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DEVELOPMENT OF A GAN FETS BASED FULLY DIGITAL CORRECTION MAGNET POWER SUPPLY PLATFORM FOR TAIWAN PHOTON SOURCE

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Abstract

Since its operation in 2013, Taiwan Photon Source (TPS) has been constantly maintaining and developing new technologies to improve its power electronics systems. The availability of GaN FETs power devices with integrated drivers and protection functions has allowed designers to achieve different power density and efficiency levels in these systems. This paper explains how to use GaN FETs for power supply development and PCB design and how to incorporate them into the TPS correction magnet power supply architecture, using a TI TMS320F28335 controller and GaN FETs power modules to increase output current bandwidth, complete PI compensation algorithms, high switching frequencies, PWM switching modes, and communication functions.

Finally, we implemented a GaN FETs-based fully digital TPS correction magnet power supply development platform, which strongly supports the future development of new TPS correction magnet power converters.

INTRODUCTION

In this design and development platform, our primary focus was on the modularity of the GaN FETs power switch module and improving the system power's immunity to interference when operating at a high frequency of 400 KHz. In addition, we have also isolated the signals of each block to ensure that there is no interference when the digital signal processor is in operation. The design of this platform also continues the previous central circuit architecture, interlock protection circuit, pin assignment of the interface, digital control and analogy-to-digital conversion circuit, and temperature control box design. We have redesigned a four-layer PCB layout that is compatible with existing systems and convenient for future development [1, 2].

Figure 1 shows the system architecture diagram, which includes four major parts. The first part is the leading circuit structure components, which include a full-bridge DC-to-DC power converter structure composed of two sets of GaN FETs half-bridge modules, a choke inductor, and an output low-pass LC filter, among others. The second part is the temperature control box circuit design, which includes circuits such as the INA253 current sensing circuit, analog-to-digital converter (ADC) card, and temperature control circuit compensator design. The third part is the isolated power supply design and interlock protection circuit. The isolated power supply design provides independent power for signal isolation level conversion needed for DSP, interlock signals, GaN FETs drive signals, and ADC timing signals to ensure that the DSP is not affected by noise interference during power switch switching. Additionally, the interlock protection circuit includes input current overload protection, output overcurrent protection, auxiliary power supply level protection, power switch heatsink protection, and output oscillation protection circuit [3]. The fourth part is the digital control and interface, which includes the TI TMS320F28335, ADC, GaN FETs power switch isolation drive circuit, and LabVIEW communication control interface. In this article, the TI TMS320F28335 is selected as the control core, responsible for generating various timing signals, designing PID compensators, and PWM switching strategies, writing control function instructions, and creating the LabVIEW control interface [4, 5].

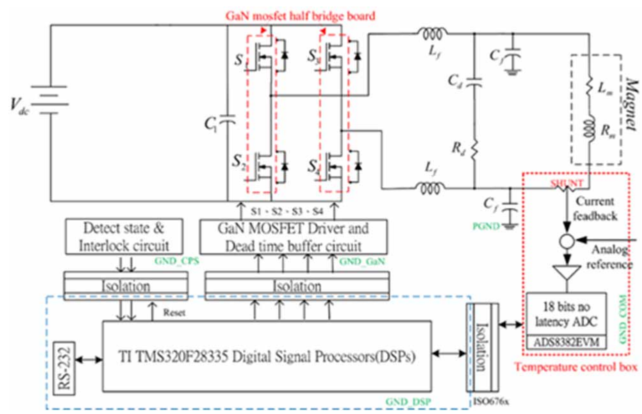

Figure 1: System architecture diagram.

DESIGN OF GAN FETS POWER CONVERTER MODULE

This section discusses creating a half-bridge power converter using multiple GaN FETs power switches. The design is explained based on the different packaging and driving characteristics of each type of GaN FET. It is implemented with the corresponding driving isolation circuit to create a modular half-bridge power module board. The GaN FETs types used in this design include LMG3410R070, LMG5200, GS61008T, and GS66508T; their specifications are listed in Table 1.

Table 1: Specification of GaN FETs device

GaN	Volt/Amp	packet	Size	R_{DS}
LMG3410	600/30A	Qfn32	8*8mm	70mΩ
LMG5200	100/10A	QFM(9)	6*8mm	15mΩ
GS66508T	650/30A	GaNpx	7*4.5mm	50mΩ
GS61008T	100/90A	GaNpx	7*4.5mm	7mΩ

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When designing various GaN FETs into a half-bridge power module, using the recommended driver IC and isolation circuit from the datasheet and creating the exact pin definition for different GaN FETs models to achieve module interchangeability. Figures 2, 3, and 4 show the layout diagrams of the LMG3410, LMG5200, and GS66058T half-bridge power conversion boards, respectively. It can be observed that when the GaN FETs receive the PWM signal, power isolation is required to prevent high-frequency harmonics from affecting the digital controller.

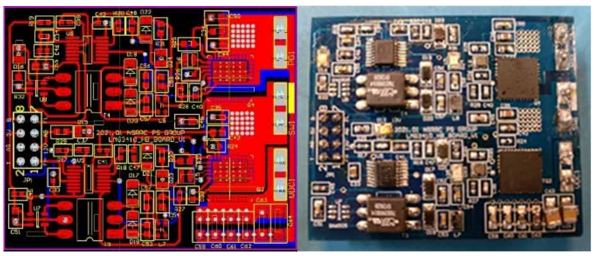

Figure 2: LMG3410 layout diagrams and converter board.

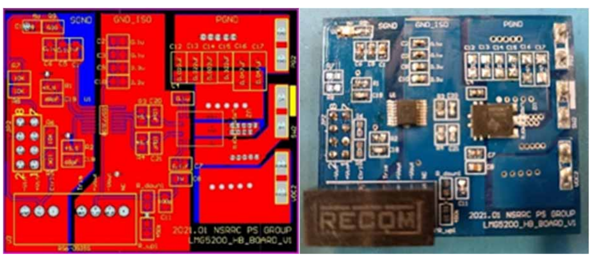

Figure 3: LMG5200 layout diagrams and converter board.

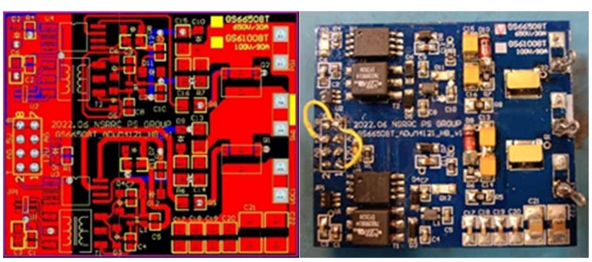

Figure 4: GS66058T layout diagrams and converter board.

DIGITAL CONTROL CARD AND ANALOG-TO-DIGITAL CONVERTER CARD DESIGN

The digital control uses TI TMS320F28335 as the control core, which is responsible for computing PI compensation, generating PWM, and timing to capture data from the analog-to-digital converter card for current feedback control. The ADC adopts the 18-bit SAR architecture TI ADS8382. However, to reduce output current drift caused by temperature changes, the current feedback path requires all circuit components, including the shunt conversion circuit, temperature control circuit, and analogy-to-digital converter card, to be installed within the 81.74 mm * 46 mm temperature control copper box. This reduces the time required for thermal equilibrium on the feedback path components, making it easier for the entire converter to achieve a stable state. Figure 5 shows the PCB layout diagram of the newly designed ADS8382 and the new conversion circuit board.

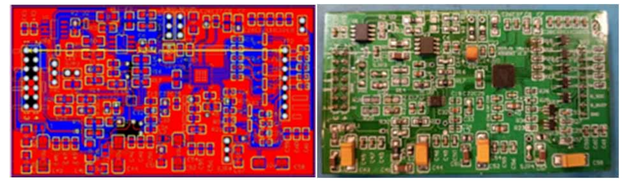

Figure 5: ADS8382 layout diagrams and new ADC board.

DESIGN NEW CORRECTION MAGNET POWER CONVERTER BOARD

When developing a new version of the fully digital GaN FETs-based correction magnet power converter board, the design must consider the compatibility of the correction magnet power supply specifications, interface, and protection signals currently operating with TPS. At the same time, the TMDSCNCD28335PG controller, ADC module, two sets of GaN FETs half-bridge power modules, a high-precision current feedback circuit, temperature control circuit, output low-pass filter, protection circuit, and isolation signal conversion circuit need to be integrated. In addition, the Protel 99se tool is used to perform reintegration and establish various components. Sch and .pcb databases, perform circuit diagram, component positioning, four-layer board, and wiring layout design to complete the power converter development board platform circuit board design. The top layer diagram shown in Fig. 6 for the new board demonstrates good PCB layout component placement and routing, which helps to reduce EMI and EMC noise interference.

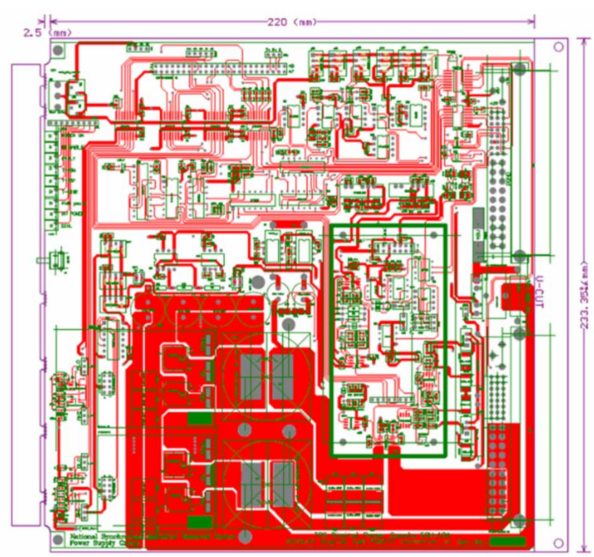

Figure 6: Top Layer of New converter board.

Figure 7 shows the component family of the fully digital GaN FETs-based correction magnet power converter board, which includes three different GaN modules, a DSP control card, an ADS conversion board, a temperature control copper box, and other control components.

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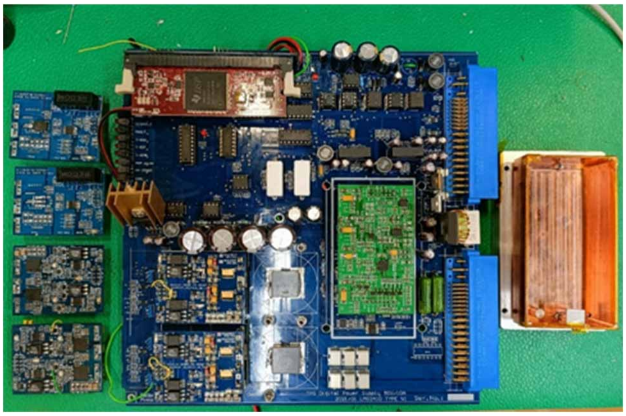
Figure 7: The component family of the fully digital GaN FETs-based correction magnet power converter.

CONCLUSION

The successful development of a fully digital GaN FETs-based corrective magnet power converter platform design has been achieved in this study. After completing the PCB circuit design and fabrication, various components and modules can be installed and developed according to different voltage and current specifications, which reduces the time and cost required for a complete system redesign.

The platform design adopted the existing TPS correction magnet power supply interface and protection circuit. It incorporated digital control, a new shunt current feedback circuit, and a GaN FETs half-bridge modular design. This involved experience in circuit design, program writing, communication protocol definition, PCB layout design, and LabVIEW virtual interface development, which is of great help in developing a new generation of TPS correction magnet power supplies.

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