of the ac line is designed to operate at 500kHz at low line peak upwards to 1MHz at the high line peak.

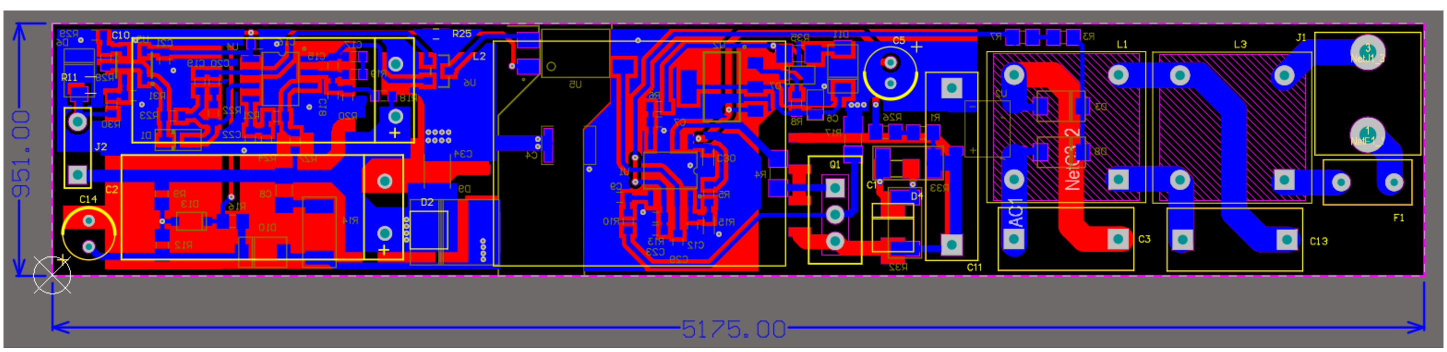

Figure 1: GaN based 20W Isolated LED Driver

Secondary side current mode and voltage mode error amplifiers regulate the LED current and or output voltage in the event of an open circuit condition. The bandwidth of the current error amplifier must be limited to less than 120Hz to avoid disruption the unity power factor controlled on the primary.

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

At the heart of the design is a 1-ohm JFET from NexGen's 1st generation of Vertical GaN devices, and it is the main boost switch cascoded with a silicon control switch. The Vertical GaN JFET has incredibly low $C_{oss} \approx 8pF$, $C_{iss} \approx 30pF$, and $C_{rss} \approx 8pF$. NexGen's 2nd generation JFET will further push these limits with improvements to the current process and device design in the form of an enhancement JFET. The high switching frequency does help to reduce the transformer size, but the output capacitor filter size is driven by the 120Hz ripple requirements and therefore does not decrease with an increase in the switching frequency for a typical PFC application.

Table 1. Electrical Performance Specifications

Parameter	Test Condition	Min	Typ	Max	Units
Input Characteristics					
Voltage Range		90		240	V
Maximum Input Current	At 90Vac input voltage		277		mA
Output Characteristics					
Output Voltage	At I_{out}=0.45A		50	53.8	V
Output Load Current, I_{out}	Total Output Current	350	400	450	mA
Output Current Line Regulation	90Vac-240Vac		0.75		%
Output Current Ripple	2 strings of 17 LEDs		148		mApp
Constant Voltage Level	Open LED String		53.8		V
System Characteristics					
Maximum Switching Frequency	90Vac to 240Vac (peak line)	0.5		1M	MHz
Efficiency	120Vac, 2 strings of 17 LEDs at 49.7V		81.4		%
Power Factor	120Vac, 2 strings of 17 LEDs at 49.7V		0.995		
Efficiency	220Vac, 2 strings of 17 LEDs at 49.7V		76.4		%
Power Factor	220Vac, 2 strings of 17 LEDs at 49.7V		0.979		

Transformer Requirements

Using the UCC28810 Flyback PWM controller with the transformer designed to force the high switching frequency operation. The output voltage is set at 48V with a 400mA LED current for 20W output for 17 LEDs in series and up to 4 parallel strings. The initial design goal is to set the switching frequency at the peak of low line (90Vac) to 500kHz while reaching a peak switching frequency of 1MHz at 240Vac. The switching frequency increases as the power demand decreases in the line cycle to meet the unity power factor requirements.

Because the converter operates at the CCM/DCM border the duty cycle is the same as in CCM. (i.e. no DCM dead time where the there is no inductor current. The ratio of the on time to the period is shown in 1.

$$D = \frac{1}{1+\frac{Vin}{Vo \cdot n}} \quad (1$$

The peak AC line power is 2x the average input power so the input current at the peak of low line is.

$$I_{in} = \frac{2 \cdot Pin}{Vrms \cdot \sqrt{2}} = \frac{2 \cdot 20W}{90V \cdot \sqrt{2}} = 314mA \quad (2$$

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

From this the peak current required is calculated from equation 3.

$$IL_{pk} = \frac{2 \cdot I_{in}}{1+\frac{Vin}{Vo \cdot n}}$$ (3

The primary inductance of the Flyback transformer is selected to set the peak current required and fixes the effective switching frequency. The duty cycle required is set by equation 1 where the transformer turns ratio (n) is selected to keep the duty cycle near 50% and keep the primary switch voltage and secondary diode voltage within device limits. Selecting a primary to secondary transformer turns ratio of 3 results in a duty cycle of

$$D = \frac{1}{1+\frac{Vin}{Vo \cdot n}} = \frac{1}{1+\frac{90V \cdot \sqrt{2}}{48V \cdot 3}} = 0.53$$ (4

$$IL_{pk} = \frac{2 \cdot Iin}{D} = \frac{2 \cdot 314mA}{0.53} = 1.18A$$ (5

To force the 500kHz operation at the peak of low line, the required inductance is:

$$Lp = \frac{Vin \cdot D \cdot Ts}{ILpk} = \frac{90V \cdot \sqrt{2} \cdot 0.53 \cdot 2\mu s}{1.18A} = 114\mu H$$ (6

A value of 128uH was ultimately chose to which give a switching frequency ranges from 500kHz at low line to close to 1MHz at the peak of high line. The duty cycle ranges from 53% at the peak of low line to 33 % at the peak of high line. The transformer.

The Flyback transformer is Würth Electronik part number ST750318816 was developed to meet the requirements with a primary to secondary turns ratio of 3 with a primary inductance of 128uH and a primary saturation current of 1.5A.

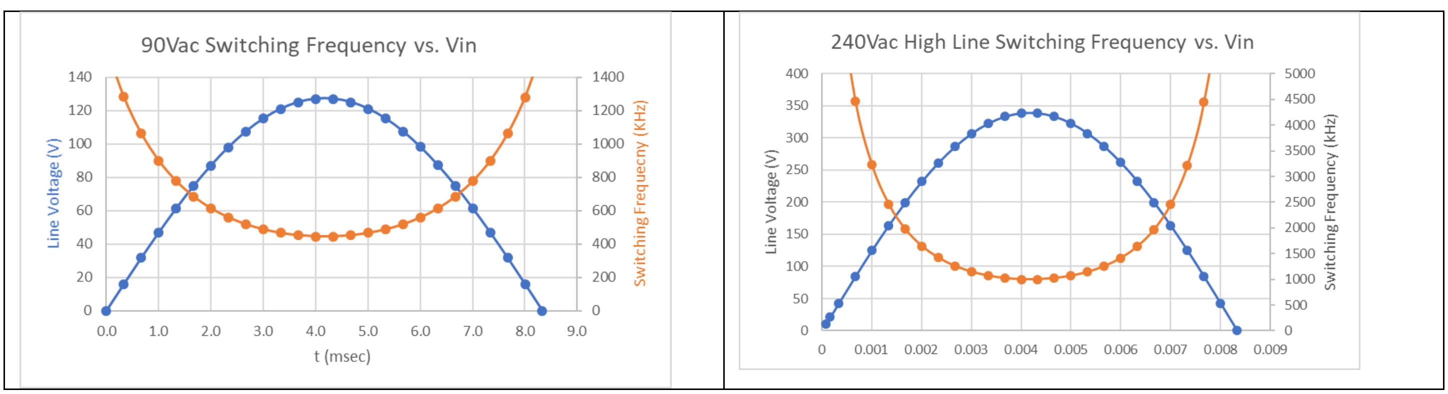

Figure 2. Calculated Switching Frequency vs. Instataneous AC input voltage

Figure 1: tbd

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

NEXGEN POWER SYSTEMS

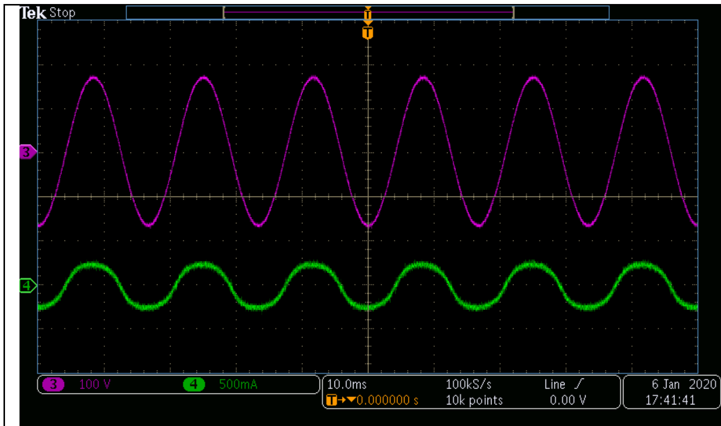

Figure 3. Input Voltage (top) and Input Curent (bottom) 120Vac PF=0.993

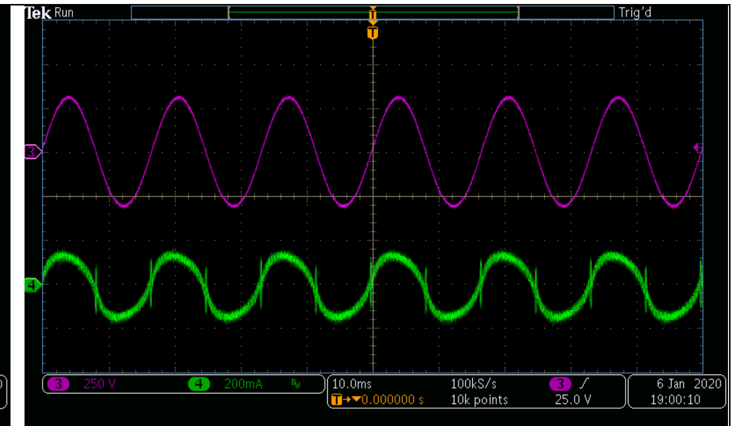

Figure 4. Input Voltage (top) and Input Curent (bottom) 220Vac PF=0.976

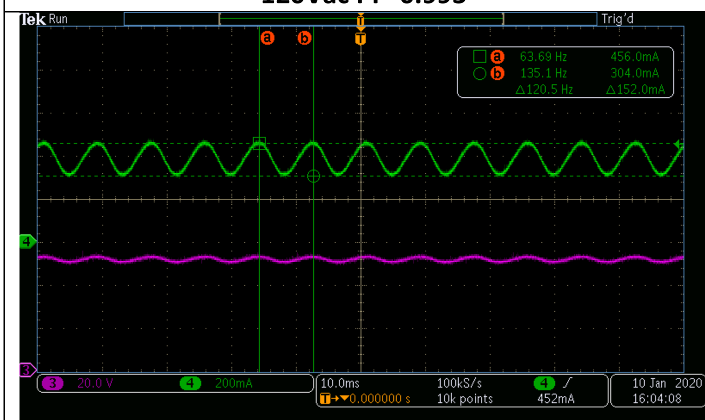

Figure 5. 110Vac LED Current (top) and Output Voltage (bottom)

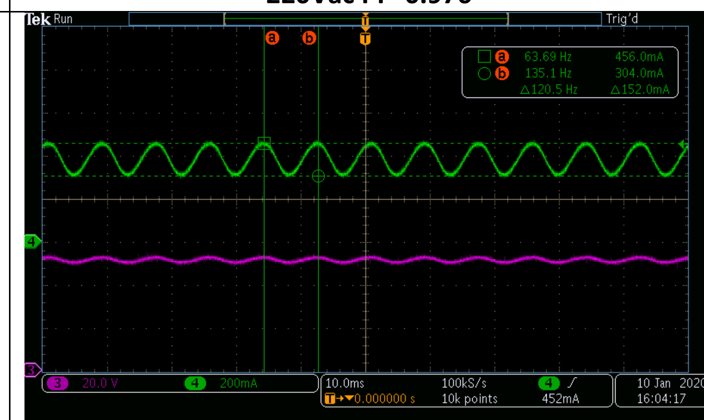

Figure 6. 220Vac LED Current (top) and Output Voltage (bottom)

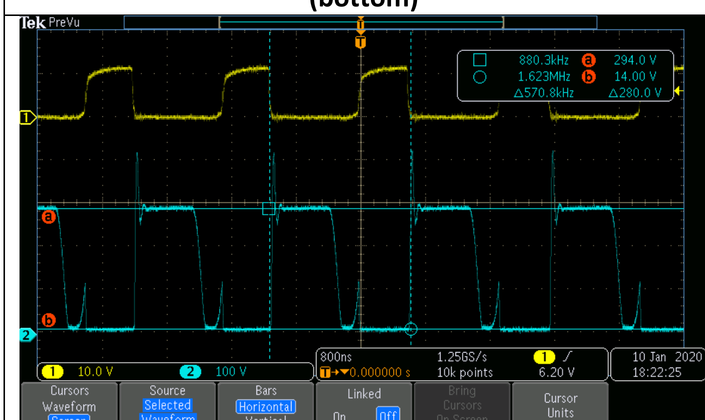

Figure 7. Typical Switching Waveform 156V dc (110Vac peak)

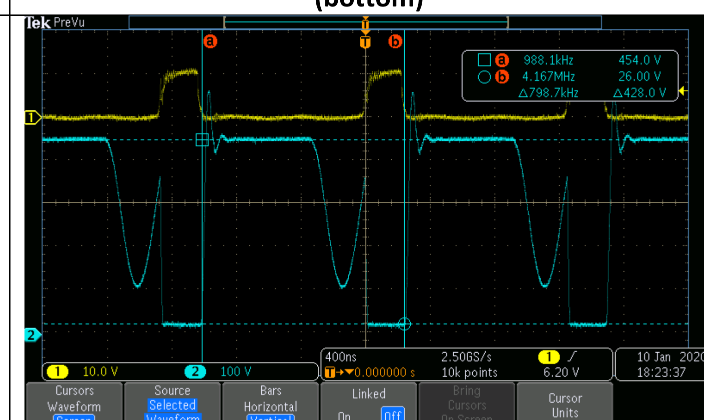

Figure 8. Typical Switching Waveforms 311V dc (220Vac peak)

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

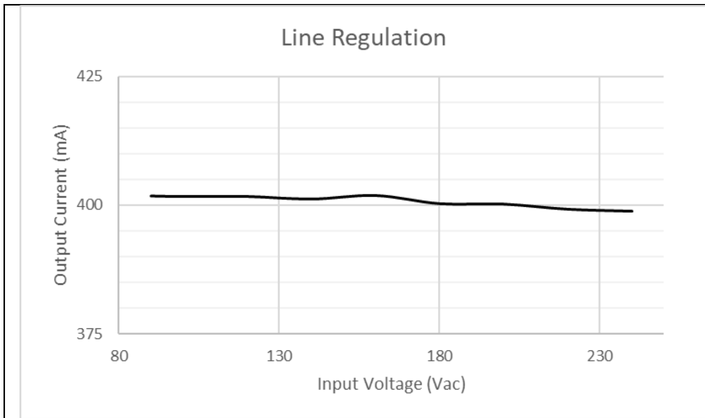

Figure 9. Output Current Line Regulation

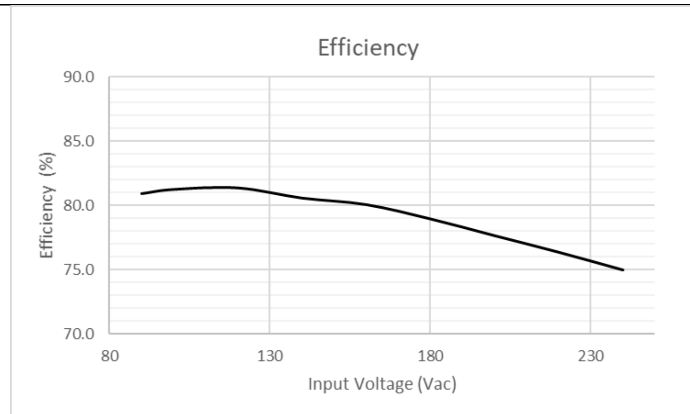

Figure 10. Efficiency vs. Input Voltage

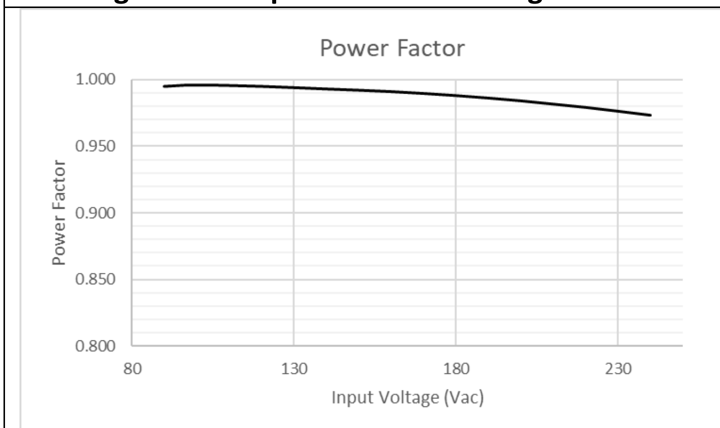

Figure 11. Power Factor vs. Input Voltage

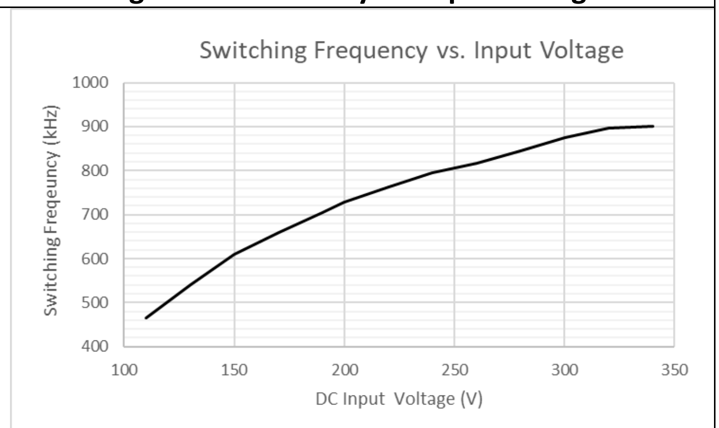

Figure 12. Switching Frequency vs. Input Voltage

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

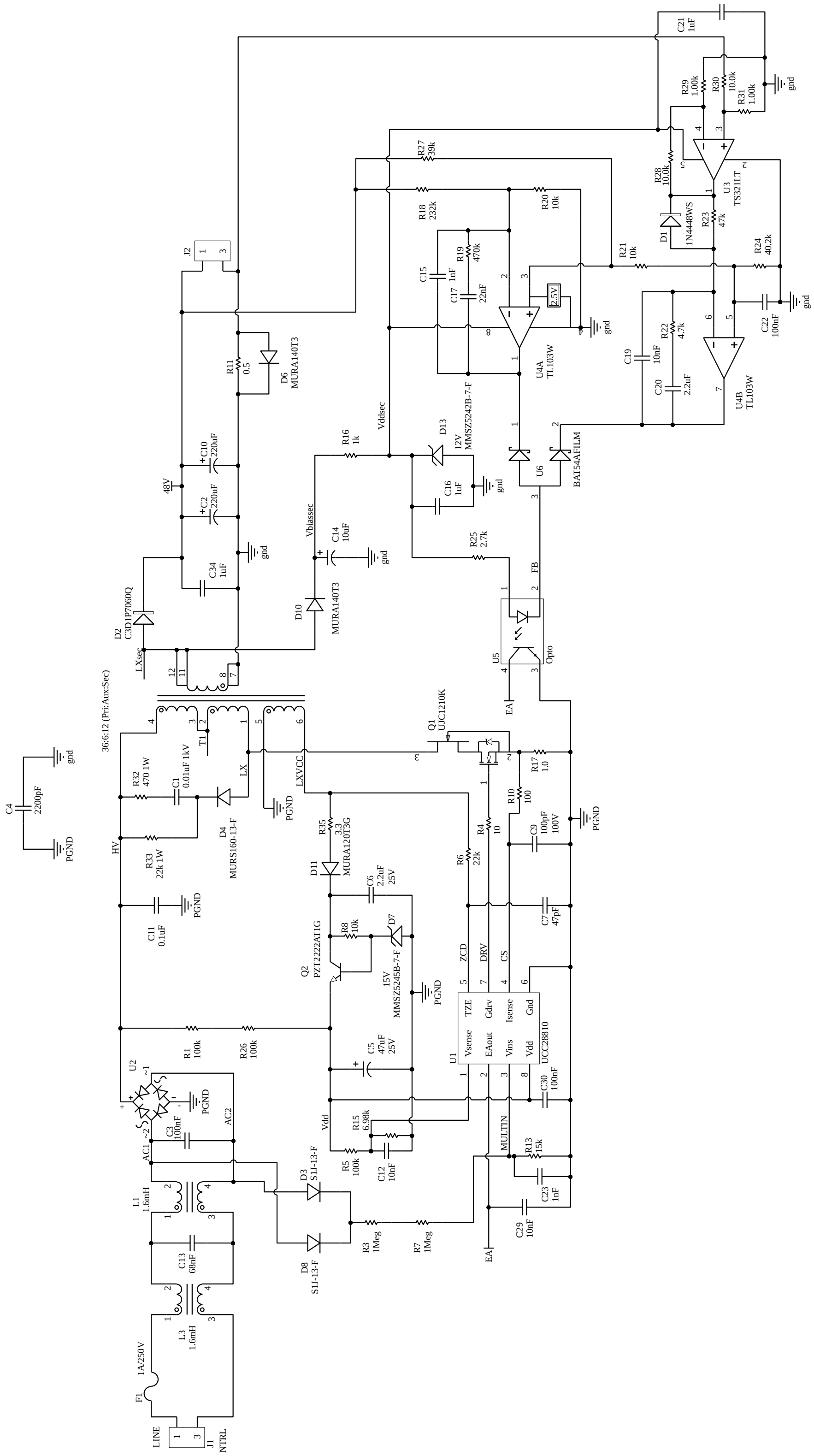

Figure 13. 20W T8 LED Driver Schematic

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

Table 2. 20W T8 LED Driver BOM

Designator	Qty	Description	Footprint	Manufacturer	Part Number
L2	1	Wurth PFC DCM Flyback Transformer	Wurth ST750318816	Wurth	ST750318816
C1	1	CAP CER 10000PF 1KV X7R	1206	Yageo	CC1206KKX7RCBB103
C2, C10	2	CAP ALUM 220UF 20% 63V RADIAL	10mm Dia, 5mm LS	Panasonic	EEU-FR1J221L
C3	1	0.1µF Film Capacitor 305V 630V Polypropylene (PP) Radial	13mm x 6mm	EPCOS (TDK)	B32921C3104M000
C4	1	CAP CER 2200PF 250VAC X7R	1812	Murata	GA343QR7GD222KW01L
C5	1	CAP ALUM 47UF 20% 25V RADIAL	5mm Dia, 2.5mm LS	Nichicon	UFW1E470MDD1TD
C6	1	CAP CER 2.2UF 25V X7R	0805	AVX Corporation	08053C225KAT2A
C7, C9	2	CAP CER 47PF 100V C0G/NP0	0603	KEMET	C0603C470J1GACTU
C8 (DNP)	1	CAP CER 47PF 500V C0G/NPO	1206	Yageo	CC1206JRNPOBBN470
C11	1	CAP FILM 0.1UF 10% 450VDC RADIAL	18mmx5mm	EPCOS (TDK)	B32672Z4104K000
C12, C19, C29	3	CAP CER 10000PF 25V X7R	0603	Yageo, Taiyo Yuden	CC0603KRX7R8BB103
C13	1	0.068µF Film Capacitor 305V 630V Polypropylene (PP) Radial	13mm x 6mm	EPCOS (TDK)	B32921C3683M289
C14	1	CAP ALUM 10UF 20% 63V RADIAL	5mm Dia 2.5mm LS	Panasonic	ECA-1JM100I
C15, C23	2	CAP CER 1000PF 25V X7R	0603	Murata	CC0603KRX7R8BB102
C16, C21	2	CAP CER 1UF 25V X5R	0603	Murata	CC0603MRX5R8BB105
C17	1	CAP CER 0.022UF 100V X7R	0603	Taiyo Yuden	C0603C223K1RACTU
C18,C22,C30	3	CAP CER 0.1UF 25V X5R	0603	Taiyo Yuden	TMK107BJ104KA-T
C20	1	CAP CER 2.2UF 25V X5R	0603	Murata	GRM188R61E225KA12D
C34	1	CAP CER 1UF 100V X5R	1210	Taiyo Yuden	HMK325BJ105MN-T
D1	1	DIODE GEN PURP 75V 150MA	SOD323F	ON Semiconductor	MMBD914LT1HTSA1
D2	1	DIODE SCHOTTKY 600V 1.7A 10PQFN	QFN 3.3	Cree/Wolfspeed	C3D1P7060Q
D3, D8	2	DIODE GEN PURP 600V 1A	SMA	Diodes Incorporated	S1J-13-F
D4	1	DIODE GEN PURP 600V 1A	SMB	Diodes Incorporated	MURS160-13-F
D6, D10	2	DIODE GEN PURP 400V 2A	SMA	ON Semiconductor	MURA140T3G
D7	1	DIODE ZENER 15V 500MW	SOD-123	Diode Inc.	MMSZ5245B-7-F
D9 (DNP)	1	DIODE GEN PURP 400V 3A	SMCJ	ON Semiconductor	MURS340T3G
D11	1	DIODE GEN PURP 200V 2A	SMA	ON Semiconductor	MURA120T3G
D13	1	DIODE ZENER 12V 500MW	SOD-123	Diodes Incorporated	MMSZ5242B-7-F
F1	1	1A 250V Fuse Board Mount Through Hole Radial	Fuse SS-5F	Eaton - Electronics Division	SS-5F-1A-AP
J1	1	3 pin 0.156" header with #2 voided	0.156"	Molex, LLC	26624030
J2	1	3 pin 0.100" header with #2 voided	0.100"	Molex, LLC	22232031
L1, L3	2	1.6mH @ 10kHz 2 Line Common Mode Choke Through Hole 1.5A DCR	14mm x 14mm	Schaffner EMC Inc.	RN102-1.5-02-1M6
Q1	1	GaN Cascode Power JFET	X Daughter Card Header	NexGen	CasGaNsw1
Q2	1	TRANS NPN 40V 0.6A	SOT223	ON Semiconductor	PZT2222AT1G
R1, R26	2	Resistor 100K OHM 5% 1/4W	0805	KOA Speer Electronics, Inc.	RK73B2ATTD104G
R3, R7	2	Resistor SMD 1M OHM 1% 1/8W	0805	Yageo	RC0805FR-071ML
R4	2	Resistor 10 OHM 1% 1/2W	1206	Stackpole Electronics Inc	RNCP1206FTD10R0
R35	1	Resistor SMD 3.3 OHM 1% 1/4W	1206	Yageo	AC1206FR-073R3L
R5	1	Resistor 100K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F100K
R6	1	Resistor 22K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F22K
R8,R20,R21,R28,R30	5	Resistor 10K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F10K
R10	1	Resistor 100 1% 0.1W	0603	TE Connectivity	CRGCQ0603F100R
R13	1	Resistor 15k 1% 0.1W	0603	TE Connectivity	CRGCQ0603F15k
R9, R12	2	Resistor 24 kOhms ±1% 0.25W, 1/4W	0805	Stackpole Electronics Inc	RK73H2ATTD2402F
R11	1	Resistor 0.5 OHM 1% 1/2W	1206	Stackpole Electronics Inc	CSR1206FTR500
R14 (DNP)	1	Resistor 47 OHM 1% 1W	2010	Stackpole Electronics Inc	RMCP2010FT47R0
R15	1	Resistor SMD 6.98K OHM 1% 1/10W	0603	Vishay Dale	CRCW06036K98FKEA
R16	1	Resistor 1K OHM 1% 1/4W	0805	Stackpole Electronics Inc	RNCP0805FTD1K00
R17	1	Resistor 1 OHM 1% 1/2W	1206	Stackpole Electronics Inc	CSR1206FT1R00
R18	1	Resistor SMD 232K OHM 1% 1/10W	0603	Yageo	RC0603FR-07232KL
R19	1	Resistor SMD 470K OHM 1% 1/10W	0603	Yageo	RC0603FR-07470KL
R22	1	Resistor 4K7 1% 0.1W	0603	TE Connectivity	CRGCQ0603F4K7
R23	1	Resistor 47K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F47K
R24	1	Resistor 40.2K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F40K2
R25	1	Resistor 2.7K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F2K7
R27	1	Resistor 39K 1% 0.1W	0603	TE Connectivity	CRGCQ0603F39K
R29, R31	2	Resistor 1K0 OHM 1% 1/8W	0603	Stackpole Electronics Inc	RNCP0603FTD1K00
R32	1	Resistor 470 OHM 1% 1W	R_2010	Stackpole Electronics Inc	RMCP2010FT470R
R33	1	Resistor SMD 22K OHM 5% 1W	R_2010	Vishay Dale	CRCW201022K0JNEFHP
U1	1	IC LED DRIVER OFFL DIM	SO-8	Texas Instruments	UCC28810DR
U2	1	BRIDGE RECT 1PHASE 600V 2A ABS	ABS24TR	SMC Diode Solutions	ABS26TR
U3	1	IC OPAMP GP 1 CIRCUIT	SOT23-5	STMicroelectronics	TS321ILT
U4	1	IC OPAMP GP 2 CIRCUIT	8-SOIC	Texas Instruments	TL103WAIDR
U5	1	OPTOISOLATOR 5KV TRANSISTOR	4-SMD Gull Wing	Broadcom Limited	HCPL-817-300E
U6	1	DIODE ARRAY SCHOTTKY 40V	SOT23-3	STMicroelectronics	BAT54AFILM

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential

Summary

Vertical GaN, offers potential for reduced size and cost for many applications. This paper presents an example of how typical product switching frequency can be increased to take advantage of Vertical GaN's performance. With high frequency comes higher power density. With higher power density comes less materials in components, less board area, less copper, and less mass. With less materials the power system cost is reduced.

Future Tasks.

1. EMI design specifics and testing.
2. Input Cusp Current Spike (cause and relevance)
3. Primary Current limit soft start and modify start up circuit appropriately (or inductor saturation current increase).
4. Loss analysis Summary and Efficiency Improvement.
    a. Switching loss reduction
    b. Optimize controller ZVS sensing

Revision History

Revision	Date	Description of Change
V00	12/11/2019	Initial draft.
V01	1/10/2019	2nd PCB revision with design changes

© Copyright 2019 NexGen Power Systems Inc. | Proprietary and Confidential