45 W Auxiliary Power Supply Reference Design Using GeneSiC G2R1000MT17J

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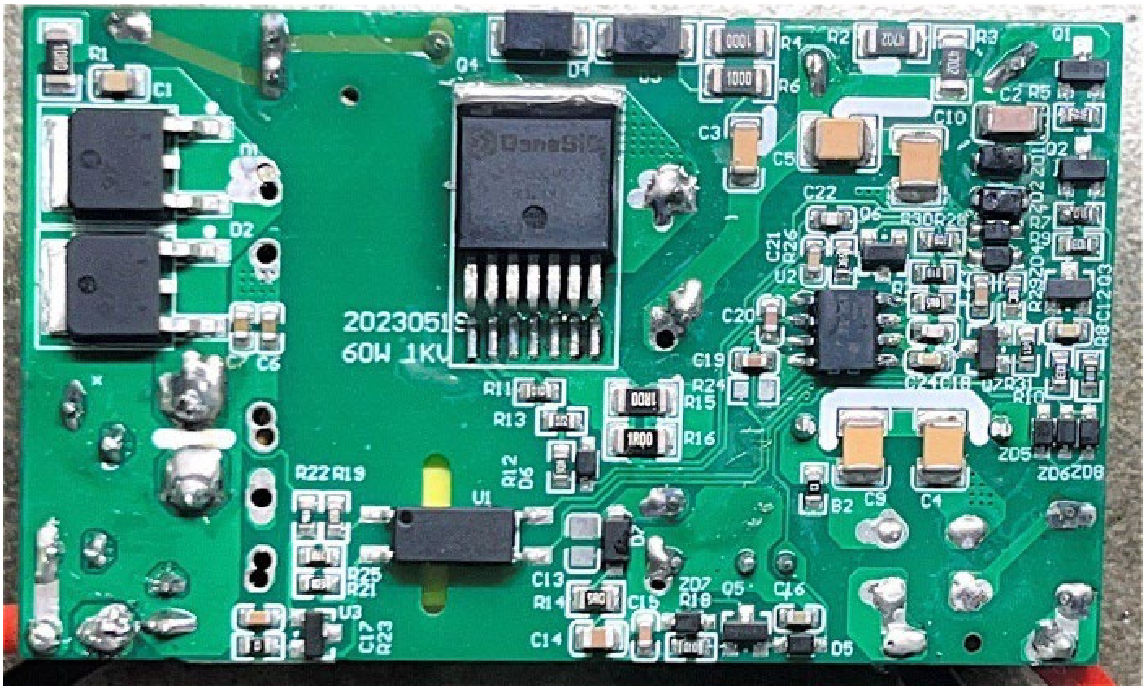


Figure 1: Hardware overview

1. Features

Power stage for auxiliary power supply

- Single switch flyback converter
- Wide input voltage ranges from 50V to 1000V DC
- Output voltage 12V DC
- 45W maximum output power without heatsink.
- Peak efficiency > 89%
- Small form factor
- Dimensions 68mm×40mm×21mm(L×W×H)
- 2-layer PCB

Environmental

- RoHS, Pb-free, REACH-compliant

2. Applications

- Auxiliary power supply for EV.
- Auxiliary power supply for energy storage.
- Auxiliary power supply for UPS system.

3. Description

This reference design shows how to use the Navitas demo boards populated with G2R1000MT17J. Boards are available to enable an easy evaluation of the shown converter circuit.

4. Typical Application

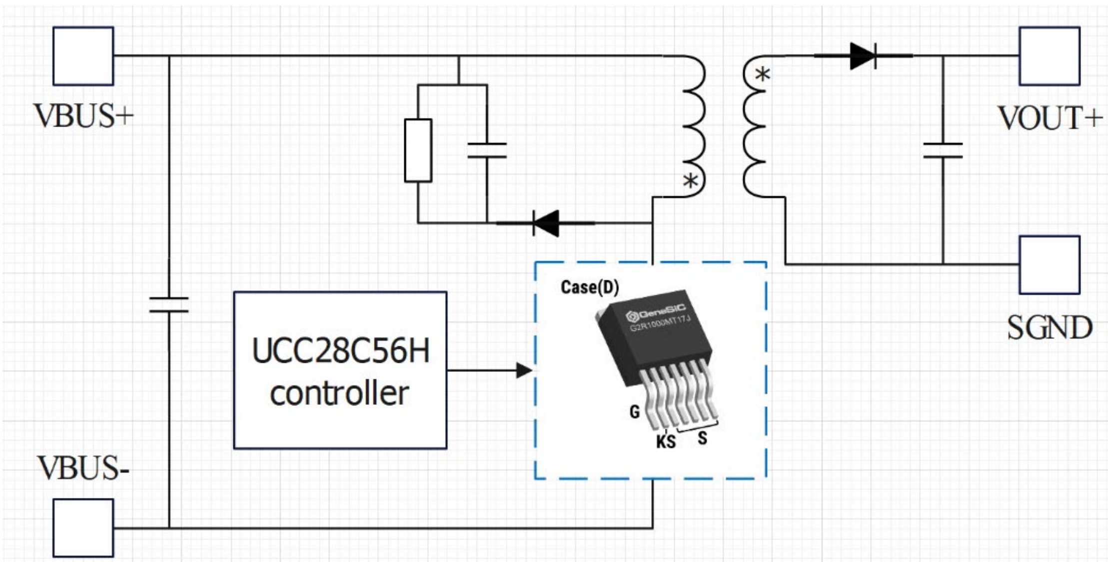


Figure 2: Flyback converter for auxiliary power supply

5. Specifications

5.1 Absolute Maximum Ratings(1)

(With respect to GND node unless noted)

SYMBOL	PARAMETER	MAX	UNITS
V_{BUS}	Input DC Bus Voltage	1000	V
I_o	Output Current (@ $T_A = 25°C$)	3.9(2)	A

(1) Absolute maximum ratings are stress ratings; devices subjected to stresses beyond these ratings may cause permanent damage.

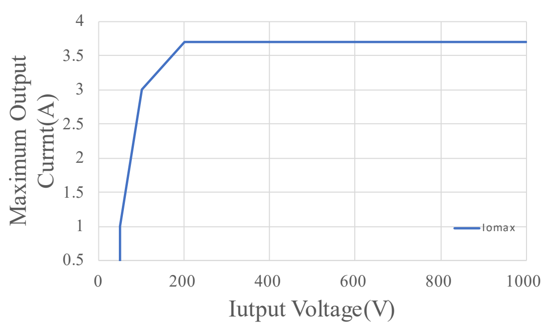
(2) Measured at T_{AMB}=25°C, V_{in}=200V. When I_o is larger than 3.9A the controller enters OLP and the output voltage will drop below 12V quickly.

5.2 Recommended Operating Conditions(3)

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS
V_{BUS}	Input DC Bus Voltage	50(4)	-	1000	V
I_o (5)	Output Current	0	-	3.7	A
V_{out}	Output Voltage	-	12	-	V
I_{in} (5)	Input Current	0	-	0.27	A
T_{AMB}	Operating Ambient Temperature	-	25	-	ºC

(3) Exposure to conditions beyond the maximum recommended operating conditions for extended periods of time may affect device reliability.

(4) The user can use a lower input DC voltage below 200V with reduced output power to extend input voltage range; 50V input voltage can achieve 1A output current and 12W output power; 100V input voltage can achieve 3A output current and 36W output power. The maximum output current vs. input voltage relationship is shown below.



(5) Board operated without heatsink at T_{AMB}=25°C.

6. 45 W Flyback Converter Demo Board Connections

The electrical connections of the flyback converter demo board are shown in Fig 3. The input power and output load should be connected to the corresponding pads of the board with wires.

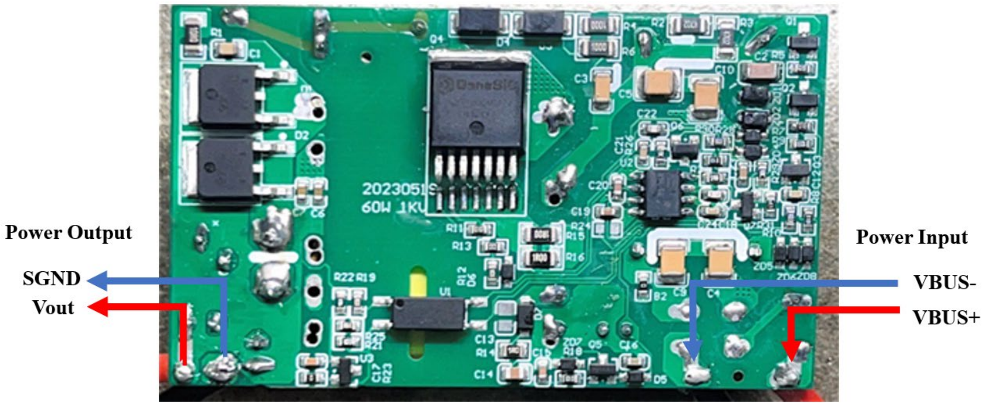


Figure 3: Demo board connections

7. 45 W Flyback Converter Schematic

The 45 W flyback converter circuit is shown in Fig 4. The high voltage sections and low voltage sections are separated by dotted lines.

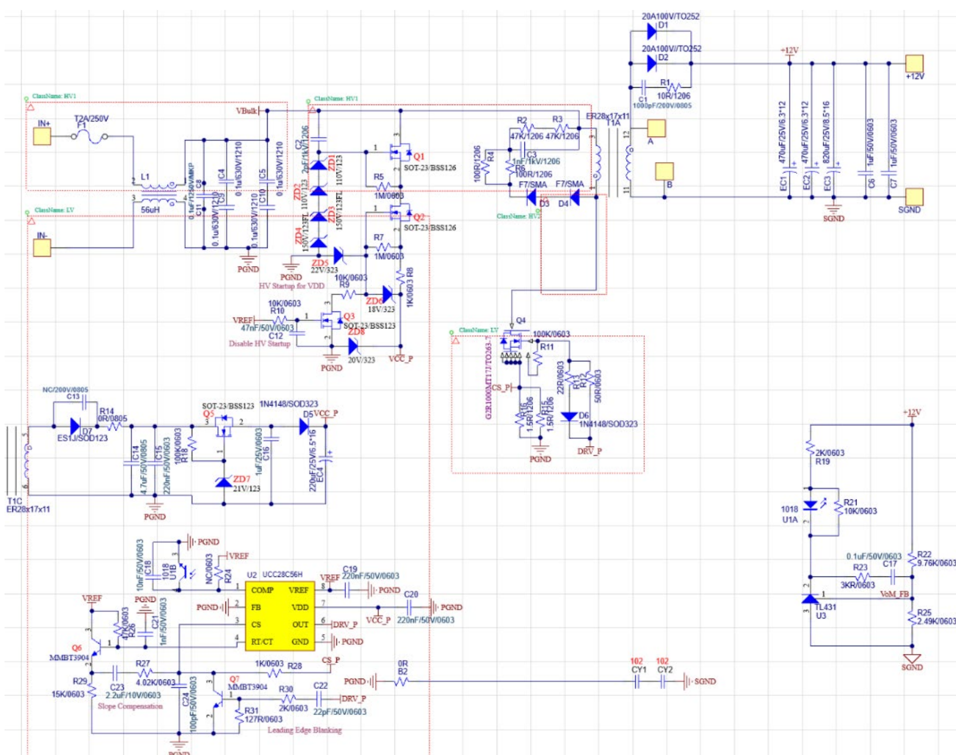


Figure 4: 45W flyback converter schematic

8. Functional Description

8.1 Transformer design

The design paraments of the flyback transformer are shown in Fig 5. The transformer adopts the sandwich structure, with the primary winding on the outside and secondary windings in the middle. This method can improve the coupling between the primary and secondary side and reduce the leakage inductance of the transformer, which can boost the efficiency of the converter and reduce the voltage stress of the primary MOSFET.

1. Wind 28 turns of the primary winding from Pin 1 (connect to the drain of the SiC MOSFET).
2. Wind the shielding layer from the Pin 6 and leave the end of the wire connected to NC Pin (open end).
3. Wind 3 turns of the secondary windings from Pin 12 (anode of the secondary side rectifier diode) to Pin 11 (secondary side ground).
4. Add another shielding layer.
5. Use the wire left in the first step to wind the remaining 27 turns of primary winding and connected the end to Pin 3.
6. In the end, wind 6 turns of auxiliary windings from Pin 5 to Pin 6 (primary ground).

It should be noted that 3 layers of isolation tapes are needed between each layer to comply with isolation standard between primary side and secondary side. Also make sure the core is reliably connected to Pin 6 (primary ground). The primary and secondary turns radio N_{ps} of the transformer is 55:3 and the primary inductance L_p is 1.2 mH.

45W12V PQ2620 Transformer (Core PC40 Ae120 Slot width 9mm)								
Sequence	Winding				Winding paramenters		Winding method	Lp=1.2mH
	Start	Casing	Slots	End	Wire diameter	Laps		
N1	1			C	2UEWΦ0.28*1P	28	winding densely	
tape1						3		
N2	6			NC	2UEWΦ0.15*2	15	Close to Pins	
tape2						2		
N3	12			11	TEXΦ0.1*70P*2	3	winding densely into a layer	
tape3						3		
N4	6			NC	2UEWΦ0.15*2	15	winding densely at center	
tape4						3		
N5	C			3	2UEWΦ0.28*1P	27	winding densely	
tape5						3		
N6	5			6	2UEWΦ0.15*1	6	Close to Pins	
tape6						2		
Note： The core is reliably connected to Pin6								

Figure 5: Transformer design

8.2 Drive voltage of SiC MOSFETs

As the Gate-Source Voltage (V_{GS}) increases, the On-State Resistance ($R_{DS,on}$) of the SiC MOSFET decreases (as shown in Fig 6). Within the safe allowance range, the higher V_{GS}, the smaller $R_{DS,on}$, the lower the conduction loss of the power device. The recommended operation V_{GS} of the 1.7kV SiC device from GeneSiC (G2R1000MT17J) is -5/20 V. As shown in Fig 6, $R_{DS,on}$ in 20V V_{GS} at 25°C is 1000 mΩ while in 16V V_{GS} at 25°C is 1550 mΩ, and the difference becomes greater in 12V V_{GS}[1].

UCC28C56H is a controller chip specially designed to drive SiC MOSFETs. Its maximum allowable power supply voltage is 30V, which meets the requirement to drive a SiC MOSFET in the safe range. In addition, with a UVLO of 15.5 V, which is higher than traditional Si controller, it makes sure that the driving voltage will never go below 15V. The higher driving voltage improves the efficiency of the system, lowers down the junction temperature of the SiC MOSFET and as a result, improves its lifetime.

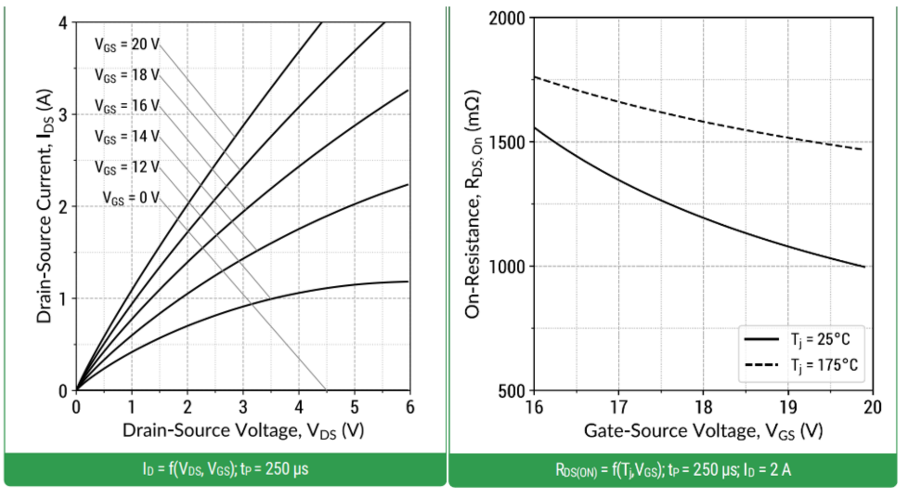


Figure 6: G2R1000MT17J on-state resistance vs. gate-source voltage

8.3 High voltage start-up

This reference design implements a high voltage start-up circuit. When the input voltage of the converter rises, current flows through Q1 and Q2 and charges Vcc of the controller. When Vcc increases to 18.8V, the controller starts to operate and VREF is set high. VREF high turns on Q3, which turns off Q1 and Q2 to block the current path. ZD1-ZD4 guarantee voltage balance between Q1 and Q2. After the controller has PWM output, Vcc will be powered by the auxiliary windings of the transformer. Using this start-up circuit instead of a current-limiting resistor allows for fast start-up speed, good protection, and lower static power loss in a wide input voltage range. The detailed start-up circuits are shown in Fig 7.

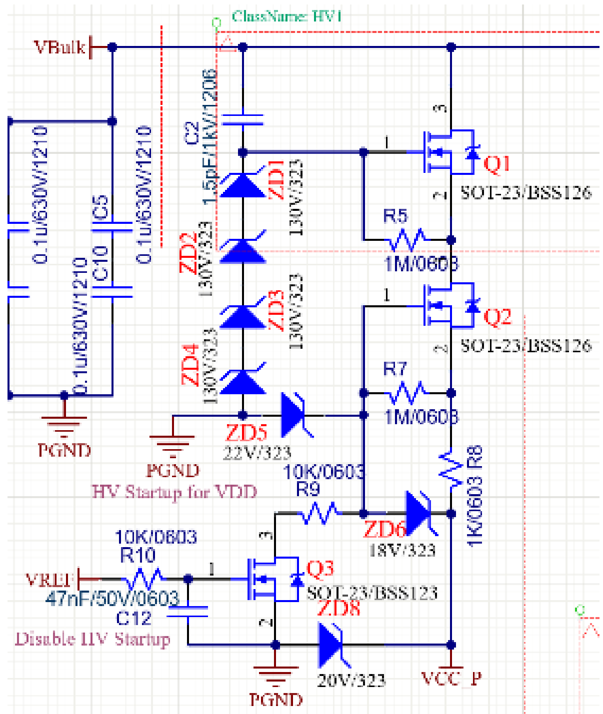


Figure 7: Start-up circuit

8.4 Slope compensation

For the flyback converter with a continuous current control mode (CCM), slope compensation is necessary to avoid the subharmonic oscillation when the duty cycle exceeds 50%. The slope compensation also improves stability of the system when the duty cycle is less than 50% either CCM or discontinuous mode (DCM). The oscillator inside the controller sends waveform with the sense current to the CS pin to implement the slope compensation. By adding a fixed ramp signal on the current, the effect of the current closed loop can be better suppressed. By connecting the RT/CT pin with a transistor base, the load on the oscillator is effectively reduced and the ramp signal is provided by VREF. For more information, please refer to the data sheet of UCC28C56H[2].

8.5 Leading Edge Blanking

To prevent spike current fed back to CS pin of controllers when the switch turns on, causing false control or even damage of the device, a leading-edge blanking (LEB) is added for protection. The LEB technology is that when the gate signal turns high, the current sense circuit does not detect the current until a period passed, which can avoid the effect of current spikes on the device caused by parasitic capacitor discharging. This time is called LEB time and its typical value is 270 ns. The LEB circuit is shown in Fig 8.

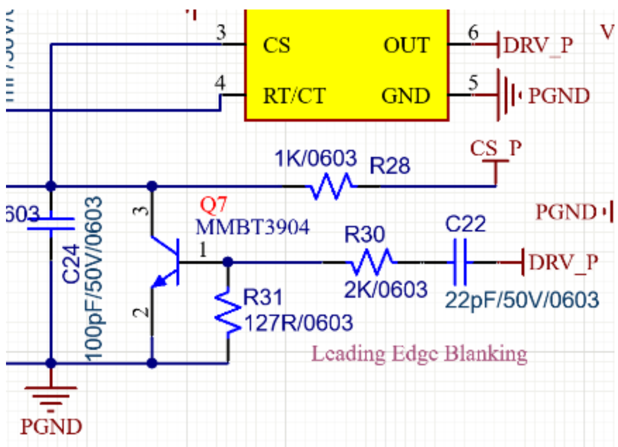
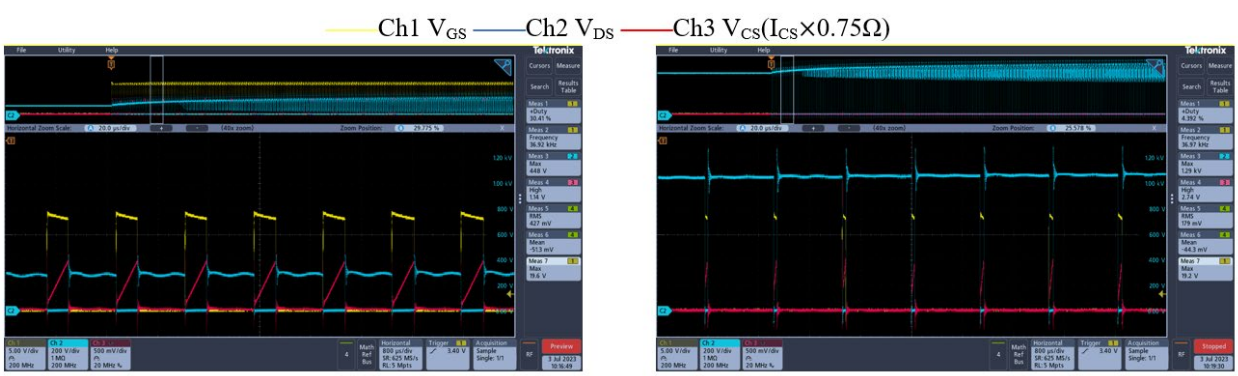


Figure 8: LEB circuit

9. Measurement Results

The 45 W auxiliary power supply demo board working waveform, power efficiency, thermal behavior and dynamic performance are characterized, and the results are shown in this section.



(a)200V V_{in} Startup (b)1000V V_{in} Startup

Figure 9: Measured converter startup waveform with 3.7A load

During the startup of the converter, it will enter CCM at the beginning because there is not enough time to de-magnetize the transformer. However, the converter will gradually exit CCM and go into DCM when the output voltage rises.

(a)200V V_{in} Steady state (b)1000V V_{in} Steady state

Figure 10: Measured converter steady waveform with 3.7A load

When the converter works in steady state, it will be in DCM, which can significantly reduce the turn-on loss of the primary SiC MOSFET.

The measured converter waveform (Fig 9 and Fig 10) shows the maximum voltage and current stress of the primary SiC MOSFET in all working state, which means the selected devices are in the safety margin. The maximum V_{DS} and V_{GS} stress are 1.4kV and 20.2V (at 1000V V_{in} with 3.7A load). The maximum I_{DSPEAK} (V_{CS}/0.75Ω) is limited to 1.47A by the controller IC.

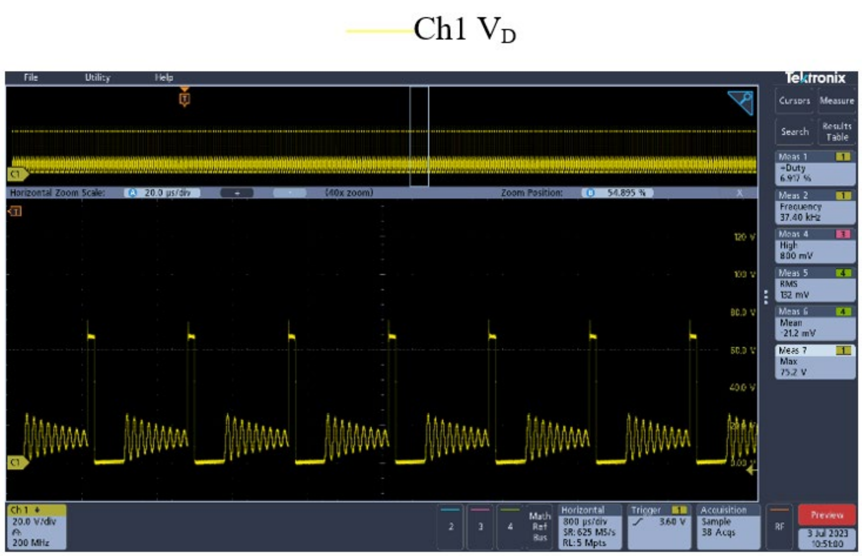


Figure 11: Measured diode voltage waveform

The maximum secondary side diode voltage stress VD1 is 75.2V (at 1000V V_{in} with 3.7A load) shown in Fig 11. So, we select a 100V working peak reverse voltage diode with a typical 0.8V forward voltage drop at 25°C to reduce the loss of secondary side.

The measured dynamic performance at 1000V V_{in} (Fig 11) shows that the converter has a good dynamic performance when the load has a large variation. When the converter change load from 3.7A to no load, it can keep working normally with 400mV voltage fluctuations at 200V – 1000V V_{in}.

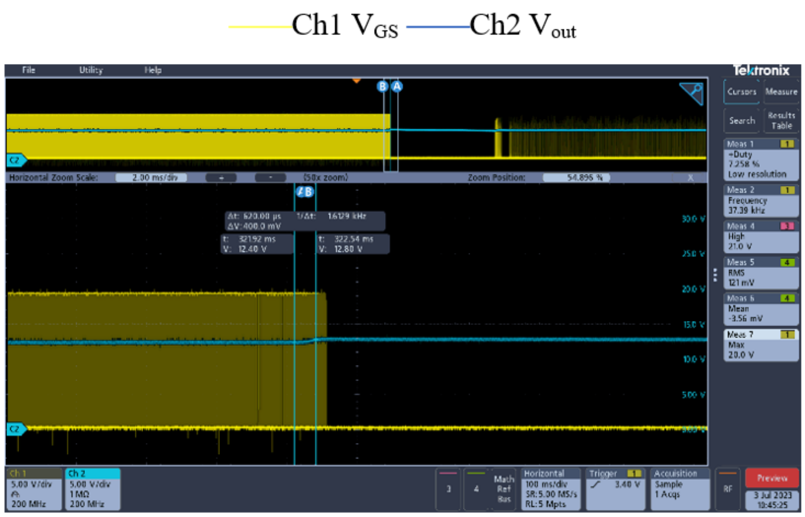


Figure 12: Measured dynamic performance

The maximum power efficiency is 89.5% at 500 V V_{in} with 3A load shown in Fig 13. And the efficiency of 200V - 1000V V_{in} at full load are all above 87%. The designed power has a good efficiency performance.

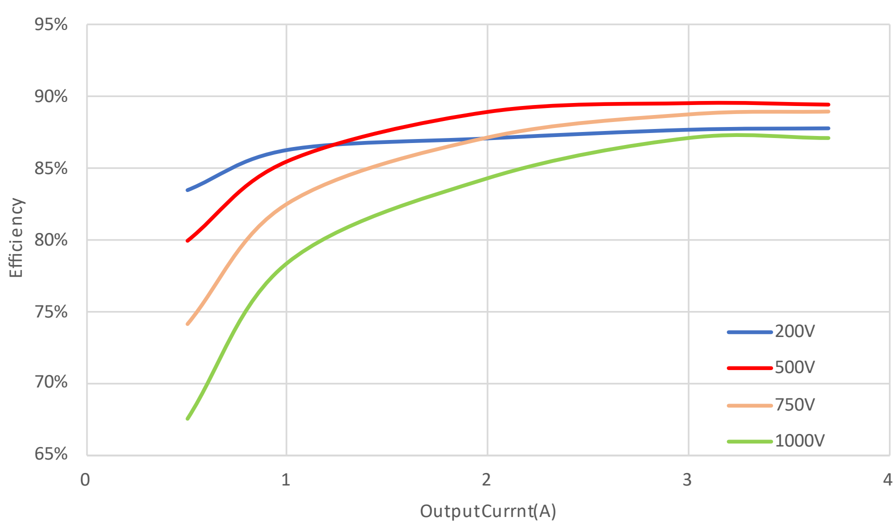
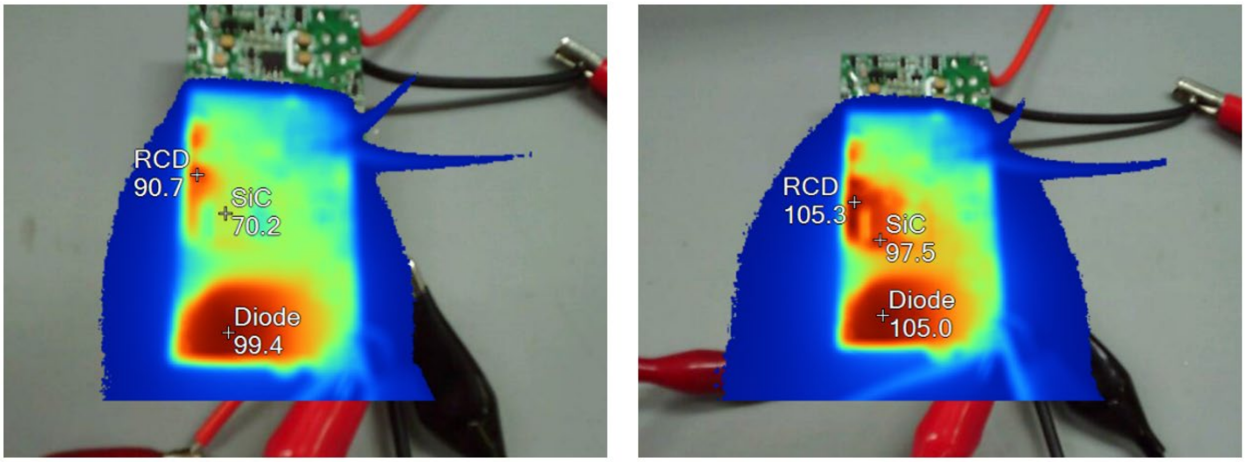


Figure 13: Measured power efficiency

The measured maximum device case temperature without heatsink indicates that this flyback converter auxiliary power supply can be operated safely at 45 W output power within 200V to 1000V input voltage range (Fig 14). The temperature of devices is measured by a thermal camera during the tests. The maximum case temperature of the SiC MOSFET is below 100°C (at 1000V Vin, 25°C room temperature).

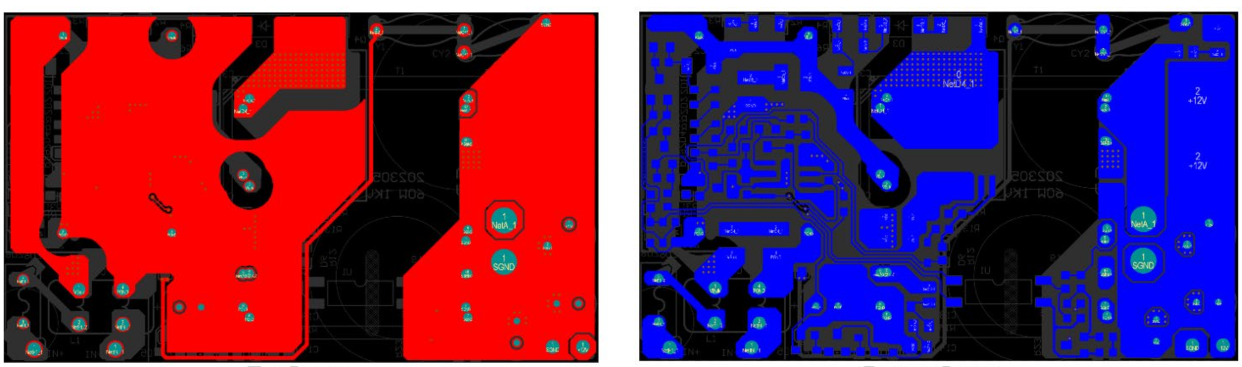


200V Vin 3.7A Load   1000V Vin 3.7A Load

Figure 14: Board temperatures with a thermal camera (P_{out} = 45 W)

10. PCB Layout

The demo board was implemented on a round PCB with a dimensions 68mm×40mm×21mm. A standard 2-layer PCB stack-up was used with 1 oz (35 µm) base copper layer thickness between top layer and bottom layer.



Top Layer   Bottom Layer

Figure 15: PCB Layout - Copper layers

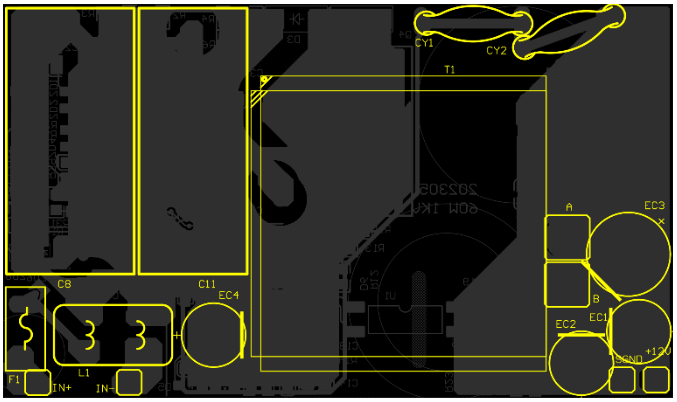


Figure 16: PCB Layout – Top Overlay

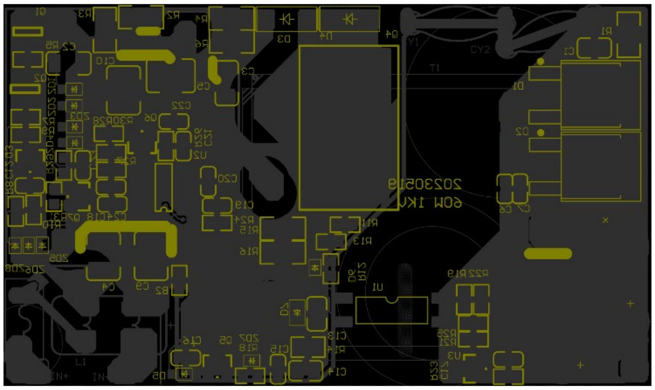


Figure 17: PCB Layout – Bottom Overlay

Figure 18: PCB Layout - Mechanical layers

11. Bill of Material

Designator	Description	Footprint	Manufacturer	Manufacturer Part Number	Qty	Value	Rating
C1	Capacitor	CC0805N	YAGEO	CC0805KRX7RABB102	1	1nF	200V
C2	Capacitor	CC1206N	FH	1206CG2R0C102NT	1	2pF	1kV
C3	Capacitor	CC1206N	FH	1206B102K202NT	1	1nF	2kV
C4, C5, C9, C10	Capacitor	CC1210N	FH	1210B104K631NT	4	0.1uF	630V
C6, C7	Capacitor	CC0603N	SAMSUNG	CL10A105KB8NNNC	2	1uF	50V
C8, C11	MKP Capacitor	CAP_X684(22.5_13)	KNSCHA	MMK104J3CESKN158G2	2	100nF	1.6kV
C12	Capacitor	CC0603N	FH	0603B473K500NT	1	47nF	50V
C13	Capacitor	CC0805N			-	NC	-
C14	Capacitor	CC0805N	SAMSUNG	CL21A475KBQNNNE	1	4.7uF	50V
C15, C19, C20	Capacitor	CC0603N	CCTC	TCC0603X7R224K500CT	3	220nF	50V
C16	Capacitor	CC0603N	FH	0603B105K250NT	1	1uF	25V
C17	Capacitor	CC0603N	YAGEO	CC0603KRX7R9BB104	1	0.1uF	50V
C18	Capacitor	CC0603N	YAGEO	CC0603KRX7R9BB103	1	10nF	50V
C21	Capacitor	CC0603N	YAGEO	CC0603KRX7R9BB102	1	1nF	50V
C22	Capacitor	CC0603N	YAGEO	CC0603JRNPO9BN220	1	22pF	50V
C23	Capacitor	CC0603N	SAMSUNG	CL10A225KP8NNNC	1	2.2uF	10V
C24	Capacitor	CC0603N	YAGEO	CC0603JRNPO9BN101	1	100pF	50V
CY1, CY2	Capacitor	Y-2	STE	Q07F1D102MN0B0S0N0	2	1000pF	400V
D1, D2	Diode	TO-252	SMC	MBRD20100	2	-	20A/100V
D3, D4	Diode	SMAF	YONGYUTAI	FR107	2	-	1A/1000V
D5, D6	Diode	SOD-323	CJ	1N4148WS	2	-	150mA/100V
D7	Diode	SOD-123	晶导微电子	US1M	1	-	500mA/600V
EC1, EC2	Electrolytic capacitors	D5.5xL16mm	NJCON	4710250516R00	2	470uF	25V
EC3	Electrolytic capacitors	D8xL16mm	NJCON	8210250816R00	1	820uF	25V
EC4	Electrolytic capacitors	D6.3xL11mm	AISHI	ERS1EM221E11OT	1	220uF	25V
B2	Resistor	CR0603N	UNI-ROYAL	0603WAF0000T5E	1	0R	100mW
F1	FUSE	FUSE-P5.0MM-AI-DS	TLC	SQT2.00M	1	-	2A/250V
L1	Common mode Choke	LCM-12X6-V1			1	47uH	-

Q1, Q2	Depletion mode MOS	SOT-23-HV	Infineon	BSS126H6327	2	-	600V
Q3, Q5	Depletion mode MOS	SOT-23	CJ	BSS123	2	-	100V
Q4	GeneSiC Mos	TO263-7	Navitas semi	G2R1000MT17J	1	-	1700V
Q6, Q7	NPN General Purpose Amplifier	SOT-23	CJ	MMBT3904	2	-	40V
R1	Resistor	CR1206N	UNI-ROYAL	1206W4F100JT5E	1	10R	0.25W
R2, R3	Resistor	CR1206N	UNI-ROYAL	1206W4F4702T5E	2	47k	0.25W
R4, R6	Resistor	CR1206N	UNI-ROYAL	1206W4F1000T5E	2	100R	0.1W
R5, R7	Resistor	CR0603N	UNI-ROYAL	0603WAF1004T5E	2	1M	0.1W
R8, R28	Resistor	CR0603N	YAGEO	RT0603BRD071KL	2	1k	0.1W
R9, R10, R21	Resistor	CR0603N	YAGEO	RC0603JR-0710KL	3	10k	0.1W
R11, R18	Resistor	CR0603N	UNI-ROYAL	0603WAF1003T5E	2	100k	0.1W
R12	Resistor	CR0603N	YAGEO	RT0603BRE0750RL	1	50R	0.1W
R13	Resistor	CR0603N	UNI-ROYAL	0603WAF220JT5E	1	22R	0.1W
R14	Resistor	CR0805N	UNI-ROYAL	0805W8F0000T5E	1	0R	0.125W
R15, R16	Resistor	CR1206N	UNI-ROYAL	1206W4F150KT5E	2	1.5R	0.25W
R19, R30	Resistor	CR0603N	UNI-ROYAL	0603WAF2001T5E	2	2k	0.1W
R22	Resistor	CR0603N	FOJAN	FRC0603F9761TS	1	9.76k	0.1W
R23	Resistor	CR0603N	UNI-ROYAL	0603WAF3001T5E	1	3kR	0.1W
R24	Resistor	CR0603N			-	NC	-
R25	Resistor	CR0603N	UNI-ROYAL	0603WAF2491T5E	1	2.49k	0.1W
R26	Resistor	CR0603N	UNI-ROYAL	0603WAF4702T5E	1	47k	0.1W
R27	Resistor	CR0603N	YAGEO	RC0603FR-074K02L	1	4.02k	0.1W
R29	Resistor	CR0603N	YAGEO	AC0603FR-0715KL	1	15k	0.1W
R31	Resistor	CR0603N	FH	RS-03K1270FT	1	127R	0.1W
T1	Transform	T-ER28H+PQ26V			1	-	-
U1	Optocoupler	SOP-4-250mil-2.54mm	UMW	EL1018	1	-	-
U2	Gate Driver	SO8	TI	UCC28C56H	1	-	-
U3	Controllable precision voltage regulator source	SOT-23	JSMSEMI	TL431	1	-	-

ZD1, ZD2	Zener diode	SOD-123	晶导微电子	MM1W100	2	-	100V
ZD3, ZD4	Zener diode	SOD-123FL	ROHM	UDZLVTE-17150	2	-	150V
ZD5	Zener diode	SOD-323	CJ	BZT52C22S	1	-	22V
ZD6	Zener diode	SOD-323	CJ	BZT52C18S	1	-	18V
ZD7	Zener diode	SOD-123	ROHM	KDZTR20B	1	-	20.8V
ZD8	Zener diode	SOD-323	CJ	BZT52C20S	1	-	20V

12. Datasheet Links

1. https://genesicsemi.com/sic-mosfet/G2R1000MT17J/G2R1000MT17J.pdf
2. https://www.ti.com/product/UCC28C56H-Q1

IMPORTANT NOTICE:

Hazardous voltages are present on this demo board. Personal contact with high voltages may result in injury or death. Correct handling and safety procedures must be observed. Boards are for lab bench evaluation only. Not for installation in end-user equipment.

CAUTION:

This board contains parts that are susceptible to damage by electrostatic discharge (ESD). Always follow ESD prevention procedures when handling the product.

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