Application Note AN-91
BridgeSwitch Family

Triangular PCB vs. Slotted Linear PCB Configuration for Three-Phase Inverter Applications

Introduction

For 3-phase inverter applications, each InSOP-24C surface mount package dissipates a third of the total inverter losses. The heat distribution allows the construction of a motor drive without an external heat sink. Two exposed pads facilitate heat transfer from the power switches to the printed circuit board (PCB). They are marked HD and HB in Figure 1.

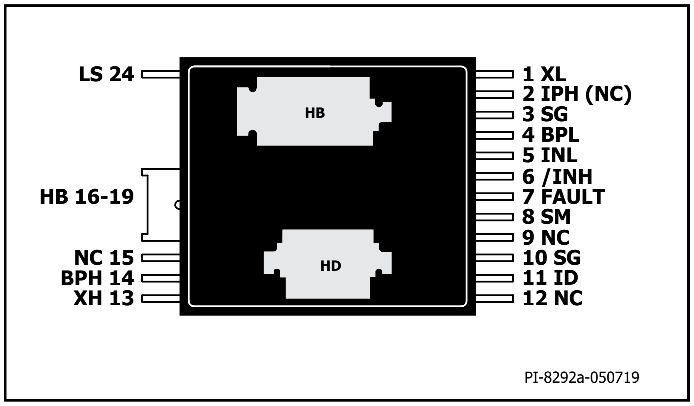


Figure 1. BridgeSwitch InSOP-24C (Bottom View).

The thermal performance is affected by the placement of the devices, the distance between them, the size of the copper-clad areas connected to the exposed pads, and the thickness of the copper used for heat sinking. In the PCB configurations previously evaluated for the whitepaper, "Impact of Printed Circuit Board Layout on Device Temperature in 3-Phase Inverters Using BridgeSwitch" (https://motor-driver.power.com/design-support/articles/impact-of-printed-circuit-board-layout-on-device-temperature-in-3-phase-inverters-using-bridgeswitch/), the results show an increase in the device case temperatures for the linear PCB configuration as seen in Figure 3. Due to the heat converging at the center, the middle device exhibits a higher case temperature compared to the adjacent devices.

The linear PCB configuration offers a smaller and more compact PCB layout that is desirable for some applications. Slots were added between the BridgeSwitch devices to maximize the advantage of the linear device placement resulting in the slotted linear PCB configuration in Figure 4. This addition will prevent the heat from the adjacent devices from affecting the temperature of the middle IC.

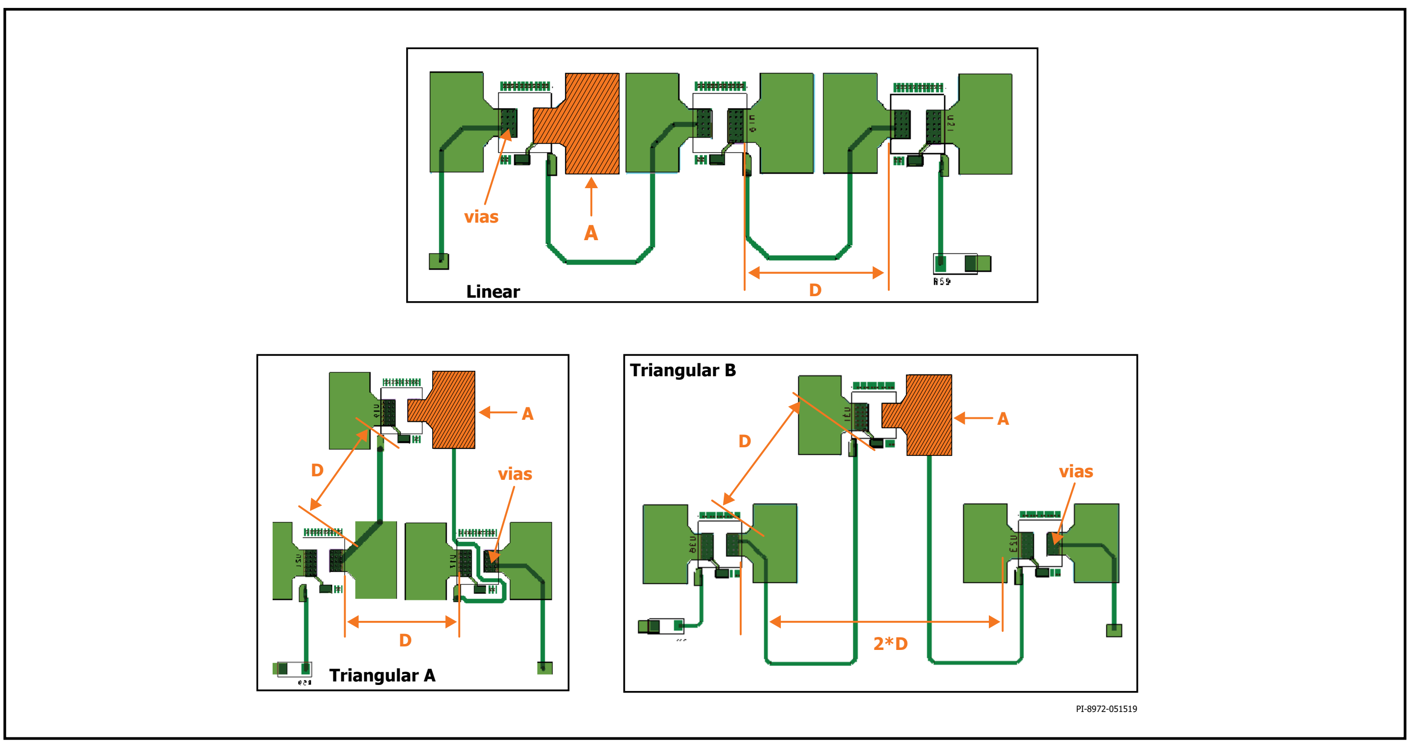
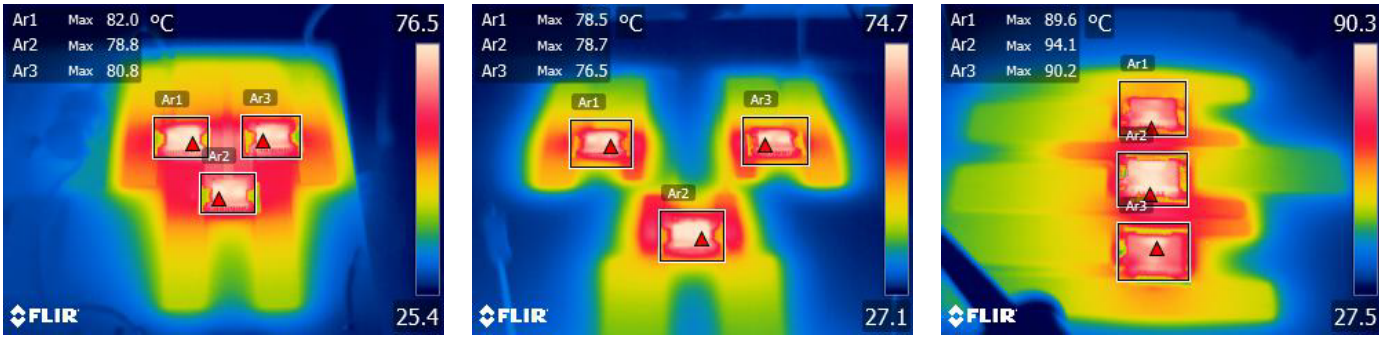


Figure 2. Linear, Triangular A, and Triangular B Device Configurations.

Note: A = PCB copper area, D = distance between devices



a) Triangular A Configuration, D=17 mm, A=600 mm²

b) Triangular B Configuration, D=17 mm, A=600 mm²

c) Linear Configuration, D=17 mm, A=600 mm²

Figure 3. Thermal Device Scans (Triangular A, Triangular B, and Linear Configurations).

Scope

This application note compares the thermal performance of the triangular PCB configuration to the slotted linear PCB configuration with regards to case temperature rise above ambient temperature and temperature variations between adjacent BridgeSwitch devices using BridgeSwitch reference design boards.

It includes the following sections:

- Layout Revision
- Test Conditions
- Test Results
  - Triangular PCB Configuration
  - Slotted Linear PCB Configuration
  - PCB Configuration Comparison
- Conclusion

Related Technical Documents

- Impact of Printed Circuit Board Layout on Device Temperature in 3-Phase Inverters Using BridgeSwitch
- AN-83 – BridgeSwitch Design Tips, Techniques, and Troubleshooting Guide
- RDR-853 – 300 W High Thermal Performance 3-Phase Inverter Using BridgeSwitch Motor Driver and LinkSwitch-TN2

All documents are available for download at www.power.com: https://motor-driver.power.com/products/bridgeswitch-family/bridgeswitch/.

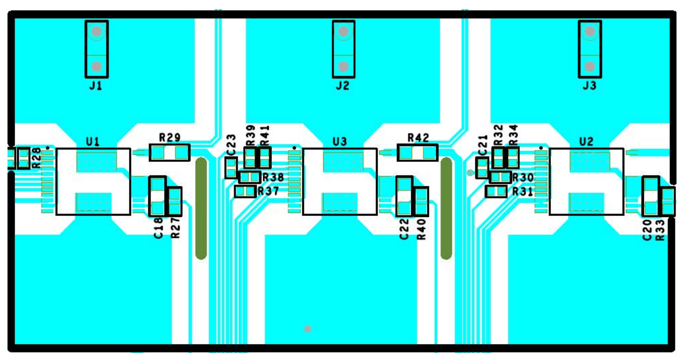


Figure 4. Slotted Linear Device Configuration.

Note: The dark green lines correspond to the PCB slots.

Layout Revision

A 300 W 3-phase inverter reference design, the RD-853 board, was used to collect the triangular PCB configuration data. The layout is shown in Figure 5. For heat sinking, it makes use of a 34.53 cm^2 copper-clad area on the top layer and 49.24 cm^2 on the bottom layer resulting in a total copper area of 83.77 cm^2. Both layers connect through thermal vias placed directly underneath the exposed pads of the InSOP-24C package. There is a distance of approximately 25 mm between the devices.

The RD-853 layout was revised to add slots that are 1.50 mm in width and 12.93 mm in length between adjacent ICs, resulting in the slotted linear PCB configuration shown in Figure 6. The 25 mm approximate distance between devices was maintained to provide accurate comparison data. With the copper area trimmed down, a 25.00 cm^2 copper-clad area on the top layer and 36.93 cm^2 on the bottom layer resulting in a 61.93 cm^2 effective copper area – about 20 cm^2 less than the preceding triangular layout revision remains on the board.

This decrease in the copper area is based on the results of a study wherein a reduction in the copper area was gradually made until the device temperature difference between the two configurations is approximately equal. Further reduction in the copper area would result in a considerable increase in the case temperatures for the slotted linear configuration, significantly increasing its difference compared to the triangular configuration. The top and bottom copper layers connect through thermal vias placed underneath the exposed pads of each device. The revised layout is shown in Figure 6.

For both boards, the PCB material used is FR4 laminate with 2 oz of copper and a thickness of 1.2 mm. For both layout revisions, the thermal vias connecting the top and bottom copper-clad areas have an outer diameter of 0.6 mm and an inner diameter of 0.3 mm with plating.

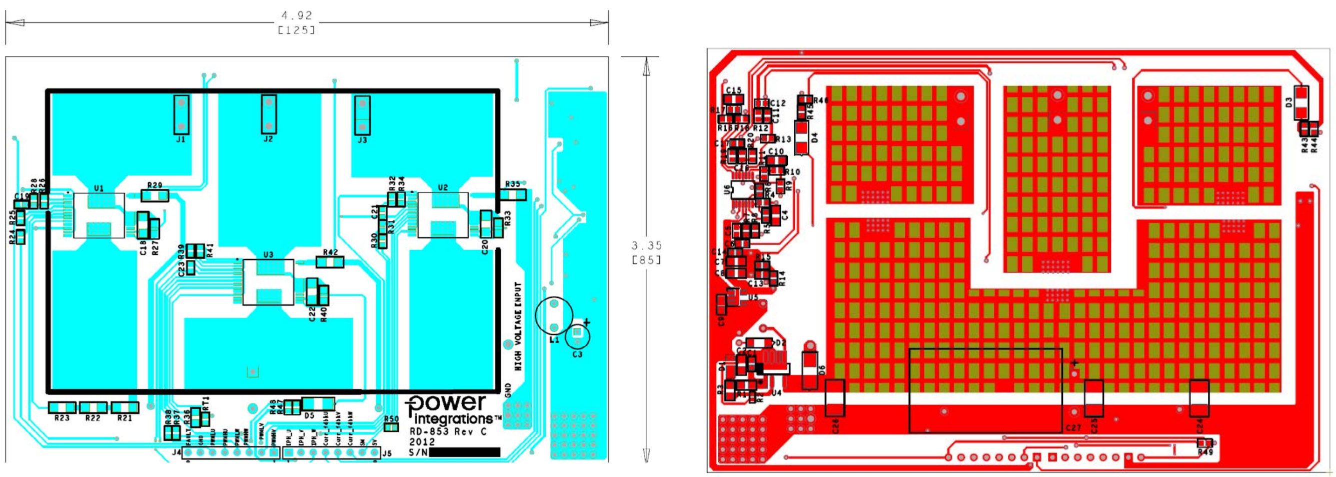


Figure 5. Triangular PCB Configuration Layout (125 mm x 85 mm).

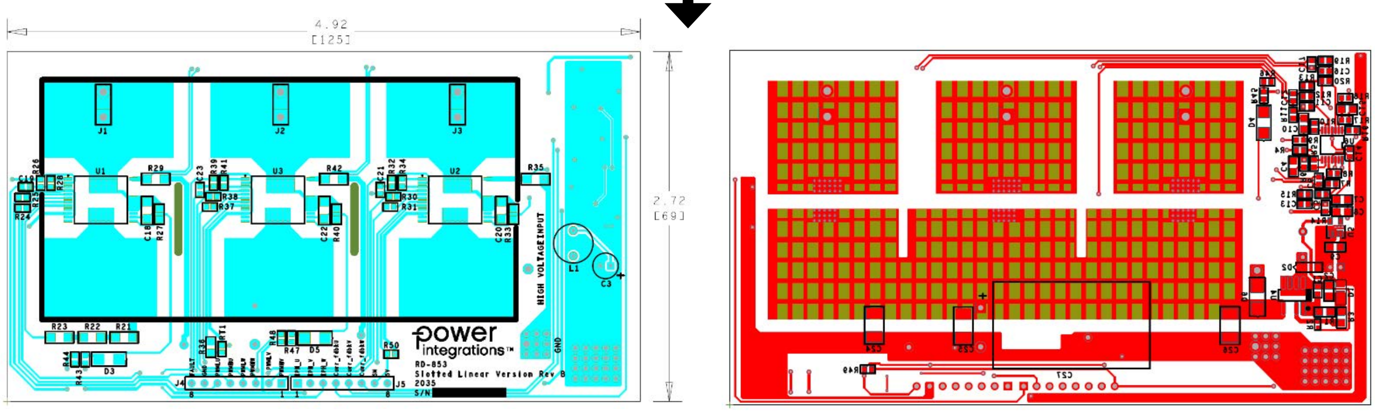


Figure 6. Slotted Linear PCB Configuration Layout (125 mm x 69 mm).

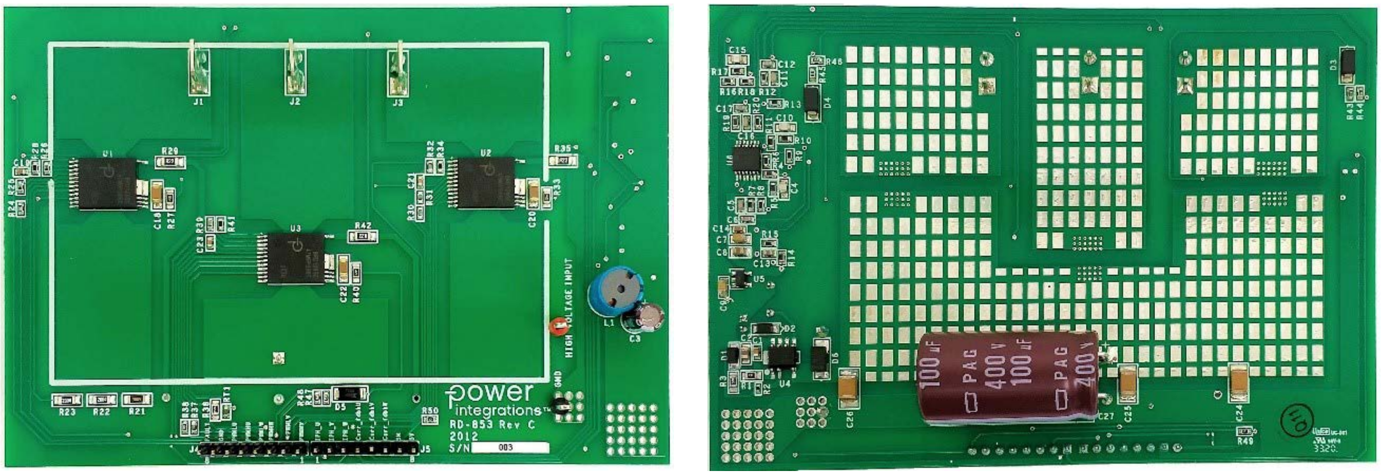


Figure 7. Triangular PCB Configuration Board (125 mm x 85 mm).

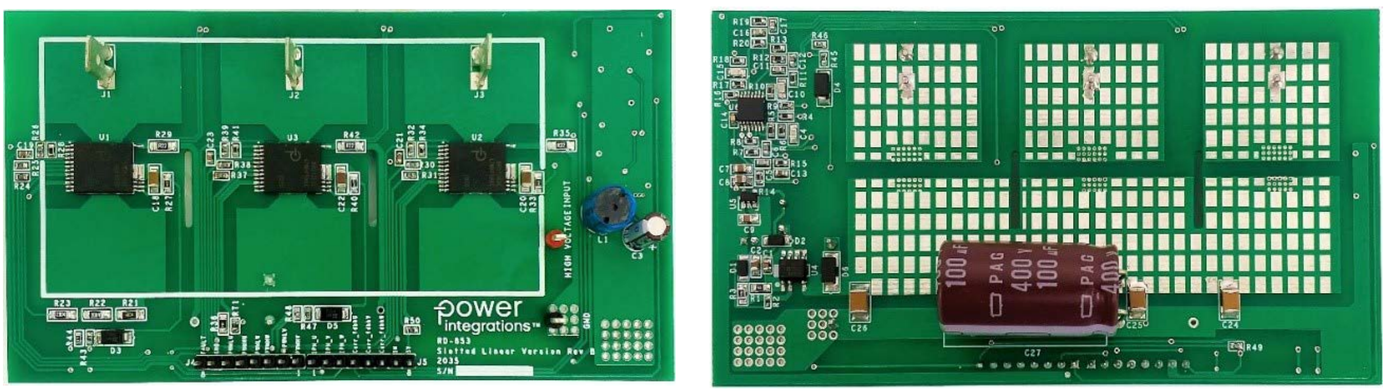


Figure 8. Slotted Linear PCB Configuration Board (125 mm x 69 mm).

Test Conditions

Both configurations operate at the following test conditions:

- Input Voltage: 340 V_{DC}
- Average Phase RMS Current:
  - 350 mA_{RMS} at 100 W Inverter Output Power
  - 660 mA_{RMS} at 200 W Inverter Output Power
  - 1000 mA_{RMS} at 300 W Inverter Output Power
- PWM Carrier Frequency: 12 kHz
- Output Speed: 5000 RPM
- Control Scheme: FOC
- Modulation Type: 3-phase Modulation

The auxiliary circuit, +5 V linear regulator, and input diode were disabled to solely reflect the inverter temperature by depopulating components U4, U5, and D6. An external +5 V_{DC} supply was used to power the microcontroller and provide a reference voltage for the current sense amplifier. During tests using external supply voltage mode, the low-side and high-side gate drives require an additional +17 V_{DC} supply.

External supply operation is optional for applications that require lower inverter no-load input power or operate at elevated ambient temperatures. Resistors R43, R44, R45, R46, R47, R48, and diodes D3, D4, and D5 are responsible for providing external supply to the BPL and BPH pin through device U4. If deactivated, the BridgeSwitch IC will operate in self-supply mode wherein the BPL and BPH supplies are drawn internally through the device.

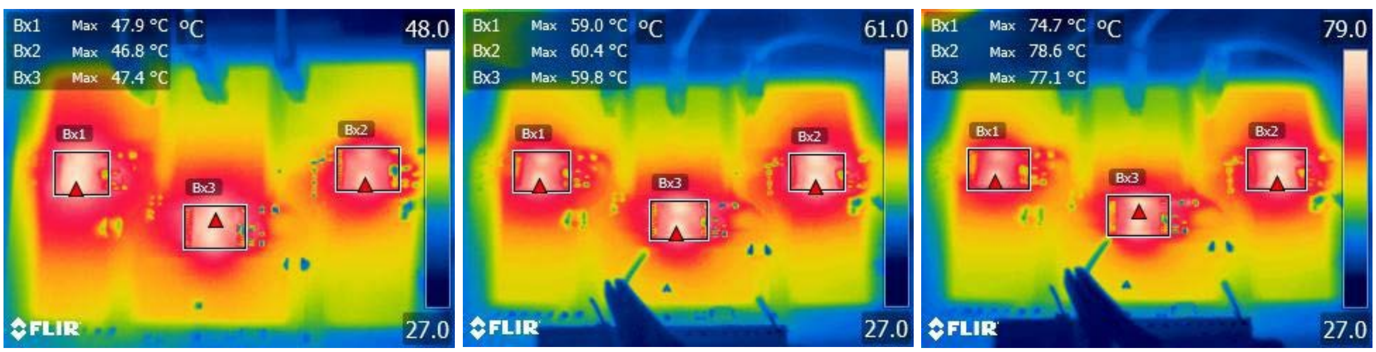
The schematic diagram is accessible from the design example document, "RD-853 – 300 W High Thermal Performance 3-Phase Inverter Using BridgeSwitch Motor Drive and LinkSwitch-TN2". It is available for download at https://motor-driver.power.com/products/bridgeswitch-family/bridgeswitch/.

Test Results

I. Triangular PCB Configuration

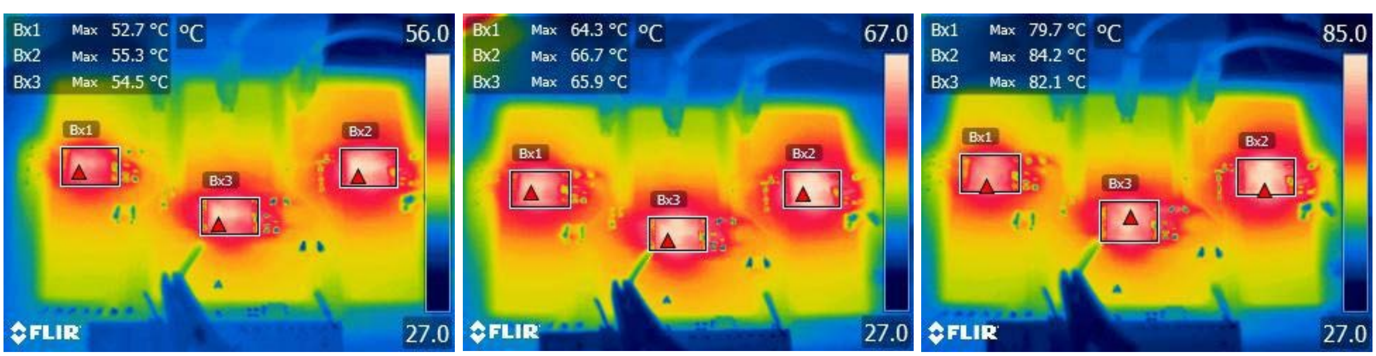
The thermal scans shown in Figure 9 depict on-board device thermal performance after 15 minutes of soak time each at 100 W, 200 W, and 300 W inverter output power at an ambient temperature of 27 °C.

External Supply Mode



a) 100 W Inverter Output Power   b) 200 W Inverter Output Power   c) 300 W Inverter Output Power

Self-Supply Mode



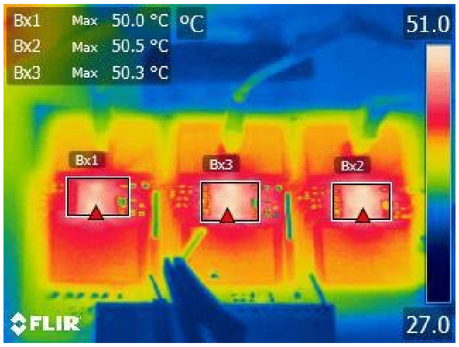
d) 100 W Inverter Output Power   e) 200 W Inverter Output Power   f) 300 W Inverter Output Power

Figure 9. Thermal Device Scans (Triangular PCB Configuration).

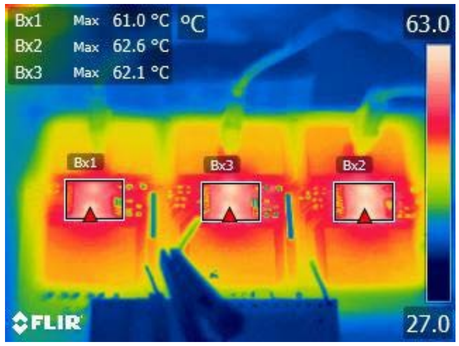
II. Slotted Linear PCB Configuration

The thermal scans shown in Figure 10 depict on-board device thermal performance after 15 minutes of soak time each at 100 W, 200 W, and 300 W inverter output power at an ambient temperature of 27 °C.

External Supply Mode



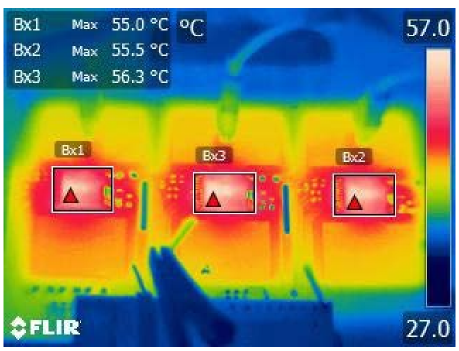
a) 100 W Inverter Output Power



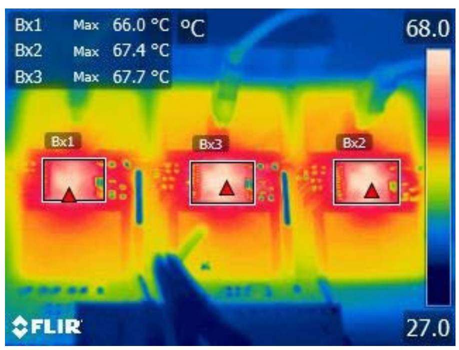
b) 200 W Inverter Output Power

c) 300 W Inverter Output Power

Self-Supply Mode



d) 100 W Inverter Output Power



e) 200 W Inverter Output Power

f) 300 W Inverter Output Power

Figure 10. Thermal Device Scans (Slotted Linear PCB Configuration).

III. PCB Configuration Comparison

Table 1 summarizes the average device case temperature rise above an ambient temperature of 27 °C at various loading conditions. Given below is the formula used to compute the values. Figure 11 plots the data presented in Table 1.

$$\text{Average Trise above } T_{AMB} = \left(\frac{T_{CASE}1 + T_{CASE}2 + T_{CASE}3}{3}\right) - T_{AMB}$$

Where:
Average Trise = Average temperature rise
T_{AMB} = Ambient temperature
$T_{CASE}1$ = BridgeSwitch 1 case temperature
$T_{CASE}2$ = BridgeSwitch 2 case temperature
$T_{CASE}3$ =BridgeSwitch 3 case temperature

	Supply Mode	**Configuration**	**Inverter Ouput Power**		
			100 W	**200 W**	**300 W**
Average Temperature Rise above Ambient Temperature (27 °C)	**External**	Triangular	20.4 °C	32.7 °C	49.8 °C
		Slotted Linear	23.3 °C	34.9 °C	52.4 °C
		ΔTrise	2.9 °C	2.2 °C	2.6 °C
	Self	Triangular	27.2 °C	38.6 °C	55.0 °C
		Slotted Linear	28.6 °C	40.0 °C	56.5 °C
		ΔTrise	1.4 °C	1.4 °C	1.5 °C

Table 1. Average Temperature Rise above Ambient Temperature (27 °C).

Note: ΔTrise = Average Temperature Rise Difference at 100 W, 200 W, and 300 W

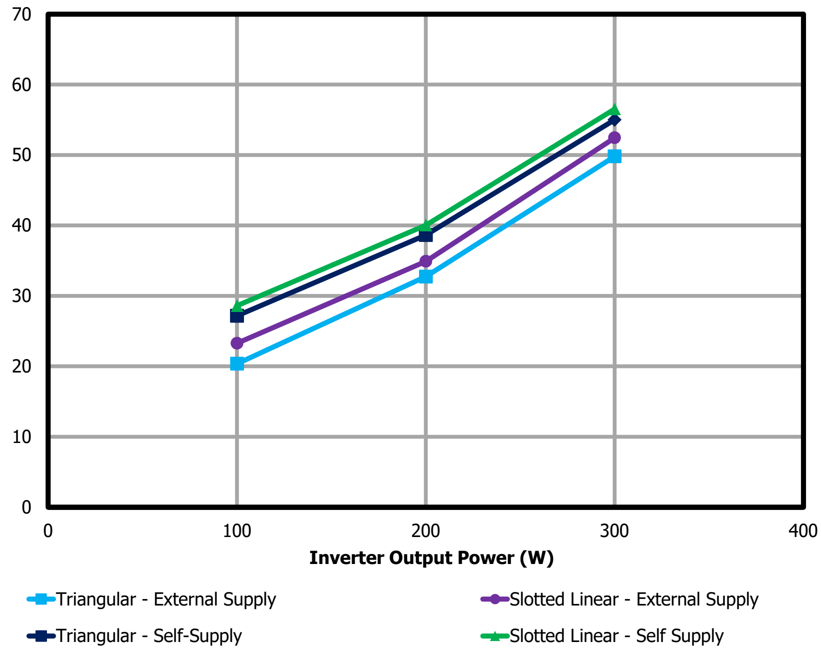


Figure 11. Average Temperature Rise above 27 °C vs. Inverter Output Power.

Based on the values in Table 1, the average case temperature rise for the devices in a triangular PCB configuration is slightly lower for the same operating conditions. There is a maximum difference in average temperature rise of 2.9 °C when operating in external supply mode and 1.5 °C during self-supply mode. From the thermal scans provided in Figures 9 and 10, the maximum temperature variation between adjacent devices is 2.4 °C for the triangular PCB configuration (at 300 W, external and self-supply mode) and 2.1 °C for the slotted linear PCB configuration (at 300 W, external supply mode). These show that for the triangular and slotted linear PCB configurations, the device heat distribution is relatively equal.

The differences in device case temperature are caused by small discrepancies (about 20 mA) in the motor winding phase currents. The heat originating from the devices remains in the surrounding area based on the thermal scans, effectively minimizing heat sharing and preventing adjacent devices from affecting the temperature of the middle IC.

Conclusion

The placement of the device plays a significant role in determining the board size and thermal performance of the BridgeSwitch devices. The triangular PCB configuration results in a close temperature match between devices and lower case temperatures at the expense of a larger board size. The slotted linear PCB configuration allows a reduction in board size critical in applications with tight PCB space requirements while also maintaining a close temperature match between devices. However, there is a minimal increase in case temperature caused by the smaller PCB copper area, as well as a decrease in PCB mechanical strength as a result of the slots on the board.

Due to its comparable thermal performance to the triangular PCB configuration, the slotted linear PCB configuration offers flexibility in device placement, thereby providing more options for applications requiring a more compact PCB layout.

Notes

Revision	Notes	Date
A	Initial release.	11/20

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