(1)

Power Management Reference Design for a Wearable Device with Wireless Charging Using the bq51003 and bq25120

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ABSTRACT

Wearable devices require advanced power management to achieve long battery run times with always-on functionality. Additionally, the devices need to use small rechargeable batteries and enable small footprint designs. This application note shows the implementation of a scalable power management solution for wearables that can be tailored for activity monitors, watches, and more. The design provides a wireless charging input, highly configurable battery management solution with Li-Ion battery charger and low quiescent current (Iq) DC/DC buck, boost converter for PMOLED display, boost converter for Heart Rate Monitor (HRM), and low Iq DC/DC buck.

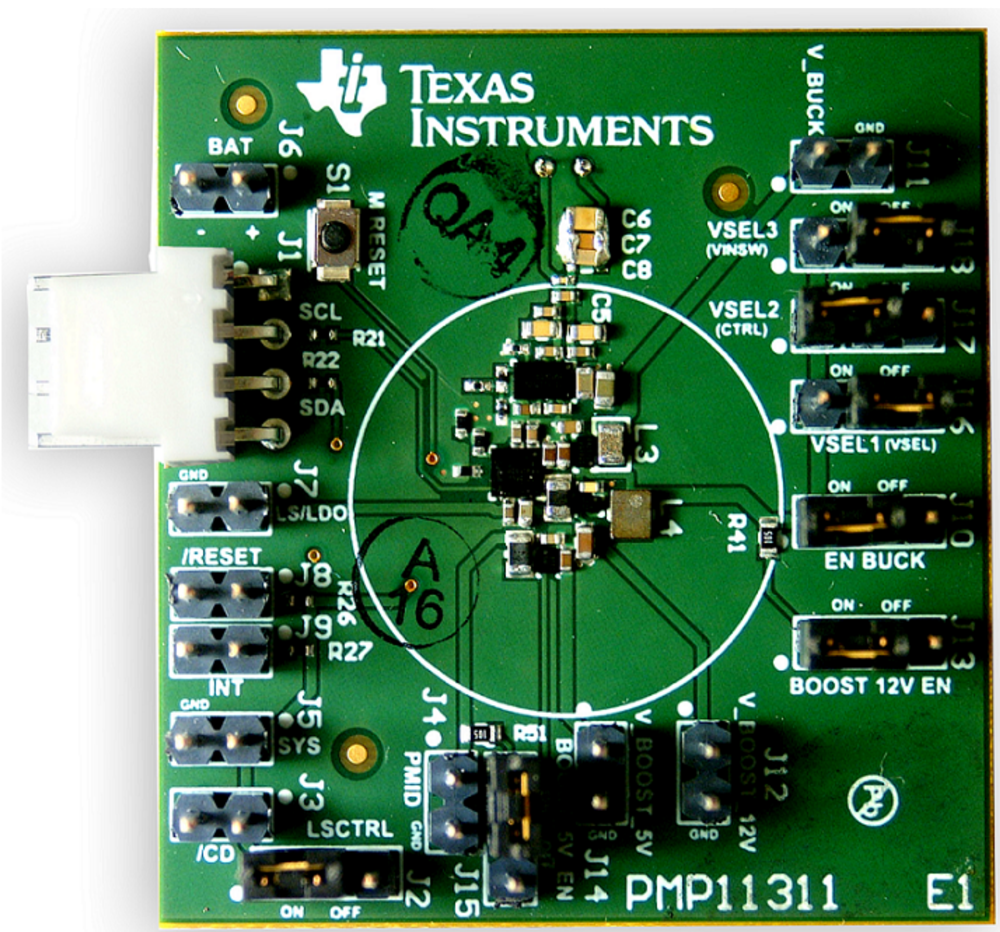

Figure 1. PCB Top Assembly

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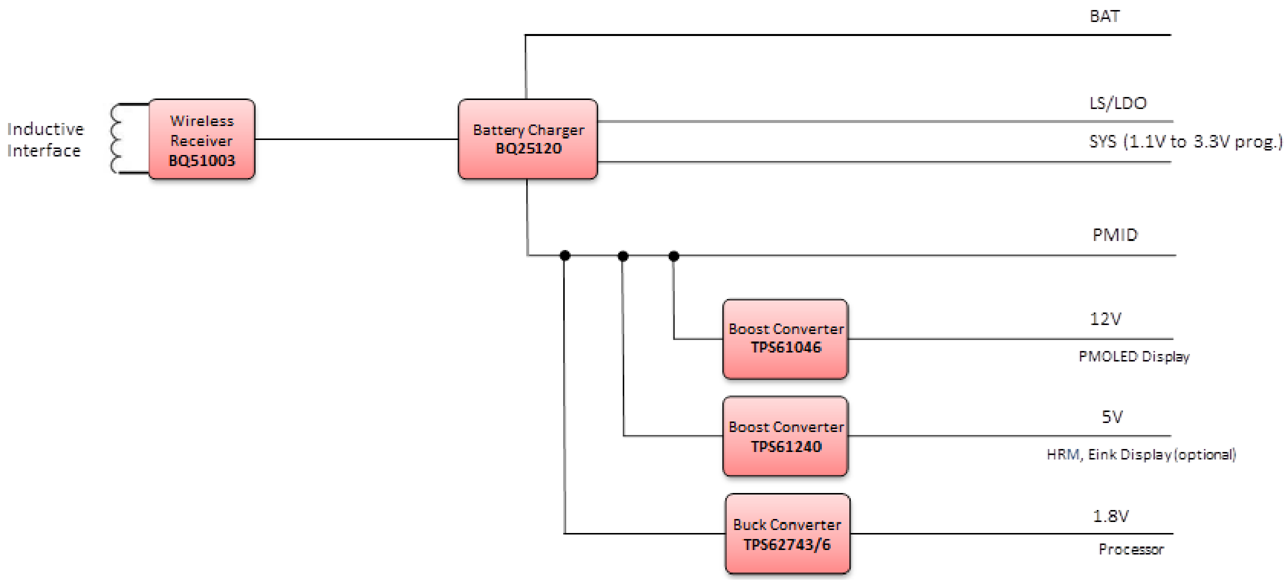

Figure 2. Block Diagram of Wearable Power Management

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1 Wearable Power Design

Table 1. Wearable Power Requirements

DESCRIPTION	VALUE
Input Voltage (VIN)	5 V USB input or Qi Wireless Transmitter
Input Current	Up to 500 mA
Output Voltage for Li-Ion Battery	3.6 V to 4.65 V
Fast Charge Current For Li-Ion Battery	5 mA to 300 mA
Termination Current for Li-Ion Battery	500 µA to 37 mA
Output Voltage for MCU (SYS rail)	1.8 V nominal (Adjustable from 1.1 V to 3.3 V)
Output Current for MCU (SYS rail)	Up to 300 mA
Output Voltage for Second Buck Rail	1.8 V
Output Current for Second Buck Rail	Up to 300 mA
Output Voltage for PMOLED Display	12 V
Output Current for PMOLED Display	Up to 100 mA
Output Voltage for Heart Rate Monitor	5 V
Output Current for Heart Rate Monitor	Up to 300 mA
Output Voltage for Sensors or Radio (LDO)	0.8 V to 3.3 V
Output Current for Sensors or Radio (LDO)	Up to 100 mA

1.1 Wireless Charging Input

A large number of low-power wearable devices such as smart watches, fitness wrist bands and headphones are adopting wireless charging. The BQ51003 is an advanced, integrated receiver tailored for wearable applications. A standard Qi-compliant design will deliver 5W with a 50-mm coil. Figure 3 is modified from a Qi-compliant design with a smaller 30-mm coil and adjustable 500 mW to 1500 mW capabilities. When used with a Qi-compliant wireless transmitter, the RX_OUT supplies the input to a Li-Ion charger, in this case the bq25120. This better matches the wearable form factor and battery requirements, and is optimized for the device to stay cooler during power transfer.

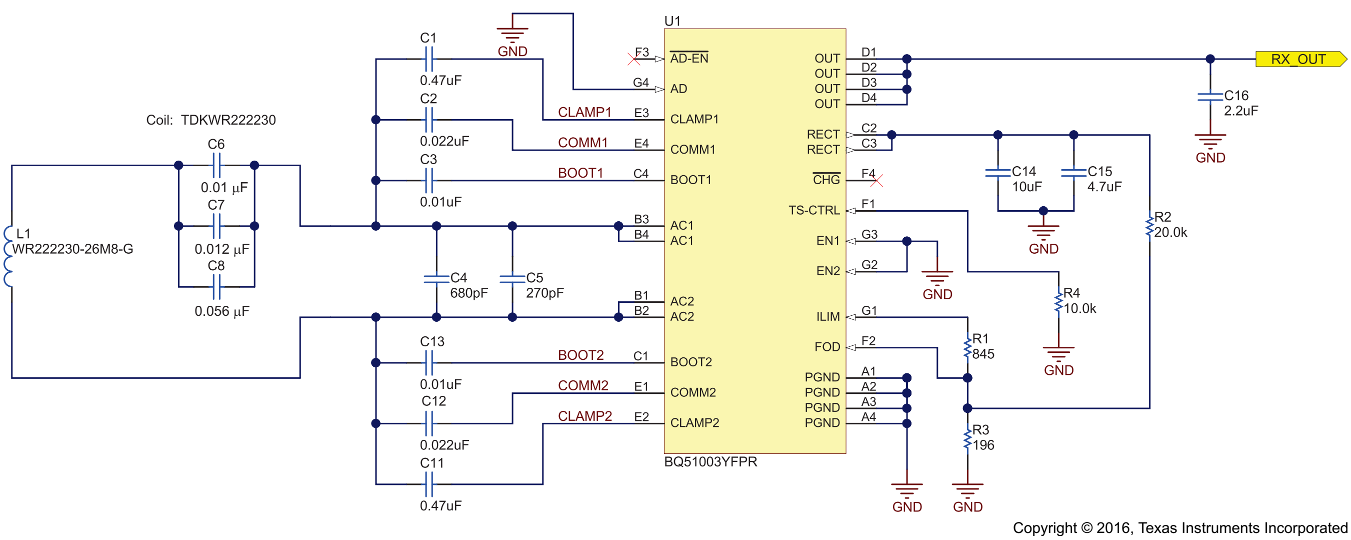

Figure 3. Schematic of Wireless Charging Receiver Using the bq51003

1.2 Battery Charger, MCU, Radio, and Sensor Power

The BQ25120 is a highly integrated battery charge management solution that integrates the most common functions for wearable devices: Linear charger, buck output, load switch or LDO, manual reset with timer, and battery voltage monitor. The integrated buck converter is a high efficiency, low Iq switcher using DCS control that extends light load efficiency down to 10 µA load currents. The low quiescent current during operation and shutdown enables maximum battery life. The BQ25120 has an I^{2}C interface that allows configuration of key parameters including charge current, termination threshold, battery regulation voltage, DC/DC buck output voltage, load switch or LDO voltage, pushbutton timers and reset parameters, input current limit, battery undervoltage threshold, safety timer limit, battery monitor reads, and fault conditions. The design procedure for the BQ25120 can be found in the datasheet.

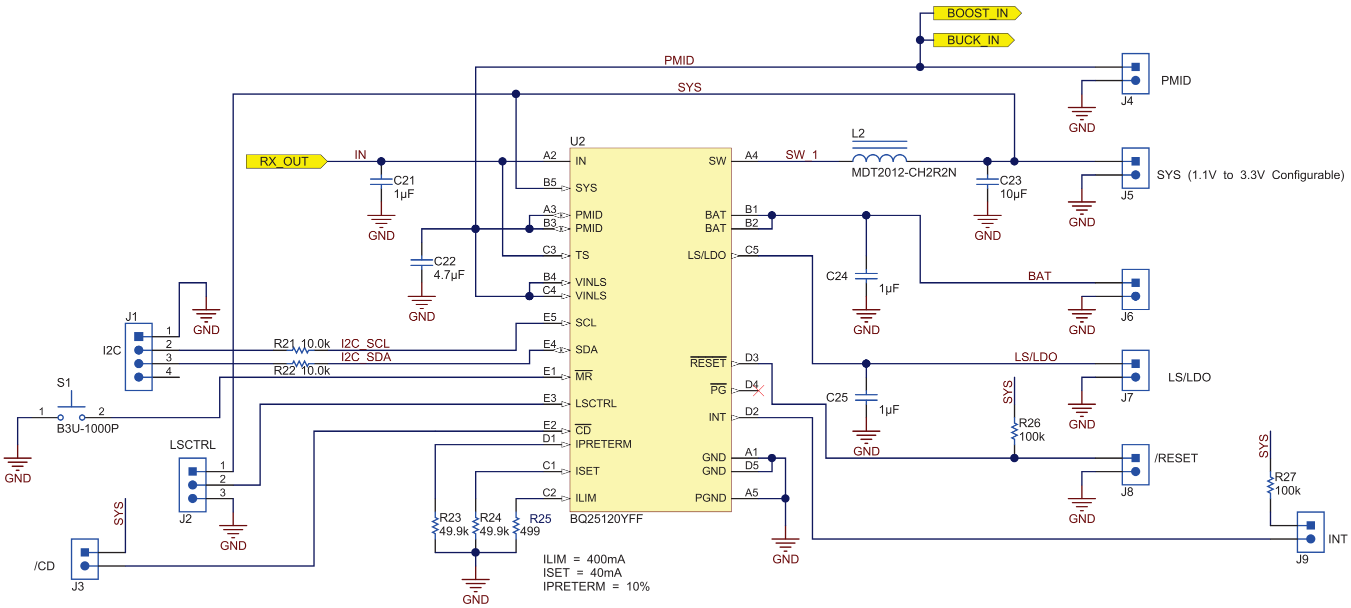

Figure 4. Schematic of Battery Charger, MCU, Radio, and Sensor Power

1.3 Second Buck Output for MCU, Radio or Sensor

While the bq25120 integrates a single, ultra-low power step-down converter for one rail, some systems, such as an MCU, radio or sensor, need a second high-efficiency rail with a different voltage. For these sub-systems, a discrete ultra-low power step-down converter with similar performance to the bq25120 converter is required. PMP11311 includes a TPS62743 which contains a user-selectable choice of 8 different output voltages from 1.2 V to 3.3 V.

If the more common 1.2-V or 1.8-V rail is needed, then the pin-to-pin compatible TPS62746 may be used instead to obtain the extra feature of an input voltage switch (VIN switch). The VIN switch allows a no-leakage measurement of the battery voltage by the host MCU. More details about the TPS62743 and TPS62746 and their implementation are found in the data sheets in the references. Either device requires a total solution size of less than 10 mm^2.

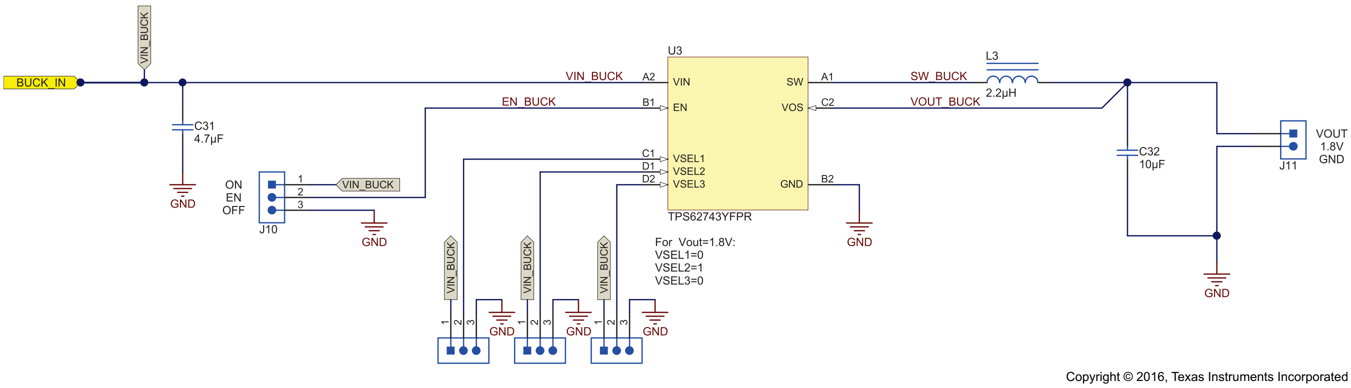

Figure 5. Schematic of Second Buck for MCU, Radio or Sensor Power

2 PMOLED Display Power Design

- A PMOLED display is often used in the wearable device because of its low power consumption and low cost. The TPS61046 is a perfect boost converter to power the PMOLED display because of its features as following:True Disconnection between Input and Output during Shutdown.
- Small package size of 0.80-mm × 1.20-mm WCSP
- Output Voltage Up to 28 V capability and Output Over-Voltage Protection.
- Output Short Circuit Protection

At fixed 12 V output voltage condition, the device only needs three external components, as in Figure 6. More details about TPS61046 pin function, characteristics and external component selection can be found its datasheet. The method of using the device to power a PMOLED display and the performance waveforms can be found in another reference design “PMP9775”.

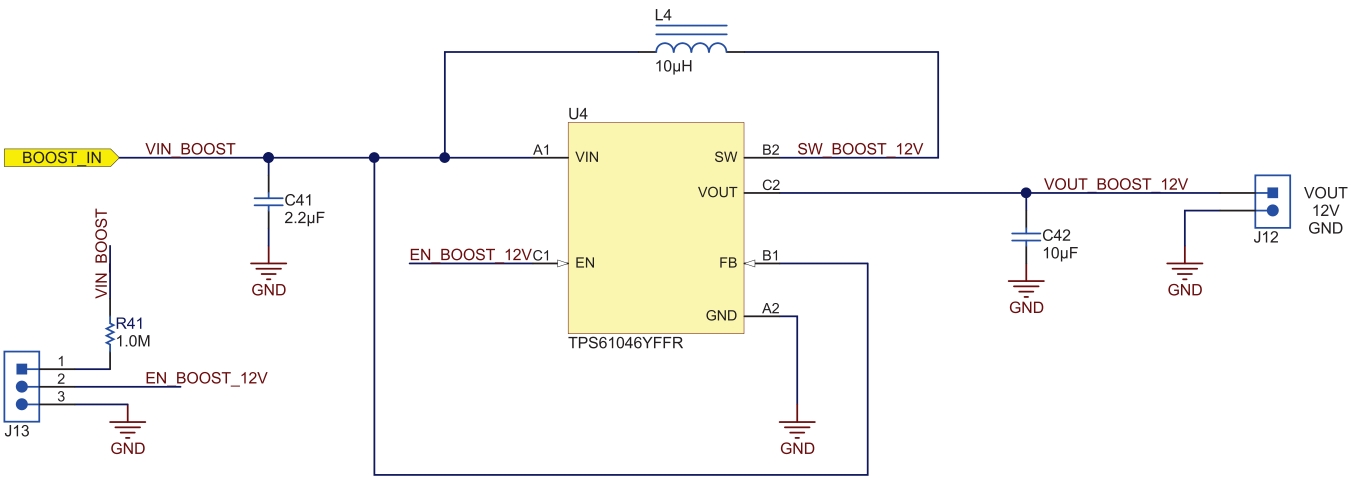

Figure 6. Schematic of Boost for PMOLED Display Power

3 Heart Rate Monitor or e-Ink Power Design

The TPS61240 is a high efficiency boost converter optimized for lithium-ion battery input and fixed 5-V output application. it features 3.5 MHz switching frequency and only needs three small surface-mount external components as shown in Figure 7 with solution size smaller than 13 mm^2. The 5-V output can be used to power the heart rate monitor module or e-Ink display in a wearable device

The function, characteristics and external component selection are found in the datasheet

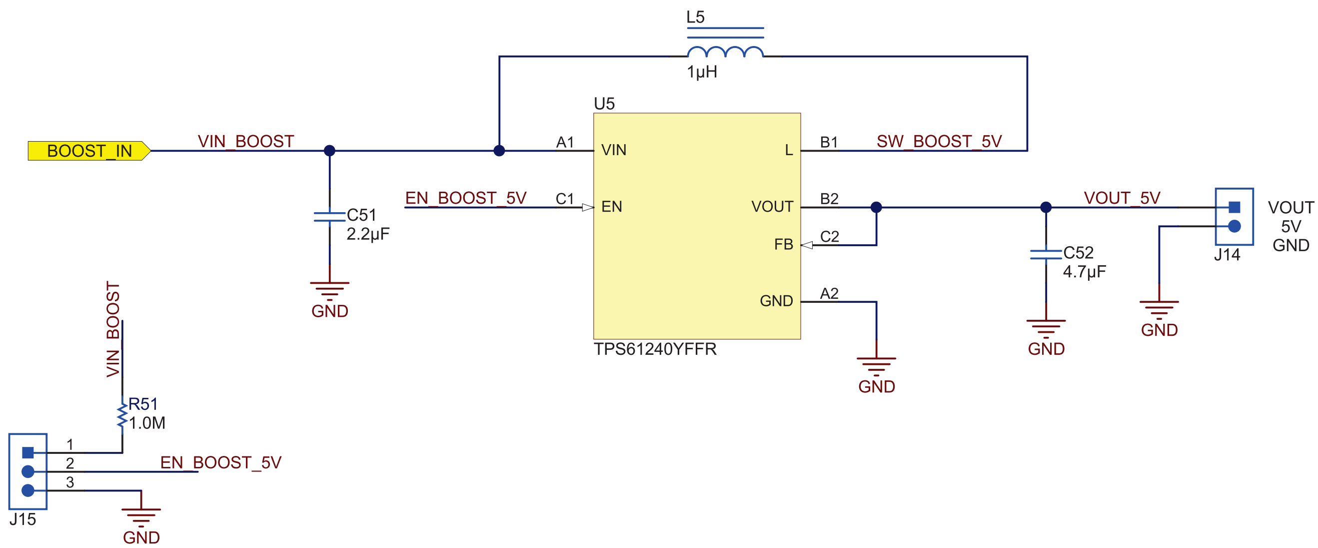

Figure 7. Schematic of Boost for Heart Rate Monitor Power

4 Layout Guidelines for Wearable Design

Size is key in a wearable design and it must be taken into account when the different components are placed. In order to follow the power flow the layout is started from the wireless receiver to the battery charger and finishing on the buck and boost for the different power rails provided.

4.1 Wireless Receiver (bq51003)

- In-via pads are required in this device. Via interconnect on GND is critical for thermal performance.
- Place the AC capacitors (C6, C7, C8) close to the coil connection keeping the trace thick to lower its resistance.
- Output and RECT capacitors should be placed close to the OUT and RECT pins in the IC.
- BOOT, COMM and CLAP capacitors should be placed close to the pins. If vias are required, it is recommended to shield the traces from sensing traces to avoid interferences.
- Preferably provide a ground copper area underneath the sensing traces, REC, ILIM, FOD to shield them from the power and noisy traces.

4.2 Linear Charger (bq25120)

- Input capacitor (C21) must be placed close to the IC input pin. It is recommended to place the BAT capacitor close to the pin. Therefore, in this design the input trace coming from the output of the wireless receiver is connected through a via in an inner layer in order to reduce the size of the solution.

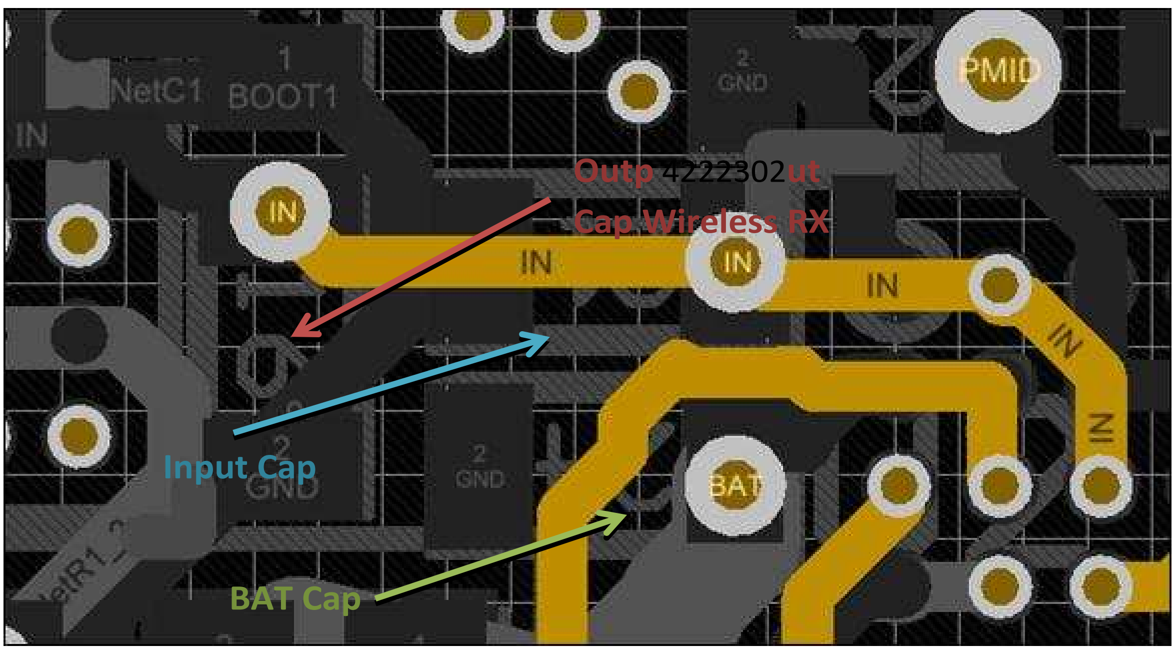

Figure 8. bq25120 Capacitors Placement

- The inductor should be placed close to the SW pin to reduce the size of the switching node.
- The output capacitors for the power rails (SYS, PMID, LS/LDO) need to be placed close to the pins.

4.3 Buck Converter (TPS62743/6)

- The input capacitor must be placed close to the Vin pin of the IC.
- The switching node should be as short as possible.
- Connect the output cap with a trace –no via- away from the SW node and noisy signals.

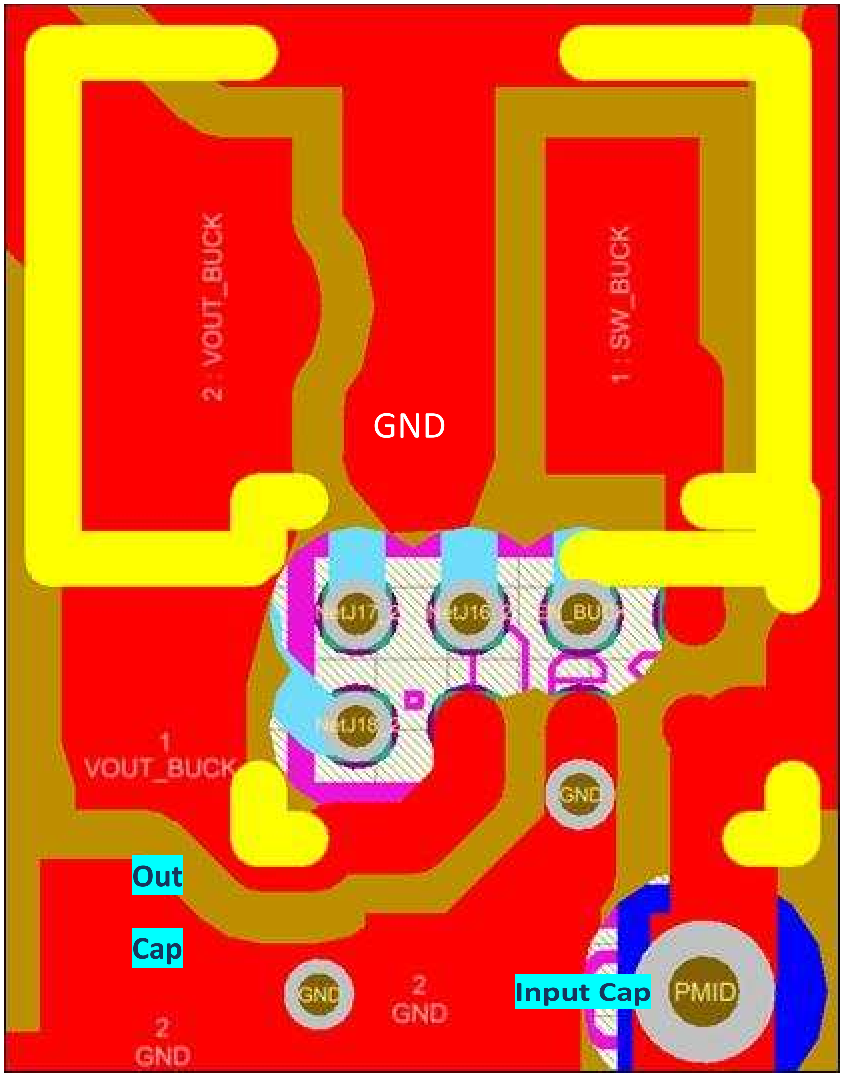

Figure 9. TPS62743 Layout

4.4 Boost Converters (TPS61046 and TPS61240)

- The switching node should be as short as possible.
- It is recommended to place the input capacitor close not only to the VIN and GND pins.
- The output capacitor must be placed close to the IC and it is recommended to be close to the ground pin. If possible, the ground for the input and output capacitor should be on the same plane. In the TPS61046 it was not possible to follow this rule due to the placement for reduced size. Therefore, a solid ground with vias was provided on the next layer making sure the connection is adequate.

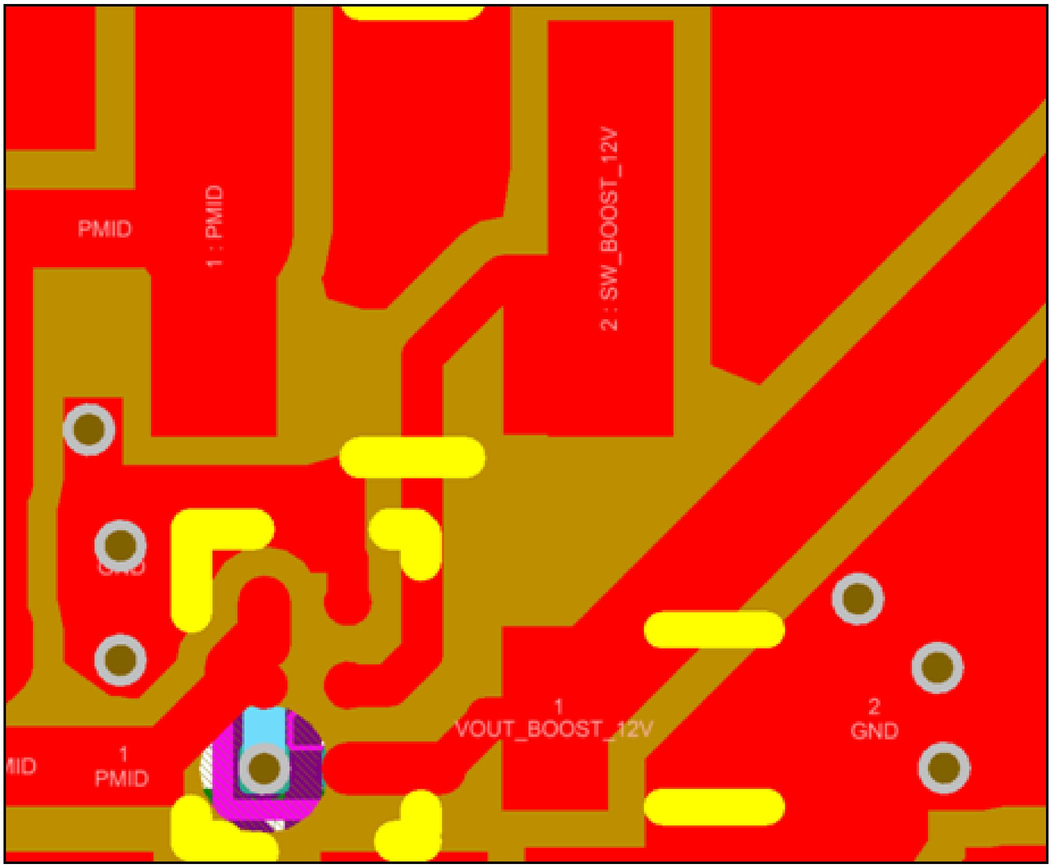

Figure 10. Capacitor Grounding TPS61046

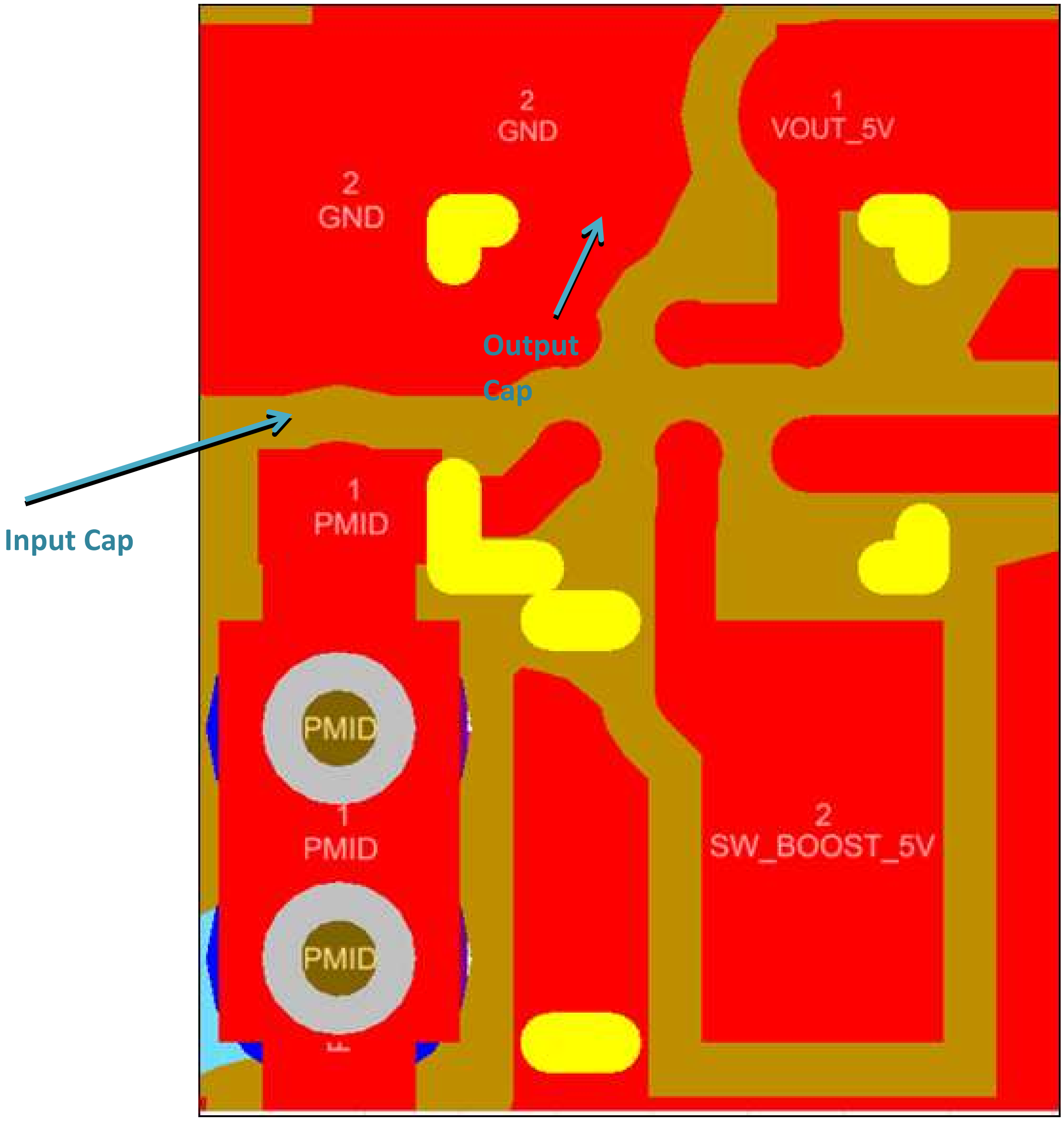

Figure 11. TPS61240 Layout

4.5 General Considerations

- PMID powers the buck converter and the two boost converters. Due to the size restrictions a solid plane is provided in the bottom layer to connect the different devices through bigger vias.
- The ground return for the capacitor should be connected through one via in small signal capacitors and two vias in power capacitors.

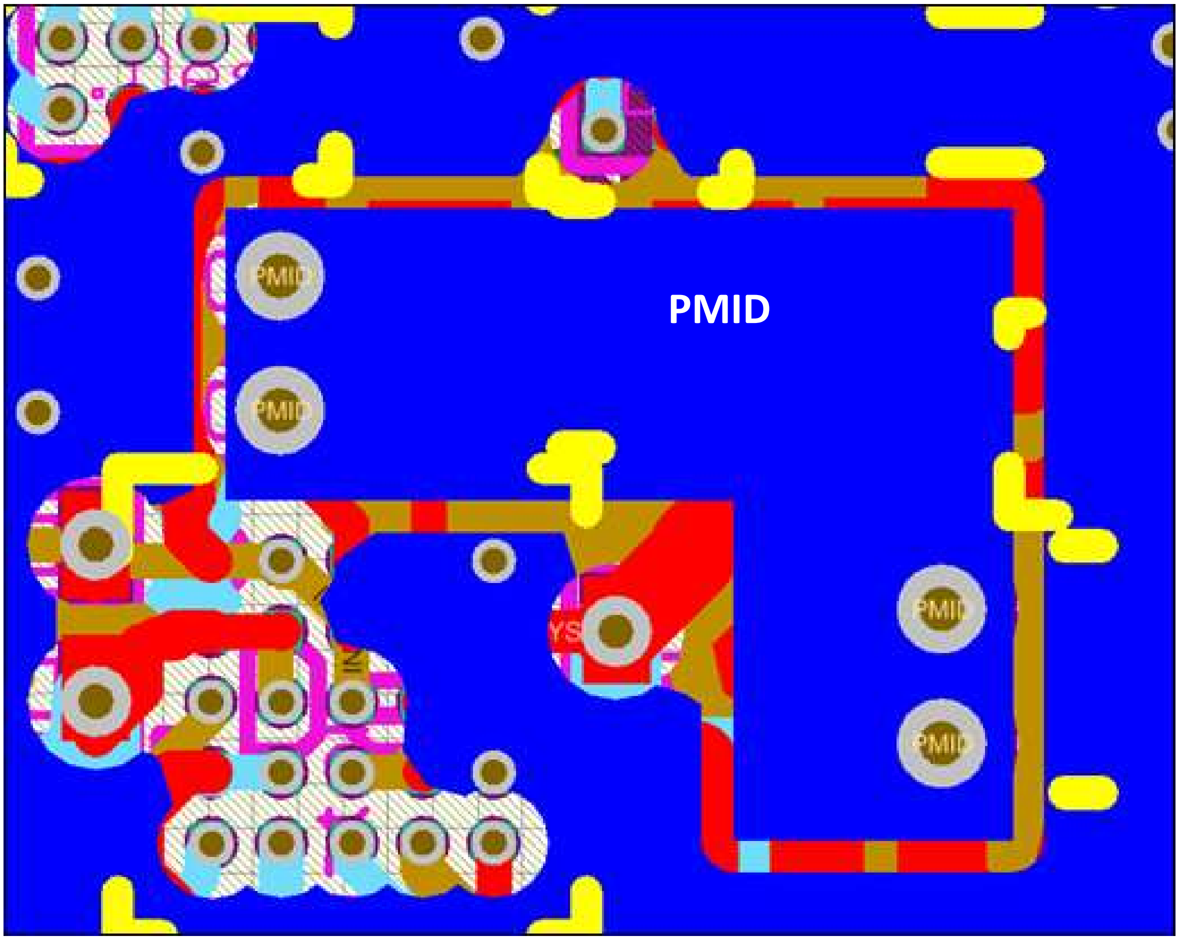

Figure 12. PMID Plane in Bottom Layer

5 References

bq25120 700-nA Low IQ Highly Integrated Battery Charge Management Solution (SLUSBZ9)

bq51003 Highly Integrated Wireless Receiver Qi (WPC v1.1) Compliant Power Supply (SLUSBC8)

Adapting Qi-compliant wireless-power solutions to low-power wearable products (SLYT570)

TPS62743 Tiny Ultra Low Quiescent Current Buck Converter (SLVSCQ0)

TPS62746 High Efficiency Buck Converter with Ultra-low Quiescent Current and VIN Switch (SLVSD28)

Accurately measuring efficiency of ultralow-IQ devices (SLYT558)

High-efficiency, low-ripple DCS-Control offers seamless PWM/pwr-save transitions (SLYT531)

*TPS61046 28-V Output Voltage Boost Converter in WCSP Packag*e (SLVSCQ7)

TPS6124x 90% Efficient Boost Converter with 800mA Switch (SLVS806)

PMP9775

Experimental Results

A.1 Experimental Results

Efficiency of Wireless Input Stage. The figure shows the efficiency across the power range with the bq51003. This is the total DC/DC system efficiency including the transmitter, coils and receiver. Testing was done with the TIDA-00334 Small Form Factor Transmitter reference design (5-V input) and the TDK WR222230-26M8-G coil. The TIDA-00334 reference design is pictured below with the results.

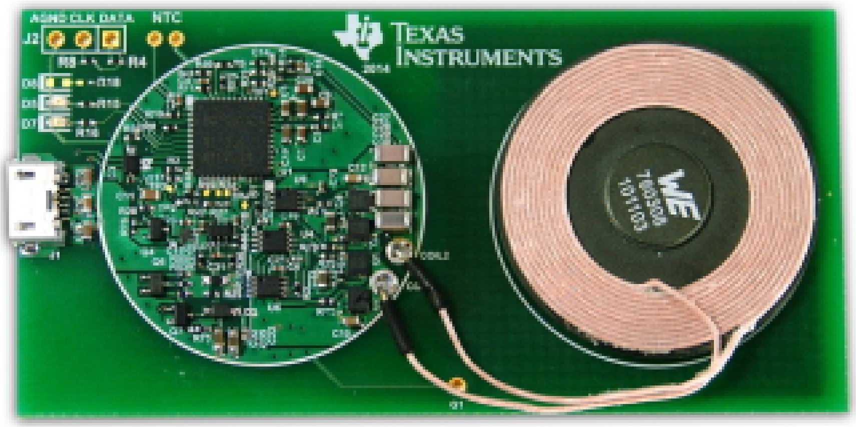

Figure 13. TIDA-00334 Board

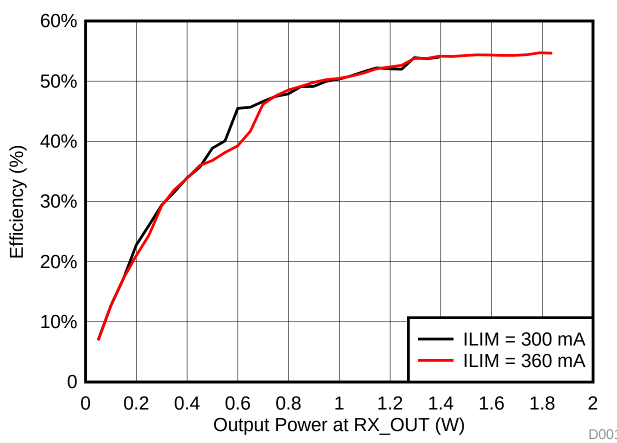

Figure 14. Wireless Power Efficiency

Figure 15 and Figure 16 show the efficiency and load regulation of the bq25120 1.8V buck output with a 3.8V VBAT input. For full performance data of the BQ25120, see the datasheet.

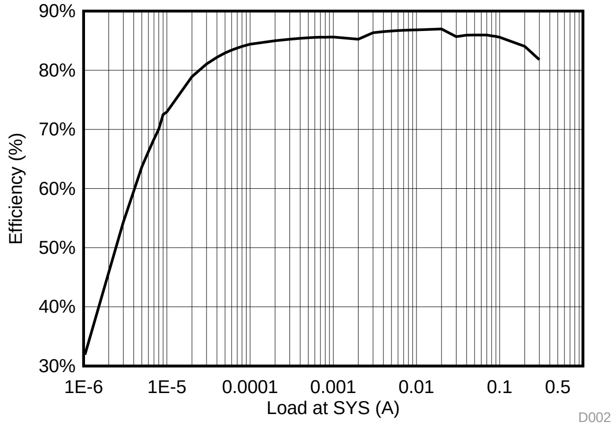

Figure 15. BQ25120 Buck Efficiency

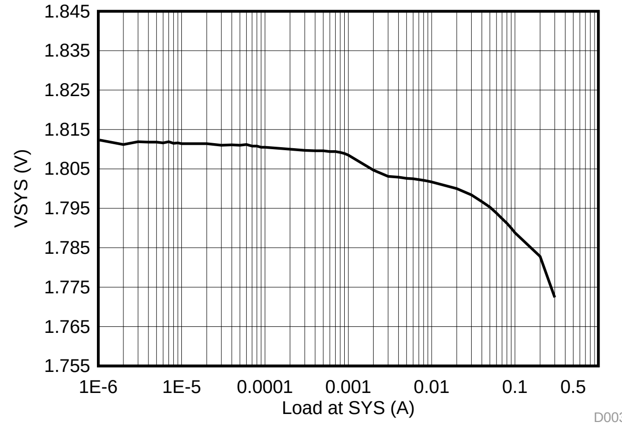

Figure 16. BQ25120 Buck Load Regulation

Figure 17 and Figure 18 show the efficiency and load regulation of the TPS62743 1.8 V Buck Output from a 3.8V VBAT input. The input to the TPS62743 is connected to PMID, so the efficiency includes the drop through the bq25120 battery discharge FET. For full performance data of the TPS62743, see the datasheet.

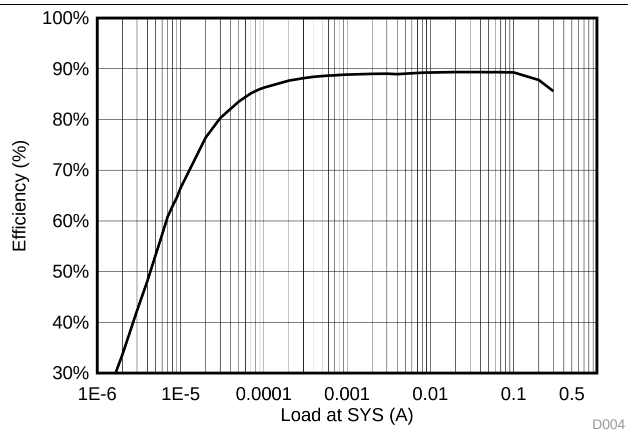

Figure 17. TPS62743 Buck Efficiency

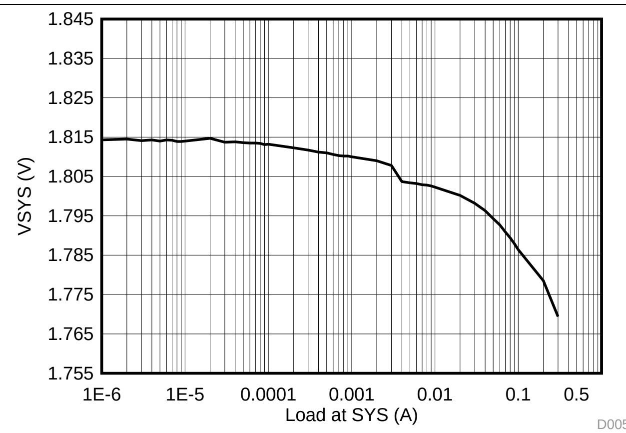

Figure 18. TPS62743 Buck Load Regulation

Figure 19 and Figure 20 show the efficiency and load regulation of the TPS61046 12 V Boost Output from a 3.8V VBAT input. The input to the TPS61046 is connected to PMID, so the efficiency includes the drop through the bq25120 battery discharge FET. For full performance data of the TPS61046, see the datasheet.

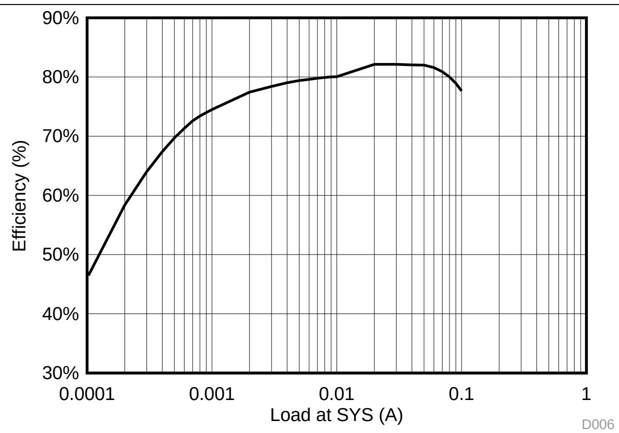

Figure 19. TPS61046 Boost Efficiency

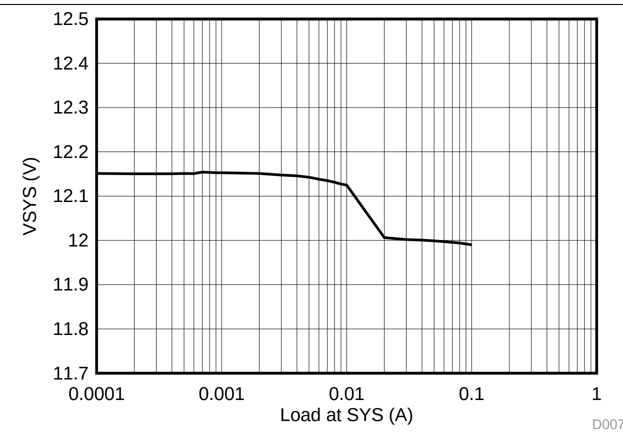

Figure 20. TPS61046 Boost Load Regulation

Figure 21 and Figure 22 show the efficiency and load regulation of the TPS61240 5 V Boost Output from a 3.8V VBAT input. The input to the TPS61240 is connected to PMID, so the efficiency includes the drop through the bq25120 battery discharge FET. For full performance data of the TPS61240, see the datasheet.

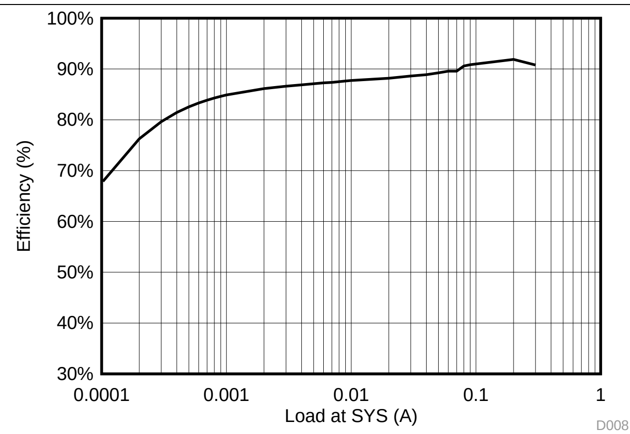

Figure 21. TPS61240 Boost Efficiency

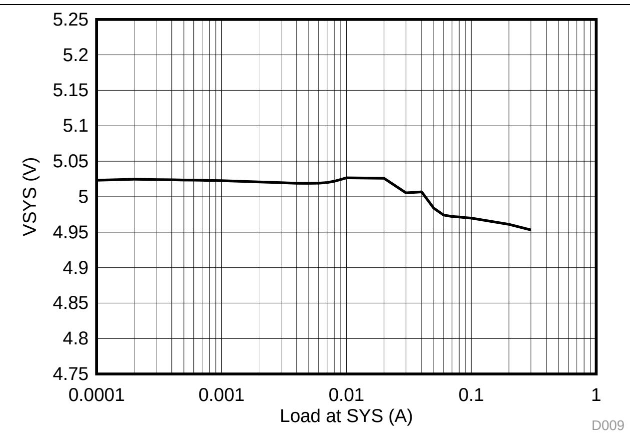

Figure 22. TPS61240 Boost Load Regulation

The following thermal images are of the board with various outputs and loads applied.

Table 2. Board Outputs and Loads

	BQ25120 SYS	BQ25120 LS/LDO	TPS61046 BOOST 12V	TPS61240 BOOST 5V	TPS62743 V_BUCK	CURRENT FROM VBAT (A)	(1) BOARD MAX TEMP °C	(2) BQ25120 MAX TEMP °C	AMBIENT TEMP °C
Image 1	200 mA	0 mA	0 mA	0 mA	0 mA	0.11117	27.08	25.28	22.5
Image 2	200 mA	100 mA	0 mA	0 mA	0 mA	0.20982	28.08	26.58	22.5
Image 3	200 mA	100 mA	100 mA	0 mA	0 mA	0.67541	57.72	37.95	22.5
Image 4	200 mA	100 mA	100 mA	200 mA	0 mA	1.0723	69.2	53.51	22.5
Image 5	200 mA	100 mA	100 mA	200 mA	200 mA	1.19482	80.79	64.66	22.5
Image 6	0 mA	0 mA	0 mA	0 mA	0 mA	0.000041	24.47	23.29	22.5

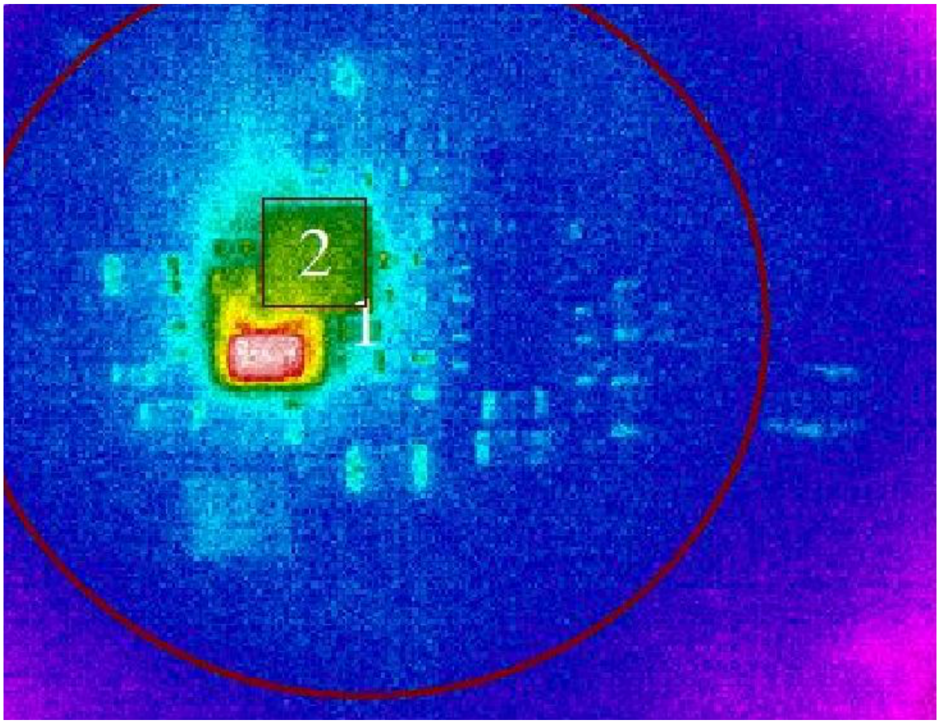

Figure 23. Image 1

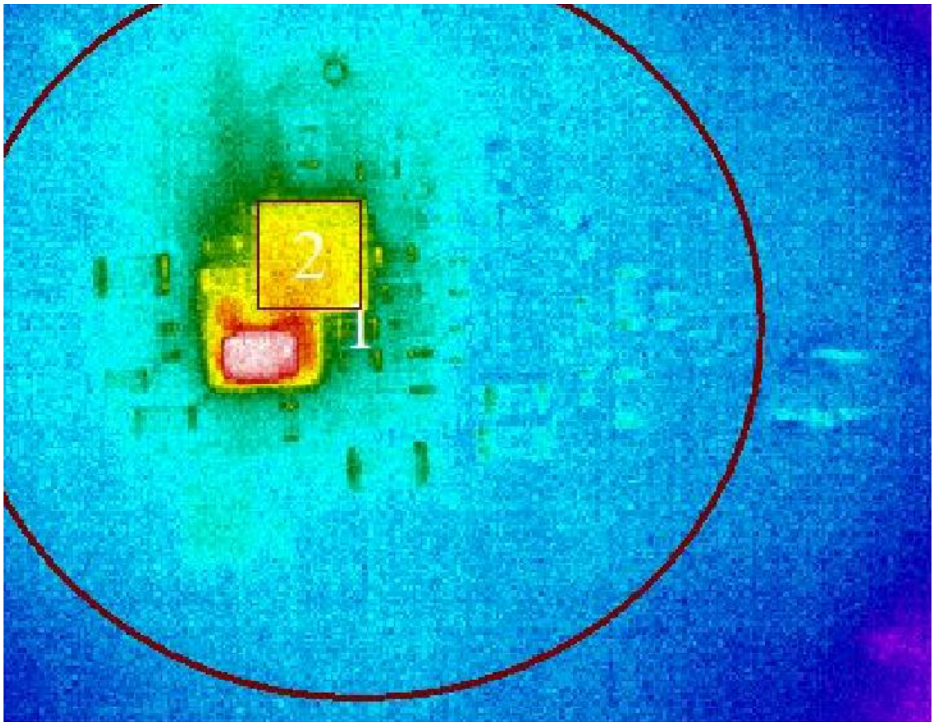

Figure 24. Image 2

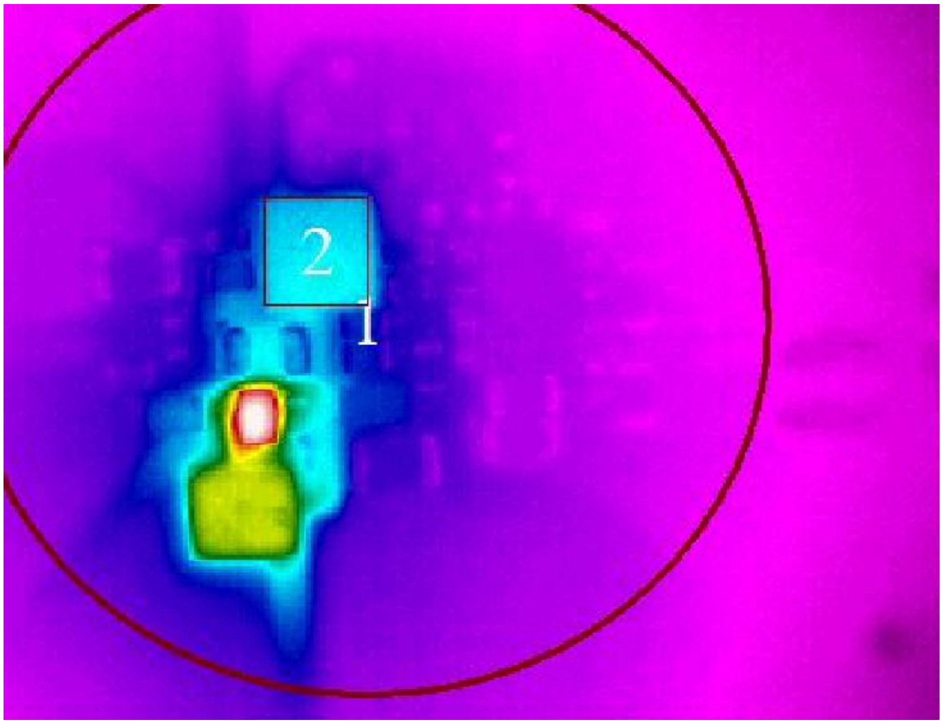

Figure 25. Image 3

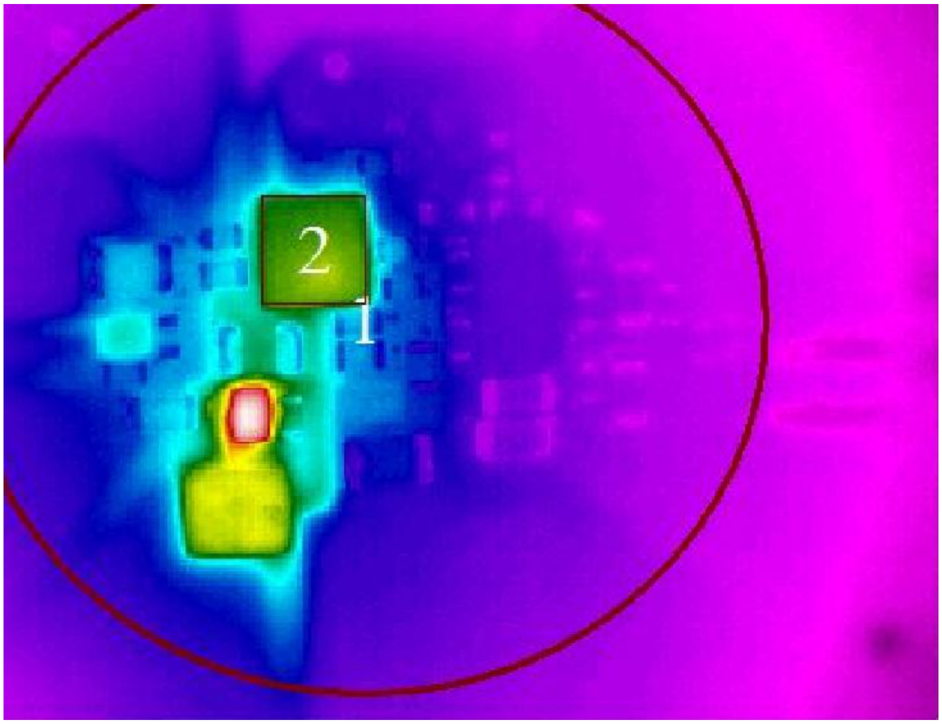

Figure 26. Image 4

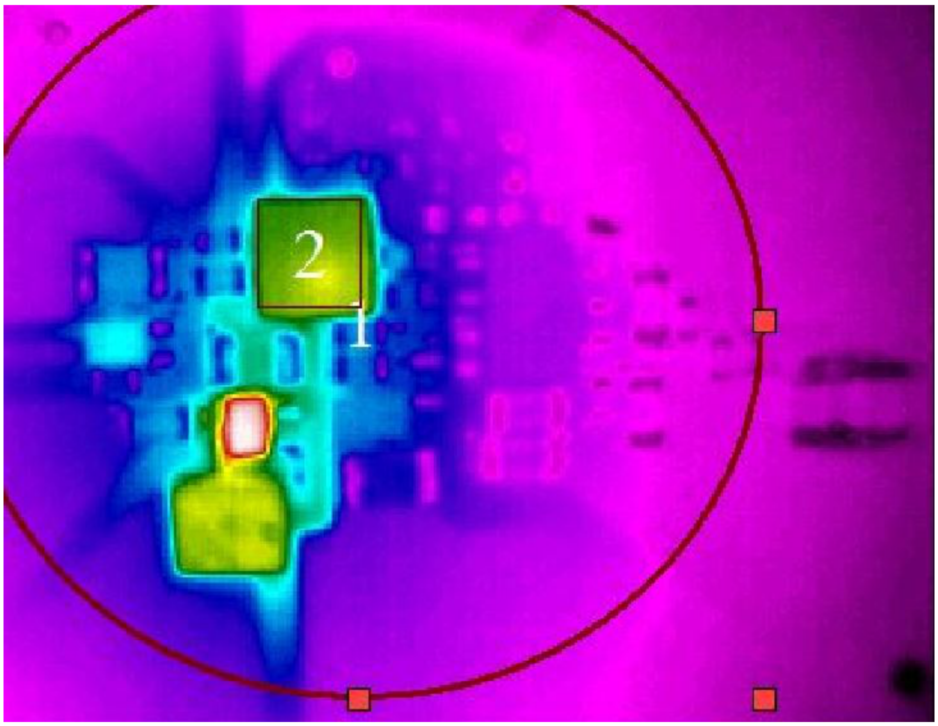

Figure 27. Image 5

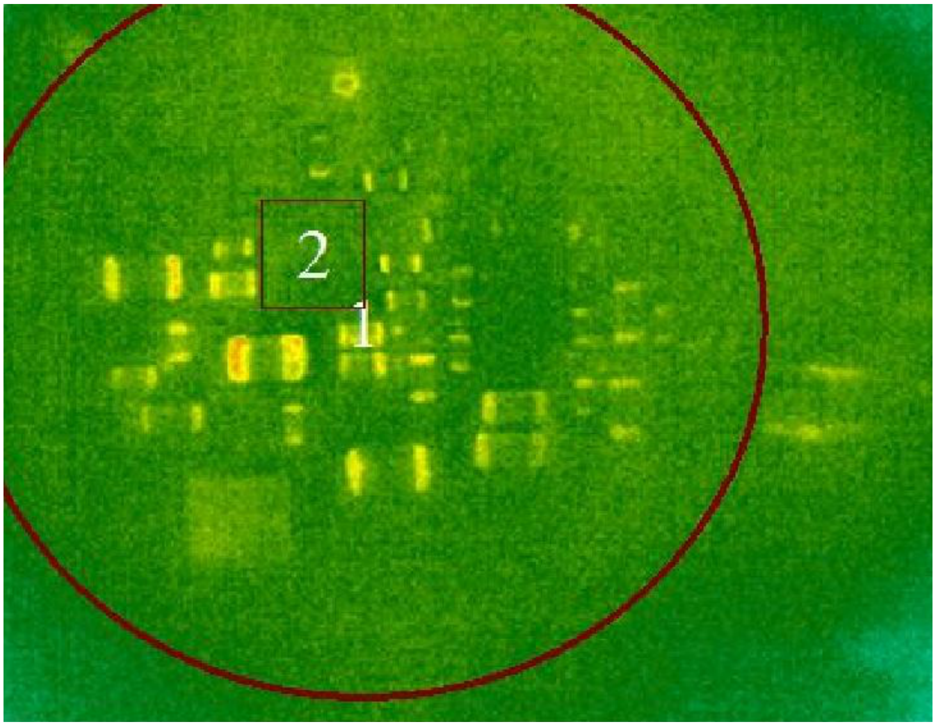

Figure 28. Image 6

Table 3. Board Outputs and Loads

	BQ51003	BQ25120 SYS	BQ25120 LS/LDO	TPS61046 BOOST 12 V	TPS61240 BOOST 5 V	TPS62743 V_BUCK	(1) BQ25120 MAX TEMP °C	(2) BQ51003 MAX TEMP °C	AMBIENT TEMP °C
Image 7	On	100 mA Fast Charge	Off	Off	Off	Off	31.7	32.18	22.5
Image 8	On	200 mA Fast Charge	Off	Off	Off	Off	39.66	34.31	22.5
Image 9	On	300 mA Fast Charge	Off	Off	Off	Off	35.13	38.52	22.5

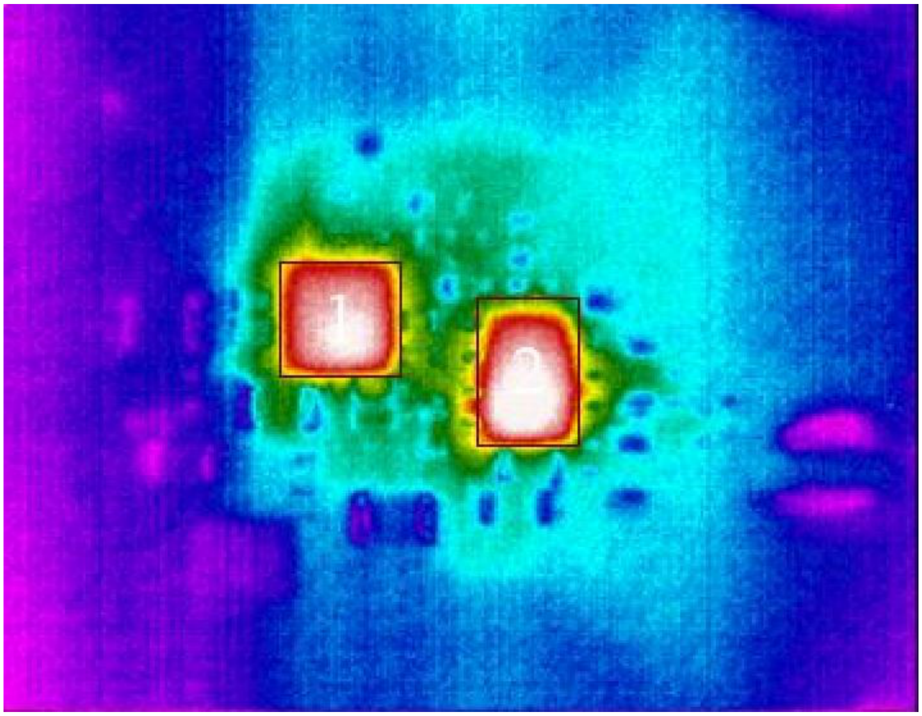

Figure 29. Image 7

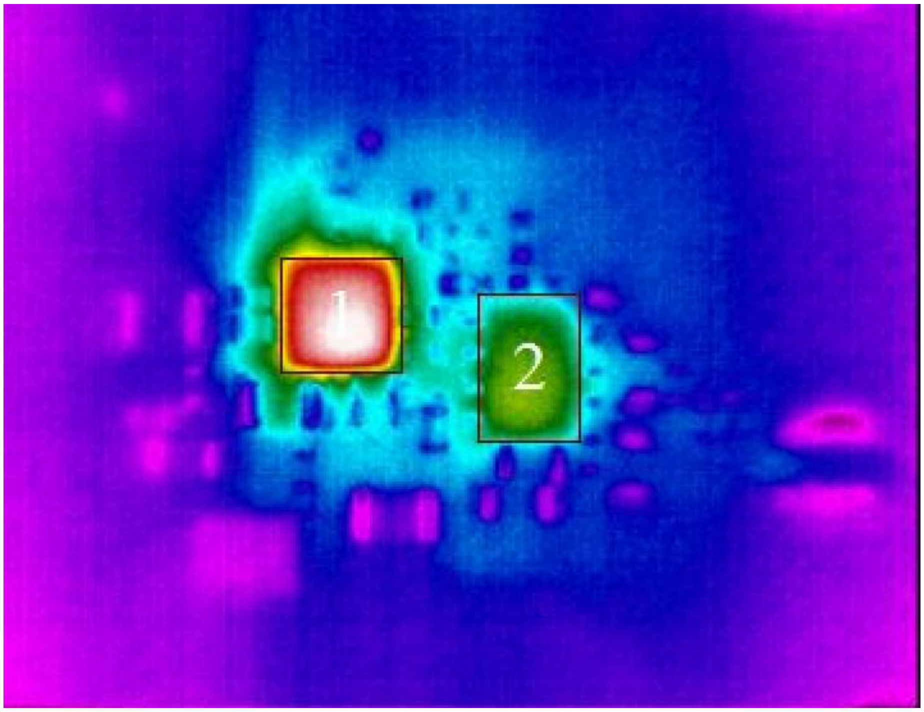

Figure 30. Image 8

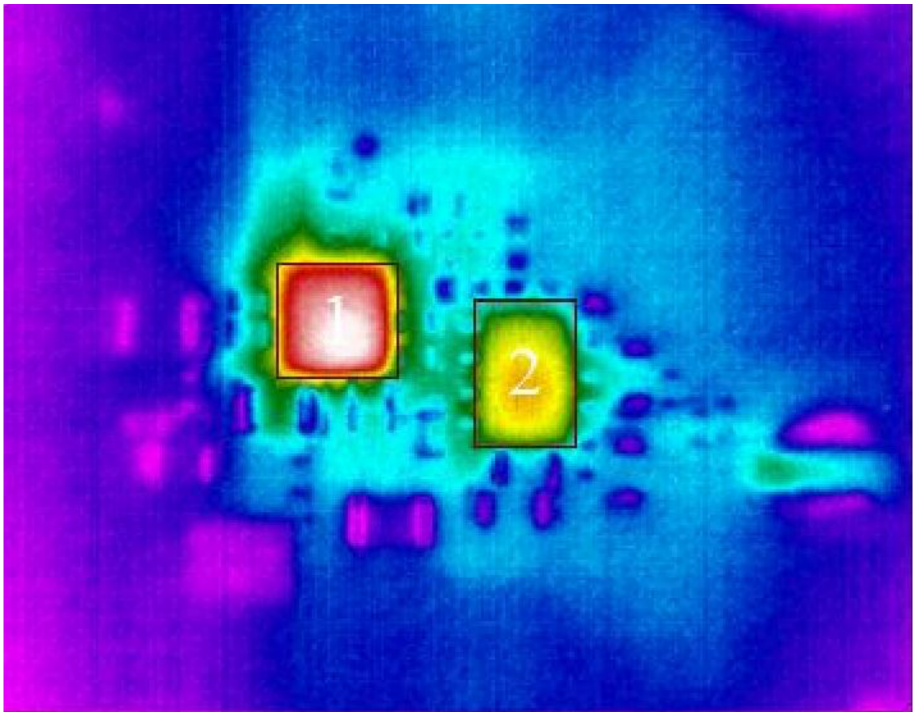

Figure 31. Image 9

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (December 2015) to A Revision	Page
• Changed values for C6, C7, ad C8 in Figure 3	4