

TPS543C20A SWIFT™ Step-Down Converter Evaluation Module User's Guide



ABSTRACT

This user's guide describes the characteristics, operation, and use of the TPS543C20AEVM-054 evaluation module (EVM). The user's guide includes test information, descriptions, and results. A complete schematic diagram, printed-circuit board layouts, and bill of materials are also included in this document. Throughout this user's guide, the abbreviations EVM, TPS543C20AEVM-054, and the term evaluation module are synonymous with the TPS543C20AEVM-054, unless otherwise noted.

Table of Contents

| | |
|---|-----------|
| 1 Introduction | 3 |
| 1.1 Before You Begin..... | 3 |
| 2 Description | 4 |
| 2.1 Typical End-User Applications..... | 4 |
| 2.2 EVM Features..... | 4 |
| 3 EVM Electrical Performance Specifications | 5 |
| 4 Schematic | 6 |
| 5 Test Equipment | 7 |
| 6 BSR054EVM | 8 |
| 7 List of Test Points, Jumpers, and Switch | 9 |
| 8 Test Procedure | 10 |
| 8.1 Line and Load Regulation Measurement Procedure..... | 10 |
| 8.2 Efficiency..... | 10 |
| 8.3 Equipment Shutdown..... | 11 |
| 9 Performance Data and Typical Characteristic Curves | 11 |
| 9.1 Efficiency..... | 11 |
| 9.2 Power Loss..... | 11 |
| 9.3 Load Regulation..... | 12 |
| 9.4 Transient Response..... | 12 |
| 9.5 Output Ripple..... | 13 |
| 9.6 Control On..... | 14 |
| 9.7 Control On and Off..... | 15 |
| 9.8 Thermal Image..... | 16 |
| 10 EVM Assembly Drawing and PCB Layout | 17 |
| 11 List of Materials | 27 |
| 12 Revision History | 29 |

List of Figures

| | |
|--|----|
| Figure 4-1. BSR054EVM Schematic..... | 6 |
| Figure 6-1. BSR054EVM Overview..... | 8 |
| Figure 6-2. Tip and Barrel Measurement..... | 8 |
| Figure 9-1. Efficiency of 0.9-V Output vs Load..... | 11 |
| Figure 9-2. Power Loss of 0.9-V Output vs Load..... | 11 |
| Figure 9-3. Load Regulation of 0.9-V Output..... | 12 |
| Figure 9-4. Transient Response of 0.9-V Output at 12-V _{IN} , Transient is 15 A to 25 A to 15 A, the Step is 10 A at 40 A/μs..... | 12 |
| Figure 9-5. Output Ripple and SW Node of 0.9-V Output at 12-V _{IN} , 40-A Output..... | 13 |
| Figure 9-6. Output Ripple and SW Node of 0.9-V Output at 12-V _{IN} , 0-A Output..... | 13 |
| Figure 9-7. Start up from Control, 0.9-V Output at 12-V _{IN} , 10-mA Output..... | 14 |
| Figure 9-8. 0.5-V Pre-bias start up from Control, 0.9-V Output at 12-V _{IN} , 20-A Output..... | 14 |

| | |
|--|----|
| Figure 9-9. Output Voltage Start-up and Shutdown, 0.9-V Output at 12-V _{IN} , 0.5-A Output..... | 15 |
| Figure 9-10. Thermal Image at 0.9-V Output at 12 V _{IN} , 40-A Output, at 25°C Ambient..... | 16 |
| Figure 10-1. BSR054EVM Top Layer Assembly Drawing (Top View)..... | 17 |
| Figure 10-2. BSR054EVM Top Solder Mask (Top View)..... | 18 |
| Figure 10-3. BSR054EVM Top Layer (Top View)..... | 19 |
| Figure 10-4. BSR054EVM Inner Layer 1 (Top View)..... | 20 |
| Figure 10-5. BSR054EVM Inner Layer 2 (Top View)..... | 21 |
| Figure 10-6. BSR054EVM Inner Layer 3 (Top View)..... | 22 |
| Figure 10-7. BSR054EVM Inner Layer 4 (Top View)..... | 23 |
| Figure 10-8. BSR054EVM Bottom Layer (Top View)..... | 24 |
| Figure 10-9. BSR054EVM Bottom Solder Mask (Top View)..... | 25 |
| Figure 10-10. BSR054EVM Bottom Overlay Layer (Top View)..... | 26 |

List of Tables

| | |
|--|----|
| Table 3-1. BSR054EVM Electrical Performance Specifications..... | 5 |
| Table 7-1. Test Point Functions..... | 9 |
| Table 8-1. List of Test Points for Line and Load Measurements..... | 10 |
| Table 8-2. List of Test Points for Efficiency Measurements..... | 10 |
| Table 11-1. BSR054EVM List of Materials..... | 27 |

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The BSR054EVM evaluation module uses the TPS543C20AEVM-054 device. The TPS543C20AEVM-054 is a highly integrated synchronous buck converter that is designed for up to 40-A current output.

1.1 Before You Begin

The following warnings and cautions are noted for the safety of anyone using or working close to the TPS543C20AEVM-054. Observe all safety precautions.



Warning

The TPS543C20AEVM-054 circuit module may become hot during operation due to dissipation of heat. Avoid contact with the board. Follow all applicable safety procedures applicable to your laboratory.



Caution

Do not leave the EVM powered when unattended.

WARNING

The circuit module has signal traces, components, and component leads on the bottom of the board. This may result in exposed voltages, hot surfaces or sharp edges. Do not reach under the board during operation.

CAUTION

The circuit module may be damaged by over temperature. To avoid damage, monitor the temperature during evaluation and provide cooling, as needed, for your system environment.

CAUTION

Some power supplies can be damaged by application of external voltages. If using more than 1 power supply, check your equipment requirements and use blocking diodes or other isolation techniques, as needed, to prevent damage to your equipment.

CAUTION

The communication interface is not isolated on the EVM. Be sure no ground potential exists between the computer and the EVM. Also be aware that the computer is referenced to the Battery- potential of the EVM.

2 Description

The BSR054EVM is designed as a single output DC/DC converter that demonstrates the TPS543C20AEVM-054 in a typical low-voltage application while providing a number of test points to evaluate the performance. It uses a nominal 12-V input bus to produce a regulated 0.9-V output at up to 40-A load current.

2.1 Typical End-User Applications

- Enterprise storage, SSD, NAS
- Wireless and wired communication infrastructure
- Industrial PCs, automation, ATE, PLC, video surveillance
- Enterprise server, switches, routers
- ASIC, SoC, FPGA, DSP core and I/O rails

2.2 EVM Features

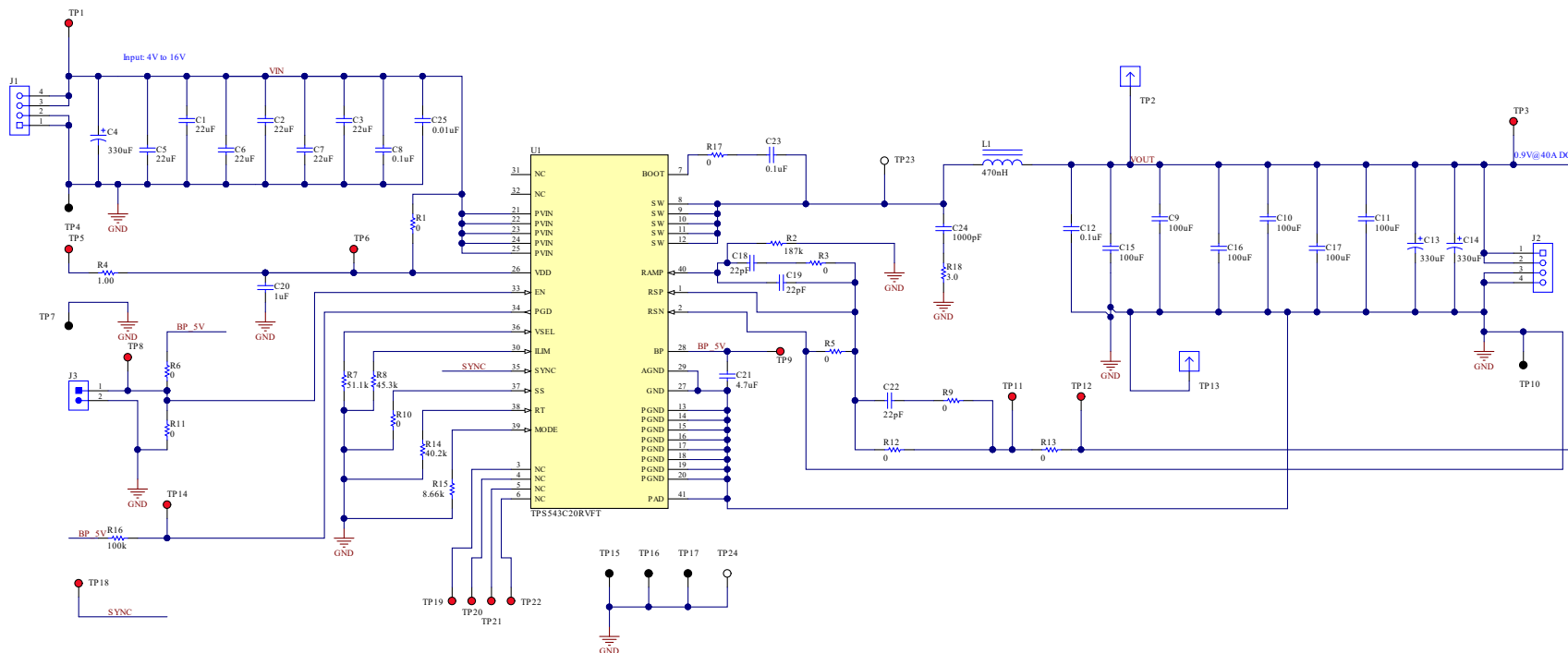
- Regulated 0.9-V output up to 40-A, steady-state output current
- Convenient test points for probing critical waveforms

3 EVM Electrical Performance Specifications

Table 3-1. BSR054EVM Electrical Performance Specifications

| Parameter | Test Conditions | Min | Typ | Max | Units |
|---------------------------------|---|-----|------|-----|------------------|
| Input Characteristics | | | | | |
| Voltage range | V_{IN} tied to VDD | 5 | 12 | 16 | V |
| Maximum input current | $V_{IN} = 12\text{ V}$, $I_O = 40\text{ A}$, $V_{OUT} = 0.9\text{ V}$, $F_{SW} = 500\text{ kHz}$ | | | 3.5 | A |
| No load input current | $V_{IN} = 12\text{ V}$, $I_O = 0\text{ A}$ | | 50 | | mA |
| Output Characteristics | | | | | |
| V_{OUT} Output voltage | Output current = 0 A to 40 A | | 0.9 | | V |
| I_{OUT} Output load current | $I_{OUT(min)}$ to $I_{OUT(max)}$ | 0 | | 40 | A |
| Output voltage regulation | Line regulation: input voltage = 5 V to 16 V | | 0.5% | | |
| | Load regulation: output current = 0 A to $I_{OUT(max)}$ | | 0.5% | | |
| V_{OUT} Output voltage ripple | $V_{IN} = 12\text{ V}$, $I_{OUT} = 40\text{ A}$ | | 10 | | mV _{PP} |
| V_{OUT} Output overcurrent | | | 46 | | A |
| Systems Characteristics | | | | | |
| Switching frequency | F_{SW} | | 500 | | kHz |
| V_{OUT} Peak efficiency | $V_{IN} = 12\text{ V}$, $I_O = 17\text{ A}$, $F_{SW} = 500\text{ kHz}$ | | 90% | | |
| Operating temperature | T_{oper} | 0 | | 85 | °C |

4 Schematic



Copyright © 2018, Texas Instruments Incorporated

Figure 4-1. BSR054EVM Schematic

5 Test Equipment

Voltage Source: The input voltage source V_{IN} must be a 0-V to 18-V variable DC source capable of supplying at least 10 A_{DC}. Also, the output impedance of the external voltage source must be much less than 100 k Ω .

Multimeters: It is recommended to use two separate multimeters [Figure 6-1](#). One meter is used to measure V_{IN} and one to measure V_{OUT} .

Output Load: A variable electronic load is recommended for testing [Figure 6-1](#). It must be capable of 40 A at voltages as low as 0.6 V.

Oscilloscope: An oscilloscope is recommended for measuring output noise and ripple. Output ripple must be measured using a tip-and-barrel method or better as shown in [Figure 6-2](#). The scope must be adjusted to 20-MHz bandwidth, AC coupling at 50 mV/division, and must be set to 1- μ s/division.

Fan: During prolonged operation at high loads, it may be necessary to provide forced air cooling with a small fan aimed at the EVM. Temperature of the devices on the EVM must be maintained below 105°C.

Recommended Wire Gauge: The voltage drop in the load wires must be kept as low as possible in order to keep the working voltage at the load within its operating range. Use the AWG 14 wire (2 wires parallel for V_{OUT} positive and 2 wires parallel for the V_{OUT} negative) of no more than 1.98 feet between the EVM and the load. This recommended wire gauge and length should achieve a voltage drop of no more than 0.2 V at the maximum 40-A load.

6 BSR054EVM

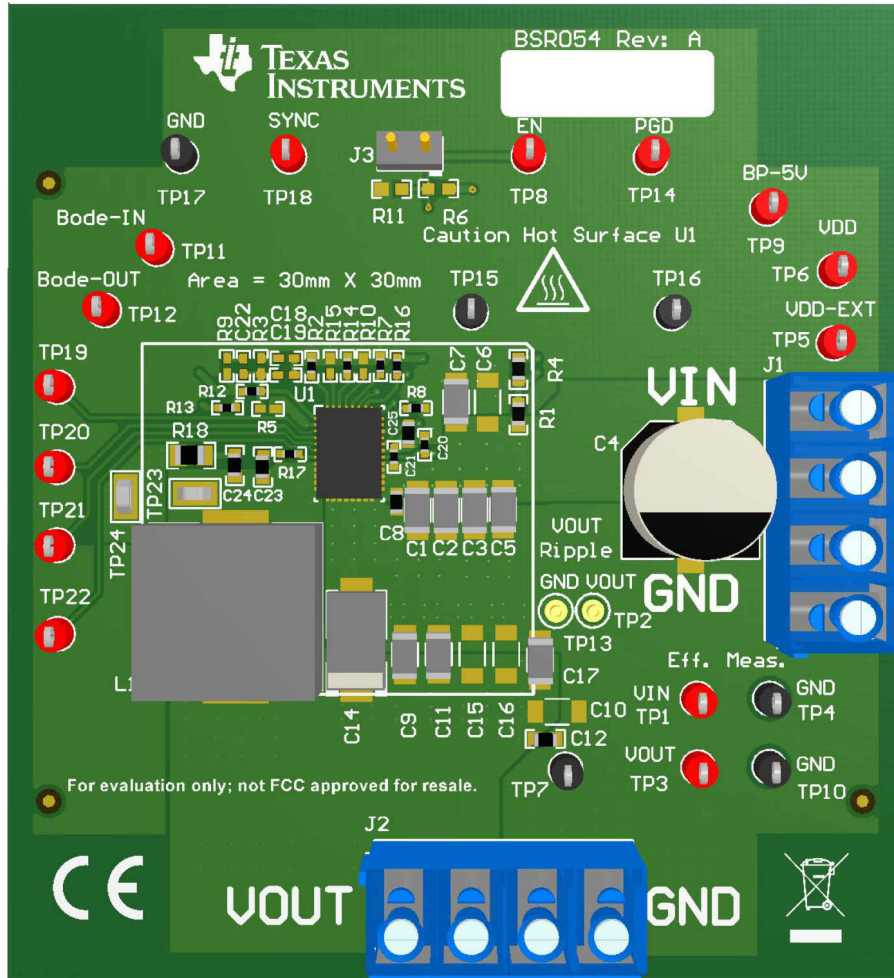


Figure 6-1. BSR054EVM Overview

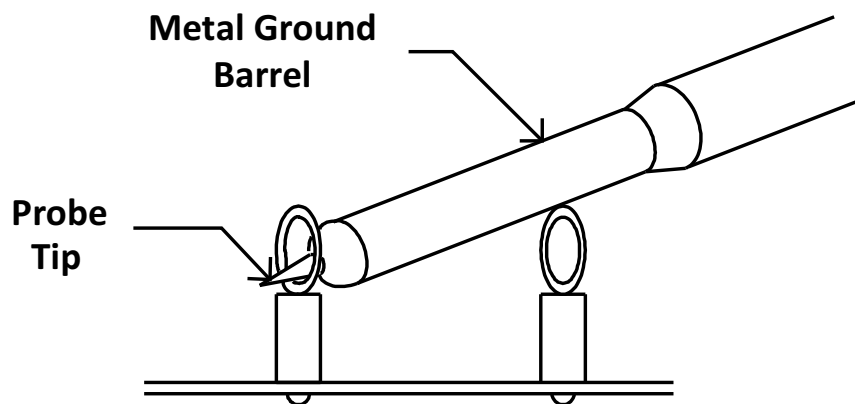


Figure 6-2. Tip and Barrel Measurement

7 List of Test Points, Jumpers, and Switch

Table 7-1. Test Point Functions

| Item | Type | Name | Description |
|---------------------------|--------------|-------|---|
| TP23 | T-H loop | SW | Power supply Switch node |
| TP11 | T-H loop | CH-A | Measure loop stability |
| TP12 | T-H loop | CH-B | Measure loop stability |
| TP3 | T-H loop | LocS+ | Sense VOUT + locally across C11. Use for efficiency and ripple measurements |
| TP10 | T-H loop | LocS- | Sense VOUT- locally across C11. Use for efficiency and ripple measurements |
| TP1 | T-H loop | PVIN | Sense VIN + across C8 |
| TP4 | T-H loop | PGND | Sense VIN – across C8 |
| TP6 | T-H loop | VDD | Supplies the internal circuitry |
| TP9 | T-H loop | BP | LDO output |
| TP14 | T-H loop | PG | Power good |
| TP7, TP15, TP16, TP17 | T-H loop | PGND | Common GND |
| TP19, TP20, TP21, TP22 | T-H loop | | Not used |
| TP18 | T-H loop | SYNC | Synchronize with external switching frequency |
| JP3 | 2-pin jumper | EN | Enable or disable TPS543C20AEVM-054 IC |

8 Test Procedure

8.1 Line and Load Regulation Measurement Procedure

1. Connect V_{OUT} to J2 and V_{OUT_GND} to J2 [Figure 6-1](#).
2. Ensure that the electronic load is set to draw 0 A_{DC}.
3. Ensure the jumper provided on the EVM shorts on J3 before V_{IN} is applied
4. Connect V_{IN} to J1 and V_{IN_GND} to J1 [Figure 6-1](#).
5. Increase V_{IN} from 0 V to 12 V using the digital multimeter to measure input voltage.
6. Remove the jumper on J3 to enable the controller.
7. Use the other digital multimeter or the oscilloscope to measure output voltage V_{OUT} at TP3 and TP10.

Table 8-1. List of Test Points for Line and Load Measurements

| Test Point | Node Name | Description |
|------------|-----------|---|
| TP3 | LocS+ | Sense V _{OUT} + locally across C11. Use for efficiency and ripple measurements |
| TP10 | LocS- | Sense V _{OUT} - locally across C11. Use for efficiency and ripple measurements |
| TP1 | PVIN | Sense V _{IN} + across C8 |
| TP4 | PGND | Sense V _{IN} - across C8 |

8. Vary the load from 0 A_{DC} to maximum rated output 40 A_{DC}. V_{OUT} must remain in regulation as defined in [Table 3-1](#).
9. Vary V_{IN} from 5 V to 16 V. V_{OUT} must remain in regulation as defined in [Table 3-1](#).
10. Decrease the load to 0 A.
11. Put the jumper back on JP3 to disable the converter.
12. Decrease V_{IN} to 0 V or turn off the supply.

8.2 Efficiency

To measure the efficiency of the power train on the EVM, it is important to measure the voltages at the correct location. This is necessary because otherwise the measurements will include losses in efficiency that are not related to the power train itself. Losses incurred by the voltage drop in the copper traces and in the input and output connectors are not related to the efficiency of the power train, and they must not be included in efficiency measurements.

Table 8-2. List of Test Points for Efficiency Measurements

| Test Point | Node Name | Description |
|------------|-----------|---|
| TP3 | LocS+ | Sense V _{OUT} + locally across C11. Use for efficiency and ripple measurements |
| TP10 | LocS- | Sense V _{OUT} - locally across C11. Use for efficiency and ripple measurements |
| TP1 | PVIN | Sense V _{IN} + across C8 |
| TP4 | PGND | Sense V _{IN} - across C8 |

Input current can be measured at any point in the input wires, and output current can be measured anywhere in the output wires of the output being measured. Using these measurement points result in efficiency measurements that do not include losses due to the connectors and PCB traces.

8.3 Equipment Shutdown

1. Reduce the load current to 0 A.
2. Reduce input voltage to 0 V.
3. Shut down the external fan if in use.
4. Shut down equipment.

9 Performance Data and Typical Characteristic Curves

Figure 9-1 through Figure 9-10 present typical performance curves for the BSR054EVM.

9.1 Efficiency

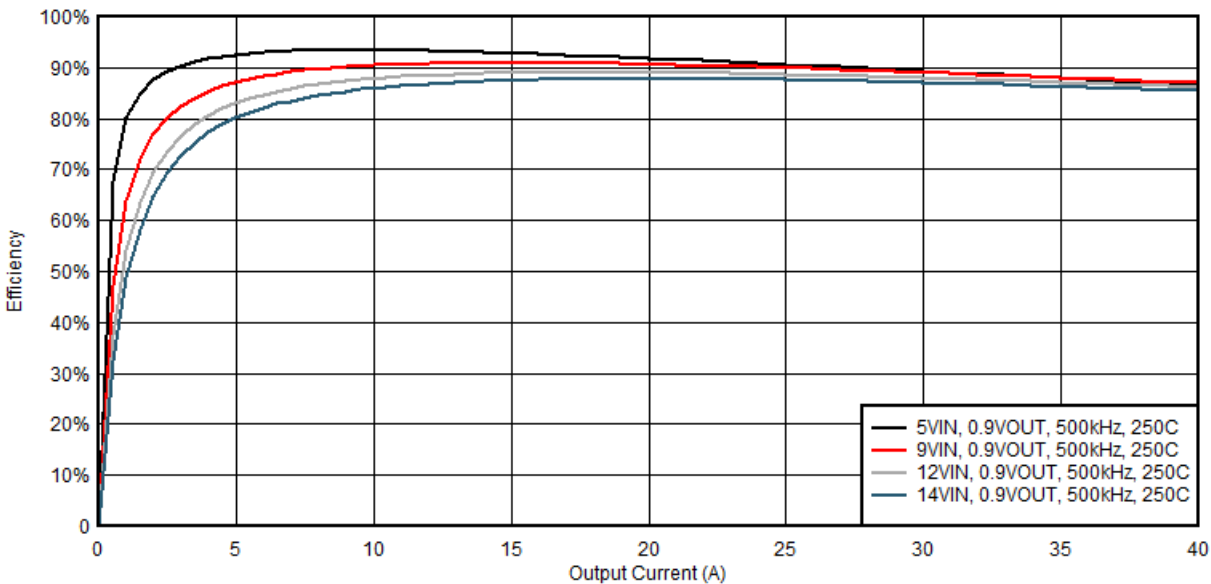


Figure 9-1. Efficiency of 0.9-V Output vs Load

9.2 Power Loss

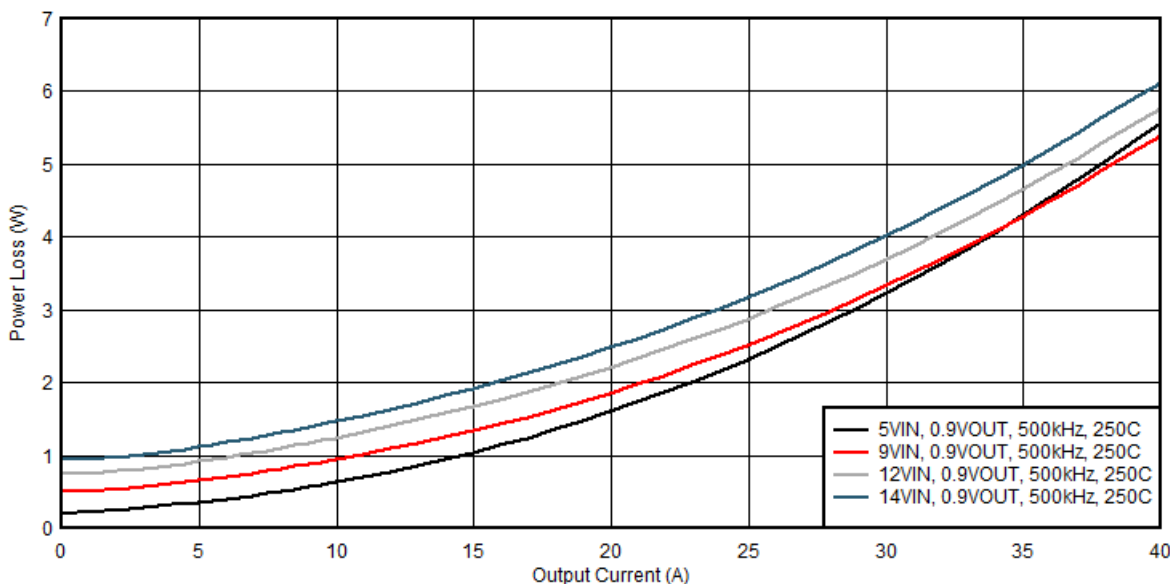


Figure 9-2. Power Loss of 0.9-V Output vs Load

9.3 Load Regulation

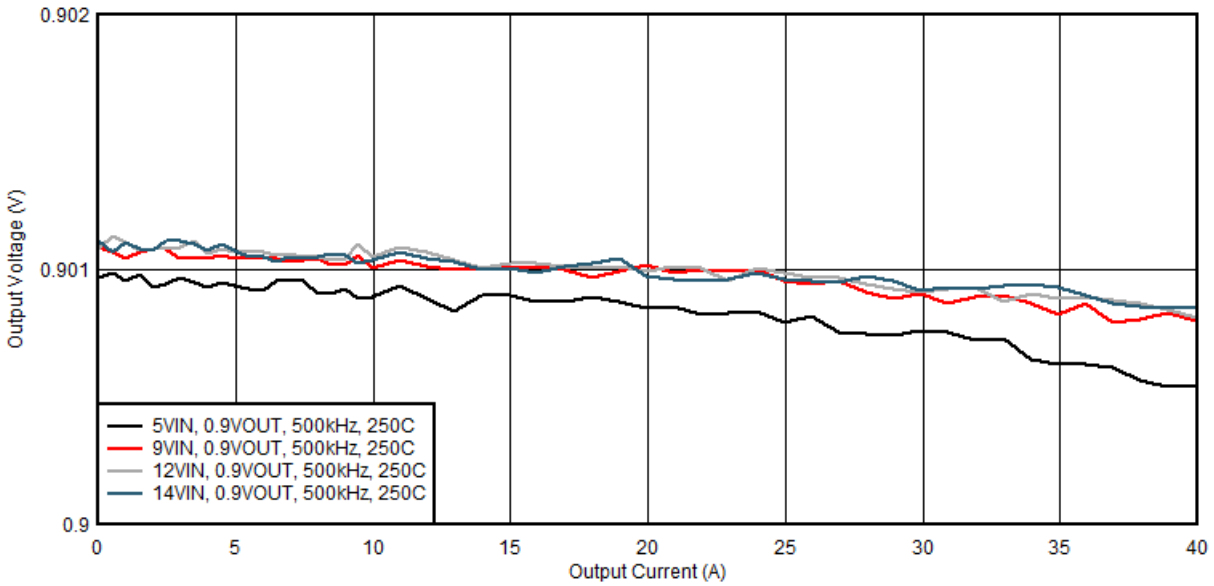


Figure 9-3. Load Regulation of 0.9-V Output

9.4 Transient Response

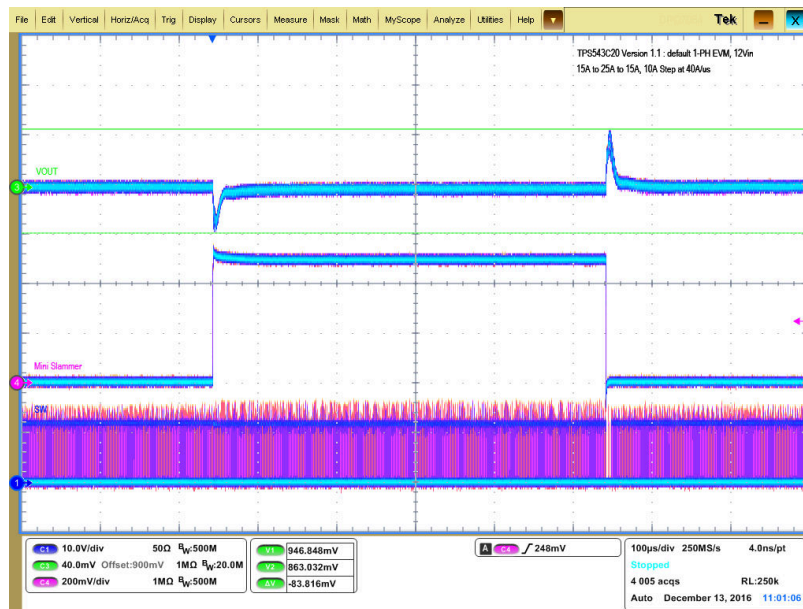


Figure 9-4. Transient Response of 0.9-V Output at 12-V_{IN}, Transient is 15 A to 25 A to 15 A, the Step is 10 A at 40 A/µs

9.5 Output Ripple

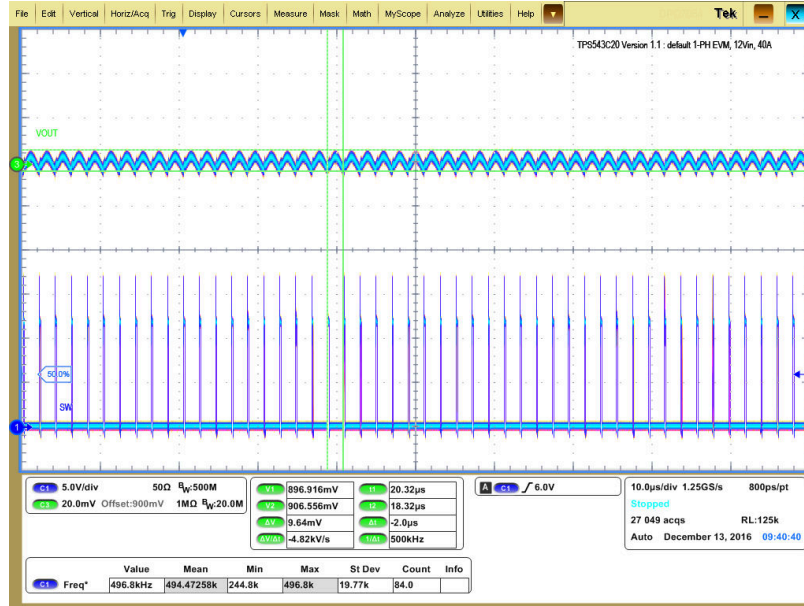


Figure 9-5. Output Ripple and SW Node of 0.9-V Output at 12-V_{IN}, 40-A Output

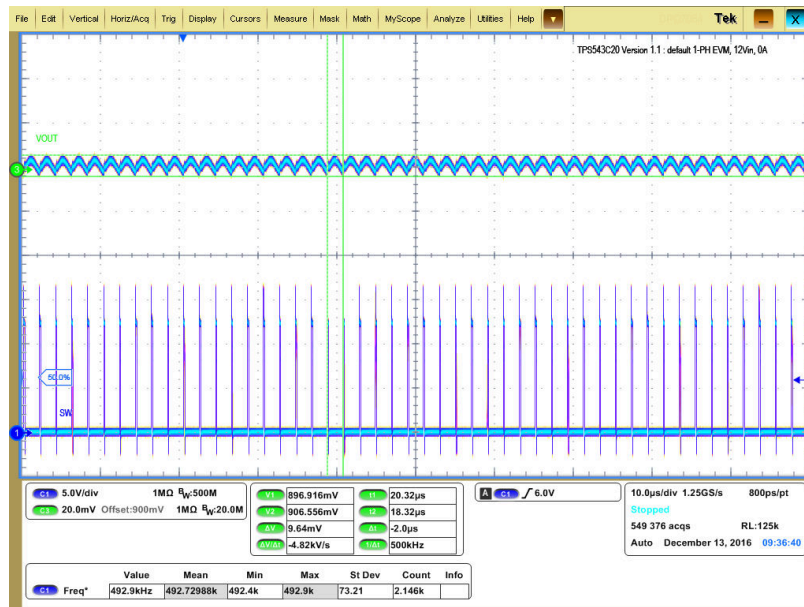


Figure 9-6. Output Ripple and SW Node of 0.9-V Output at 12-V_{IN}, 0-A Output

9.6 Control On

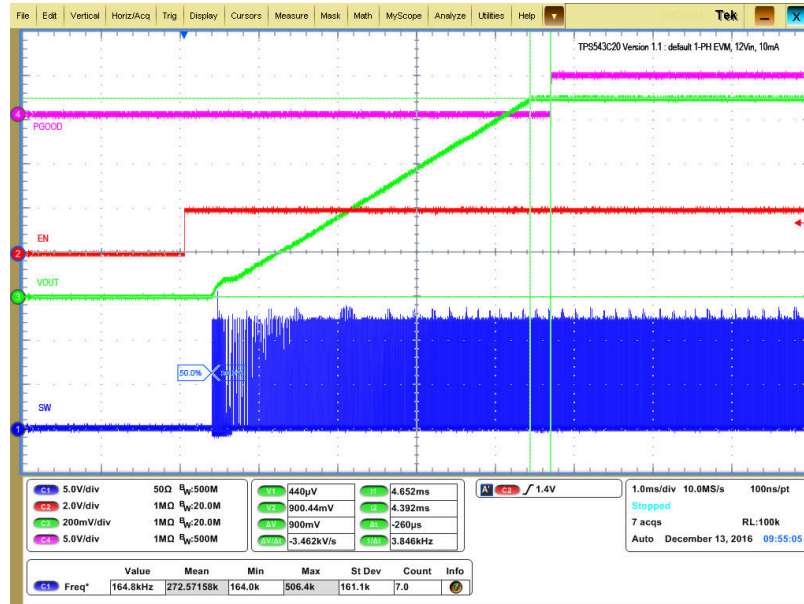


Figure 9-7. Start up from Control, 0.9-V Output at 12-V_{IN}, 10-mA Output

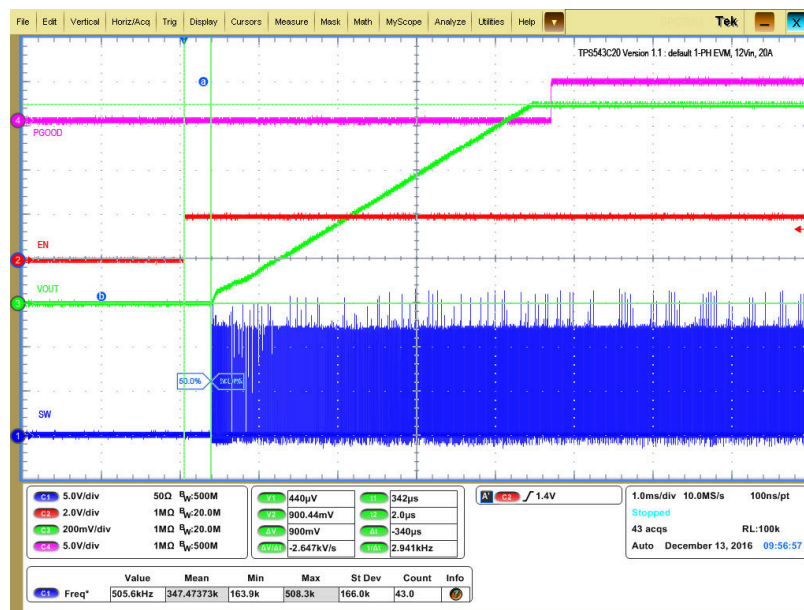


Figure 9-8. 0.5-V Pre-bias start up from Control, 0.9-V Output at 12-V_{IN}, 20-A Output

9.7 Control On and Off

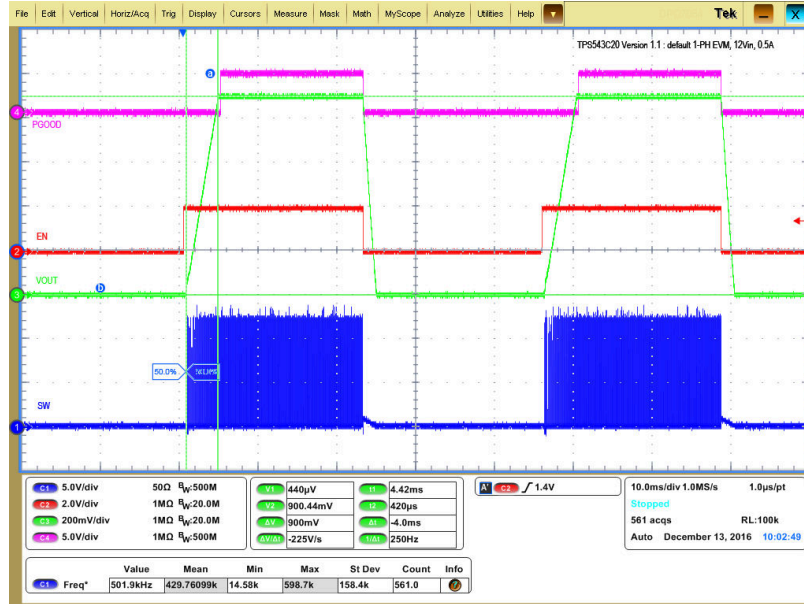


Figure 9-9. Output Voltage Start-up and Shutdown, 0.9-V Output at 12-V_{IN}, 0.5-A Output

9.8 Thermal Image

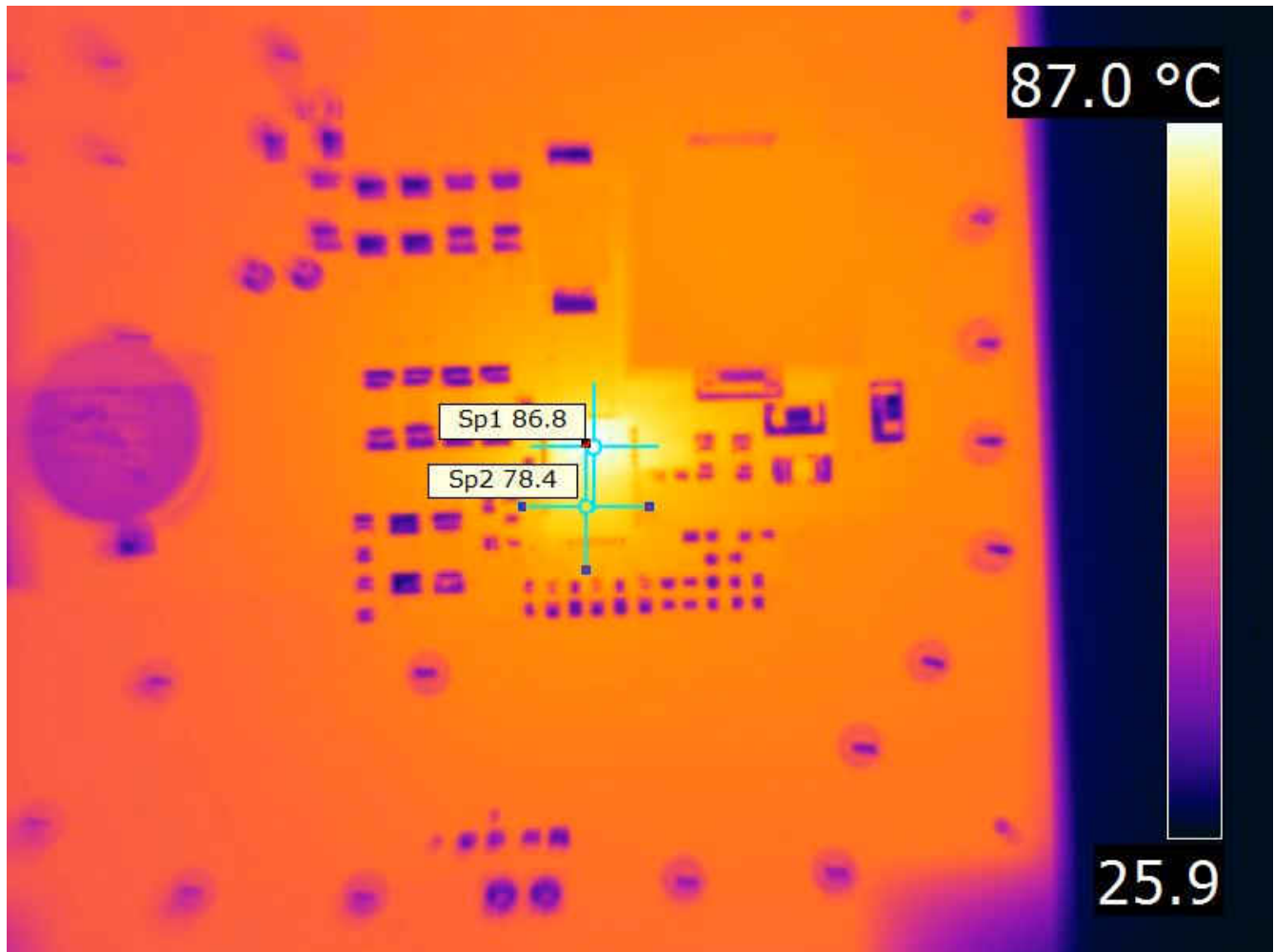


Figure 9-10. Thermal Image at 0.9-V Output at 12 V_{IN}, 40-A Output, at 25°C Ambient

10 EVM Assembly Drawing and PCB Layout

Figure 10-1 through Figure 10-8 show the design of the BSR054EVM printed-circuit board (PCB). The BSR054EVM has a 2-oz. copper finish for all layers.

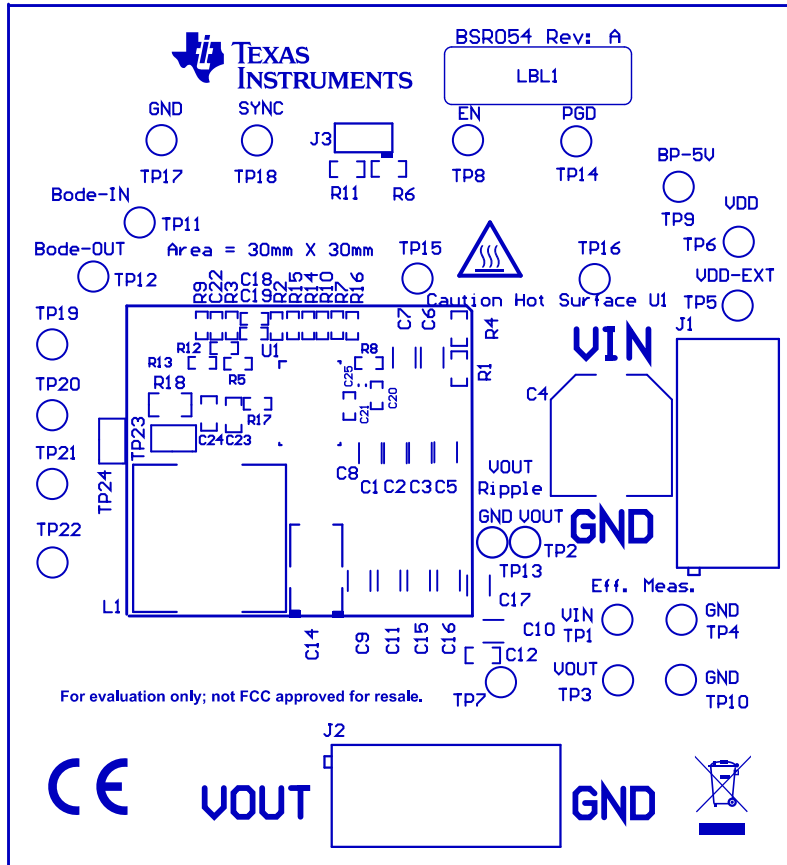


Figure 10-1. BSR054EVM Top Layer Assembly Drawing (Top View)

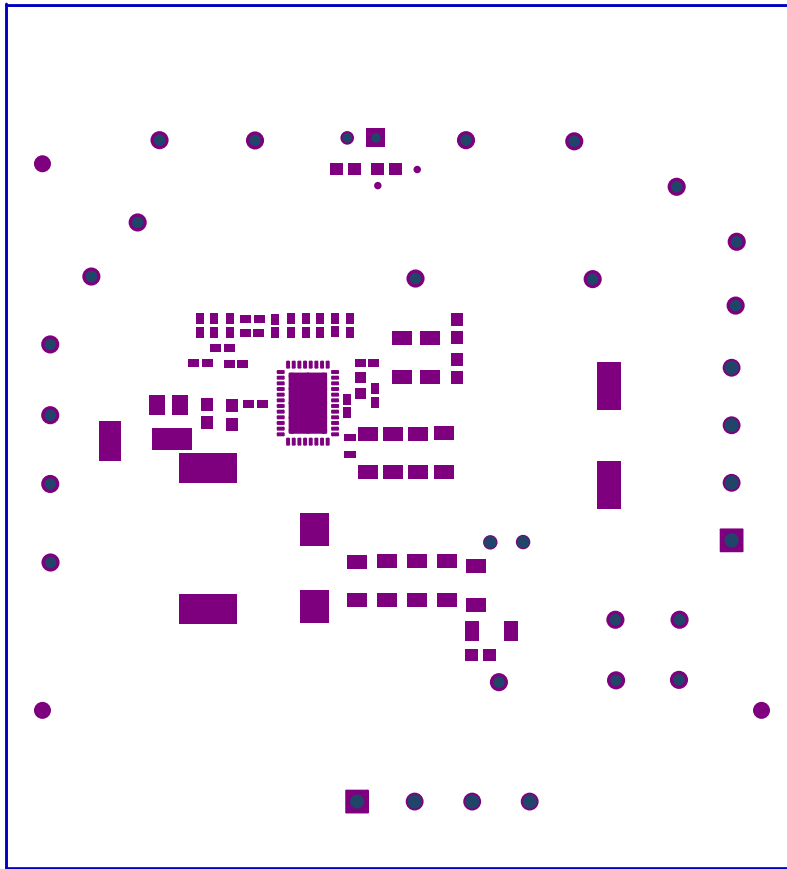


Figure 10-2. BSR054EVM Top Solder Mask (Top View)

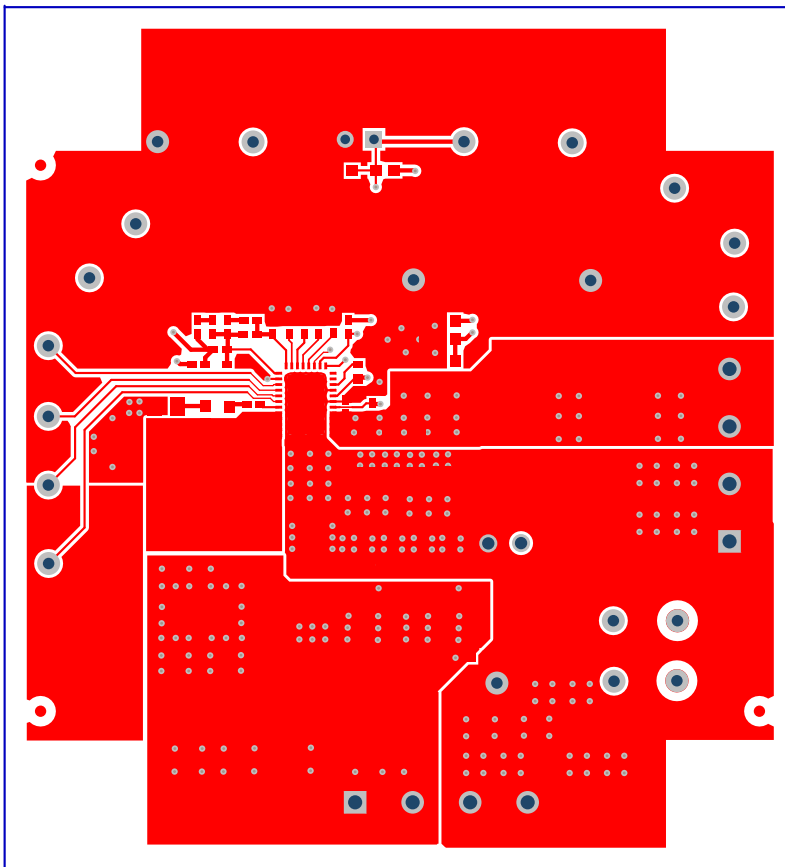


Figure 10-3. BSR054EVM Top Layer (Top View)

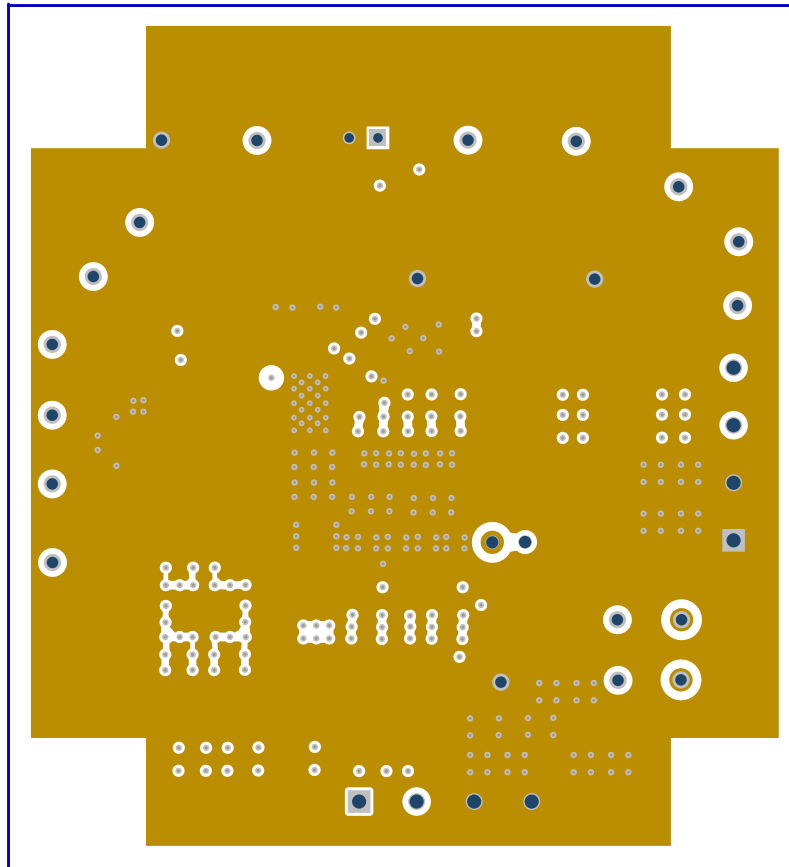


Figure 10-4. BSR054EVM Inner Layer 1 (Top View)

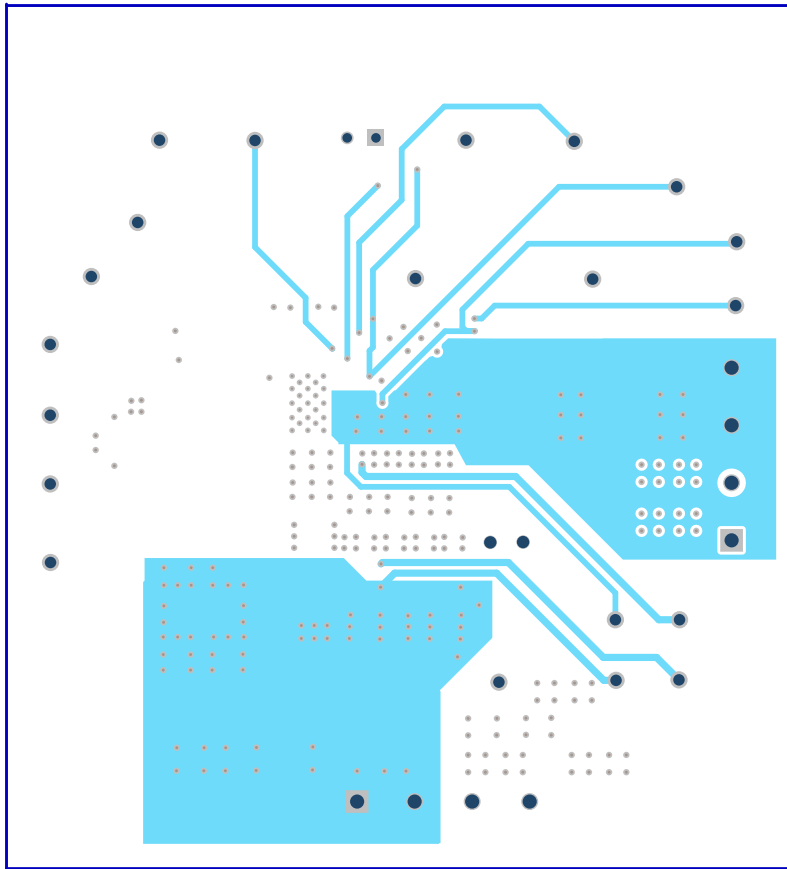


Figure 10-5. BSR054EVM Inner Layer 2 (Top View)

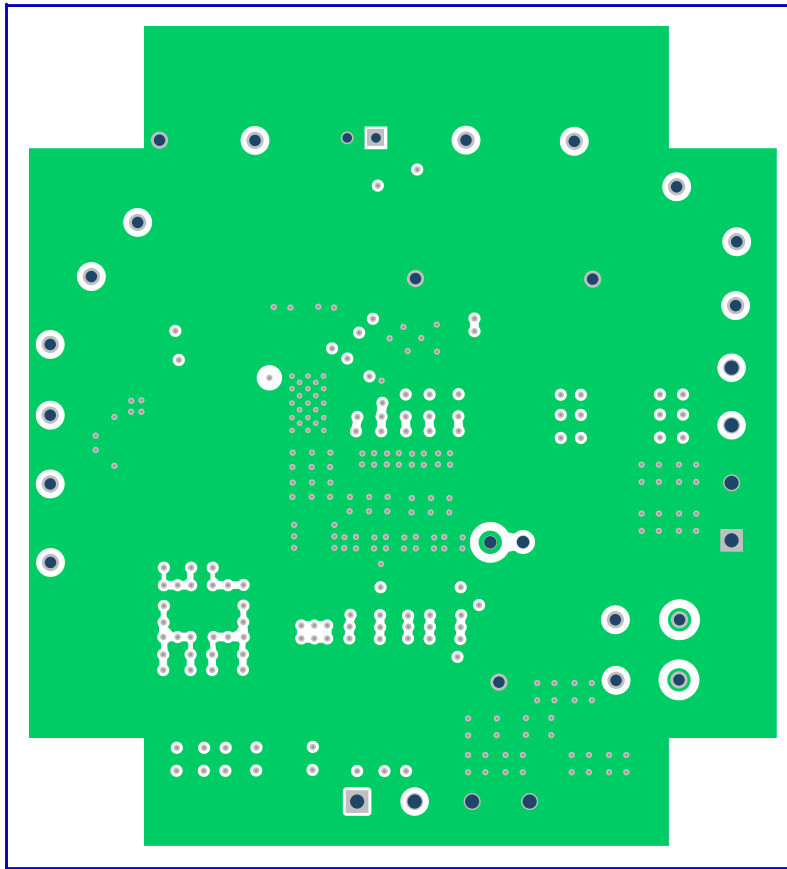


Figure 10-6. BSR054EVM Inner Layer 3 (Top View)

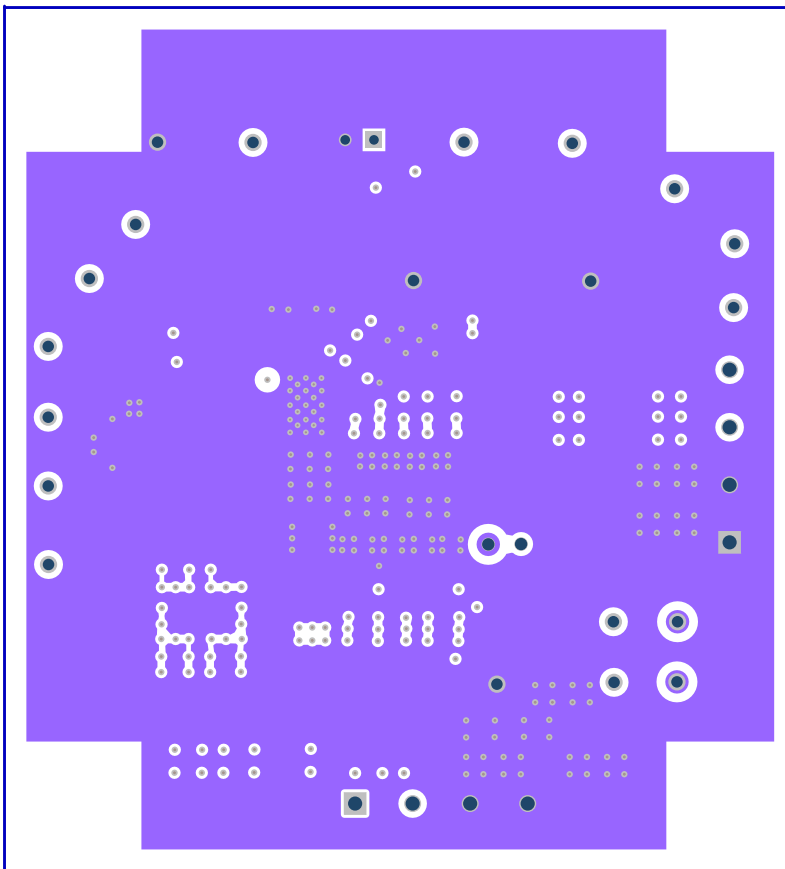


Figure 10-7. BSR054EVM Inner Layer 4 (Top View)

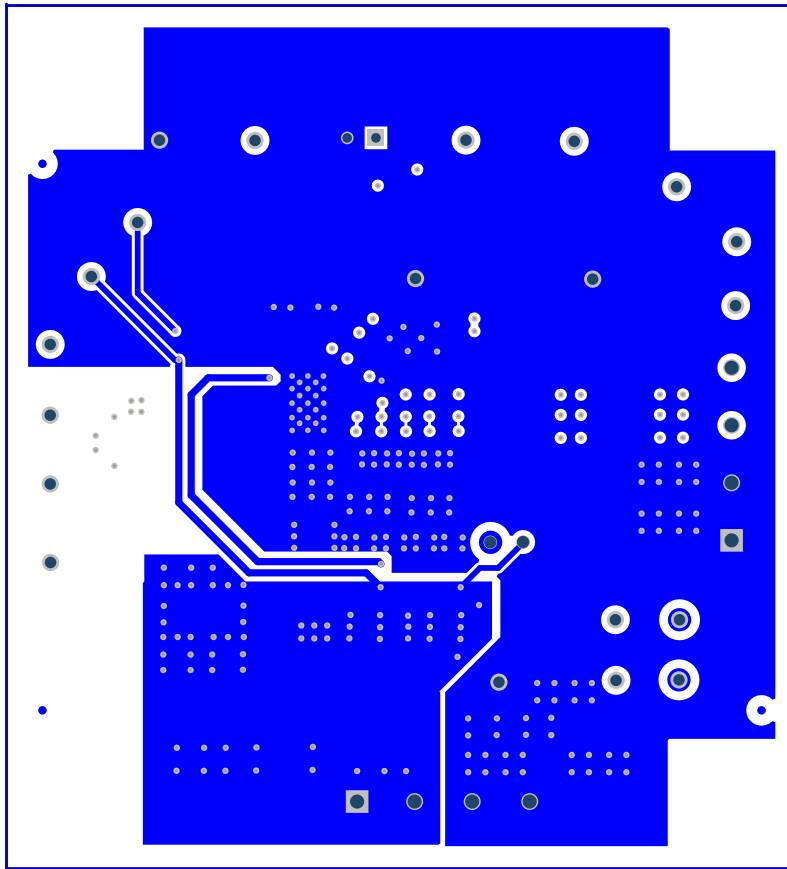


Figure 10-8. BSR054EVM Bottom Layer (Top View)

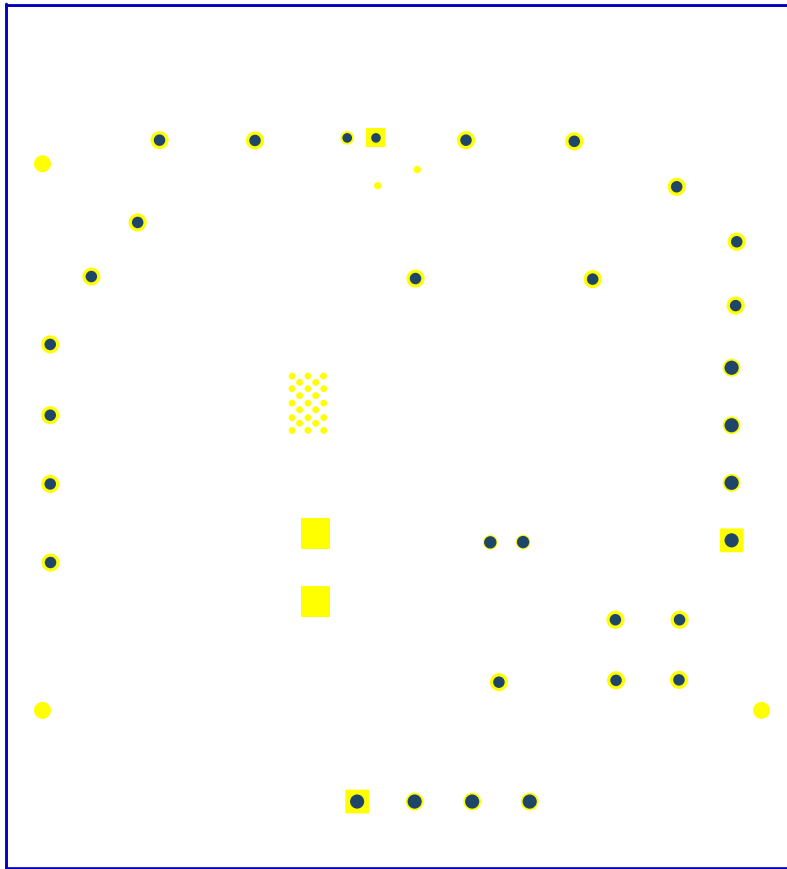


Figure 10-9. BSR054EVM Bottom Solder Mask (Top View)

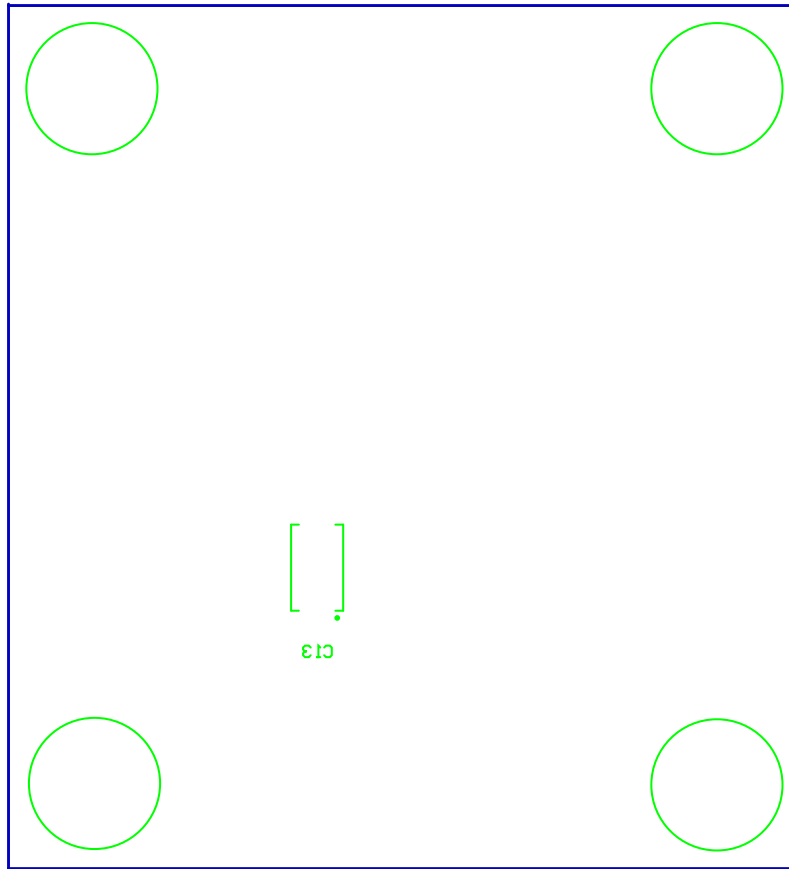


Figure 10-10. BSR054EVM Bottom Overlay Layer (Top View)

11 List of Materials

The EVM components list, according to the schematic, is shown in [Table 11-1](#).

Table 11-1. BSR054EVM List of Materials

| Designator | Quantity | Value | Description | Package Reference | PartNumber | Manufacturer | Alternate Part Number ⁽¹⁾ | Alternate Manufacturer ⁽¹⁾ |
|--|----------|---------|---|------------------------------|-------------------------|---------------------|--------------------------------------|---------------------------------------|
| !PCB | 1 | | Printed Circuit Board | | BSR054 | Any | - | - |
| C1, C2, C3, C5, C7 | 5 | 22 µF | CAP, CERM, 22 µF, 25 V, ±20%, X5R, 1206_190 | 1206_190 | C3216X5R1E226M160AB | TDK | | |
| C4 | 1 | 330 µF | CAP, AL, 330 µF, 25 V, ±20%, 0.15 Ω, SMD | SMT Radial G | EEE-FC1E331P | Panasonic | 865230457008 | Würth Elektronik |
| C8 | 1 | 0.1 µF | CAP, CERM, 0.1 µF, 25 V, ±10%, X7R, 0603 | 0603 | GRM188R71E104KA01D | MuRata | 885012206071 | Würth Elektronik |
| C9, C11, C17 | 3 | 100 µF | CAP, CERM, 100 µF, 6.3 V, +/- 20%, X5R, 1206 | 1206 | GRM31CR60J107ME39L | MuRata | 885012108005 | |
| C12 | 1 | 0.1 µF | CAP, CERM, 0.1 µF, 10 V, ±10%, X7R, 0603 | 0603 | C0603X104K8RACTU | Kemet | | Würth Elektronik |
| C13, C14 | 1 | 330 µF | CAP, Aluminum Polymer, 330 µF, 2 V, ±20%, 0.003 Ω, 7.3 × 1.8 × 4.3 mm SMD | 7.3 × 1.8 × 4.3 mm | EEFGX0D331R | Panasonic | | |
| C20 | 1 | 1 µF | CAP, CERM, 1 µF, 25 V, ±10%, X5R, 0402 | 0402 | GRM155R61E105KA12D | MuRata | | |
| C21 | 1 | 4.7 µF | CAP, CERM, 4.7 µF, 16 V, ±10%, X5R, 0603 | 0603 | GRM188R61C475KAAJ | MuRata | | |
| C23 | 1 | 0.1 µF | CAP, CERM, 0.1 µF, 50 V, ±10%, X7R, 0603 | 0603 | 06035C104KAT2A | AVX | 885012206095 | Würth Elektronik |
| C24 | 1 | 1000 pF | CAP, CERM, 1000 pF, 50 V, ±10%, C0G/NP0, 0603 | 0603 | 06035A102KAT2A | AVX | 885012006062 | Würth Elektronik |
| C25 | 1 | 0.01 µF | CAP, CERM, 0.01 µF, 50 V, ±5%, X7R, 0402 | 0402 | C0402C103J5RACTU | Kemet | | |
| H9, H10, H11, H12 | 4 | | Bump, Hemisphere, 0.44 × 0.20, Clear | Transparent Bump | SJ-5303 (CLEAR) | 3M | | |
| J1, J2 | 2 | | Terminal Block, 5.08 mm, 4 × 1, Brass, TH | 4 × 1 5.08 mm Terminal Block | ED120/4DS | On-Shore Technology | 61300211121 | Würth Elektronik |
| J3 | 1 | | Header, 100 mil, 2 × 1, TH | Header, 2 × 1, 100 mil, TH | 800-10-002-10-001000 | Mill-Max | 691242510004 | Würth Elektronik |
| L1 | 1 | 470 nH | Inductor, Shielded Drum Core, Ferrite, 470 nH, 40.5 A, 0.000165 Ω, SMD | 12.5 × 13 mm | 744309047 | Würth Elektronik | | |
| LBL1 | 1 | | Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll | PCB Label 0.650"H × 0.200"W | THT-14-423-10 | Brady | | |
| R1 | 1 | 0 | RES, 0, 5%, 0.1 W, 0603 | 0603 | CRCW06030000Z0EA | Vishay-Dale | | |
| R2 | 1 | 187 k | RES, 187 k, 1%, 0.063 W, 0402 | 0402 | CRCW0402187KFKED | Vishay-Dale | | |
| R4 | 1 | 1.00 | RES, 1.00, 1%, 0.1 W, 0603 | 0603 | CRCW06031R00FKEA | Vishay-Dale | | |
| R7 | 1 | 51.1 k | RES, 51.1 k, 1%, 0.063 W, 0402 | 0402 | CRCW040251K1FKED | Vishay-Dale | | |
| R8 | 1 | 45.3 k | RES, 45.3 k, 1%, 0.063 W, 0402 | 0402 | CRCW040245K3FKED | Vishay-Dale | | |
| R12, R13, R17 | 3 | 0 | RES, 0, 5%, 0.063 W, 0402 | 0402 | CRCW04020000Z0ED | Vishay-Dale | | |
| R14 | 1 | 40.2 k | RES, 40.2 k, 1%, 0.063 W, 0402 | 0402 | CRCW040240K2FKED | Vishay-Dale | | |
| R16 | 1 | 100 k | RES, 100 k, 5%, 0.063 W, 0402 | 0402 | CRCW0402100KJNED | Vishay-Dale | | |
| R18 | 1 | 3.0 | RES, 3.0 Ω, 5%, 0.125W, 0805 | 0805 | RC0805JR-073RL | Yageo America | | |
| TP1, TP3, TP5, TP6, TP8, TP9, TP11, TP12, TP14, TP18, TP19, TP20, TP21, TP22 | 14 | Red | Test Point, Miniature, Red, TH | Red Miniature Testpoint | 5000 | Keystone | | |
| TP2, TP13 | 2 | | PCB Pin, 0.04" DIA, TH | PCB Pin, 0.04" DIA, TH | 3102-2-00-21-00-00-08-0 | Mill-Max | | |

Table 11-1. BSR054EVM List of Materials (continued)

| Designator | Quantity | Value | Description | Package Reference | PartNumber | Manufacturer | Alternate Part Number ⁽¹⁾ | Alternate Manufacturer ⁽¹⁾ |
|------------------------------------|----------|-------------|--|------------------------------|-----------------------|-------------------|--------------------------------------|---------------------------------------|
| TP4, TP7, TP10, TP15, TP16, TP17 | 6 | Black | Test Point, Miniature, Black, TH | Black Miniature Testpoint | 5001 | Keystone | | |
| TP23, TP24 | 2 | SMT | Test Point, Miniature, SMT | Testpoint_Keystone_Miniature | 5015 | Keystone | | |
| U1 | 1 | | 40A FIXED FREQUENCY NON-COMPENSATION STACKABLE SYNCHRONOUS BUCK CONVERTER, RVF0040A (LQFN-CLIP-40) | RVF0040A | TPS543C20AEVM-054RVFT | Texas Instruments | | Texas Instruments |
| C6 | 0 | 22 μ F | CAP, CERM, 22 μ F, 25 V, \pm 20%, X5R, 1206_190 | 1206_190 | C3216X5R1E226M160AB | TDK | | |
| C10, C15, C16 | 0 | 100 μ F | CAP, CERM, 100 μ F, 6.3 V, \pm 20%, X5R, 1206 | 1206 | GRM31CR60J107ME39L | MuRata | 885012108005 | Würth Elektronik |
| C18, C19, C22 | 0 | 22 pF | CAP, CERM, 22 pF, 50 V, \pm 5%, C0G/NP0, 0402 | 0402 | C1005C0G1H220J050BA | TDK | 885012005057 | Würth Elektronik |
| FID1, FID2, FID3, FID4, FID5, FID6 | 0 | | Fiducial mark. There is nothing to buy or mount. | Fiducial | N/A | N/A | | |
| R3, R5, R9, R10 | 0 | 0 | RES, 0, 5%, 0.063 W, 0402 | 0402 | ERJ-2GE0R00X | Panasonic | | |
| R6, R11 | 0 | 0 | RES, 0, 5%, 0.1 W, 0603 | 0603 | CRCW06030000Z0EA | Vishay-Dale | | |
| R15 | 0 | 8.66 k | RES, 8.66 k, 1%, 0.063 W, 0402 | 0402 | CRCW04028K66FKED | Vishay-Dale | | |

(1) Unless otherwise noted in the Alternate PartNumber and/or Alternate Manufacturer columns, all parts may be substituted with equivalents.

12 Revision History

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

| Changes from Revision * (December 2018) to Revision A (September 2021) | Page |
|--|-------------|
| • Updated the numbering format for tables, figures, and cross-references throughout the document. | 3 |
| • Updated the user's guide title..... | 3 |

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#), [TI's General Quality Guidelines](#), or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.

Copyright © 2026, Texas Instruments Incorporated

Last updated 10/2025