AN-2241 SM72445 Evaluation Board

1 Introduction

The SolarMagic™ SM72445 Evaluation Board is designed to demonstrate the operation and the capabilities of the SM72445 MPPT controller. The board consists of a high efficiency, four-switch Buck-Boost DC/DC converter and a bidirectional FET based switch designed to bypass the DC/DC converter for cases when DC/DC conversion is not needed and during failure of the DC/DC converter (over-current protection, over-temperature, and so forth). The board also includes auxiliary circuits such as driver, current sensor, temperature sensor and additional OVP circuitry.

The SM72445 is designed to maximize the energy production of a photovoltaic panel through the control of a four switch buck-boost converter as well as an optional FET bi-directional switch (two FETs) designed to maximize the efficiency at 1:1 conversion ratios. The maximum voltage and power transferred depend on the component choice (driver, passive components, FET, and so forth). The SM72445 performs optimization of the operating point of the solar panel through a high speed Perturb&Observe algorithm. The input voltage and current are sampled at a high rate and digitally filtered while the algorithm updates the output PWM waveform at a rate up to 1.2ms/step. The PWM waveforms include dead-time and can be directly fed to the drivers controlling the DC/DC converter's switches. The SM72445 is designed to operate at 110kHz, 137kHz and 220kHz depending on the operating mode set. The SM72445 includes and I2C slave module with 8 address settings to communicate monitoring information and to allow remote shut-down and configuration modifications.

The SolarMagic™ SM72445 Evaluation Board is based on of the SM3320-1A1 power optimizer, and shares all of its best-in-class power optimization features. This includes its ability to mitigate real-world mismatch, its 99.5% peak efficiency, and its Panel-Mode operation. In addition, the same ultra-low profile form factor of the original SM3320-1A1 is maintained so that it can be integrated into the same junction box designs.

This evaluation module is fully operational and can be used with panels from 15V up to 50V (absolute) operating voltage and up to 300W of power. Proper heat-sinking of the Power FETs must be achieved for power levels above 50W at room temperature.

The absolute maximum output voltage is 50V. The maximum operating current is 11A.

2 System Overview

Figure 1 depicts how the SM72445 design would be implemented in its intended application. In this example, the SM72445 senses the input and output voltages and currents, filters them digitally and calculates power. It then issues four PWM pulses to the gate drivers to control the converter's switches. The SM72445 also operates an additional switch (called Panel-Mode or PM switch) to optimize efficiency when operating close to a 1:1 conversion ratio. Optionally, the switch can be omitted for reduced cost. The SM72445 then utilizes the converter at a 1:1 conversion ratio and increases efficiency by reducing the switching frequency of the converter

Figure 6 shows the detailed schematic with component references.

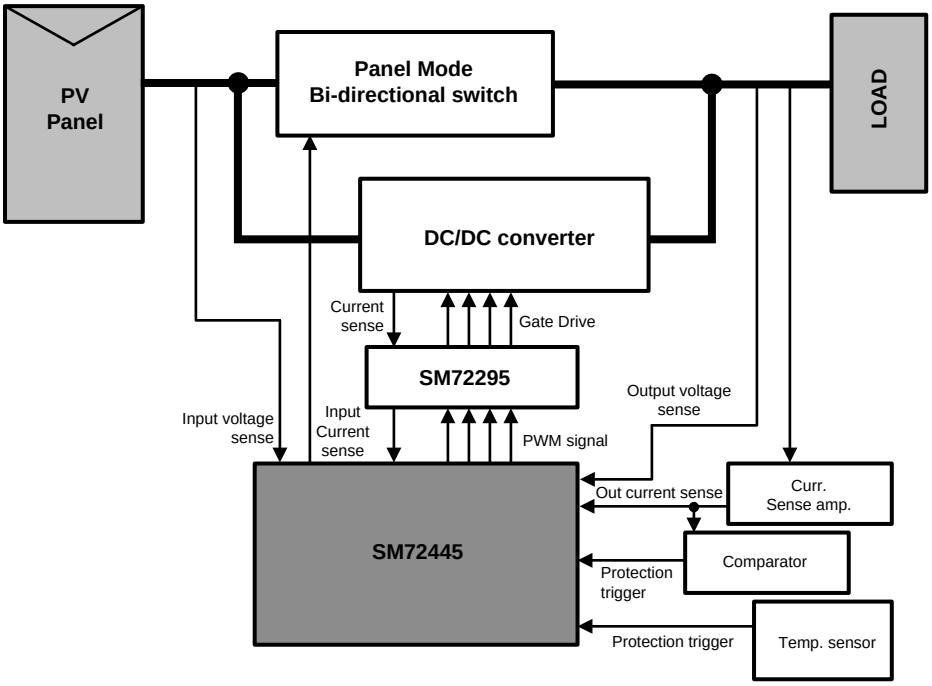

Figure 1. Evaluation Board Simplified Diagram

3 SM72445 Evaluation Module Design Specification

Symbol	Parameter	Min	Typ	Max
V_{MPP}	PV Module MPP Voltage	15 Vdc		40Vdc
P_{MPP}	PV Module Power	10 W		350 W
V_{OC}	PV Module Open Circuit Voltage			50 Vdc
I_{SC}	PV Module Short-Circuit Current			11A
V_{OUT}	Output Voltage	0 Vdc		43 Vdc
I_{OUT}	Output Current			12.5A
OVP	Overvoltage Protection Threshold		45V	
OTP	Overtemperature Protection Threshold		125ºC	
MPP_{EFF}	MPP Efficiency		98.5%	
PM_{EFF}	Panel-Mode Efficiency		99.5%	

Configuration Modes

The SM72445 is configured through I2C communication or through resistor settings on pin A0, A2, A4 and A6. The default configuration setting on the board is:

Pin name	Pin Voltage	Description
A0	3.0V	“Soft” output voltage limit of 40V (AVOUT=3V)
A2	0V	220kHz operation, uses dedicated FET switch for higher efficiency
A4	5.0V	Internal current protection not used
A6	1.56V	Long slew rate limit, 60s in a 1:1 conversion ratio at start-up before enabling optimization

Modifications to the configuration can be performed by changing the resistor settings. The change in configuration will only happen at start-up and during reset of the IC.

"Panel Mode" Operation

The board is configured to use "Panel Mode" FETs to reach the highest possible efficiency at a 1:1 conversion ratio. The SM72445 will disconnect the DC/DC converter and turn on this switch whenever it detects that the panel is matched to the load. The detail of this operation can be found in the SM72445 datasheet. Alternatively, the SM72445 can be configured to run the DC/DC converter in a Panel-Mode behavior instead, driving the high-side FETs of the converter in a mostly ONstate (Figure 2) and achieving the same function as the dedicated Panel-Mode FETs. This option optimizes the component count and the cost of the solution but slightly reduces the efficiency of the system in the band close to a 1:1 conversion ratio. To configure the board in this mode, the resistor couple R29 and R39 can be changed to modify the voltage at pin A2. In addition, T1 should be removed. Check the Prog Max Pwr Point Tracking Cntrl w/ Adjustable PWM Frequency (SNVS795) data sheet for additional details on the different configuration settings.

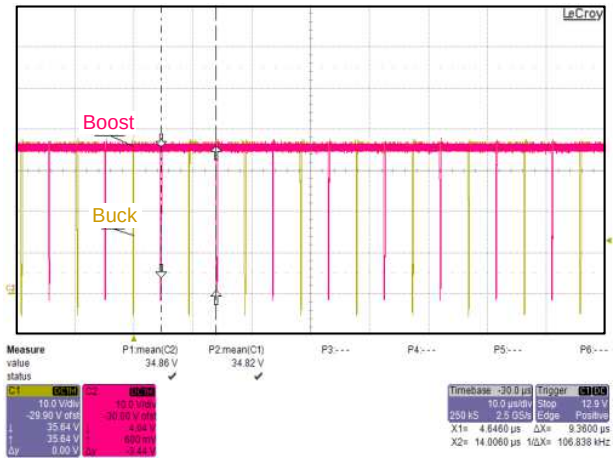

Figure 2. Panel Mode Operation Using Converter's FET ("Boost" waveform is taken at drain of Q3, "Buck" waveform was taken at drain of Q4.)

"SOFT" Output Voltage Limit

The soft output voltage limit of "Soft OVP" is designed to prevent the output voltage from reaching dangerous level when the system is running the converter in boost mode. This mechanism works by reducing the duty cycle of the converter when the voltage at pin AVOUT is increasing above the voltage at pin A0.

Slew Rate Limit

The slew rate limit is designed to limit the rate of rise of the output voltage when and only when the converter is running in boost mode. The rise of the duty cycle will be limited to ensure that the output voltage will rise in a controlled manner, especially during transients such as when the load is reduced or gets removed (before the SM72445 returns in stand-by mode). To test the slew rate limit, start-up the system with a current load at 1.5A and with an input that has a maximum power point above 3A. The output voltage will increase very rapidly until it reaches the input voltage. The output voltage will then increase slowly above the input voltage as limited by the slew rate setting programmed.

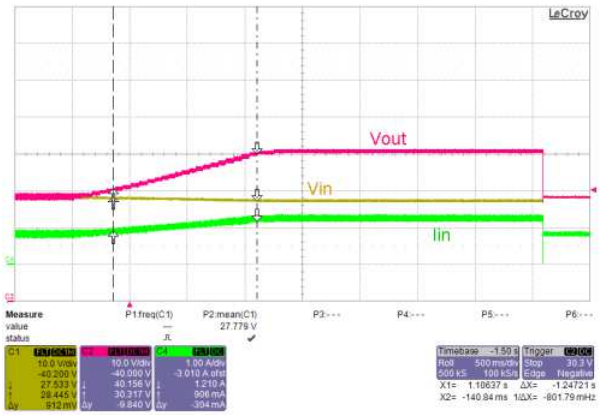

Figure 3. Slew Rate Limit (between the two markers) and Soft OVP (after the second marker)

Startup

When starting up at no load, the SM72445 will increase the duty cycle until a 1:1 conversion ratio is reached. The system will then enter a stand-by mode and wait for the detection of power by sensing the output current. When the voltage on AIOUT rises above the internal threshold, the system will wait for a typical period of 64 seconds and exit the stand-by mode. This is to allow the proper start-up of a potential inverter connected to the string of panels in which the SM72445 based optimizer would be inserted. Upon exiting stand-by mode, the system will enter “PM mode” (see SM72445 datasheet for further explanation). MPPT will be enabled if power variation is detected. If no power variation is detected such as when the system is connected to a DC Electronic load for example, MPPT will be enabled only after the “PM mode” timer expires after an additional period of 64 seconds.

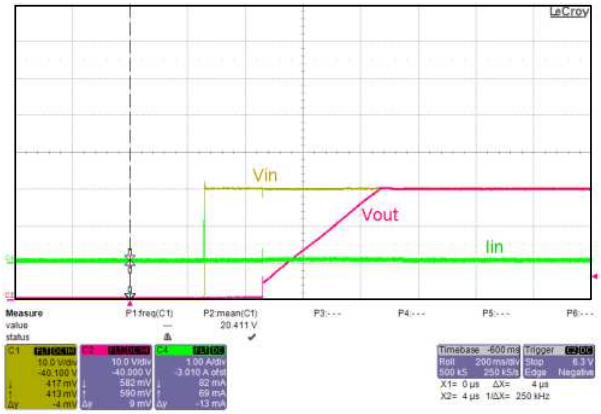

Figure 4. Start-Up Pattern With Unloaded Output

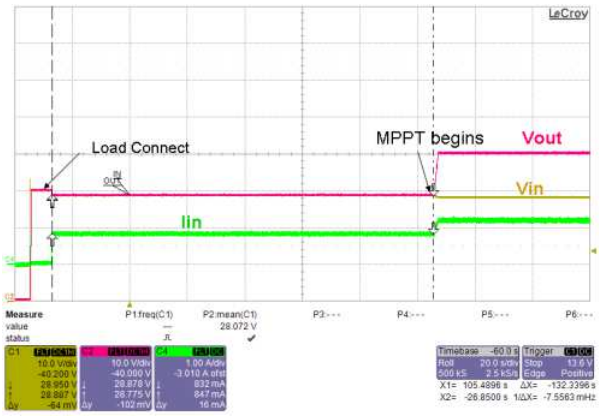

Figure 5. Load Connect and Stand-By Sequence After Start-Up

When a load is already present on the output of the board, the SM72445 will increase the duty cycle and immediately enable MPPT operation when the voltages on AIOUT and AIIN rise above the internal threshold.

Internal Current Protection

If the voltage at AIOUT rises above the value set in A4, the system will reset. If AIOUT is set at or above VDDA, this feature will be de-activated. The default setting for this board has this feature de-activated. Current protection is performed using an external comparator

Board Current Protection

The board features a current protection circuit with U11A activating the PM pin of the SM72445 and forcing the PM mode bypass switch to turn on (or the bridge to switch to 1:1 operation if the board is reconfigured) when the output current reaches 13.5A. The output current will then be limited by the input (solar panel) current. It is important to verify that the maximum solar panel current does not exceed the rating of the components.

Temperature Protection

U2 and U3 are strategically placed near the highest source of heat in the system (Q1 and Q4). When the temperature reaches the tripping point (120 C), the ICs will activate the PM mode of the SM72445 by forcing the PM pin low.

Over-Voltage Protection

U11B forces the SM72445 to reset if the output voltage rises above 44V.

Panel Mode Switch

Q5 and Q6 form a bi-directional switch controlled by the SM72445 and driven by U13 through T1. The SM72445 supplies a 440kHz square waveform to turn on the switch.

Gate Driver

U7 is a quad 3A gate driver (two high and two low). It contains high-side operational amplifiers and buffers used to sense the input current for MPPT purposes.

Heatsinking

SM72445 evaluation board does not come with a heatsink. Therefore, in order to run the evaluation board at elevated power ratings, an appropriate heatsink should be added on Q1, Q2, Q3 and Q4 as well as diode D1. Care must be taken to prevent electrical contact between the drains of the MOSFETs in the process of proper heatsinking. At elevated power operation please note the increase in temperature across these semiconductor devices.

Test Setup

To perform an evaluation on the SM72445 evaluation board, it is suggested that the user connect the input to a SAS (Solar Array Simulator) and the output to a load bank, preferably in Current mode (Voltage mode sometimes causes regulation issues with some electronic load when used with the evaluation board). The following sequence can be used to verify the operation of the board:

- **Connect S.A.S. to input.**
- **Connect Electronic load to output.**
- **Turn on SAS Verify proper startup pattern (see Figure 4).**
- **Set Electronic load to 2A and turn on Electronic load.**
- **Wait two minutes and verify that SAS is operating at Maximum Power Point. If output voltage is close to 40V, increase Electronic load current.**
- **Vary Electronic load current and verify that the SAS is operating at Maximum Power Point in step-up (lower load current) and step-down (higher load current) operation.**

4 Schematic

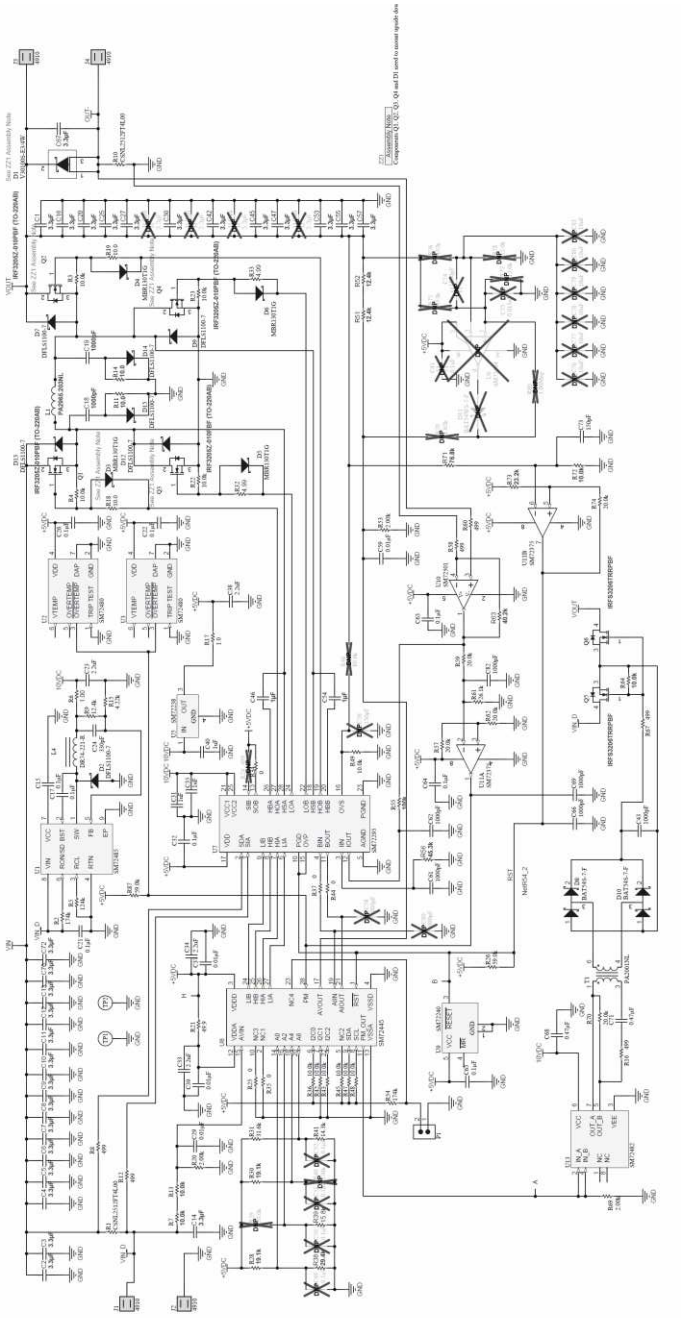

Figure 6. Circuit Schematic

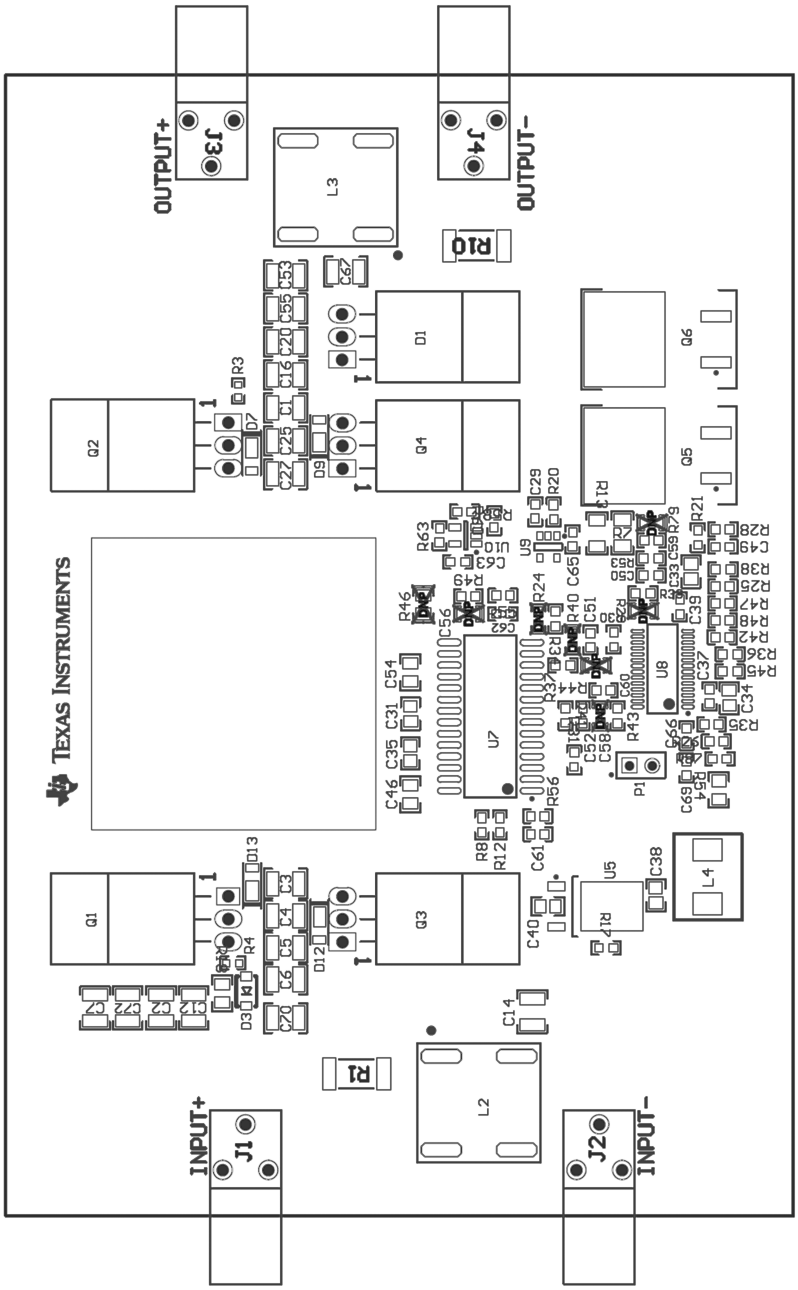

Figure 7. Top Assembly Diagram

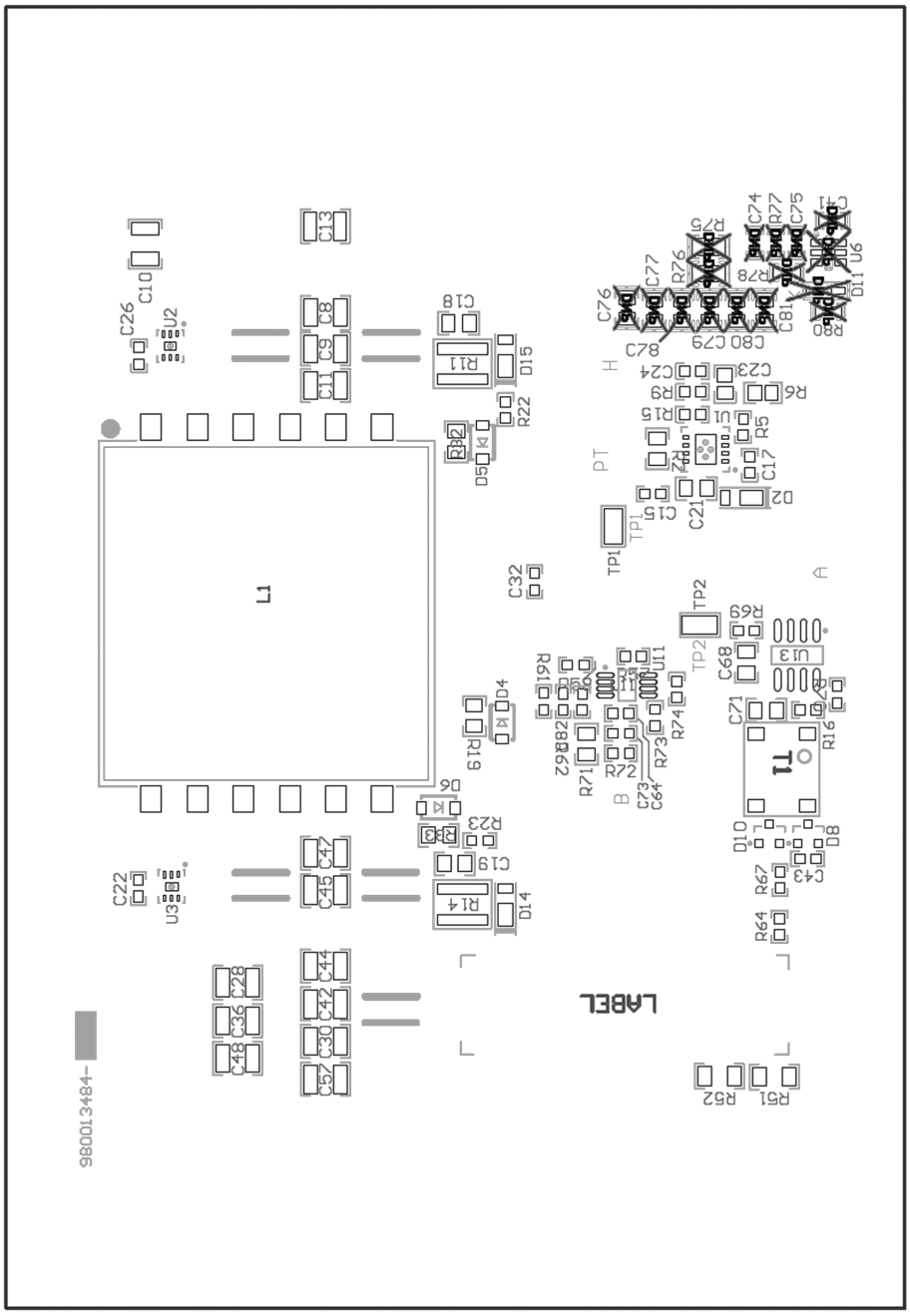

Figure 8. Bottom Assembly Diagram

5 Bill of Material

Table 1. Bill of Material

Designator	Part Description	Qty.	Manufacturer	Part number
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C16, C20, C25, C27, C30, C42, C45, C47, C53, C55, C57, C67, C70, C72	CAP, CERM, 3.3µF, 50V, ±20%, X7R, 1210	28	TDK	C3225X7R1H335M
C15, C17, C22, C26, C32, C63, C64, C65	CAP, CERM, 0.1µF, 16V, ±10%, X7R, 0603	8	Taiyo Yuden	EMK107B7104KA-T
C18, C19	CAP, CERM, 1000pF, 100V, ±10%, X7R, 0805	2	Kemet	C0805C102K1RACTU
C21	CAP, CERM, 0.1µF, 100V, ±10%, X7R, 0805	1	Kemet	C0805C104K1RACTU
C23, C33, C34, C38	CAP, CERM, 2.2µF, 16V, ±10%, X7R, 0805	4	Taiyo Yuden	EMK212B7225KG-T
C24	CAP, CERM, 330pF, 50V, ±10%, X7R, 0603	1	Kemet	C0603C331K5RACTU
C29, C37, C39, C59	CAP, CERM, 0.01µF, 50V, ±10%, X7R, 0603	4	Kemet	C0603C103K5RACTU
C31, C35, C40, C46, C54	CAP, CERM, 1µF, 16V, ±10%, X7R, 0805	5	Taiyo Yuden	EMK212B7105KG-T
C43, C61, C62, C66, C69, C82	CAP, CERM, 1000pF, 50V, ±10%, X7R, 0603	6	Kemet	C0603C102K5RACTU
C68, C71	CAP, CERM, 0.47µF, 16V, ±10%, X7R, 0805	2	TDK	C2012X7R1C474K
C73	CAP, CERM, 150pF, 50V, ±5%, C0G/NP0, 0603	1	Kemet	C0603C151J5GACTU
D1	DIODE SCHOTTKY 30A 100V TO-220AB	1	Vishay-Semiconductor	V30100S-E3/4W
D2, D7, D9, D12, D13, D14, D15	Diode, Schottky, 100V, 1A, PowerDI123	7	Diodes Inc.	DFLS1100-7
D3, D4, D5, D6	Diode, Schottky, 30V, 1A, SOD-123	4	ON Semiconductor	MBR130T1G
D8, D10	Diode, Schottky, 30V, 0.2A, SOT-23	2	Diodes Inc.	BAT54S-7-F
J1, J2, J3, J4	PC Quick-Fit 0.250 Horizontal Tab	4	Keystone Electronics	4910
L1	Inductor 20 µH EFD-30 core	1	Pulse Electronics	PA2965.203NL
L2, L3	Choke, Filter	2	Pulse	PA2972NL
L4	Inductor, Shielded Drum Core, Ferrite, 220 µH, 0.56A, 0.907 Ω, SMD	1	Coiltronics	DR74-221-R
P1	Header, TH, 100mil, 1x2, Tin plated, 230 mil above insulator	1	Samtec Inc.	TSW-102-07-T-S
Q1, Q2, Q3, Q4	MOSFET 55V, 6.5m Ω	4	International Rectifier	IRF3205Z-010PBF
Q5, Q6	MOSFET 60V, 2.4m Ω	2	International Rectifier	IRFS3206TRRPBF
R1, R10	RES .004 Ω 2W 1% 2512 SMD	2	Stackpole Electronics Inc	CSNL2512FT4L00
R2, R54	RES, 174k Ω, 1%, 0.125W, 0805	2	Vishay-Dale	CRCW0805174KFKEA
R3, R4, R22, R23, R36, R42, R43, R45, R47, R48, R49, R64, R72	RES, 10.0k Ω, 1%, 0.1W, 0603	13	Vishay-Dale	CRCW060310k0FKEA
R5	RES, 124k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW0603124kFKEA
R6	RES, 1.00 Ω, 1%, 0.125W, 0805	1	Vishay-Dale	CRCW08051R00FNEA
R7, R13	RES, 10.0k Ω, 1%, 0.25W, 1206	2	Vishay-Dale	CRCW120610K0FKEA
R8, R12, R16, R58, R60, R67	RES, 499 Ω, 1%, 0.1W, 0603	6	Vishay-Dale	CRCW0603499RFKEA
R9	RES, 12.4k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060312k4FKEA
R11, R14	RES, 10.0 Ω, 1%, 1W, 1218 SMD	2	Vishay-Dale	CRCW121810R0FKEK

Table 1. Bill of Material (continued)

Designator	Part Description	Qty.	Manufacturer	Part number
R15	RES, 4.22k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW06034k22FKEA
R17	RES, 1.0 Ω, 1%, 0.1W, 0603	1	Panasonic	ERJ3RQF1R0V
R18, R19	RES, 10.0 Ω, 1%, 0.125W, 0805	2	Vishay-Dale	CRCW080510R0FKEA
R20, R53, R69	RES, 2.00k Ω, 1%, 0.1W, 0603	3	Vishay-Dale	CRCW06032k00FKEA
R21	RES, 49.9 Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060349R9FKEA
R25, R34, R35, R37, R44	RES, 0 Ω, 5%, 0.1W, 0603	5	Vishay-Dale	CRCW06030000Z0EA
R26, R87	RES, 59.0k Ω, 1%, 0.1W, 0603	2	Vishay-Dale	CRCW060359K0FKEA
R28, R30	RES, 19.1k Ω, 1%, 0.1W, 0603	2	Vishay-Dale	CRCW060319K1FKEA
R31	RES, 31.6k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060331K6FKEA
R32, R33	RES, 4.99 Ω, 1%, 0.125W, 0805	2	Vishay-Dale	CRCW08054R99FNEA
R38	RES, 29.4k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060329K4FKEA
R39	RES, 15.8k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060315K8FKEA
R41	RES, 14.3k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060314K3FKEA
R51, R52	RES, 12.4k Ω, 1%, 0.25W, 1206	2	Vishay-Dale	CRCW120612K4FKEA
R55	RES, 100k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW0603100KFKEA
R56	RES, 45.3k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060345K3FKEA
R57, R59, R62, R70, R74	RES, 20.0k Ω, 1%, 0.1W, 0603	5	Vishay-Dale	CRCW060320K0FKEA
R61	RES, 26.1k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060326K1FKEA
R63	RES, 40.2k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060340K2FKEA
R71	RES, 76.8k Ω, 1%, 0.125W, 0805	1	Vishay-Dale	CRCW080576K8FKEA
R73	RES, 23.2k Ω, 1%, 0.1W, 0603	1	Vishay-Dale	CRCW060323K2FKEA
T1	SMT GATE TRANS 1:1 1500V 403 uH 0.60R	1	Pulse Electronics	PA2001NL
TP1, TP2	Test Point, SMT, Miniature	2	Keystone Electronics	5015
U1	100V, 150 mA Constant On-Time Buck Switching Regulator	1	Texas Instruments	SM72485
U2, U3	1.6V, LLP-6 Factory Preset Temperature Switch and Temperature Sensor	2	Texas Instruments	SM72480
U5	5V Micropower Voltage Regulator	1	Texas Instruments	SM72238
U7	Photovoltaic Full Bridge Driver	1	Texas Instruments	SM72295
U8	Programmable Maximum Power Point Tracking Controller With Adjustable PWM Frequency	1	Texas Instruments	SM72445
U9	5-Pin Microprocessor Reset Circuits	1	Texas Instruments	SM72240
U10	Precision, CMOS Input, RRIO, Wide Supply Range Amplifier	1	Texas Instruments	SM72501
U11	Dual Micropower Rail-To-Rail Input CMOS Comparator with Open Drain Output	1	Texas Instruments	SM72375
U13	Dual 5A Compound Gate Driver	1	Texas Instruments	SM72482

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