Application Note_PNDM17P650A1: Wide Input Voltage Range (300Vdc-1000Vdc) 65W Auxiliary Power Supply for Three-phase Power Converter with 1700V SiC MOSFET

About this document

This document demonstrates the solution for high input voltage DC link(>600V) 65W auxiliary power supply designs using PN Junction Semiconductor's 1700V SiC MOSFET in TO-247-3 package (P3M173K0K3) in a quasi-resonance (QR) flyback topology. The reference board can support designers targeting auxiliary power supply in three-phase converters, which can be used in motor drives, solar inverter, energy storage, fast EV-charger and UPS.

Demo Product Name: PNDM17P650A1

PN Junction Semiconductor (PNJ) Co., Ltd
PNJ Application Team

The Evaluation and Reference Boards are addressed only to qualified and skilled technical staff, for laboratory usage, and shall be used and managed according to the terms and conditions set forth in this document.

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1. Introduction

For high power and high voltage applications including motor drives, solar inverter, energy storage, fast EV-charger and UPS application, the three-phase AC input voltage ranges from 400 Vac to 690Vac, thus the DC bus voltage ranges from 300Vdc to 1000Vdc. As shown in Figure 1, low power subsystems which support these high power and high voltage systems (such as displays, cooling fans, controllers and protections) need have a low power auxiliary power supply that can take high voltage input (AC or DC) and generate low DC voltage at the output. The high AC voltage can be converted to DC voltage by diode rectifier, so the critical issue is to realize wide input DC voltage range (300Vdc-1000Vdc) auxiliary power supply for three-phase power converter.

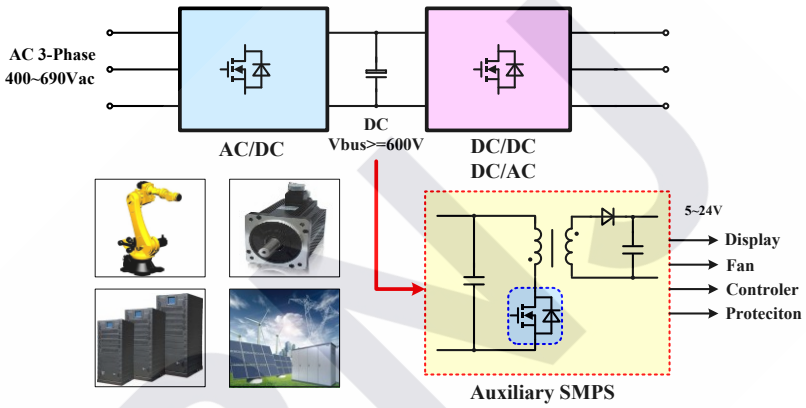

Fig. 1 Auxiliary Power Supply in Three-phase Power Converter

The conventional solution for high voltage auxiliary power supply is to use two-switch flyback with silicon 800V~1500V MOSFET, which is very complex. The application here is to use 1700 V SiC MOSFET in a TO-247-3 package (P3M173K0K3) as the main switch, which is well suited for high input voltage DC link with single-end flyback topology. Single device flyback simplifies the power design, easy to drive without high side driver and has lower total BOM (bill of materials) cost due to lower components. With low Rds(on), high efficiency and low device temperature rising can be achieved with this board. The controller works in a quasi-resonant mode to help reduce EMI noise. This application note contains an overview of the reference board, product information and technical details with measurement results.

2. Board Overview

2.1 Design Specification

The design specifications of PNJ's PNDM17P650A, 65 W flyback auxiliary power supply board are listed in Table 1.

Tab.1 Technical Specification

Parameters	Values
Input Voltage	300Vdc~1000Vdc
Output Power	65W
Output Voltage	24Vdc
Output Current	2.7A
Switch frequency	85kHz, QR Mode
Efficiency	>85%
Topology	Single-end Flyback
Power device package	TO247-3

2.2 Physical Dimensions and Pinouts

The Physical dimensions and the pinouts of PNJ's PNDM17P650A 65 W flyback auxiliary power supply board have been shown in Figure 2 and Figure 3. The board has a size of 105mm x55m x 35mm.

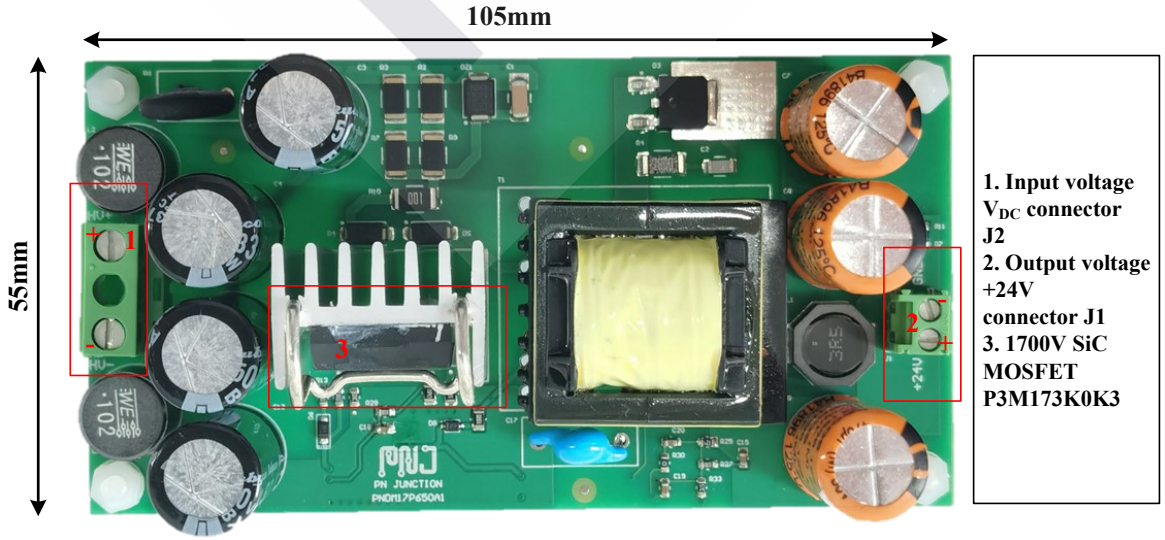

Fig. 2 Top View of PNJ's flyback auxiliary power supply board

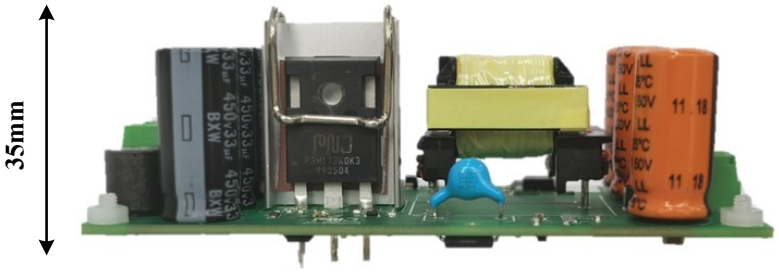

Fig. 3 Front View of PNJ's flyback auxiliary power supply board

2.3 Overview Electrical Characteristic

2.3.1 Board features

Key features of the reference board include:

- Over voltage protection
- Input under voltage protection
- Over current protection

A TI's flyback controller IC UCC28740 has been utilized in this 65 W flyback auxiliary power supply board operating in quasi-resonant QR mode. The UCC28740 isolated-flyback power-supply controller provides Constant-Voltage (CV) using an optical coupler to improve transient response to large load steps. Constant-Current (CC) regulation is accomplished through Primary-Side Regulation (PSR) techniques. This device processes information from opto-coupled feedback and an auxiliary flyback winding for precise high-performance control of output voltage and current. An internal 700-V startup switch, dynamically controlled operating states, and a tailored modulation profile support ultra-low standby power without sacrificing startup time or output transient response. This controller contains less than 10 mW no load power capability, resonant-ring valley-switching operation for highest overall efficiency, frequency dithering to ease electromagnetic interference (EMI) compliance, a clamped gate drive output for the MOSFET, and overvoltage, low line, and overcurrent protection function.

2.3.2 1700 V SiC MOSFET Overview

The 1700 V SiC MOSFET from PNJ is an excellent choice for high input voltage DC link systems like those found in auxiliary power supplies for three-phase converters. As shown in Figure 4, PNJ's PNDM17P650A, 65 W flyback auxiliary power supply board is based on PNJ's P3M173K0K3,1700V, 3Ω, TO-247-3 SiC MOSFET. PNJ's P3M173K0K3 SiC MOSFET consists of a fast-intrinsic diode with low reverse recovery charge (Qrr) and ultra-small Qgd. So, the flyback converter is able to operate in higher switch frequency with low switch loss. Meanwhile, the device can work in a high temperature, which can substantially

reduce the cooling size. The 1700V high block voltage with small Rds(on) means a single-end flyback is enough for high DC voltage auxiliary power supplies which simplify the power design compared with conventional HV two-switch flyback power supply by silicon MOSFET. Due to lower component count with single-end flyback and smaller heatsink requirement, the total BOM cost is lower than that for silicon MOSFET.

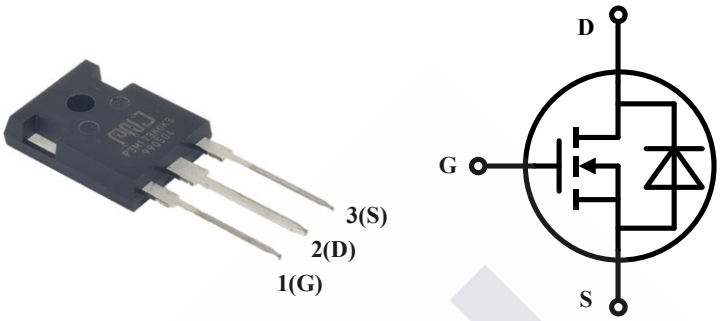

Fig.4 1700 V SiC MOSFET P3M173K0K3

Since the 1700V SiC MOSFET is used to replace conventional silicon MOSFET, Usually the flyback controller IC is designed for silicon device. In order to simplify the driver, the SiC MOSFET needs to be adjusted to work at the driver voltage of +12V/0V or +15V/0V even though the driver voltage +15V/-4V is the best choice. As can be seen in Figure 5, the Rds(on) of PNJ's 1700V SiC MOSFET P3M173K0K3 only increase slightly when working in the driver voltage (12V~15V). It means PNJ's P3M173K0K3 is a good choice to replace silicon device in HV flyback converter without any driver components increasement.

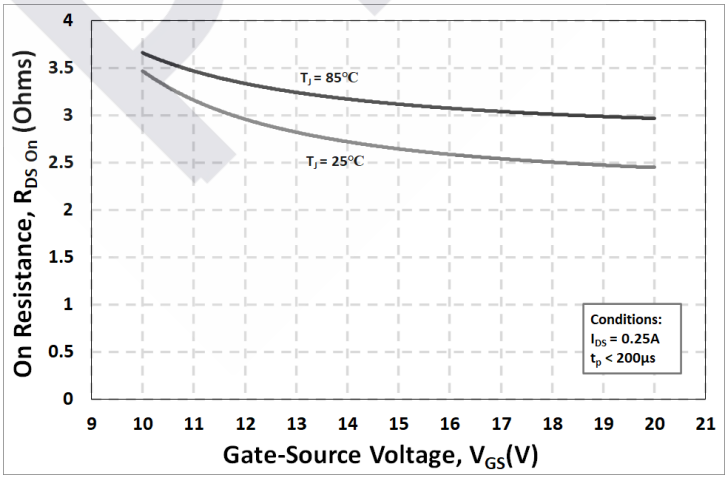

Fig.5 On-Resistance vs. Gate-Source Voltage of P3M173K0K3

3. Reference Board Description

3.1 Schematic

Figure 6 shows the schematic of the single-end flyback converter for this reference board.

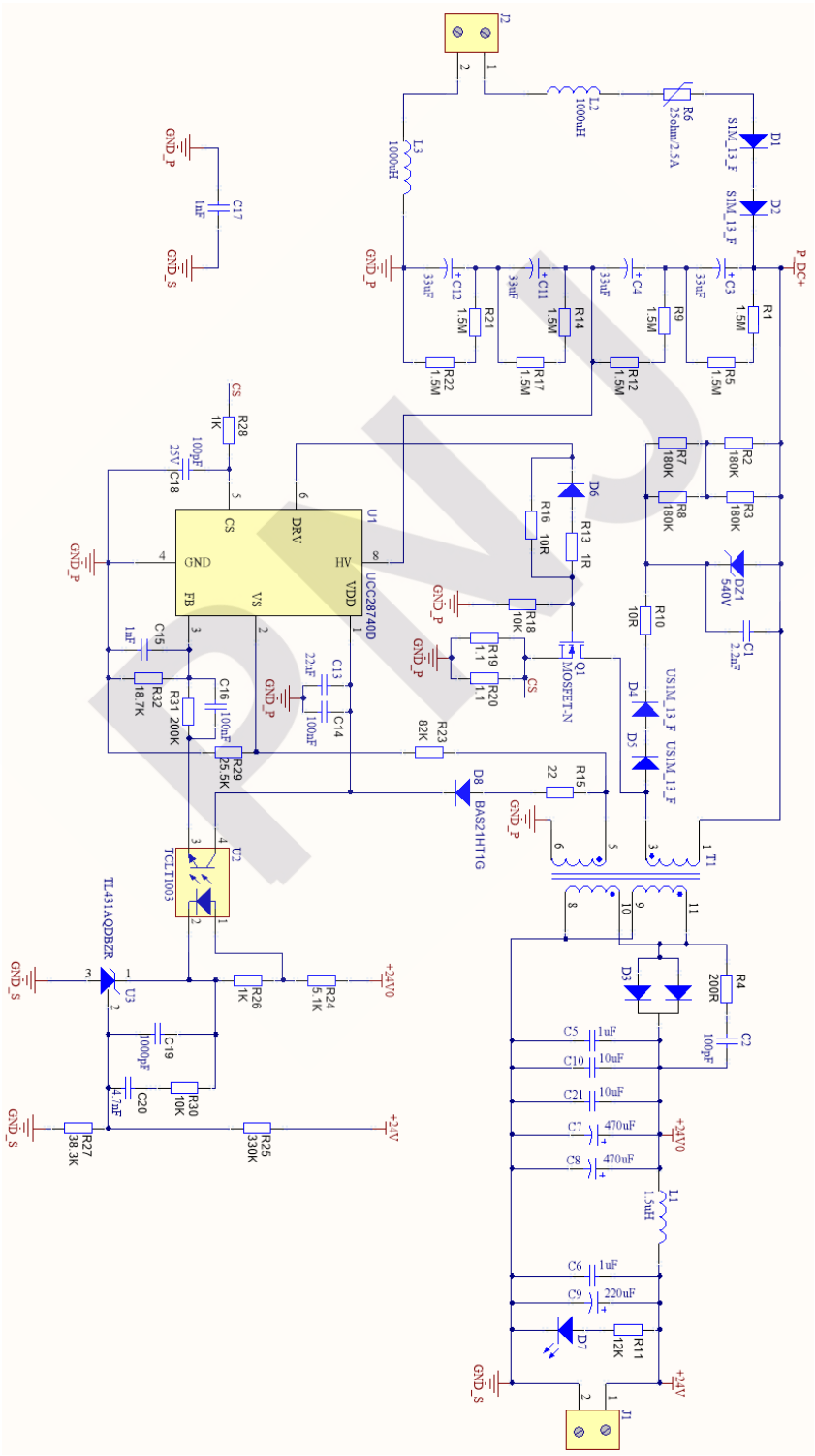

Fig.6 Schematic of PNJ's flyback auxiliary power supply board

3.2 Layout

The layout of the reference board is shown in Figure 7 and Figure 8.

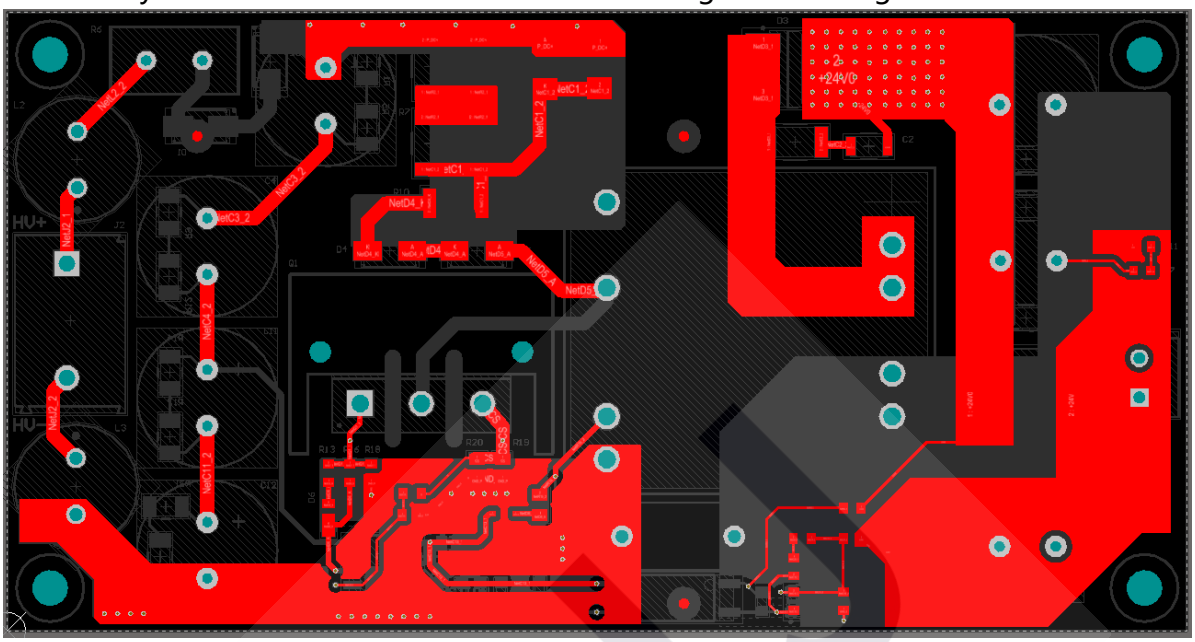

Fig.7 Top layer of the PCB

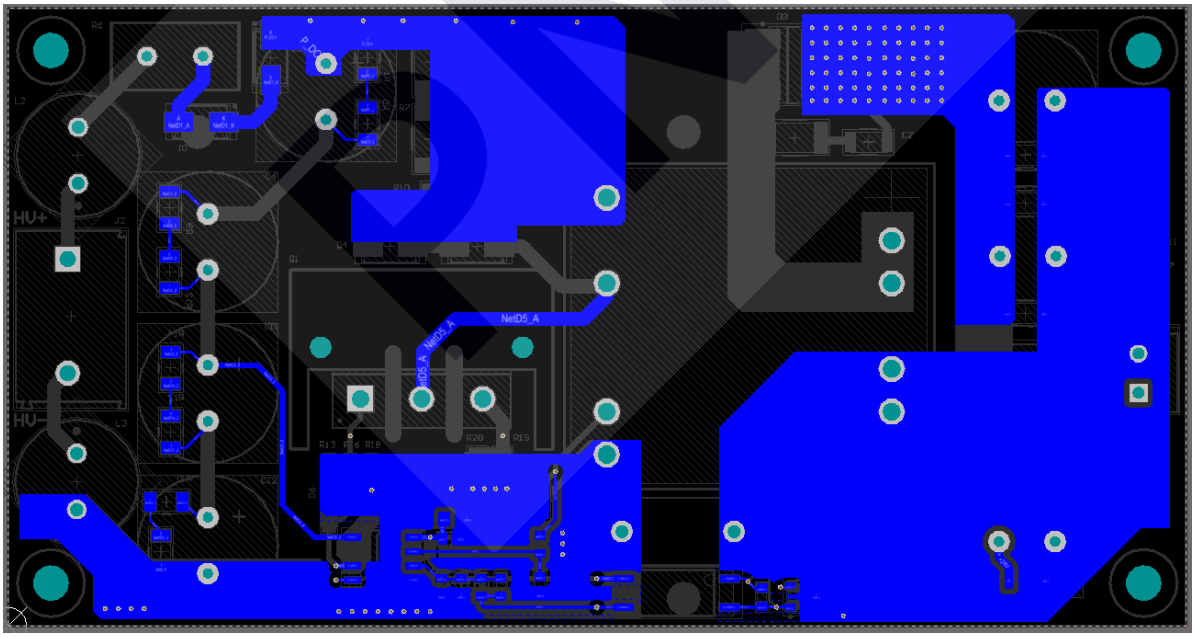

Fig.8 Bottom layer of the PCB

3.3 BOM

The BOM lists of all components used for the PCB is in shown in Tab 2.

Tab.2 Bill of Material of PNDM17P650A1 Board

Designator	Description	Manufacturer P/N	Manufacturer	Quantity
C1	MLCCs CAP X7R 2.2nF 1kV 1808_H22 belt	1808AC222KAT1A	AVX	1
C2	MLCCs CAP X7R 100pF 500V 1206_H16	CGJ5C4C0G2H101J060AA	TDK	1
C3, C4, C11, C12	E_Capacitor,33uF/450V,12.525mm	450BXW33MEFR12.5X25	Rubycon	4
C5, C6	MLCCs CAP X7R 1uF 50V 1206_H16	CGA5L3X7R1H105K160AB	TDK	2
C7, C8	E_Capacitor,470uF/50V,12.525mm	B41896E6477M000	TDK	2
C9	E_Capacitor,220uF/50V,1020mm	B41866C6227M000	TDK	1
C10, C21	MLCCs CAP X7R 10uF 50V 1206_H16	C3216X7R1H106K160AC	TDK	2
C13	CFCAP X7R 22μF 35V 0805_H14 belt	C2012X5R1V226M125AC	TDK	1
C14, C16	CAP X7R 100nF 50V 0603_H08	CC0603KRX7R9BB104	Yageo	2
C15	CAP X7R 1nF 50V 0603_H08	CC0603FRNPO9BN102	Yageo	1
C17	Y1 Capacitors,1nF,500VAC, Pitch_10mm	DE1E3RA102MN4AQ01F	Murata	1
C18	CAP X7R 100pF 25V 0603_H08	CC0603KRX7R8BB101	Yageo	1
C19	CAP X7R 1000pF 50V 0603_H08	C1608X7R1H102K080AE	TDK	1
C20	CAP X7R 4.7nF 50V 0603_H08	CC0603KRX7R9BB472	Yageo	1
D1, D2	S1M_13_F ,1A/1KV, SMA	S1M_13_F	Diodes Incorporated	2
D3	Schottky Diode,200V/20A,TO−252	RB218BM200FHTL	ROHM Semiconductor	1
D4, D5	1A/1KV surface mount ultra-fast rectifier, SMA	US1M-13-F	Diodes Incorporated	2
D6	Schottky barrier diode,30V/1A, IFSM=5A, SOD-323HE	RSX101VYM30FHTR	ROHM	1
D7	LED S green If=20mA, VF=2.2V, LG L29K-F2J1-24-Z	LG L29K-F2J1-24-Z	OSRAM Opto Semiconductors	1
D8	D_SOD323	BAS21HT1G	On Semiconductor	1
DZ1	TVS,540V , Undirectional, TPSMB series	TPSMB540A-A	Littelfuse	1
J1	Pitch_3.50 mm _ 2 pins, 350VAC/10A	691214110002S	Wurth	1
J2	pitch 10.16mm, 02p_Connector,750 VAC/24A	691216610002	Wurth	1
L1	WE-TPC SMT Tiny Power Inductor, size 1038, 1.5uH, 7.2A	7440660015	Wurth	1
L2, L3	WE-TIS Radial Leaded Wire Wound Inductor, size 1111, 1000uH, 0.6A	7447471102	Wurth	2
Q1	SiC MOSFET,1700V,3Ohms	P3M173K0K3	PN Junction Semiconductor	1

R1, R5, R9, R12, R14, R17, R21, R22	RES SMD 1.5 MOhms 1% 1/4W 1206_H6	RC1206FR-071M5L	Yageo	8
R2, R3, R7, R8	RES SMD 180KOhms 5% 2/3W 2010_H6,400V	CRCW2010180KJNEF	Vishay / Dale	4
R4	RES SMD 200 Ohms 1% 2/3W 2010_H6	RC2010FK-07200RL	Yageo	1
R6	NTC,25ohm/2.5A	B57236S0250M000	TDK	1
R10	RES SMD 10 Ohms 5% 2/3W 2010_H6	AA2010JK-0710RL	Yageo	1
R11	RES SMD 12 KOHM 1% 1/10W 0603_H6	RC0603FR-0712KL	Yageo	1
R13	RES SMD 1 OHM 1% 1/10W 0603_H6	RC0603FR-071RL	Yageo	1
R15	RES SMD 22 OHM 1% 1/8W 0805_H6	RC0805FR-0722RL	Yageo	1
R16	RES SMD 10 OHM 1% 1/10W 0603_H6	RE0603FRE0710RL	Yageo	1
R18, R30	RES SMD 10K OHM 1% 1/10W 0603_H6	RC0603FR-0710KP	Yageo	2
R19, R20	RES SMD 1.1 OHM 1% 1/8W 0805_H6	RC0805FR-071R1L	Yageo	2
R23	RES SMD 82 KOHM 1% 1/10W 0603_H6	RC0603FR-1382KL	Yageo	1
R24	RES SMD 5.1KOHM 1% 1/10W 0603_H6	RC0603FR-075K1L	Yageo	1
R25	RES SMD 330 KOHM 1% 1/10W 0603_H6	RC0603FR-07330KL	Yageo	1
R26, R28	RES SMD 1K OHM 1% 1/10W 0603_H6	RC0603FR-101KL	Yageo	2
R27	RES SMD 38.3 KOHM 1% 1/10W 0603_H6	RC0603FR-0738K3L	Yageo	1
R29	RES SMD 25.5 KOHM 1% 1/10W 0603_H6	RC0603FR-0725K5L	Yageo	1
R31	RES SMD 200 KOHM 1% 1/10W 0603_H6	RC0603FR-13200KL	Yageo	1
R32	RES SMD 18.7 KOHM 1% 1/10W 0603_H6	AC0603FR-0718K7L	Yageo	1
T1	Transformer	750344810	Wurth	1
U1	Constant-Voltage Constant-Current Flyback Controller	UCC28740DR	Texas Instruments	1
U2	Optocoupler, Ic_50mA, 5KV, SOP-4L	TCLT1003	Vishay	1
U3	Shunt Adjustable Precision References, SOT23-3	TL431AQDBZR,215	Nexperia	1

4. Test Result

4.1 Waveforms

The next six figures show the drain-source voltage (Vds) and gate-source voltage (Vgs) waveforms of the 1700V MOSFET at different input voltage with half load and full load.

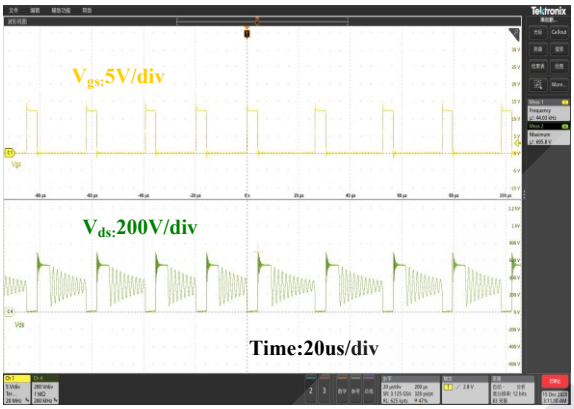

Fig. 9 Drain source and gate voltage at input voltage of 300 VDC, Io=1.4A

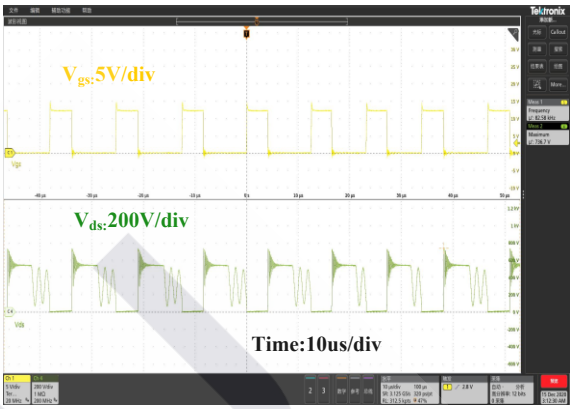

Fig. 10 Drain source and gate voltage at input voltage of 300 VDC, Full load Io=2.7A

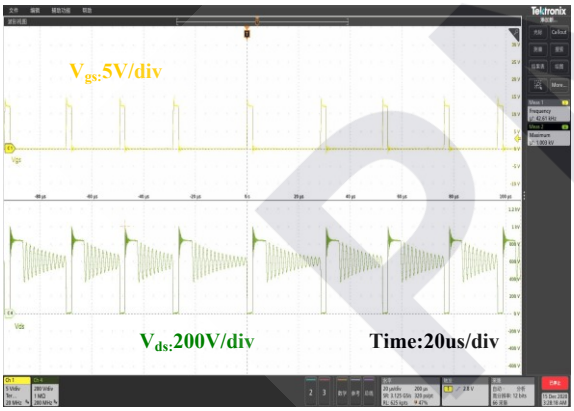

Fig. 11 Drain source and gate voltage at input voltage of 600 VDC, Io=1.4A

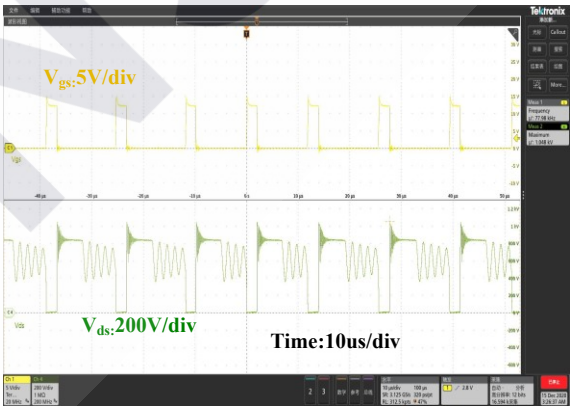

Fig. 12 Drain source and gate voltage at input voltage of 600 VDC, Full load Io=2.7A

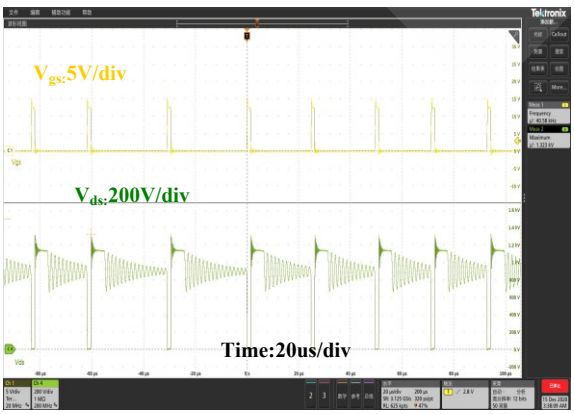

Fig. 13 Drain source and gate voltage at input voltage of 900 VDC, Io=1.4A

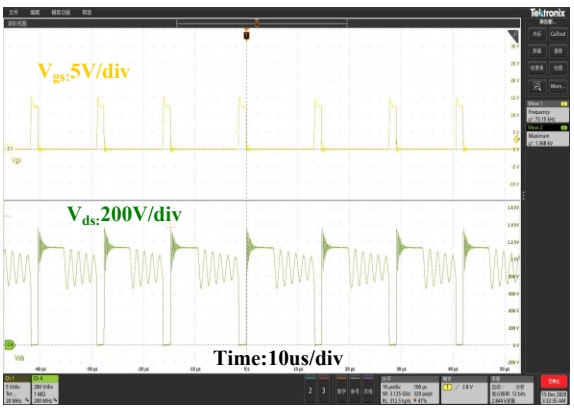

Fig. 14 Drain source and gate voltage at input voltage of 900 VDC, Full load Io=2.7A

4.2 Efficiency

The efficiency of PNJ's PNDM17P650A1, 65 W flyback auxiliary power supply board was tested in different load as shown in figure 15. These measurements were taken at 300V, 600V, 900 V DC input voltage levels and the peak efficiency achieved at each input voltage was 89% at 300 VDC, 89.4% at 600 VDC and 88% at 900 VDC.

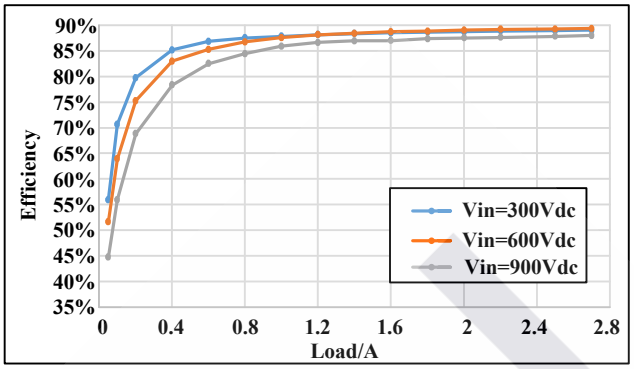

Fig. 15 Efficiency measurements of PNJ's PNDM17P650A1 65 W flyback auxiliary power supply board at 300 VDC, 600 VDC and 900 VDC input in different load

The efficiency of PNJ's PNDM17P650A1, 65 W flyback auxiliary power supply board was tested in different input voltage at full load as shown in figure 16. The peak efficiency is 89.5% at the input voltage of 500Vdc.

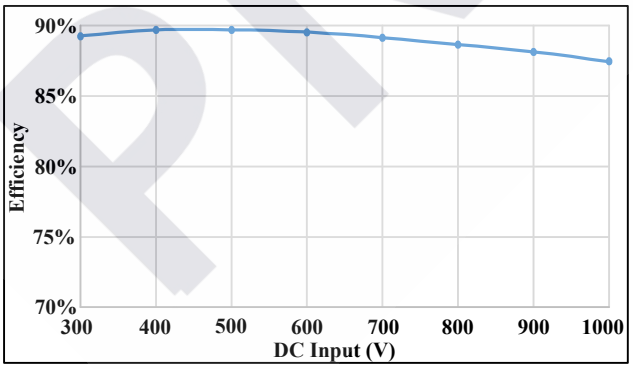

Fig. 16 Efficiency measurements of PNJ's PNDM17P650A1 65 W flyback auxiliary power supply board at full load in different input voltage

3.3 Thermal Performance

The thermal performance of PNJ’ s PNDM17P650A1, 65 W flyback auxiliary power supply board in different voltage at full load was shown in figure 17 to figure 20. P1 is the temperature of transformer, the P2 is the temperature of RCD snubber circuit and P3 is the temperature of SiC MOS. The maximum temperature of the PCB board measured at the input voltage of 1000Vdc is 82.9℃ at the secondary rectifier diode, with 66.2 ℃ at the SiC MOS and 67.1℃ at the transformer. The maximum temperature of the RCD snubber circuit at the input voltage of 300Vdc is 71.9℃。

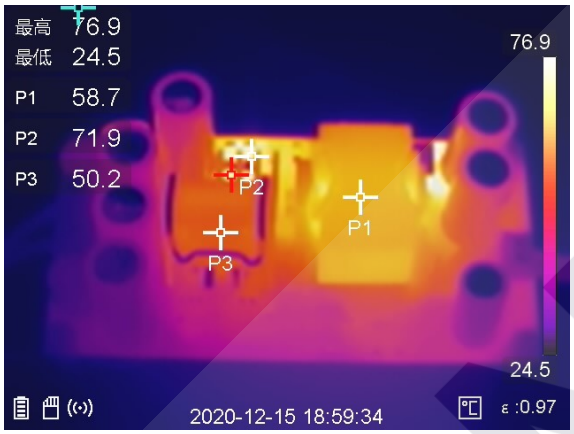

Fig. 17 Thermal Image at input voltage of 300 V, Full load Io=2.7A

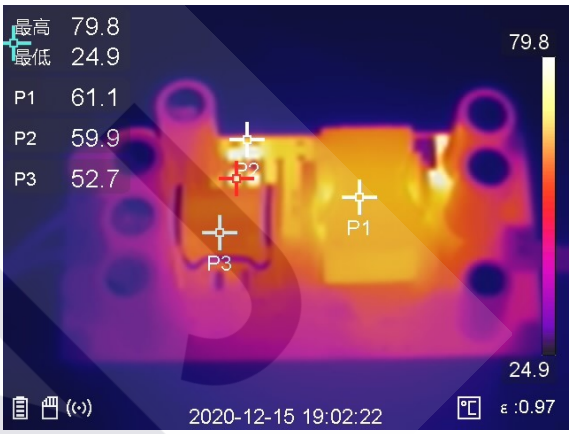

Fig. 18 Thermal Image at input voltage of 600 V, Full load Io=2.7A

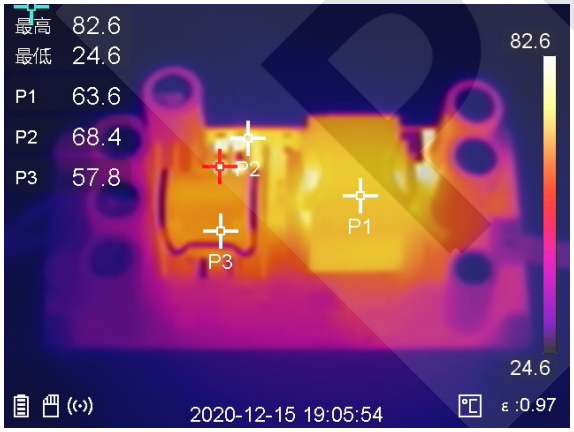

Fig. 19 Thermal Image at input voltage of 900 V, Full load Io=2.7A

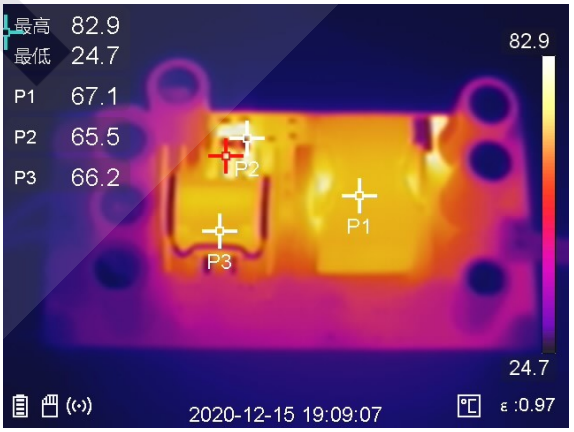

Fig. 20 Thermal Image at input voltage of 1000 V, Full load Io=2.7A

Reference

[1] P3M173K0K3 datasheet, 1700V SiC MOSFET

[2] UCC28740 datasheet, Constant-Voltage Constant-Current Flyback Controller Using Optocoupled Feedback

4. Revision History

Date	Revision	Description of change
2020.09.28	V1.0	Initial Version
2020.12.21	V1.1	Schematic Update