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AN9011

High Input Voltage, Off-line Flyback Switching Power Supply using FSC IGBT (SGL5N150UF)

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Conventionally a MOSFET, with a voltage rating of 1500V or with a Half-Bridge connection using two MOSFETs of 800-900V, would be used for SMPS applications requiring input voltages higher than 380Vac. However, these methods have the disadvantages of a complicated circuit structure and high cost. FSC developed a more effective solution: a power IGBT rated at 1500V-5A. This technical note, describes the design of the 25W flyback power supply using a SGL5N150UF. The major experimental operational characteristics of the IGBT are also explained.

Performance in High Input Voltage Flyback Converter

Figure 1 shows the design of a 25 watt flyback converter with an output at (+5V, 5A), operating at a switching frequency of 50kHz and high input voltages of 380 - 500Vac. This type of switching power supply is used for applications requiring high input voltages such as an inverter and other instruments. This discontinuous mode flyback converter using a KA3844 current mode controller features good voltage tracking by using the pulse by pulse current sensing on the primary side, and an isolated secondary feedback loop. The KA3844 PWM IC directly drives the power IGBT.

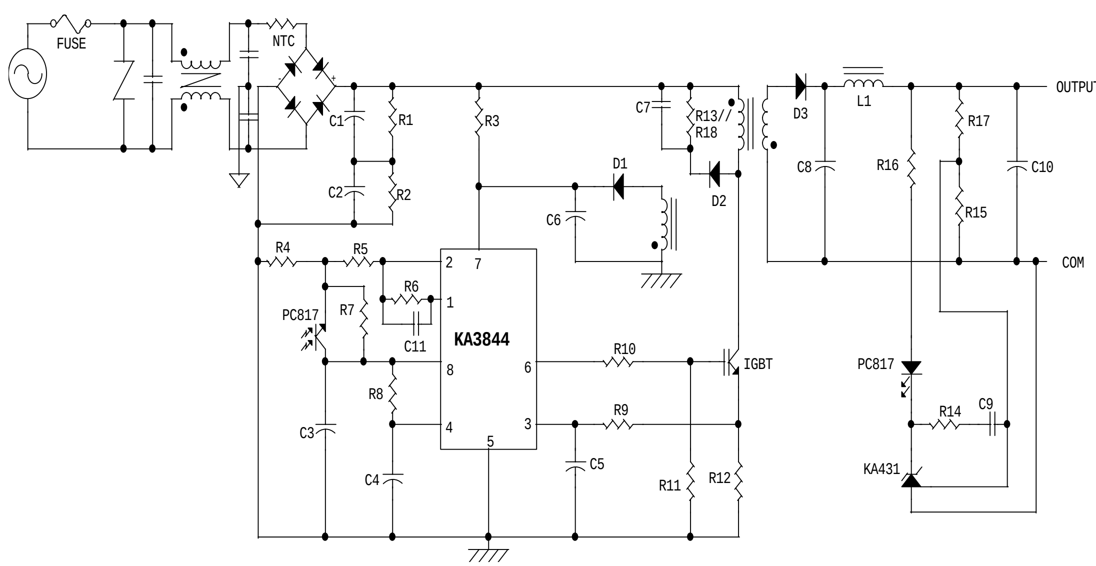


Figure 1: 25W Flyback Converter Circuit Diagram

Table 1: Power Supply Specifications

1. Operating mode	Flyback Discontinuous Mode
2. Input voltage (V_{in})	380 Vac to 500 Vac (50Hz/60Hz)
3. Switching frequency (f_{sw})	50kHz
4. Output voltage (V_{out})	DC 5V ± 5%, 5A
5. Efficiency (η)	80%

As the power IGBT sequentially turns on and off, energy is stored in the core of the transformer during on time and is then transferred to the output capacitor during off time. When the power IGBT turns off, energy stored in the leakage inductance causes a voltage spike across the collector-to-emitter terminal of the power IGBT which amounts to at least twice the input voltage (Vin + nVo + leakage inductance voltage[1]). Most applications need clamp circuits to restrict this voltage spike from exceeding the BVces rating of the IGBT. The power IGBT must have high voltage capability which can be adapted to a given system for higher efficiency.

Note

1: 'n' indicates the turns ratio of the transformer windings. The voltage
Vin + nVo + leakage inductance voltage of the transformer appears on the primary side.

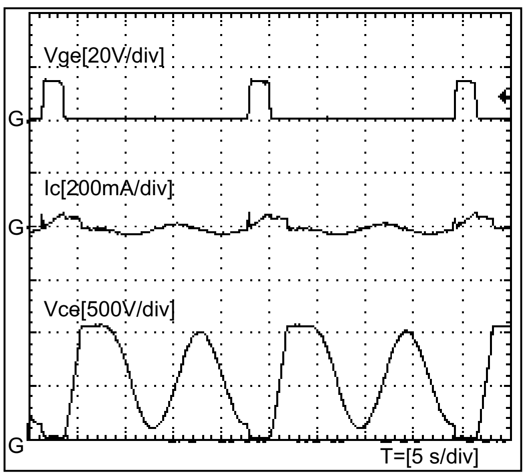


Figure 2: Operating Waveforms at Rated Conditions (V_{in}=400Vac, P_{out}=0W)

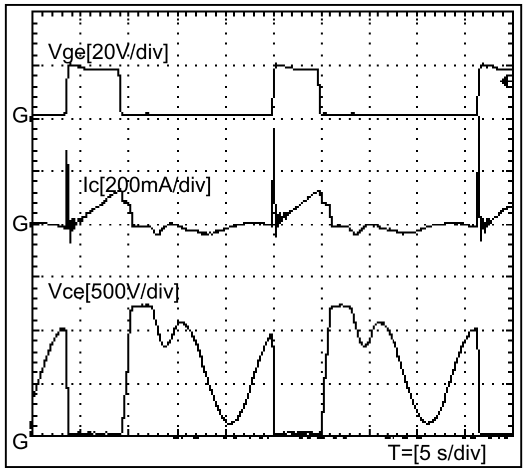


Figure 3: Operating Waveforms at Rated Conditions (V_{in}=400Vac, P_{out}=5W)

This flyback converter was tested at 400Vac input voltage, 48kHz switching frequency, and various output powers (0 watt shown in Figure 2, 5 watts in Figure 3, 15 watts in Figure 4, and 25 watts in Figure 5). These Figures show the graphs for operating conditions using an IGBT(SGL5N150UF) as the switching device. The IGBT is fully driven by the gate-emitter voltage of 20V, and the voltage spike across the collector-emitter terminal is adequately clamped to about 1300V by the addition of a clamp circuit during the off-time.

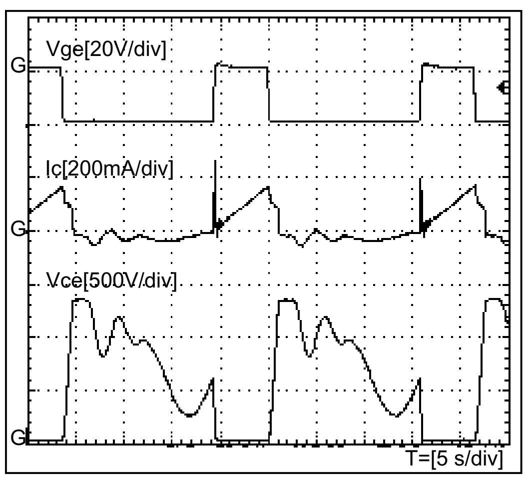


Figure 4: Operating Waveforms at Rated Conditions (V_{in}=400Vac, P_{out}=15W)

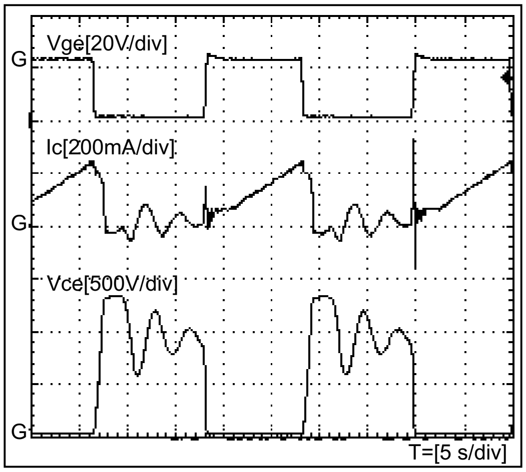


Figure 5: Operating Waveforms at Rated Conditions (V_{in}=400Vac, P_{out}=25W)

Design of the High Input Voltage Flyback Converter

Predesign Considerations

Output Power (P_o) = (5V)(5A) = 25 Watts

DC Input Voltages: $V_{in\ (min)}$ = 1.414 * $V_{in\text{-}ac\ (min)}$

= 1.414 * 380Vac = 537 Vdc

$V_{in\ (max)}$ = 1.414 * $V_{in\text{-}ac\ (max)}$

= 1.414 * 500Vac = 707 Vdc

Maximum Duty Cycle (δ_{max}) = 45%

Switching Frequency (f) = 50kHz

Efficiency (η) = 80%

Peak Transformer Current (Ipk) = 2* (P_o/η)/($V_{in(min)}$ * δ_{max})

= 2 * (25 W/0.8)/(537 Vdc * 0.45) = 0.25 Amps

Designing the Transformer

After reviewing the core size data provided by various core manufactures, it was decided that a PQ2625 core will adequately fit the winding and insulation needs of this application.

The primary inductance needed for this application is calculated below:

$L_p = V_{in(min)} * \delta_{max}/(I_{pk} * f)$

$= (537\ Vdc) * 0.45/((0.25 Amps) * (50 kHz)) = 20 mH$

The maximum operating flux density at the low input voltage of:

$B_{max} = B_{sat}(80°C)/2 = 3400\ G/2 = 1700\ G$

The minimum length of the airgap for the core is then:

$l_g = 0.4\pi * L_p * I_{pk}^2 * 108/(Ae * B_{max}^2)$

$= 0.4\pi * (20 mH) * (0.25 Apms)^2 * 10^8/((1.19 cm^2) * (1700\ G)^2) = 0.043\ cm$

The number of turns needed to produce the required primary inductance is:

$N_p = L_p * I_{pk} * 10^8/(Ae * B_{max})$

$= (20 mH) * (0.25 Apms) * 10^8/((1.19 cm^2) * (1700\ G))$

= 247.15 turns, rounded to 247 turns

The number of turns needed by the +5 V secondary inductance assuming the use of a fast recovery rectifier is:

$Ns = (Vout + Vd) * (1- \delta_{max}) * Np/(V_{in(min)} * \delta_{max})$

$= ((5\ V) + (1V)) * (1 – 0.45) * 247/((537 Vdc) * 0.45)$

= 3.37 turns, rounded to 3 turns

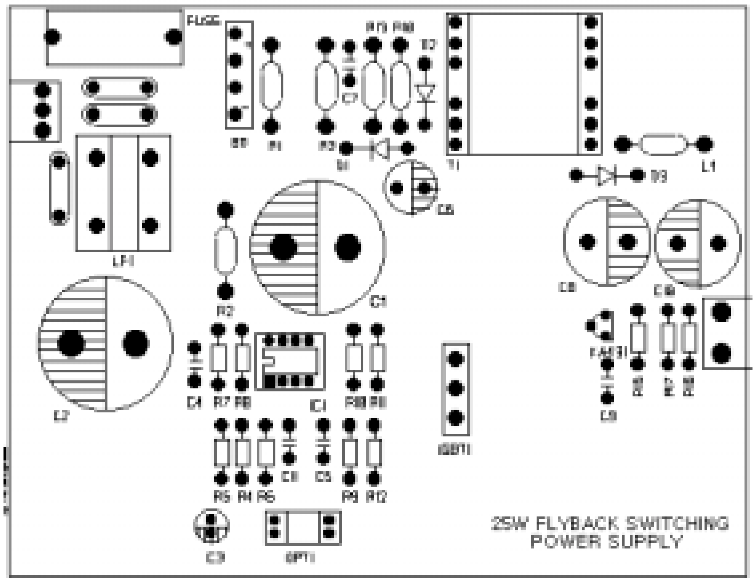
DC & AC Characteristics of SGL5N150UF

Table 2: Electrical Characteristics of SGL5N150UF

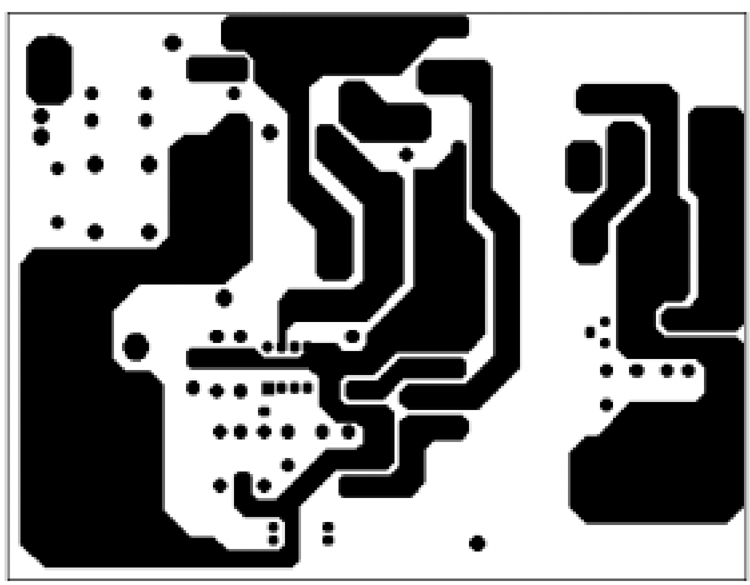
Symbol	Characteristics	Test Conditions	Min.	Typ.	Max.	Units
BVces	C-E Breakdown Voltage	Vge=0V, Ic=250µA	1500	-	-	V
ΔVces/ΔTj	Temperature Coeff. of Breakdown Voltage	Vge=0V, Ic=1mA	-	0.6	-	V/°C
Vge(th)	G-E Threshold Voltage	Vce=Vge, Ic=5mA	2.0	3.1	4.0	V
Ices	Collector cutoff Current	Vce=Vces, Vge=0V	-	-	250	µA
Iges	G-E leakage Current	Vge=Vges, Vce=0V	-	-	100	nA
Vce (sat)	Collector to Emitter Saturation Voltage	Vge=10V, Ic=5A	-	4.7	5.5	V
		Vge=10V, Ic=10A	-	6.2	-	V
Cies	Input Capacitance	Vge=0V, f = 1MHz Vce=10V		780	-	pF
Coes	Output Capacitance		-	132	-	pF
Cres	Reverse transfer Capacitance		-	68	-	pF
td(ON)	Turn on delay time	Vcc = 600V Ic = 5A Vge = 10V Rg = 10Ω Inductive Load	-	7	-	ns
tr	Turn on rise time		-	15	-	ns
td(off)	Turn off delay time		-	30	42	ns
tf	Turn off fall time		-	65	120	ns
Eon	Turn on Switching loss		-	190	-	µJ
Eoff	Turn off Switching loss		-	100	-	µJ
Ets	Total Switching loss		-	290	580	µJ
Qg	Total Gate Charge	Vcc=600V Vge=10V Ic=5A	-	30	-	nC
Qge	Gate-Emitter Charge		-	3	-	nC
Qgc	Gate-Collector Charge		-	15	-	nC

The Printed Circuit Board Layout

Component Side



Copper Side



Rev D, July 2000

Parts List

Component	Value	Component	Value	Component	Value
C1, C2	47uF	R4	1.8 kΩ	R17	5.6 kΩ
C3	10uF	R5	100 kΩ	R18	470 kΩ
C4	2200pF	R6	200 kΩ	D1	FE1D
C5	3300pF	R7	12 kΩ	D2	FR107
C6	100uF	R8	8.2 kΩ	D3	FE6D
C7	2200pF	R9	1 kΩ	L1	15µH
C8	4700uF	R10	10 Ω	IC1	KA3844
C9	470pF	R11	12 kΩ	OPT1	PC817
C10	4700pF	R12	4 Ω	IGBT	SGL5N150UF
C11	1000pF	R13	470 kΩ		
R1	220 kΩ	R14	180 Ω		
R2	220 kΩ	R15	5.6 kΩ		
R3	200 kΩ	R16	2.7 kΩ		

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