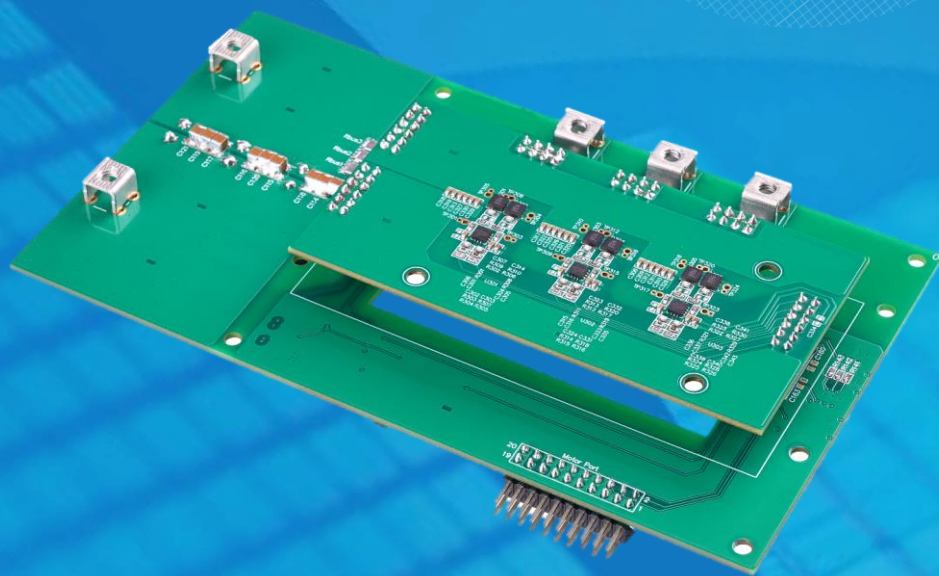


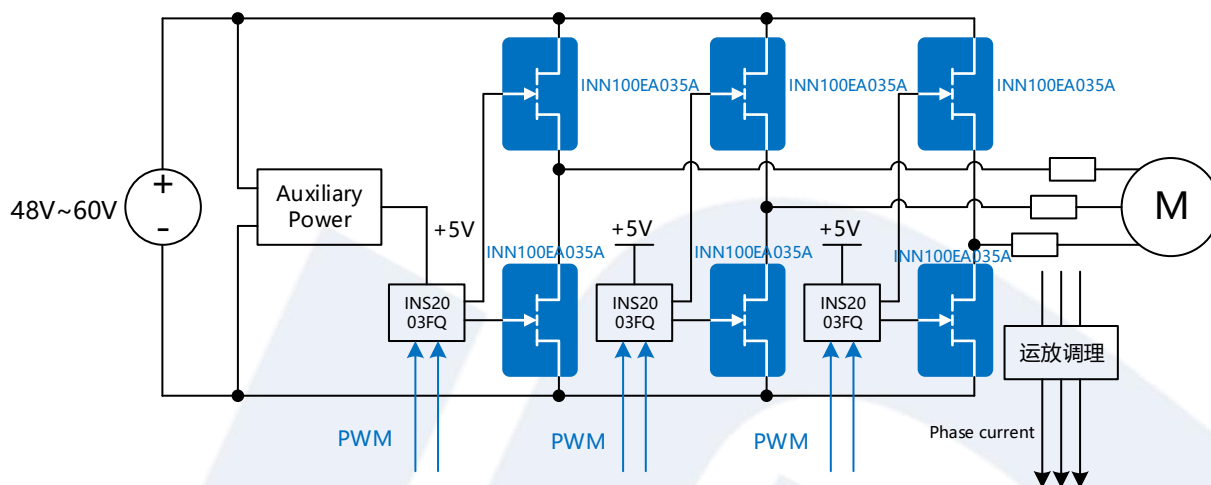
# INN DMD48V25A1

Demo Manual  
48V 25A Motor Drive  
Featuring INN100EA035A



## 48V 25A 电机驱动

## ● 三相电机驱动方案

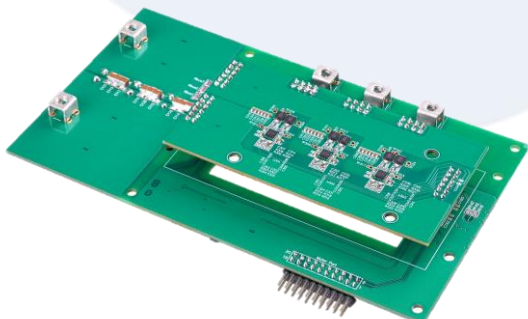


INNDMD48V25A1 功率管采用 INN100EA035A，驱动采用 INS2003FQ，输入  $48V_{dc}-60V_{dc}$ ，持续输出相电流峰值 25A，能够满足 1kW 电机驱动应用需求。INNDMD48V25A1 包含一块母版和一块功率子板，两者可以组装在一起测试 INN100EA035A 在电机驱动应用中的性能。

## ● 重点器件

- INN100EA035A\*6
- INS2003FQ\*3

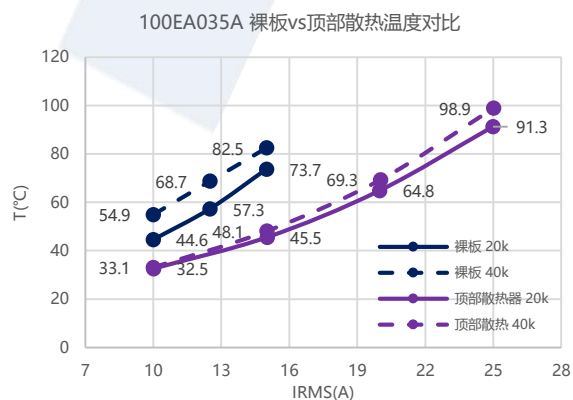
## ● 实物图



## ● 应用场景

- 机器人
- 无人机

## ● 测试数据



目 录

- 1. 概述 ..... 1
  - 1.1. 引言 ..... 1
  - 1.2. 应用场景..... 1
- 2. 关键参数..... 2
- 3. Demo方案..... 3
  - 3.1. 系统 ..... 3
  - 3.2. GaN的应用优势..... 3
  - 3.3. 重点器件介绍 ..... 4
    - 3.3.1. INN100EA035A ..... 4
    - 3.3.2. INS2003FQ..... 5
- 4. 硬件方案..... 6
  - 4.1. 硬件介绍..... 6
  - 4.2. 设计要点..... 7
    - 4.2.1. GaN Layout设计 ..... 7
- 5. Demo测试结果 ..... 8
  - 5.1. 整机测试结果 ..... 8
  - 5.2. 效率测试结果 ..... 8
  - 5.3. 温度测试结果 ..... 9
- 附录 Appendix ..... 11
  - 附录 A. 测试指导 Testing Guidance..... 11
  - 附录 B. 原理图..... 13
  - 附录 C. PCB Layout..... 15
  - 附录 D. BOM..... 18
- 历史版本..... 21

## 1. 概述

### 1.1. 引言

INNDMD48V25A1 功率管采用INN100EA035A，驱动采用INS2003FQ，输入 $48V_{dc}$ - $60V_{dc}$ ，持续输出相电流峰值25A，能够满足1kW电机驱动应用需求。INNDMD48V25A1包含一块母版和一块功率子板，两者可以组装在一起测试INN100EA035A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 °C)

| Symbol           | Parameter | Min | Nom  | Max | Unit            |
|------------------|-----------|-----|------|-----|-----------------|
| V <sub>in</sub>  | 输入电压      | 24  | 48   | 60  | V <sub>dc</sub> |
| F <sub>s</sub>   | 开关频率      | 0   | 20   | 100 | kHz             |
| T <sub>d</sub>   | 死区时间      | 20  | 100  |     | ns              |
| I <sub>OUT</sub> | 持续输出相电流   |     | 25   |     | A               |
| P <sub>OUT</sub> | 持续输出功率    |     | 1000 |     | W               |

### 3. Demo方案

#### 3.1. 系统

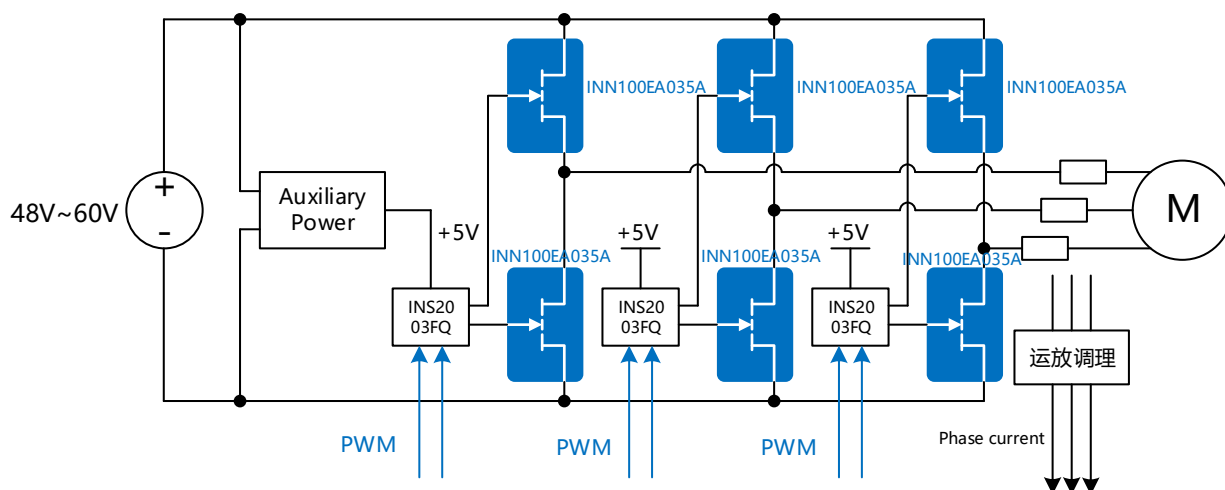


图 1 INNDMD48V25A1系统框图

INNDMD48V25A1包含三相功率半桥，每一相使用一颗100V半桥驱动INS2003FQ及两颗100V GaN器件INN100EA035A。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。

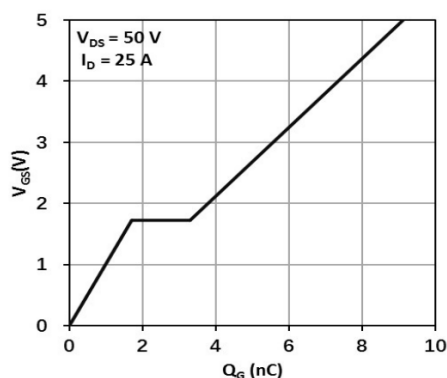


图 2 GaN典型栅极电荷

■ 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。

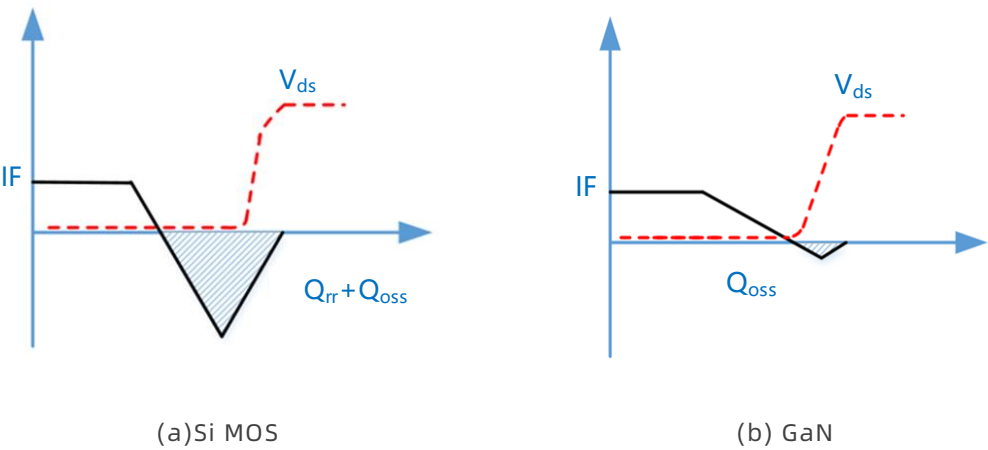


图 3 器件关断波形

3.3. 重点器件介绍

3.3.1. INN100EA035A

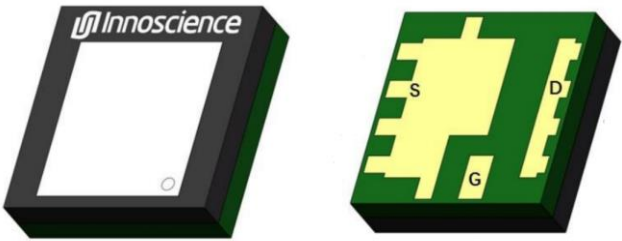


图 4 分立GaN器件100EA035A

INN100EA035A是英诺赛科的一款采用En-LGA 3mm x 3mm封装的100V 3.5mΩ硅基氮化镓增强型功率晶体管。INN100EA035A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，INN100EA035A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                 | INN100EA035A | xxx034xxxxxx |
|---------------------------|--------------|--------------|
| $R_{ds(on),max}(m\Omega)$ | 3.5          | 3.4          |
| $Q_g(nC)$                 | 7.6(0.21)    | 37           |
| $Q_{oss}(nC)$             | 42(x0.46)    | 91           |

|                         |              |       |
|-------------------------|--------------|-------|
| $Q_{rr}(nC)$            | 0(x0)        | 42    |
| $FOM(R_{on} * Q_g)$     | 31.9(x0.25)  | 125.8 |
| $FOM(R_{on} * Q_{oss})$ | 176.4(x0.57) | 309.4 |
| Package                 | En-FCLGA     | QFN   |

### 3.3.2. INS2003FQ



图 5 100V GaN驱动 INS2003FQ

INS2003FQ是英诺赛科推出的一款100V GaN专用半桥驱动器，相较于传统Si MOS驱动器，其针对GaN驱动特性进行了优化以适应GaN器件的需求。INS2003FQ使用智能自举开关对上管BST电容充电，这使得死区期间内BST电容不会出现过充电进而导致器件过压。INS2003FQ输入具有互锁功能，即使PWM输入死区时间设置为零，器件仍不会出现直通。INS2003FQ高低边输入具有独立的通道，这使得其具有极高的自由度。INS2003FQ驱动输出上拉和下拉具有独立引脚，这使得其开关速度能够分别调节，配合其本身较强的驱动能力，使得其非常适合大功率高开关频率应用场景。

## 4. 硬件方案

## 4.1. 硬件介绍

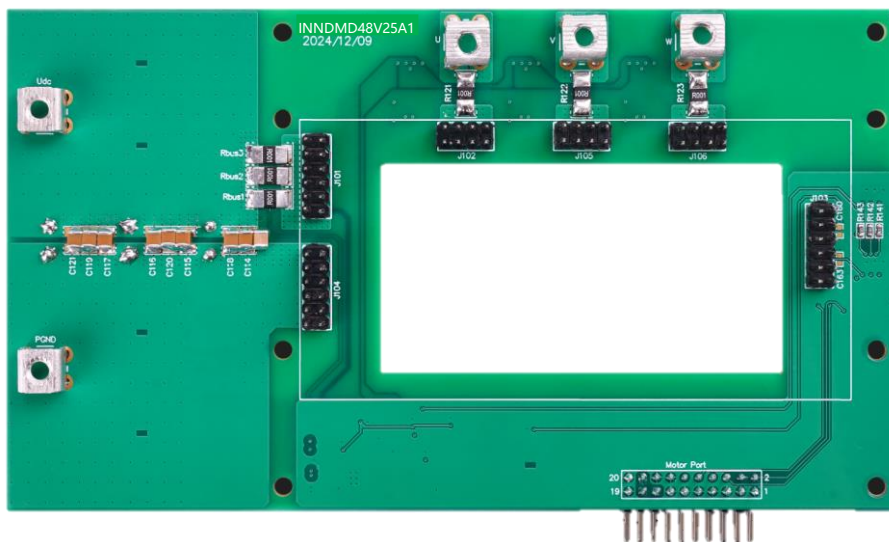


图 6 母板Top视图

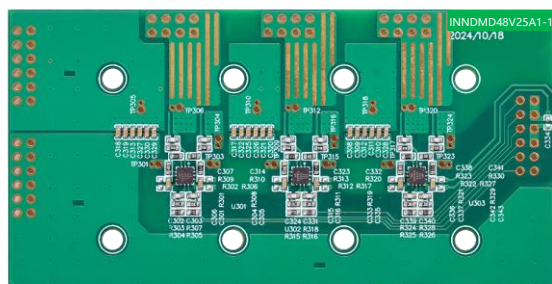


图 7 功率子板Top视图

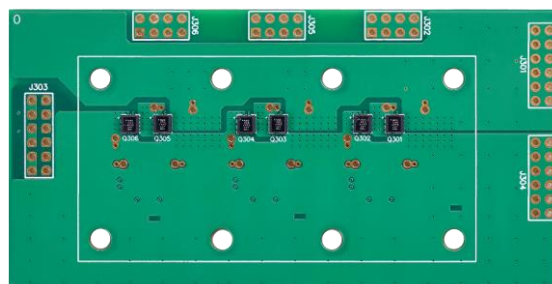


图 8 功率子板Bottom视图

INNDMD48V25A1母板与功率子板的图片如图6和图7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，每一相由一颗半桥驱动INS2003FQ和两颗GaN器件INN100EA035A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：母版包含高压辅源，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。为避免大 $di/dt$ 和 $dv/dt$ 产生大电压电流应力，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。

### 4.2.1. GaN Layout设计

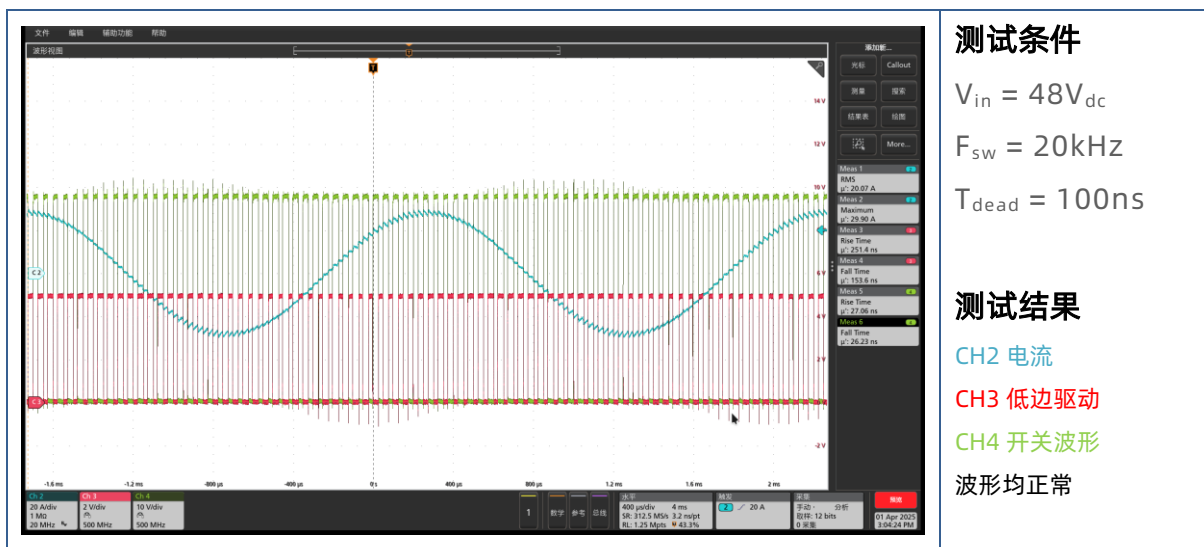
共源电感CSI、功率回路、驱动回路对GaN的工作性能都有影响，如何减小这三部分的寄生电感，是GaN Layout设计的重要关注点。在GaN的Layout设计中，我们应尽量遵循以下几个设计原则：

- 1) 共源电感CSI越小越好。
- 2) 功率回路越小越好。在大容量电容距离GaN器件的换流回路相对远了的情况下，就近增加高频无感贴片电容以减小功率换流回路。
- 3) 驱动回路越小越好，驱动电路尽量靠近GaN器件。
- 4) 驱动回路和功率回路尽量采用磁场自消除的布局和走线方式以减小回路电感。
- 5) 驱动回路和功率回路分开，避免驱动回路与功率回路的电路和空间耦合，以避免功率回路对驱动回路的干扰。

## 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。



### 5.2. 效率测试结果

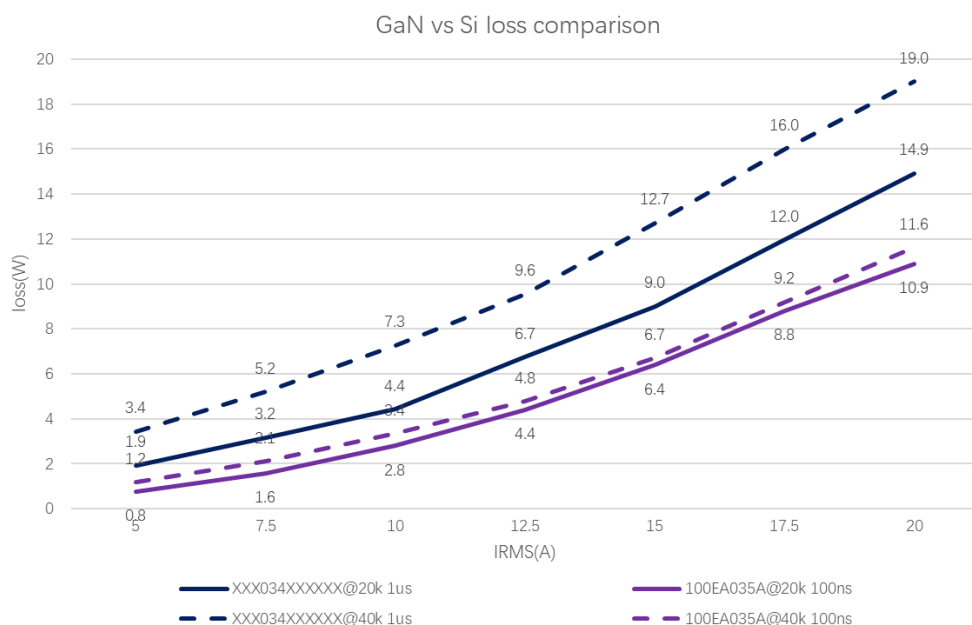


图 9 损耗对比曲线

INN100EA035A和类似参数Si MOS损耗对比数据如图 9所示，当开关频率设置为

20kHz时，相电流有效值为5A时，GaN的系统损耗从Si的1.9W降低到0.8W，降低了58%；相电流有效值为20A时，GaN的系统损耗从Si的14.9W降低到10.9W，降低了27%。当开关频率设置为40kHz时，相电流有效值为20A时，GaN的系统损耗从Si的19W降低到11.6W，降低了39%。开关频率从20kHz提高到40kHz，GaN的系统损耗增量从Si的4.1W降低到0.7W，降低了17%。

### 5.3. 温度测试结果

使用热成像仪测试无散热器时INNDMD48V25A1器件壳温，如图 10所示电流有效值为15A时，三相半桥温度基本均匀，中间相由于热量集中温度最高，最高温度约为73℃。

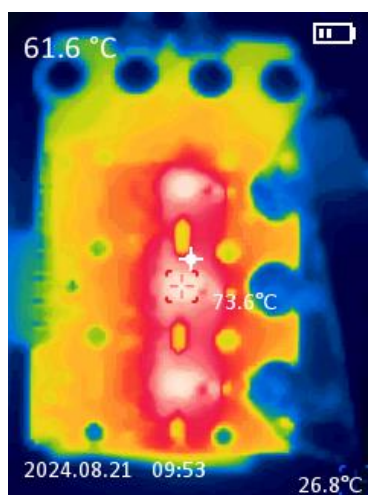


图 10 整机温度测试图片

自然冷却条件下INNDMD48V25A1不带散热器温度测试结果如图 11所示，相较于Si，GaN器件的温度在20kHz和40kHz下分别降低了14℃和30℃。

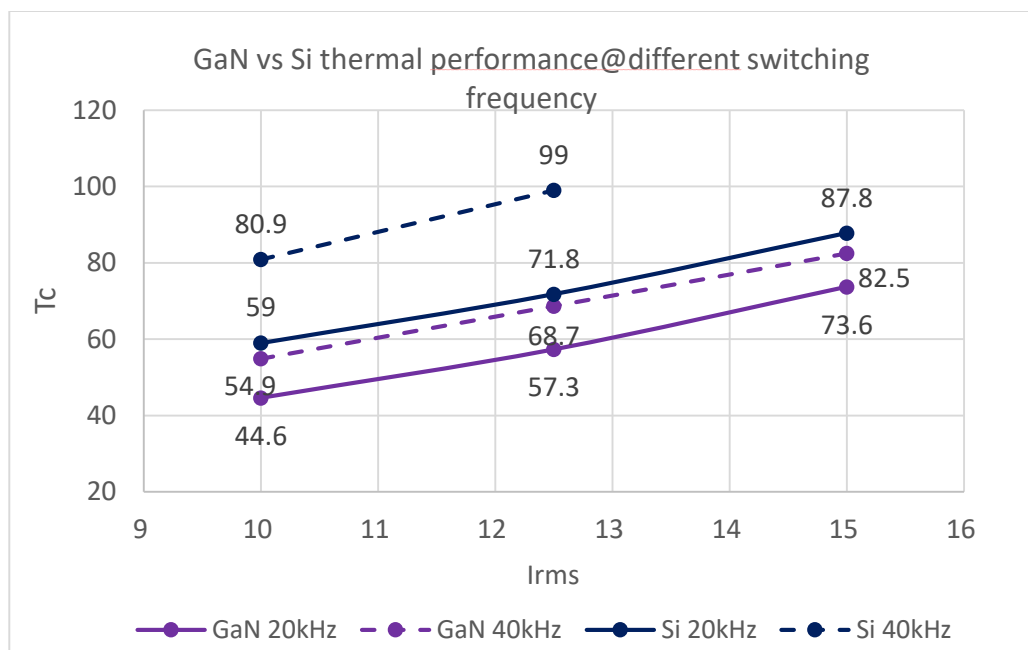


图 11 无散热器条件下温度对比

带散热器温度测试结果如图 12 所示，散热器尺寸为 70mmx35mmx25mm，散热器通过导热系数为 4W/m°C 的 TIM 连接到 INN100EA035A 顶部。测试结果显示，相较于 Si 竞品，GaN 相同电流负载情况下器件温度降低了 28°C，最大输出电流有效值扩展了 7.5A。

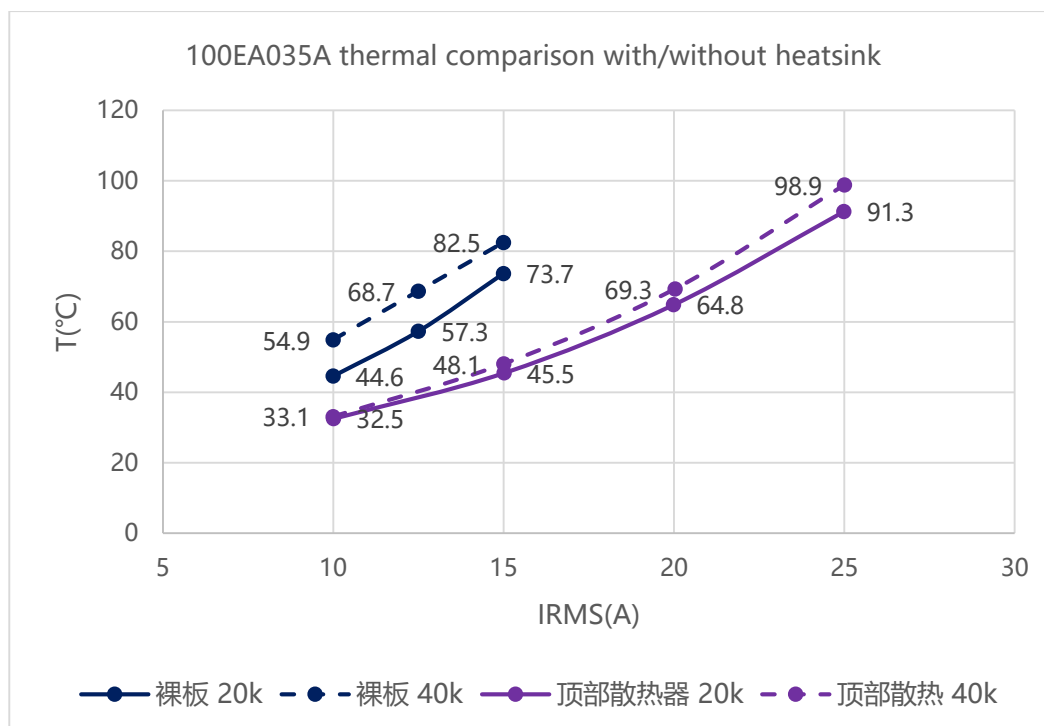


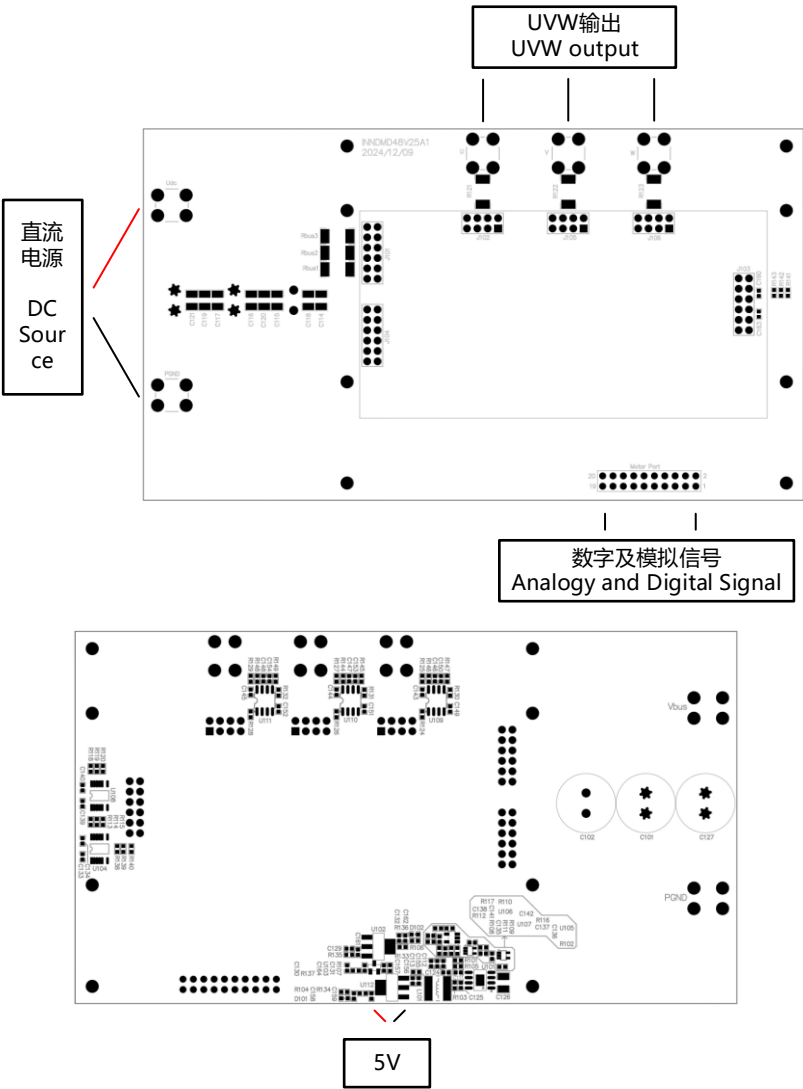
图 12 带散热器条件下温度对比

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，连接5V辅源供电，如附录图 1所示（注意极性）

Connect the DC voltage source to terminal Vin and common ground terminal GND, connect the 5V auxiliary power supply, 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.

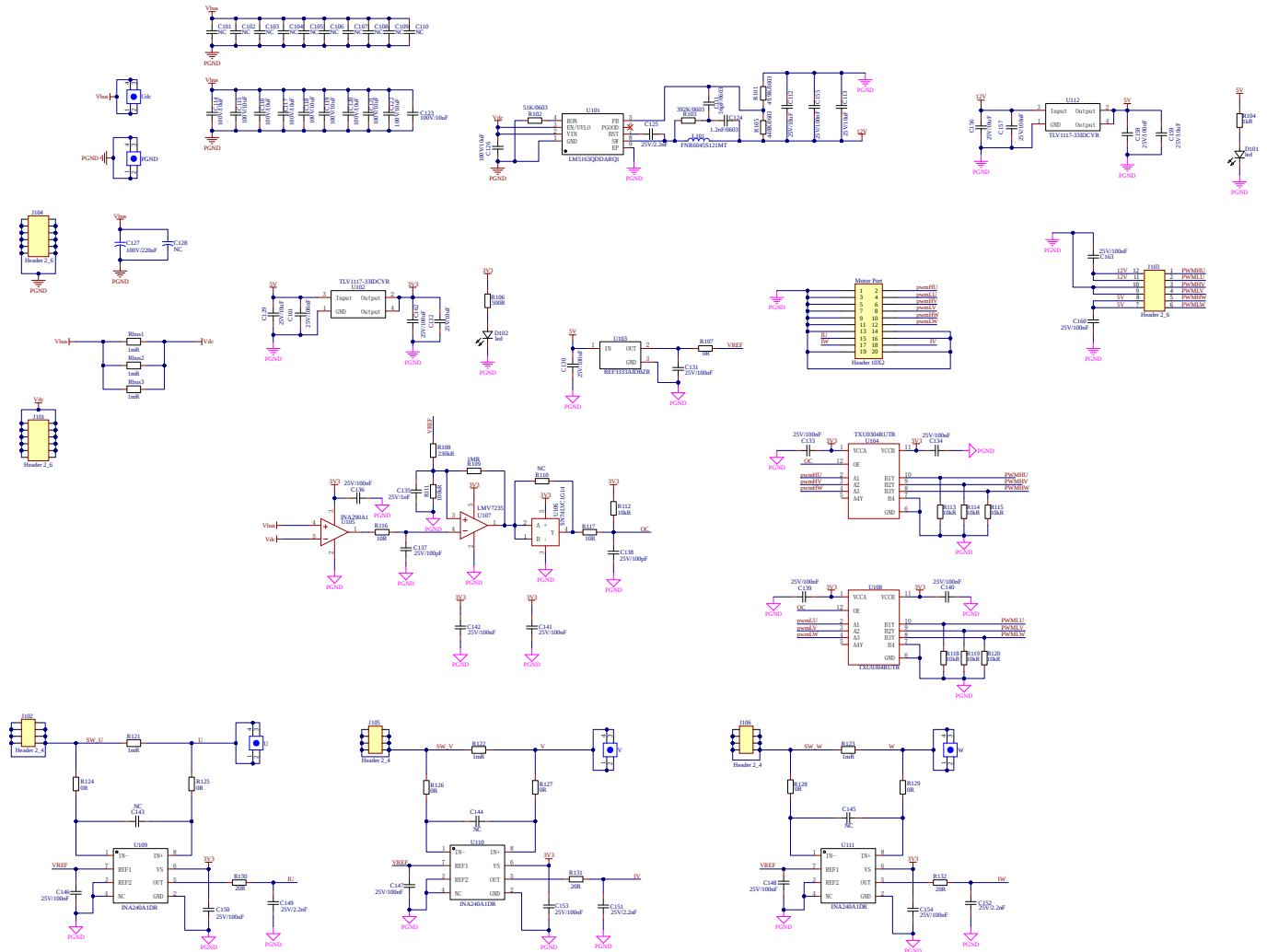
8. 关闭电源。

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

9. 关闭控制器。

Turn off the controller.

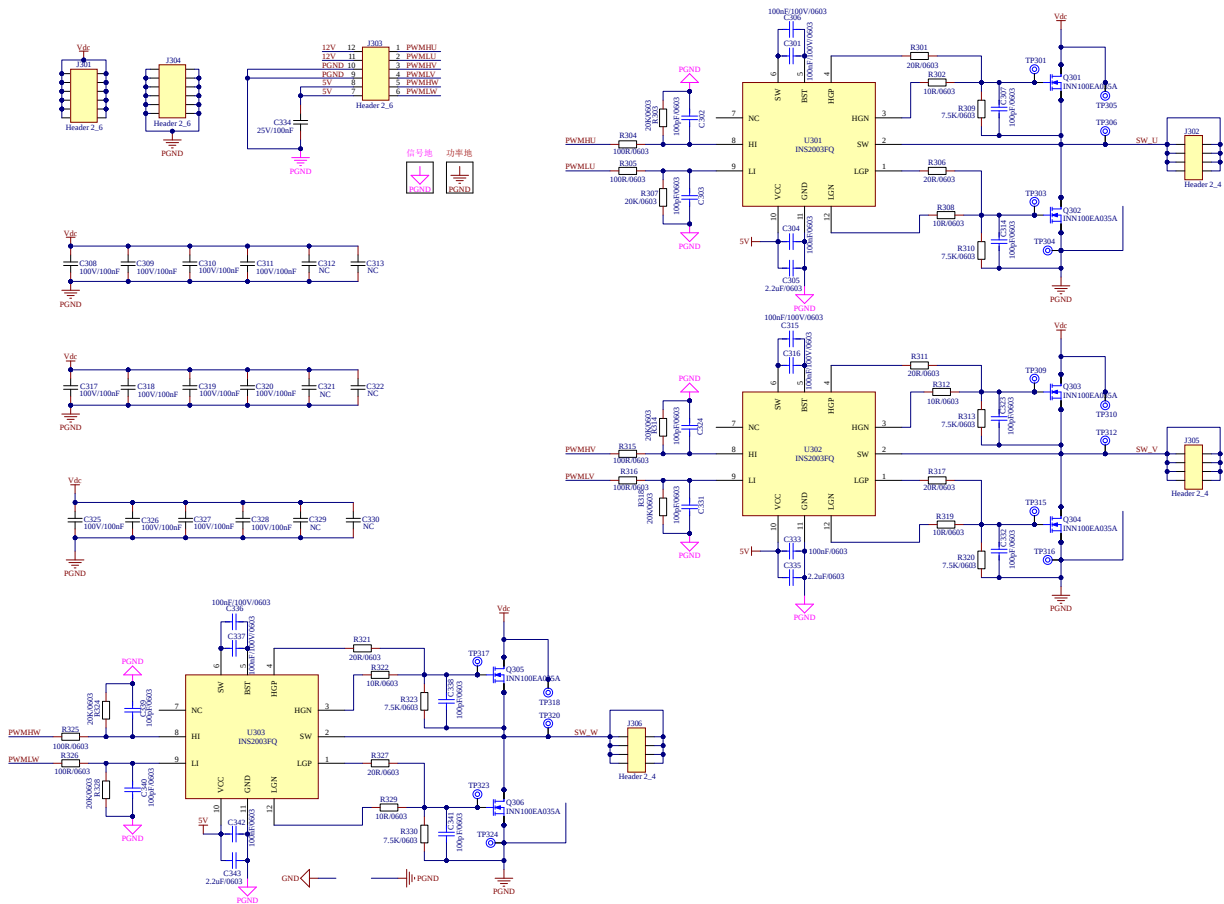
## 附录 B. 原理图



附录图 2 INNDMD48V25A1电路原理图（母板）

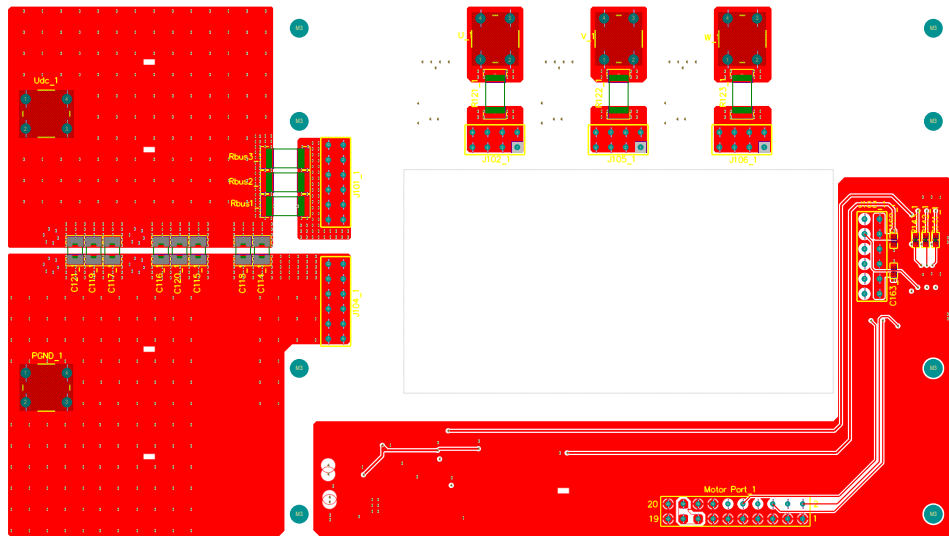
# DB042- INNDMD48V25A1

48V 25A Motor Drive Featuring INN100EA035A Demo

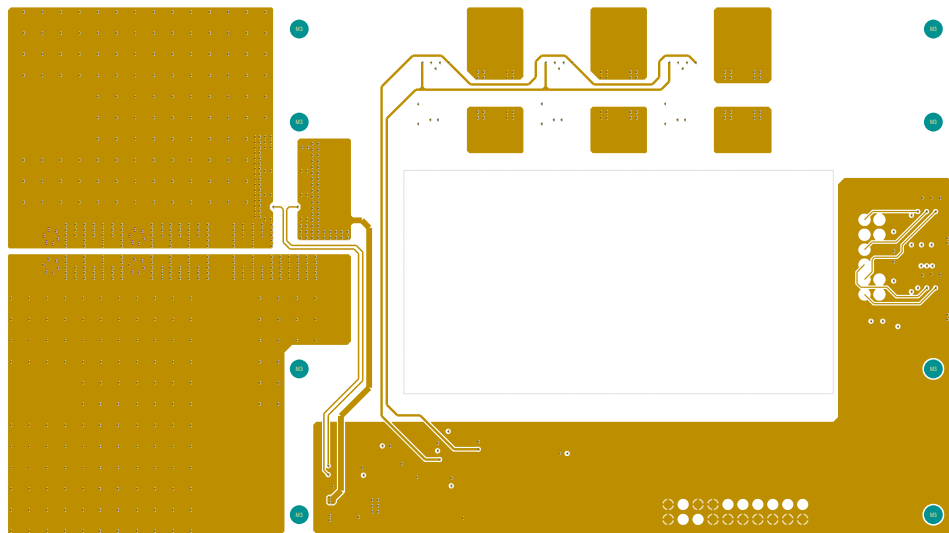


附图 3 INNDMD48V25A1 电路原理图（子板）

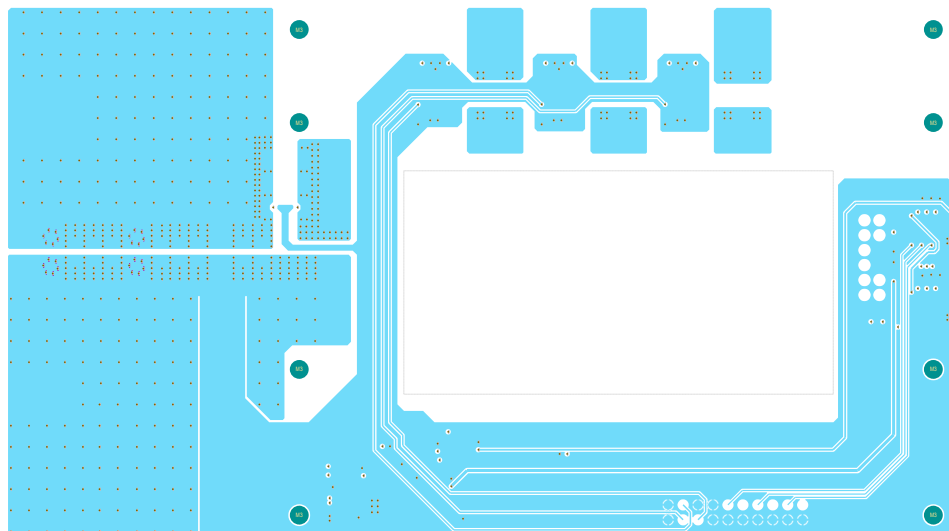
## 附录 C. PCB Layout



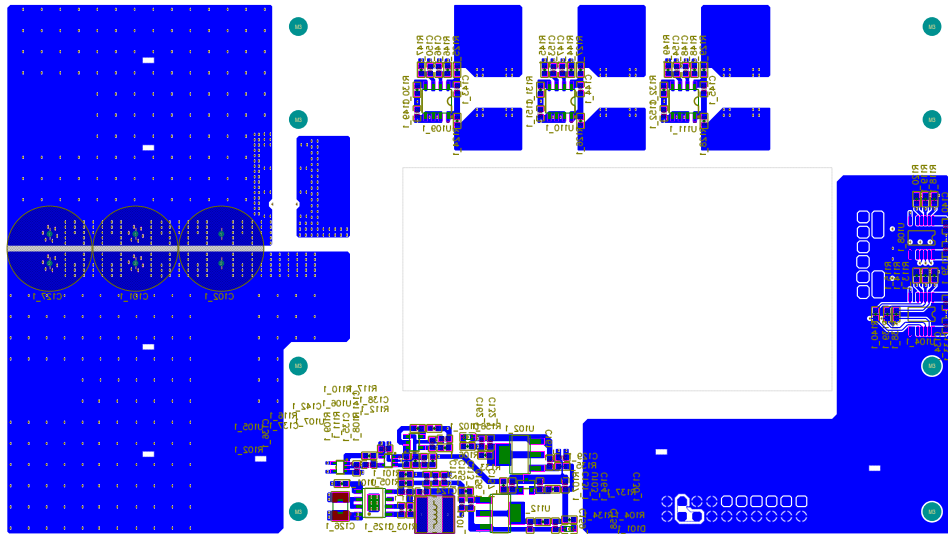
附录图 4 母板Top层



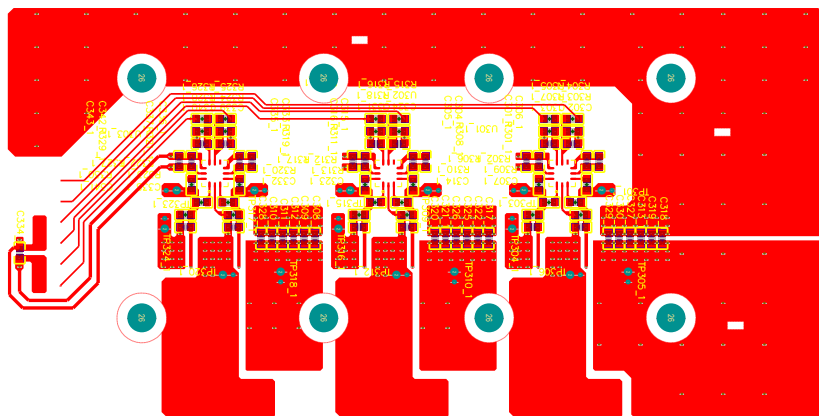
附录图 5 母板Top层



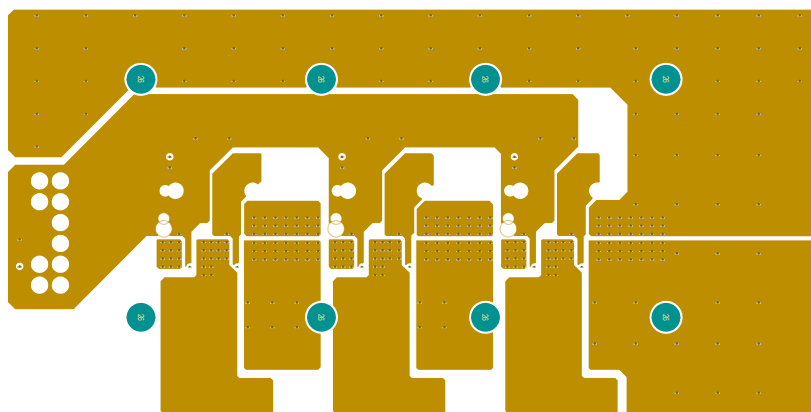
附录图 6 母板Top层



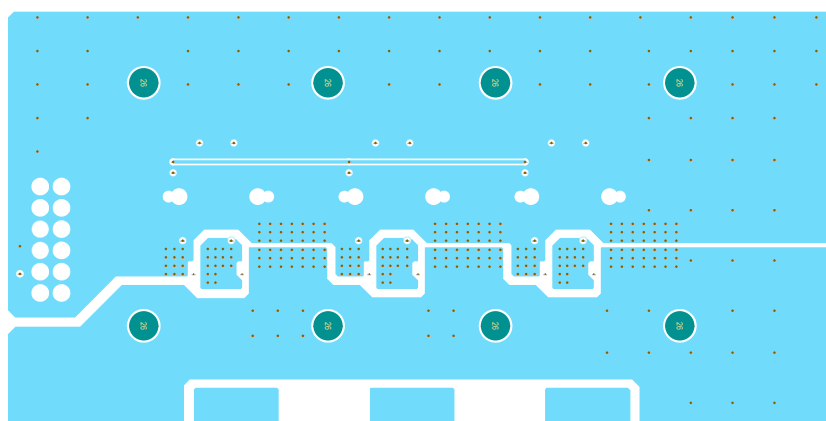
附录图 7 母板Top层



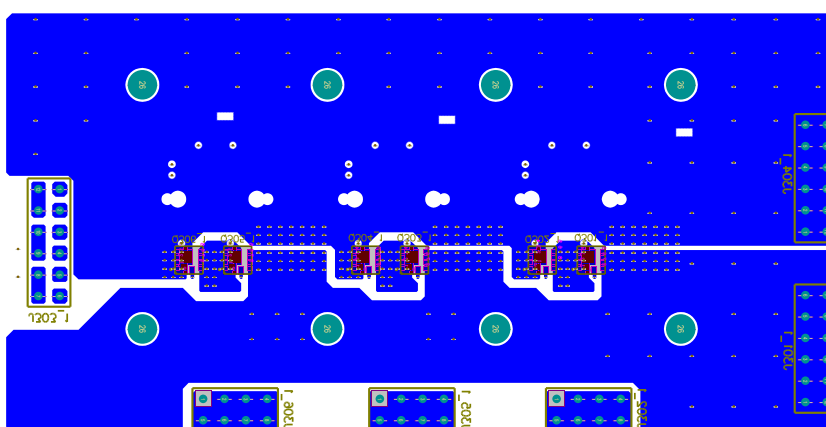
附录图 8 子板Top层



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        |
| GRM188R61E106KA73<br>D | muRate      | CAP, 10u/25V, ±5%, COG       | C112, C113, C129, C132,<br>C156, C159                                                                                                             | C0603       | 6        |
| GRM32EC72A106KE05<br>L | muRate      | CAP, 10u/100V, ±10%, X7S     | C114, C115, C116, C117,<br>C118, C119, C120, C121,<br>C122, C123, C126                                                                            | C1210       | 11       |
| CC0603JRNPO8BN122      | YAGEO       | CAP, 1.2n/25V, ±5%, NP0      | C124                                                                                                                                              | C0603       | 1        |
| CC0603KRX7R8BB222      | YAGEO       | CAP, 2.2n/25V, ±10%, X7R     | C125, C149, C151, C152                                                                                                                            | C0603       | 4        |
| ERJ1KM221W200T         | AISHI       | CAP, 220u/100V E-cap         | C127, C128                                                                                                                                        | C2-12r5-5r0 | 1        |
| CC0603KRX7R8BB104      | YAGEO       | CAP, 100n/25V, ±10%, X7R     | C130, C131, C133, C134,<br>C136, C139, C140, C141,<br>C142, C146, C147, C148,<br>C150, C153, C154, C155,<br>C157, C158, C160, C161,<br>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-0751KL        | YAGEO       | RES, 51kR, ±1%, 100mW        | R102                                                                                                                                              | R0603       | 1        |
| RC0603FR-07392KL       | YAGEO       | RES, 392kR, ±1%, 100mW       | R103                                                                                                                                              | R0603       | 1        |
| RC0603FR-071KL         | YAGEO       | RES, 1kR, ±1%, 100mW         | R104                                                                                                                                              | R0603       | 1        |
| RT0603BRD07448KL       | YAGEO       | RES, 448kR, ±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,<br>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,<br>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,<br>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,<br>C105, C106, C107, C108,<br>C109, C110                                                       | C1210        | 10 |
| NC                   |            |                          | C143, C144, C145                                                                                                       | C0603        | 3  |
| NC                   |            |                          | R110                                                                                                                   | R0603        | 1  |
| <b>Daughterboard</b> |            |                          |                                                                                                                        |              |    |
| CC0603KRX7R0BB104    | YAGEO      | CAP,100n/100V, ±10%, X7R | C301, C306, C315, C316,<br>C336, C337, C308, C309,<br>C310, C311, C317, C318,<br>C319, C320, C325, C326,<br>C327, C328 | C0603        | 18 |
| CC0603JRNPO8BN101    | YAGEO      | CAP,100p/25V, ±5%, NP0   | C302, C303, C307, C314,<br>C323, C324, C331, C332,<br>C338, C339, C340, C341                                           | C0603        | 12 |
| CC0603KRX7R8BB104    | YAGEO      | CAP,100n/25V, ±10%, X7R  | C304, C333, C342                                                                                                       | C0603        | 3  |
| CC0603KRX7R8BB222    | YAGEO      | CAP, 2.2n/25V, ±10%, X7R | C305, C335, C343                                                                                                       | C0603        | 3  |
| CC0603KRX7R8BB104    | YAGEO      | CAP,100n/25V, ±10%, X7R  | C334                                                                                                                   | C0603        | 1  |
| 0603WAF200JT5E       | YAGEO      | RES, 20R, ±1%, 100mW     | R301, R306, R311, R317,<br>R321, R327                                                                                  | R0603        | 6  |
| 0603WAF100JT5E       | YAGEO      | RES, 10R, ±1%, 100mW     | R302, R308, R312, R319,<br>R322, R329                                                                                  | R0603        | 6  |
| RT0603BRD0720KL      | YAGEO      | RES, 20kR, ±1%, 100mW    | R303, R307, R314, R318,<br>R324, R328                                                                                  | R0603        | 6  |
| RC0603FR-07100RL     | YAGEO      | RES, 100R, ±1%, 100mW    | R304, R305, R315, R316,<br>R325, R326                                                                                  | R0603        | 6  |
| RT0603BRD077K5L      | YAGEO      | RES, 7.5kR, ±1%, 100mW   | R309, R310, R313, R320,<br>R323, R330                                                                                  | R0603        | 6  |
| Header 2*6           |            |                          | J301, J303, J304                                                                                                       | Header 2*6   | 3  |
| Header 2*4           |            |                          | J302, J305, J306                                                                                                       | Header 2_4   | 3  |
| TP                   |            |                          | TP301, TP303, TP304, TP305,<br>TP306, TP309, TP310, TP312,<br>TP315, TP316, TP317, TP318,<br>TP320, TP323, TP324       | TP           | 15 |
| INN100EA035A         | Innoscence | GaN                      | Q301, Q302, Q303, Q304,                                                                                                | En-FCLGA     | 6  |

|           |             |        |                                       |         |   |
|-----------|-------------|--------|---------------------------------------|---------|---|
|           |             |        | Q305, Q306                            |         |   |
| INS2003FQ | Innoscience | driver | U301, U302, U303                      | INS2001 | 3 |
| NC        |             |        | C312, C313, C321, C322,<br>C329, C330 | C0603   | 6 |

历史版本

| 日期         | 版本  | 描述  | 编写    |
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| 2025/05/09 | 1.0 | 第一版 | AE 团队 |
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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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