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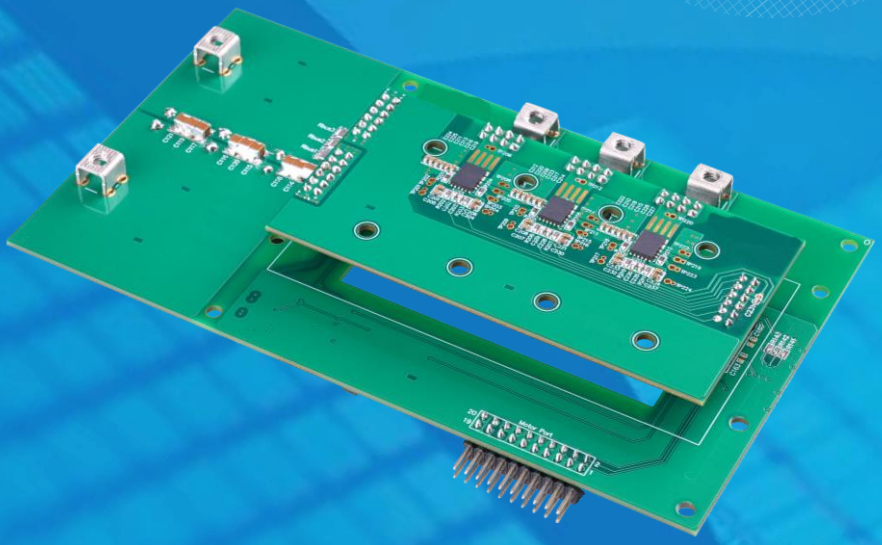
POWER THE FUTURE

INNDMD48V22A1

Demo Manual

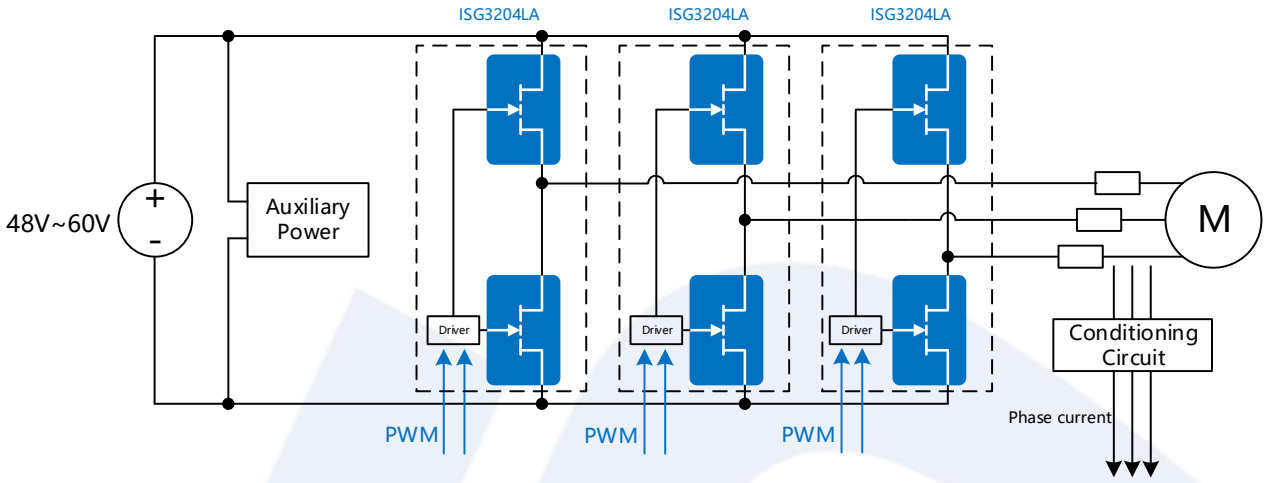
48V 22A Motor Drive

Featuring ISG3204LA



48V 22A 电机驱动

三相电机驱动方案



INNDMD48V22A1功率管采用LGA封装ISG3204LA，输入48V_{dc}-60V_{dc}，持续输出相电流有效值最大22A，能够满足1kW电机驱动应用需求。INNDMD48V22A1包含一块母版和一块功率子板，两者可以组装在一起测试ISG3204LA在电机驱动应用中的性能。

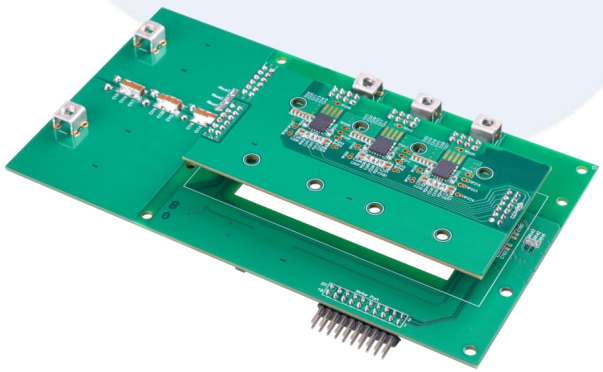
重点器件

- ISG3204LA

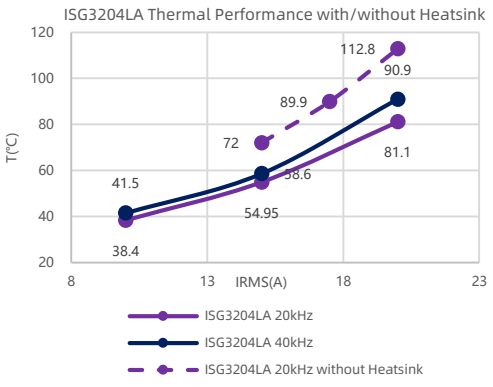
应用场景

- 机器人
- 无人机

实物图



测试数据



目 录

1. 概述

1.1. 引言

INNDMD48V22A1功率管采用ISG3204LA，输入48V_{dc}-60V_{dc}，持续输出相电流有效值最大22A，能够满足1kW电机驱动应用需求。INNDMD48V22A1包含一块母板和一块功率子板，两者可以组装在一起测试ISG3204LA在电机驱动应用中的性能。

1.2. 应用场景

- 机器人
- 无人机

2. 关键参数

表 1 关键电气参数表(Ta = 25 ℃)

Symbol	Parameter	Min	Nom	Max	Unit
V_{in}	输入电压	24	48	60	V_{dc}
F_s	开关频率		20		kHz
T_d	死区时间	20	100		ns
I_{OUT}	持续输出相电流			22	A
P_{OUT}	持续输出功率		1000		W

3. Demo方案

3.1. 系统

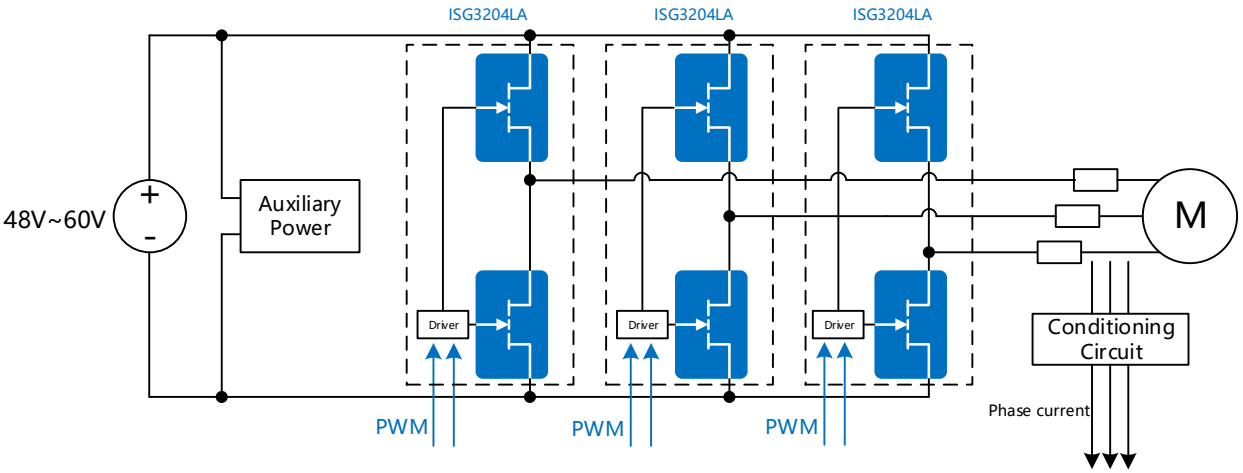


图 1 INNDMD48V22A1系统框图

INNDMD48V22A1包含三相功率半桥，每一相使用一颗具有集成栅极驱动器的100V半桥合封GaN器件ISG3204LA。PWM信号由控制器通过接口输入，相电流经过采样及调理电路后输入控制器，辅助电源为以上各部分供电。

3.2. GaN的应用优势

GaN在电机驱动应用中相比于Si有以下几点优势：

- 栅极电荷 Q_g

同样内阻的器件，GaN栅极电荷相较于Si减小5倍左右，更小的栅极电荷意味着更快的开通关断速度及更小的驱动及开关损耗。与此同时，高开关速度能够有效降低死区时间，在电机驱动系统中，这能够降低THD，转矩脉动和电机本体的机械噪声。

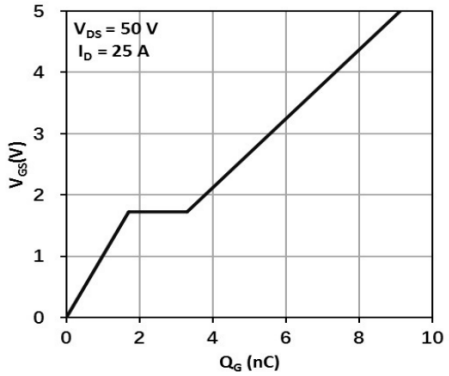
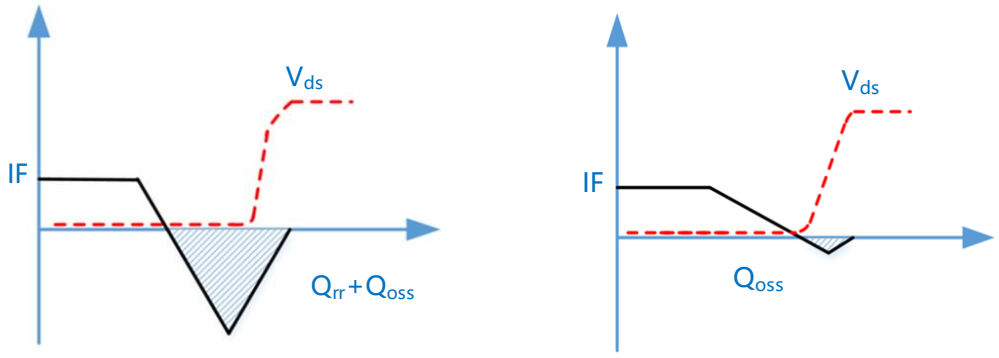


图 2 GaN典型栅极电荷

■ 反向恢复电荷 Q_{rr}

Si MOS内部寄生二极管在关断时存在较大的反向恢复电荷，这会导致开关过程引入额外的损耗及电压尖峰。GaN开关过程没有少数载流子的复合，因此没有反向恢复问题，这使得GaN非常适合电机驱动等硬开关应用。



(a)Si MOS (b) GaN

图 3 器件关断波形

3.3. 重点器件介绍

3.3.1. ISG3204LA

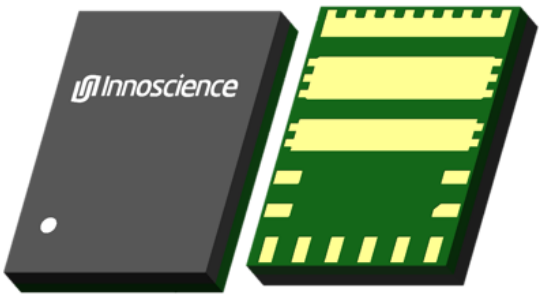


图 4 具有集成栅极驱动器的100V半桥合封GaN器件ISG3204LA

ISG3204LA是英诺赛科的一款采用LGA 5mm x 6.5mm封装的具有集成栅极驱动器的100V半桥合封硅基氮化镓增强型功率半桥。ISG3204LA能够帮助电机驱动系统实现更紧凑的PCB设计及更优秀的温度表现。与相似内阻的Si MOS相比，ISG3204LA具有更小的电容参数，且没有反向恢复，详细对比数据如表 2所示。

表 2 GaN vs Si电气性能对比

Parameter	ISG3204LA	Si Competitor
$R_{ds(on),max}$(mΩ)	3.2	3.4
Q_g(nC)	9.2(0.25)	37
Q_{oss}(nC)	50(x0.55)	91
Q_{rr}(nC)	0(x0)	42
FOM(R_{on}*Q_g)	35.3(x0.28)	125.8
FOM(R_{on}*Q_{oss})	192(x0.62)	309.4
Package	FCLGA(5mm×6.5mm)	QFN(5mm×6mm)
Configuration	Half bridge with driver	Single

4. 硬件方案

4.1. 硬件介绍

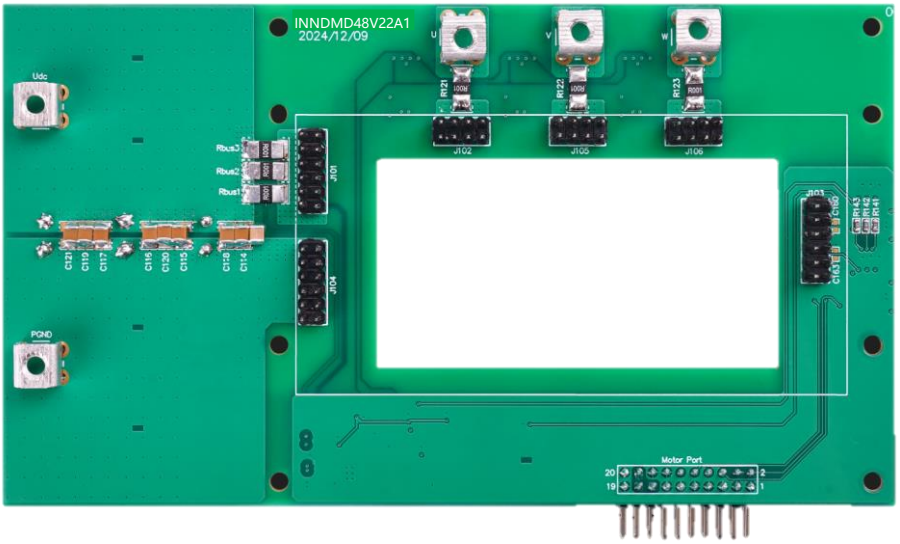


图 5 母板Top视图

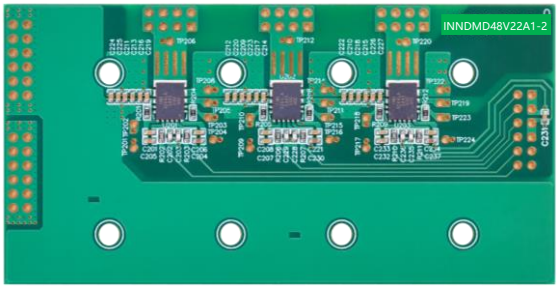


图 6 功率子板Top视图

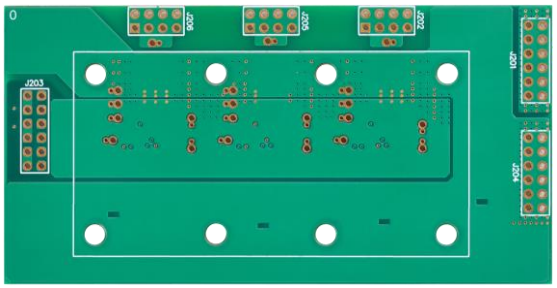


图 7 功率子板Bottom视图

INNDMD48V22A1母板与功率子板的图片如图 5和图 6所示，其具有以下功能电路：

1） 三相半桥：功率子板包含三相半桥，每一相由一颗具有集成栅极驱动器的100V半桥合封GaN器件ISG3204LA组成。

2） 电流采样：母板包含采样电阻及采样调理电路，采样三相相电流信号。

3） 辅源：母板包含高压辅源，可直接为驱动及采样电路供电。

4.2. 设计要点

GaN器件的栅极电容和米勒电容都比Si小，因此，GaN器件能够实现较快的开关速度。为避免快速开关过程中di/dt和dv/dt产生电压电流应力，需要优化栅极回路及功率回路的Layout以减小寄生参数的影响。ISG3204LA在内部基板设计中实现了优化的驱动和功率环路：（1）驱动与GaN器件的距离非常近，减小了环路寄生电感以减小驱动环路的噪声。（2）自举电容被合封在ISG3204LA内部，以减少驱动BST到Vcc的距离。（3）高低边GaN的距离保持最小以避免寄生电感导致的负压对驱动造成影响。

尽管ISG3204LA简洁的引脚分布使得其布局非常简便，优化的Layout仍能够最大化ISG3204LA的性能表现，具体Layout指南如下：

1. HGP(LGP)和HG(LG)引脚间可放置电阻用于调节开通速度，该电阻需要尽量靠近ISG3204LA。
2. Vcc引脚的去耦电容需要尽量靠近ISG3204LA。
3. 输入去耦电容需要尽量靠近Vin和PGND引脚摆放。

推荐的4层板Layout top层如下图8所示，详情参考附录C

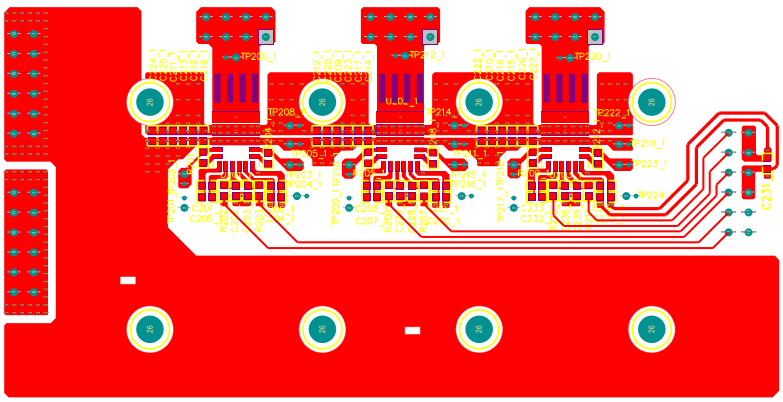
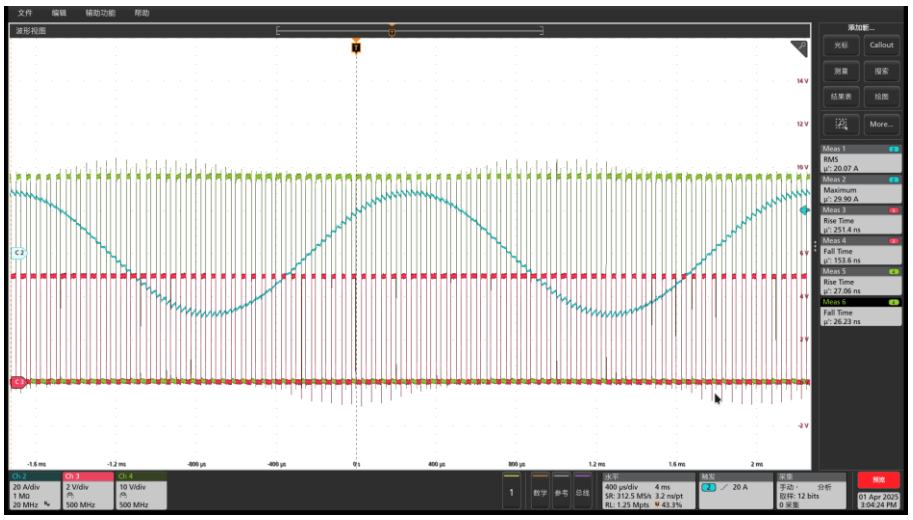


图 8 4层板推荐Layout（top层）

5. Demo测试结果

5.1. 整机测试结果

使用电抗台架测试GaN效率及温升表现，输入电压48V，开关频率20kHz，死区时间100ns，整机测试波形如下图所示，蓝色电流呈正弦波，红色低边驱动及绿色开关波形均正常。



测试条件

V_{in} = 48V_{dc}

F_{sw} = 20kHz

T_{dead} = 100ns

测试结果

CH2 电流

CH3 低边驱动

CH4 开关波形

波形均正常

5.2. 损耗测试结果

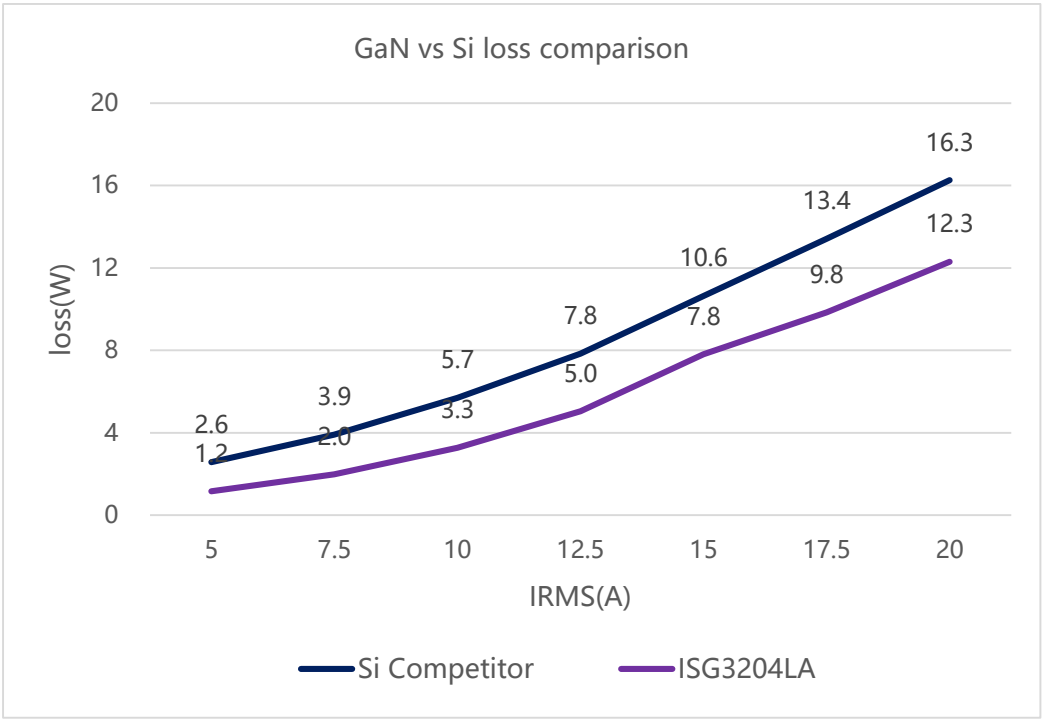


图 9 损耗对比曲线

ISG3204LA和类似导通电阻Si MOS损耗对比数据如图 9所示。开关频率设置为电机系统常用开关频率20kHz，Si死区时间设置为1us，GaN得益于较小的开关速度，死区时间设置为100ns。相电流有效值为5A时，GaN的系统损耗从Si的2.6W降低到1.2W，降低了53.9%；相电流有效值为20A时，GaN的系统损耗从Si的16.3W降低到12.3W，降低了24.5%。

5.3. 温度测试结果

自然冷却条件下INNDMD48V22A1不带散热器温度测试结果如图 10所示，相较于Si，GaN器件的温度在20kHz时降低了约20℃。

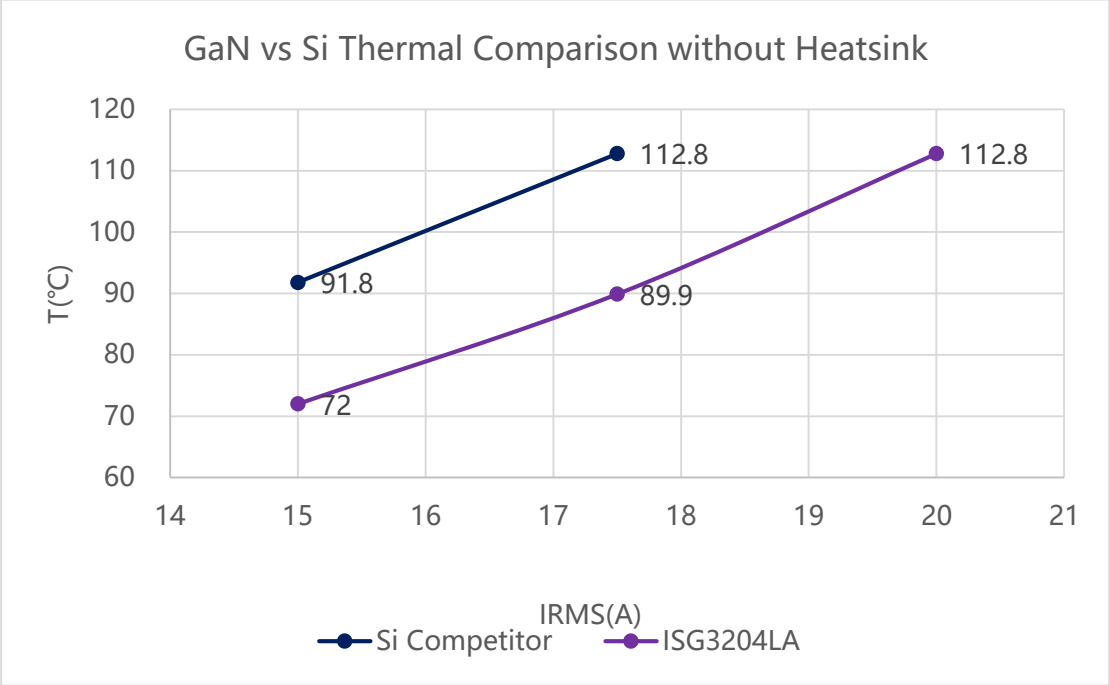


图 10 无散热器条件下温度对比

带散热器温度测试结果如图 11所示，散热器尺寸为70mmx35mmx25mm，散热器通过导热系数为4W/m℃的TIM连接到PCB底部。测试结果显示，相较于裸板，带散热器后ISG3204LA温度下降约30℃。开关频率为20kHz时，相电流有效值20A时，器件壳温约为81.1℃，开关频率提高到40kHz时，器件壳温提高约10℃。

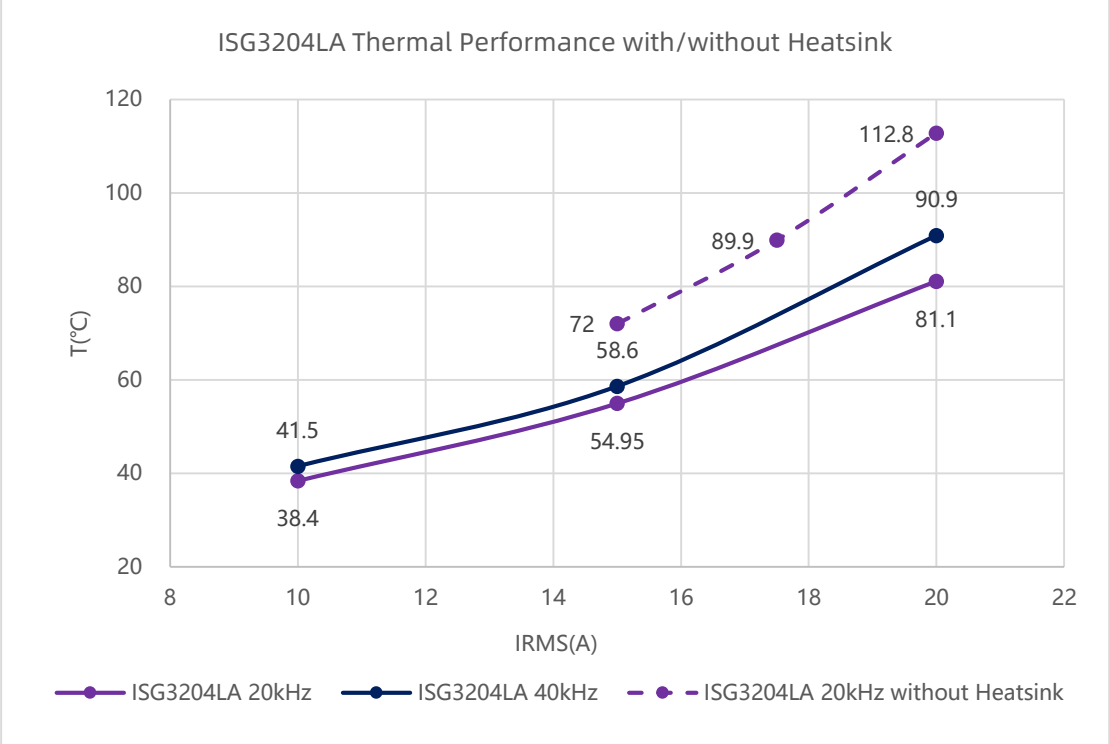


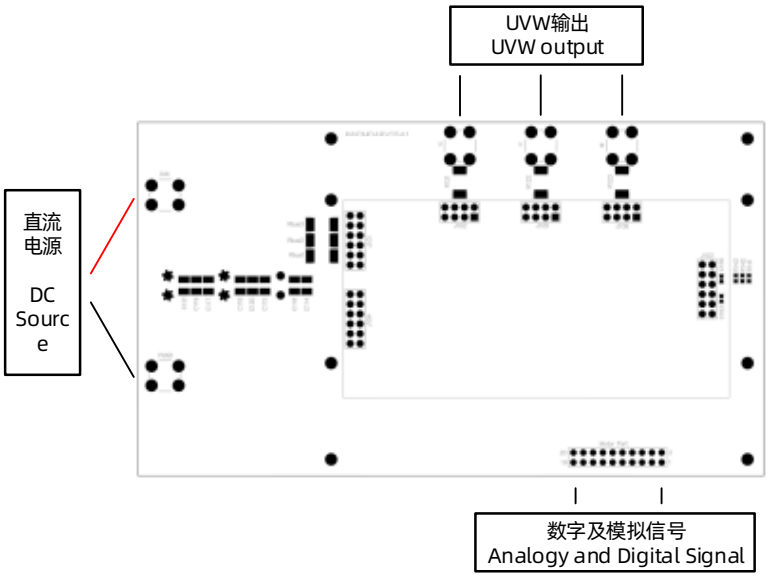
图 11 带散热器条件下温度对比

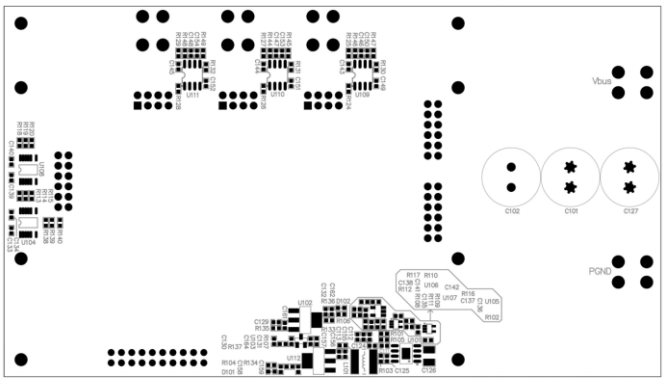
附录Appendix

附录 A. 测试指导 Testing Guidance

1、 测试点位置和接线示意图

Test point location and wiring diagram





附录图 1 系统接线图

附录表 1 数字及模拟接口定义

Pin	2	4	6	8	10	12	14	16	18	20
Description	PWMHU	PWMLU	PWMHV	PWMLV	PWMHW	PWMLW	GND	GND	IV	GND
Pin	1	3	5	7	9	11	13	15	17	19
Description	ENC_H1	ENC_H2	ENC_H3	GND	GND	GND	GND	IU	IW	GND
PWMXX	PWM signal									
ENC_HX	level shift for encoder									
IX	current sample signal									

2、 上/下电顺序

Power on/off sequence

1. 确保所有电源处于下电状态。

   Ensure all the power supplies are off.

2. 将电源连接至Demo板Vin及GND端口，如附录图 1所示（注意极性）

   Connect the DC voltage source to terminal Vin and common ground terminal GND, as shown in Appendix Figure1(note polarity).

3. 将电机或电抗负载连接至Demo板UVW端口，如附录图 1所示。

   Connect the Motor or RL load to UVW output terminal, as shown in Figure.

4. 将控制器PWM信号，模拟信号及GND连接至Demo板对应端口，如附录表 1所示。

   Connect the controller to demo board including PWM signals, analog signals and GND.

5. 检查控制器输出及反馈信号波形，确保各波形与理论一致。

   Turn on the controller and output the PWM signal with the required duty ratio and frequency, ensure PWM input of each ISG3204 is same as controller output.

6. 缓慢增加电源输出电压，并确保电源输出电压不超过60V。

   Make sure the initial input supply voltage is 0 V, turn on the power and slowly increase the voltage to the desired value (do not exceed the absolute maximum voltage).

7. 测试各关键节点波形及器件性能。

   Ensure three-phase SW waveforms are correct before controlling motor as wanted.

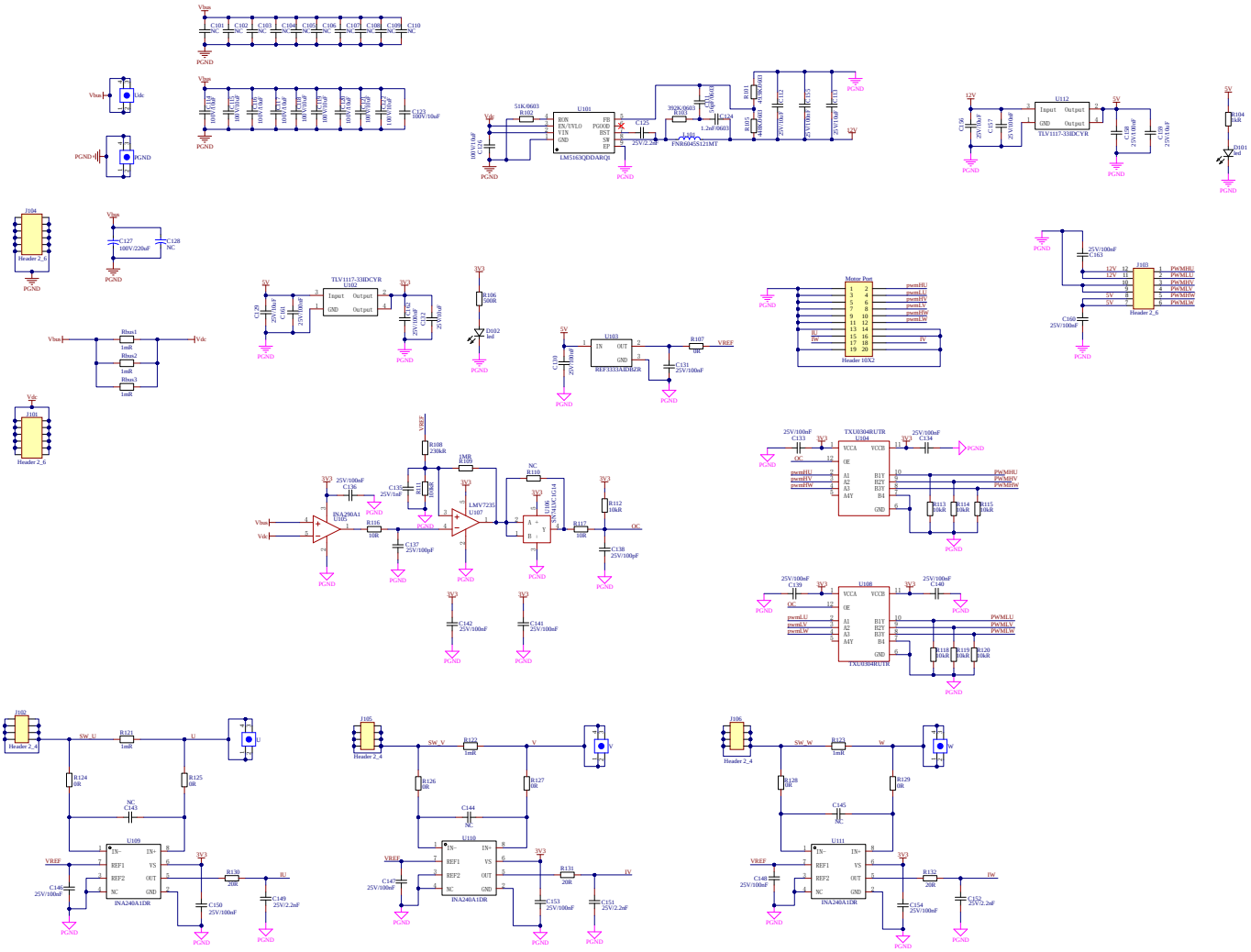
8. 关闭电源。

   Turn off the DC voltage source if all measurement is done.

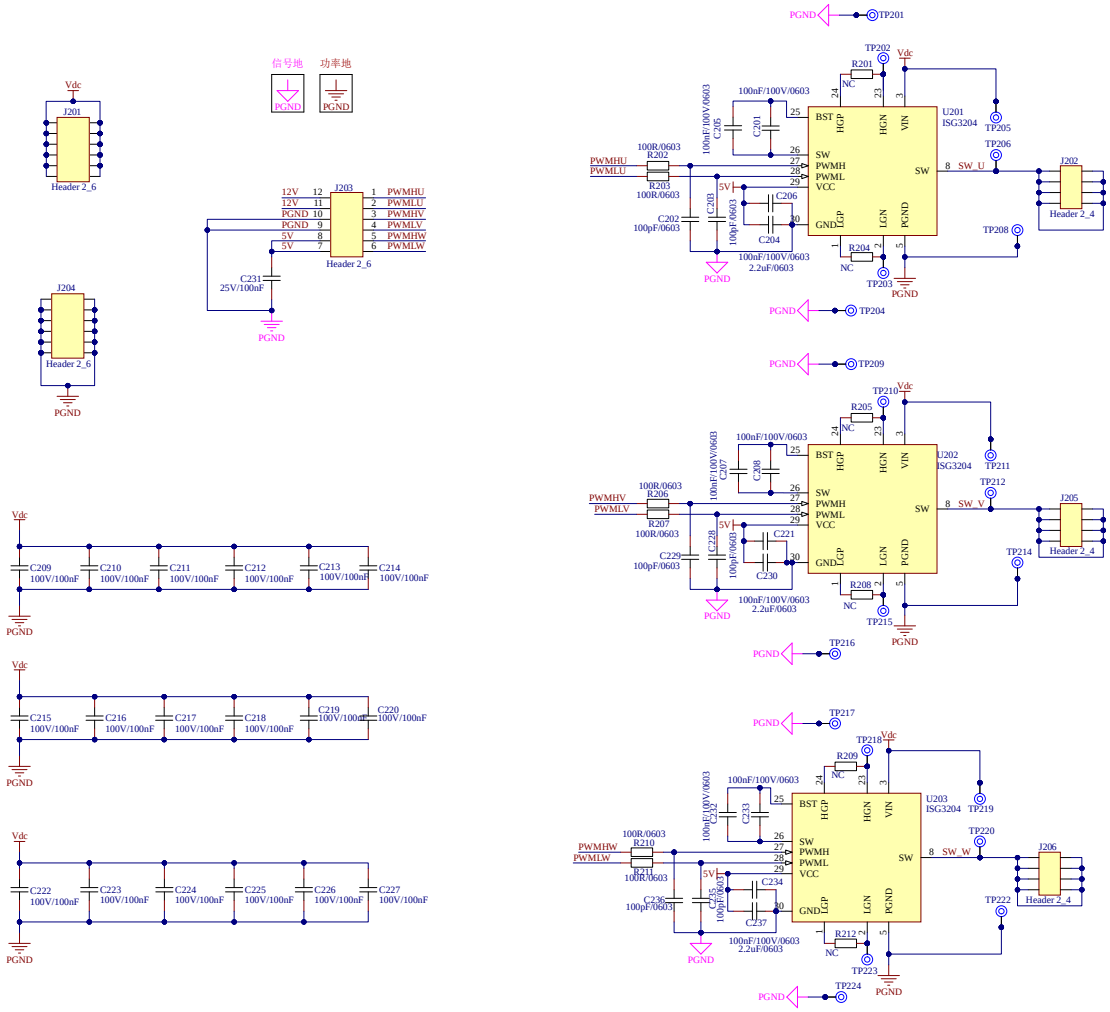
9. 关闭控制器。

   Turn off the controller.

附录 B. 原理图

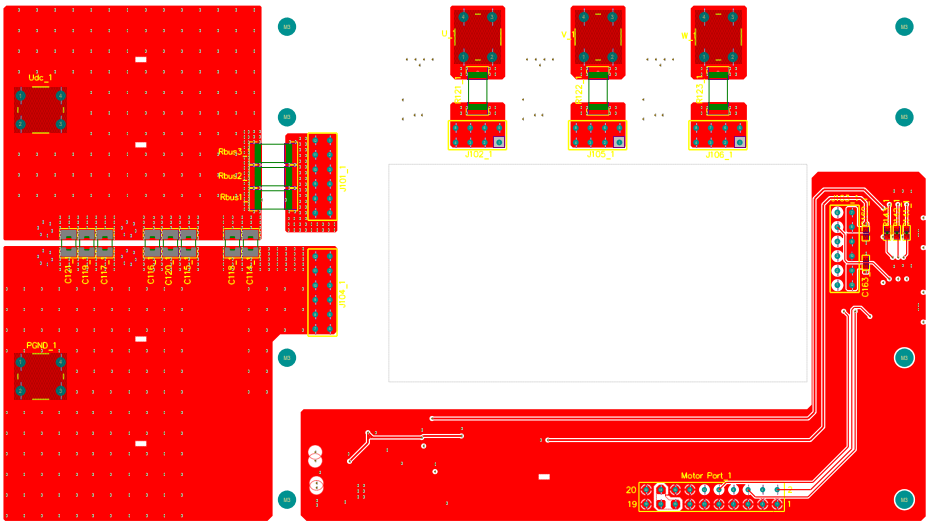


附录图 2 INNDMD48V22A1电路原理图（母板）

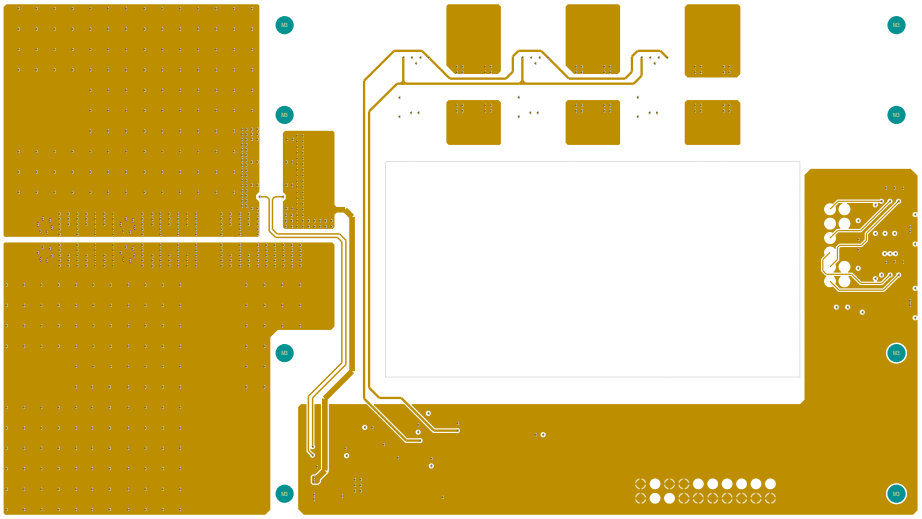


附录图 3 INNDMD48V22A1电路原理图（子板）

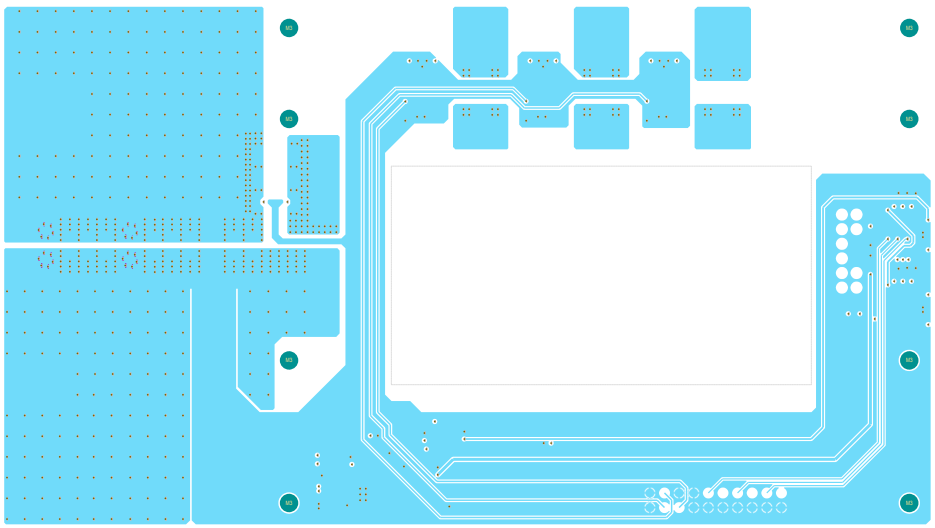
附录 C. PCB Layout



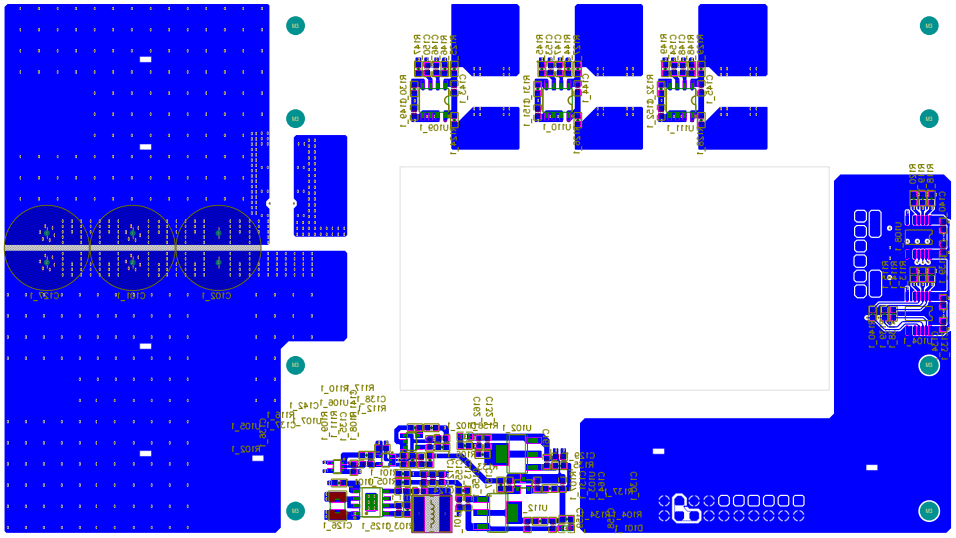
附录图 4 母板Top层



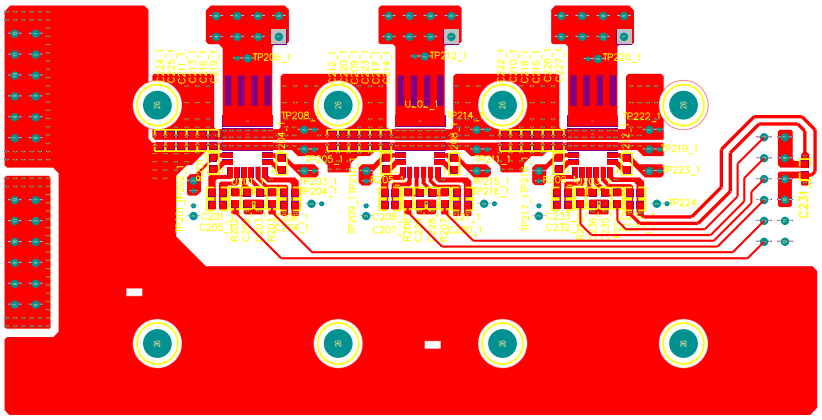
附录图 5 母板Mid1层



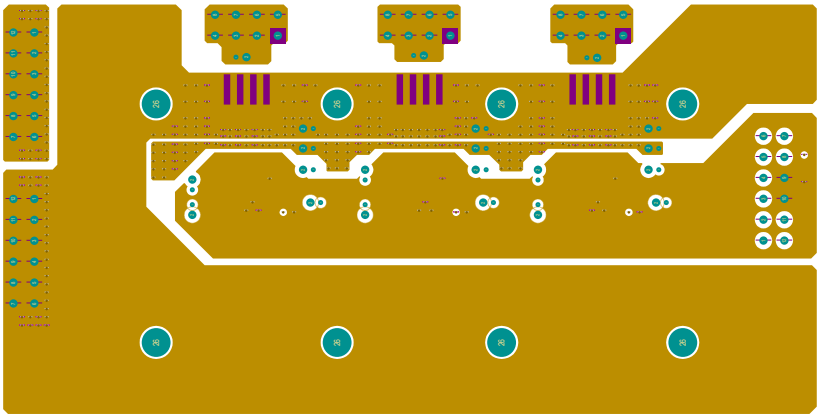
附录图 6 母板Mid2层



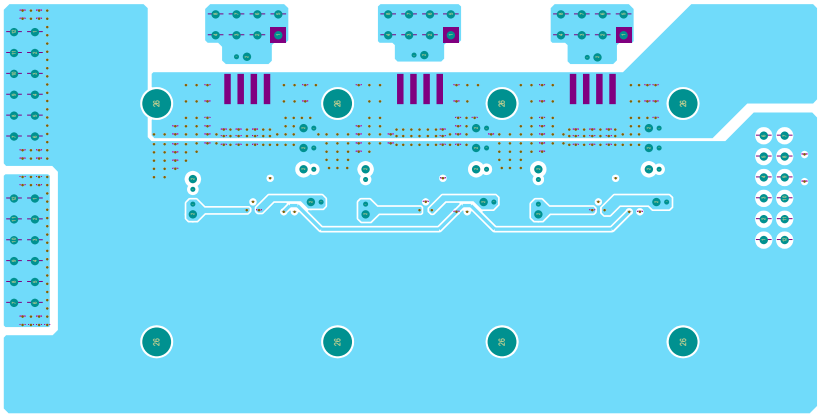
附录图 7 母板Bottom层



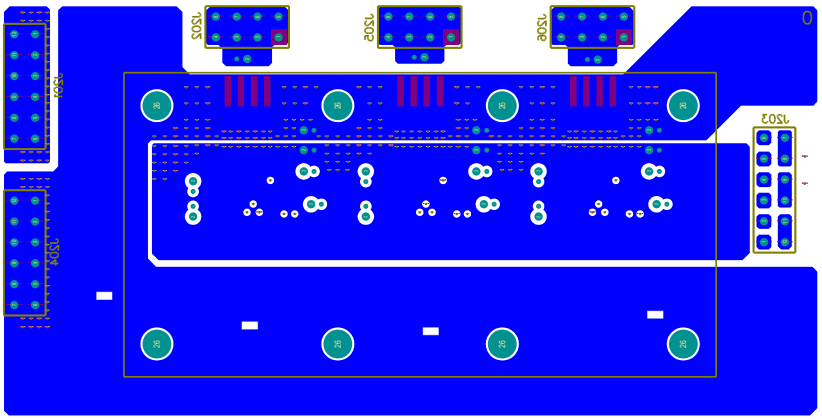
附录图 8 子板Top层



附录图 9 子板Mid1层



附录图 10 子板Mid2层



附录图 11 子板Bottom层

附录 D. BOM

Part Number	Manufacture	Description	Designator	Footprint	Quantity
Motherboard					
C0603X560K3HAC7867	KEMET	CAP, 56p/25V, ±10%, X8R	C111	C0603	1
GRM188R61E106KA73D	muRata	CAP, 10u/25V, ±5%, C0G	C112, C113, C129, C132, C156, C159	C0603	6
GRM32EC72A106KE05L	muRata	CAP,10u/100V, ±10%, X7S	C114, C115, C116, C117, C118, C119, C120, C121, C122, C123, C126	C1210	11
CC0603KRX7R9BB332	YAGEO	CAP, 3.3n/25V, ±5%, NP0	C124	C0603	1
CC0603KRX7R8BB222	YAGEO	CAP, 2.2n/25V, ±10%, X7R	C125, C149, C151, C152	C0603	4
ERJ1KM221W20OT	AISHI	CAP,220u/100V E-cap	C127,C128	C2-12r5-5r0	1
CC0603KRX7R8BB104	YAGEO	CAP,100n/25V, ±10%, X7R	C130, C131, C133, C134, C136, C139, C140, C141, C142, C146, C147, C148, C150, C153, C154, C155, C157, C158, C160, C161, C162, C163	C0603	22
CC0603KRX7R8BB102	YAGEO	CAP,1n/25V, ±10%, X7R	C135	C0603	1
CC0603JRNPO8BN101	YAGEO	CAP,100p/25V, ±5%, NP0	C137, C138	C0603	2
RC0603FR-0749K9L	YAGEO	RES, 49.9kR, ±1%, 99mW	R101	R0603	1
RC0603FR-07100KL	YAGEO	RES, 100kR, ±1%, 100mW	R102	R0603	1
RC0603DR-07226KL	YAGEO	RES, 226kR, ±1%, 100mW	R103	R0603	1
RC0603FR-071KL	YAGEO	RES, 1kR, ±1%, 100mW	R104	R0603	1
RT0603BRD07453KL	YAGEO	RES, 453kR, ±1%, 100mW	R105	R0603	1
RT0603BRC07500RL	YAGEO	RES, 500R, ±1%, 100mW	R106	R0603	1
RC0603FR-070RL	YAGEO	RES, 0R, ±1%, 100mW	R107, R124, R125, R126, R127, R128, R129	R0603	7
RT0603BRD07226KL	YAGEO	RES, 226kR, ±1%, 100mW	R108	R0603	1
RC0603FR-071M	YAGEO	RES, 1MR, ±1%, 100mW	R109	R0603	1
RC0603FR-07100KL	YAGEO	RES, 100kR, ±1%, 100mW	R111	R0603	1
RC0603FR-0710KL	YAGEO	RES, 10kR, ±1%, 100mW	R112, R113, R114, R115, R118, R119, R120	R0603	7
RC0603FR-0710RL	YAGEO	RES, 10R, ±1%, 100mW	R116, R117	R0603	2
HoJLR2512-3W-1mR	Milliohm	RES, 1mR, ±1%, 3W	R121, R122, R123, Rbus1, Rbus2, Rbus3	R2512	6
RC0603FR-0720RL	YAGEO	RES, 20R, ±1%, 100mW	R130, R131, R132	R0603	3
NCD0603B1		LED	D101, D102	led0603	2
FNR6045S121MT	cjiang	Inductor,120uH,±20%,940mA	L101	NR6045	1
LM5163QDDARQ1	TI	Buck	U101	ESOP_8	1
TLV1117-33IDCYR	TI	LDO	U102,	SOT_223	1
TLV1117-50IDCYR	TI	LDO	U112	SOT_223	1

REF3333AIDBZR	TI	Voltage Reference	U103	SOT_23_3	1
TXU0304RUTR	TI	Buffer	U104, U108	UQFN_12	2
INA290A1	TI	Current Sense Amplifier	U105	SC-70-5_L2.1	1
SN74LVC1G14	TI	Schmitt-Trigger Inverter	U106	SOT_23_5	1
LMV7235	TI	comparator	U107	SC_70_5	1
INA240A1DR	TI	Current Sense Amplifier	U109, U110, U111	SOIC_8	3
Header 2*6	Header		J101, J103, J104	Header 2*6	3
Header 2*4	Header		J102, J105, J106	Header 2_4	3
Header 2*5	Header		Motor Port	HDR2X10	1
Terminal			PGND, U, Udc, V, W	Terminal	5
NC			C101, C102, C103, C104, C105, C106, C107, C108, C109, C110	C1210	10
NC			C143, C144, C145	C0603	3
NC			R110	R0603	1
Daughterboard					
CC0603KRX7R0BB104	YAGEO	CAP,100n/100V, ±10%, X7R	C201, C205, C206, C207, C208, C221, C232, C233, C234， C209, C210, C211, C212, C213, C214, C215, C216, C217, C218, C219, C220, C222, C223, C224, C225, C226, C227	C0603	27
CC0603JRNPO8BN101	YAGEO	CAP,100p/25V, ±5%, NP0	C202, C203, C228, C229, C235, C236	C0603	6
CC0603KRX5R8BB225	YAGEO	CAP,2.2u/25V, ±10%, X5R	C204, C230, C237	C0603	3
CC0603KRX7R8BB104	YAGEO	CAP,100n/25V, ±10%, X7R	C231	C0603	1
RC0603FR-07100RL	YAGEO	RES, 100R, ±1%, 100mW	R202, R203, R206, R207, R210, R211	R0603	6
ISG3204LA	Innoscience	GaN	U201, U202, U203	FCLGA	3
Header 2*6			J201, J203, J204	Header 2*6	3
Header 2*4			J202, J205, J206	Header 2_4	3
TP			TP201, TP202, TP203, TP204, TP205, TP206, TP208, TP209, TP210, TP211, TP212, TP214, TP215, TP216, TP217, TP218, TP219, TP220, TP222, TP223, TP224	TP	21
NC			R201, R204, R205, R208, R209, R212	C0603	6

历史版本

日期	版本	描述	编写
2025/05/29	1.0	第一版	AE 团队

Note:
There may be a dangerous voltage on the demo board, and exposure to high voltage may lead to safety problems such as injury or death.
Proper operating and safety procedures must be adhered to and used only for laboratory evaluation demonstrations and not directly to end-user equipment.

Reminder:
This product contains parts that are susceptible to electrostatic discharge (ESD). When using this product, be sure to follow antistatic procedures.

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