High-Efficiency, Class 4 PoE Powered Device, Using the TPS23754 in Active-Clamp Flyback Converter

Donald V. Comiskey

1 Introduction

This report introduces a high-efficiency, Power-over-Ethernet (PoE) Powered Device (PD) that complies with the Type 2, Class 4 power requirements outlined in the IEEE 802.3at Draft 3.3 standard. The standard permits a Type 2, Class 4 PD to draw up to 25.5 W of power at the Power Interface (PI) when connected to compatible Type 2 Power Sourcing Equipment (PSE) using Type 2 compliant cabling. A fully powered Type 2, Class 4 PD will normally draw between 13 W and 25.5 W at the PI.

The PoE PD presented in this report employs the Texas Instruments TPS23754 in an isolated active-clamp flyback converter which produces a 5V output that is capable of currents as high as 6A. The TPS23754 includes a PoE PD Interface and a DC-to-DC controller that is optimized for isolated topologies. The features of the TPS23754 enable the flyback converter itself to provide efficiencies approaching 92%. Refer to Texas Instruments datasheet TPS23754 for more information on using the TPS23754.

The overall efficiency of the PD be affected by power losses associated with the front-end components that are commonly situated between the PI and the flyback converter. The input-bridge rectifier that is typically used to provide polarity-insensitive operation of the PD is a major contributor to these losses. This report goes on to explore the use of a MOSFET input bridge in order to minimize additional power losses and take full advantage of the 25.5 W afforded to a Type 2, Class 4 PD.

2 Demo Board

Figure 1 shows a photo of the demo board used for the Type 2, Class 4 PD. The related schematic is shown in Figure 2 and a Section 8 has been included. The demo board is seen to include a placeholder for retaining an alternate input bridge that is further discussed in Section 4.

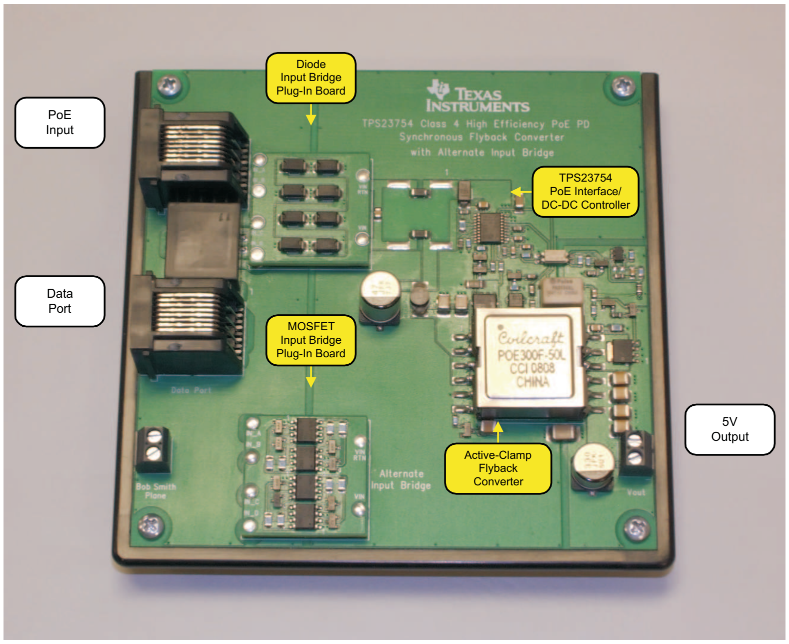

Figure 1. Class 4 PoE PD Demo Board Utilizing the TPS23754 in an Active-Clamp Flyback Converter

In general, the schematic of Figure 2 includes an input section comprising front-end components typically used by a PD, a control section comprising the Texas Instruments TPS23754 PoE Interface/DC-DC controller, and an output section comprising a synchronous flyback converter. The TPS23754 controller is shown to feature a second gate drive pin (GAT2) that works in conjunction with a programmable dead-time pin (DT), which allows the user to optimize the converter efficiency by minimizing shoot-through and switching losses associated with the primary-side and secondary-side power MOSFETs.

The GAT2 and DT features of the TPS23754 also accommodate the use of an active-clamp reset circuit which eliminates dissipative snubbers that are normally used to protect the primary-side MOSFET. The efficiency advantages of using the gate drive and active-clamp reset techniques presented in this report are further discussed in Benefits of Adding an Active Clamp to a Synchronous Flyback Power Supply , Boost Efficiency for Low-Cost Flyback Converters , and TPS23750 High Efficiency 5 V at 2.2 A PoE PD SLVU159 .

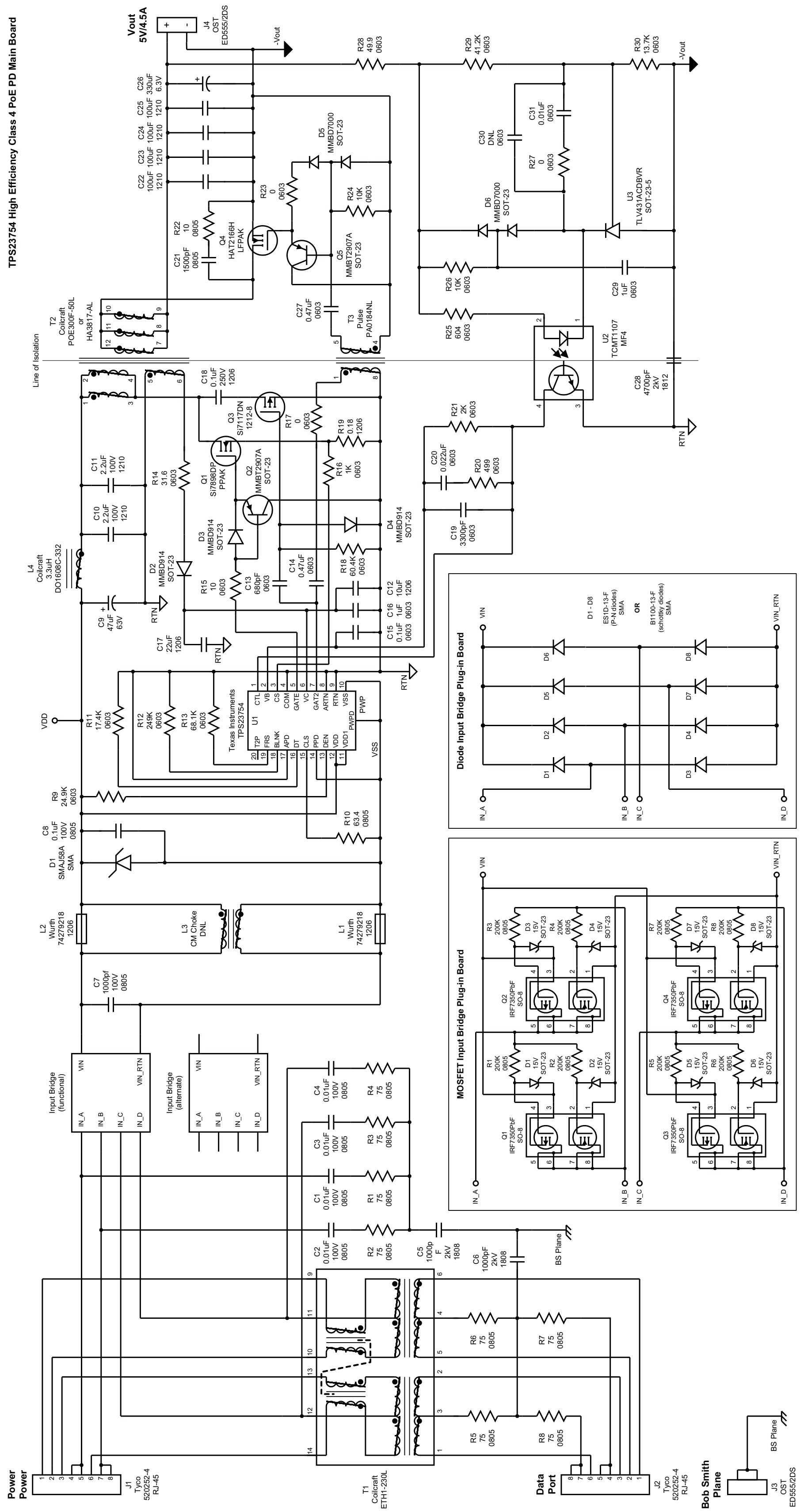

Figure 2. Schematic of the Class 4 PoE PD Demo Board

3 Flyback Converter Efficiency

Figure 3 shows the measured efficiency of the flyback converter section of the demo board. This measurement is made from the VDD to RTN pins of the TPS23754 to the J4 output connector. The component values associated with the gate drive and active-clamp circuitry discussed in Section 2 have been optimized to obtain the highest efficiencies at the power levels associated with a Type2, Class 4 PD. The efficiency graph has been further extended to cover output power levels as high as 30 W for non-standard high-power PD applications.

The flyback converter efficiency is seen to be in the range of 89% - 92% at the power levels expected for a Type 2, Class 4 PD. However, as mentioned in Section 1, the overall efficiency of the PD will be further reduced due to losses associated with the PD front-end circuitry, particularly the input-bridge rectifiers. Section 4 takes a closer look at the effects of the input bridge and how its losses can be minimized to obtain overall PD efficiencies which approach that of the flyback converter.

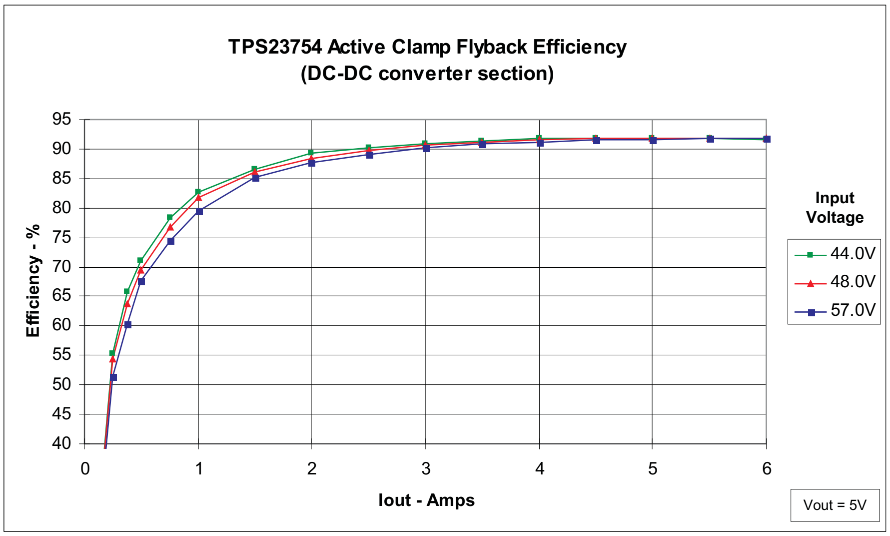

Figure 3. Efficiency of Flyback Converter Section of the Class 4 PoE PD Demo Board

4 Overall PD Efficiency for Various Input Bridge Options

As shown in Figure 1, the demo board includes two input bridge boards that are socketed into the main board. This allows for quick evaluation of the effects of various input bridge options on the overall PD efficiency. The functional input bridge is plugged into the position next to the RJ-45 input connector, while the non-functional input bridge resides in the alternate input bridge placeholder at the bottom of the demo board.

Figure 4 shows the measured overall PD efficiency of the demo board when using an input bridge consisting of discrete P-N diodes. The measurement is made from the RJ-45 input connector (J1 pins 4, 5 - 7, 8) to the J4 output connector. The overall efficiency is seen to average around 3.5% less than the flyback converter efficiency at the power levels expected for a Type 2, Class 4 PD.

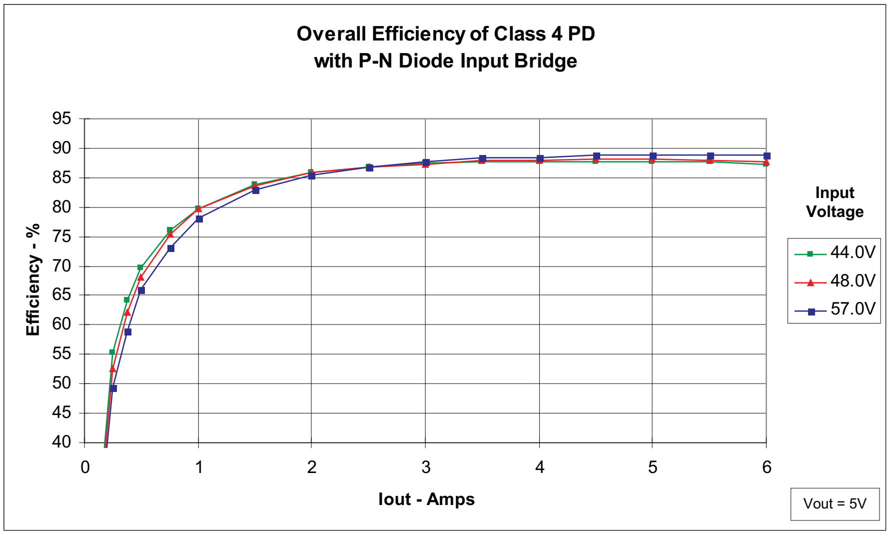

Figure 4. Overall Efficiency of the Class 4 PoE PD Demo Board with P-N Diode Input Bridge

Figure 5 shows the measured overall PD efficiency of the demo board when using an input bridge consisting of discrete schottky diodes. The efficiency is seen to average around 0.8% higher than the P-N diode results at the power levels expected for a Type 2, Class 4 PD.

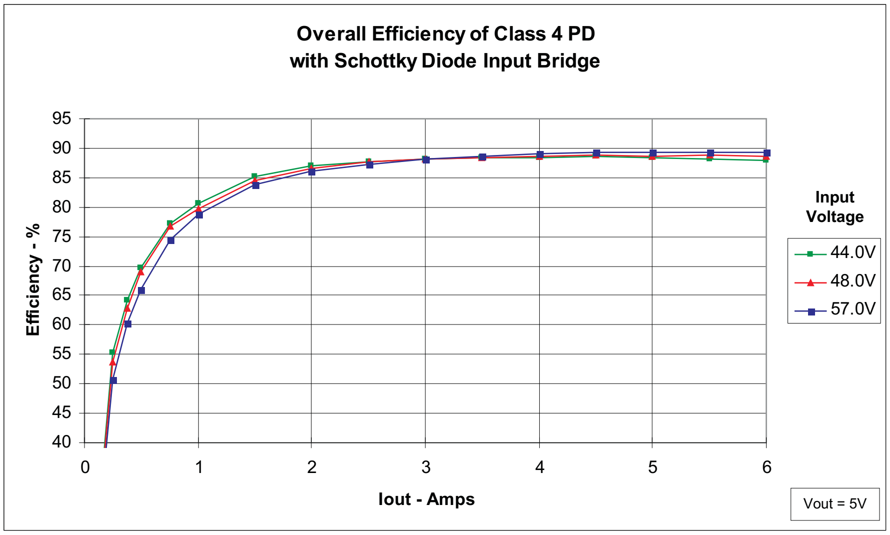

Figure 5. Overall Efficiency of the Class 4 PoE PD Demo Board with Schottky Diode Input Bridge

Figure 6 shows the measured overall PD efficiency of the demo board when using an input bridge consisting of complimentary P/N channel MOSFETs. The efficiency is seen to average around 2.5% higher than the P-N diode results at the power levels expected for a Type 2, Class 4 PD.

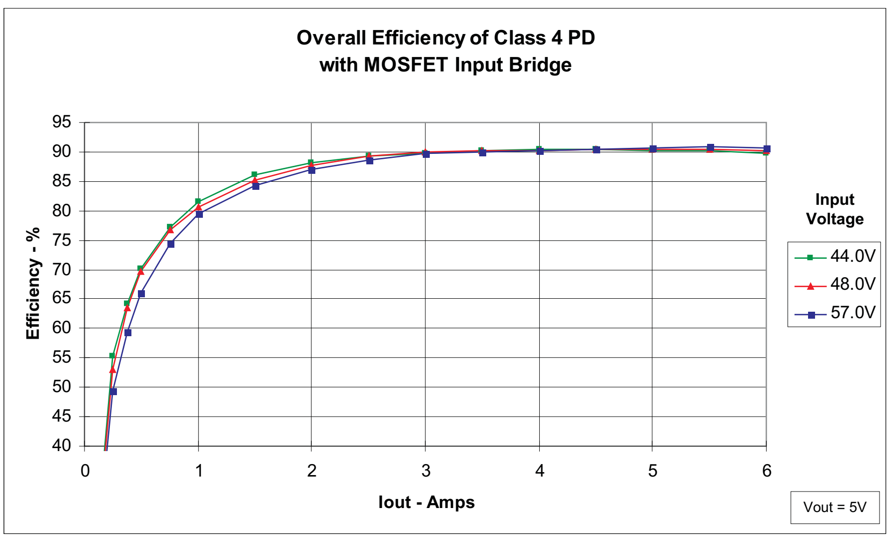

Figure 6. Overall Efficiency of the Class 4 PoE PD Demo Board with MOSFET Input Bridge

Figure 7 directly compares the TPS23754 flyback converter efficiency to the overall efficiencies when using the P-N diode, Schottky diode, and MOSFET input bridge options at an input voltage of 48 V. The graph further focuses on the output current range associated with a fully powered Type 2, Class 4 PD.

While the overall efficiencies produced by the diode bridge solutions are seen to be very respectable, overall efficiencies in the area of 90% or greater are seen to be obtainable when using the MOSFET bridge solution. The type of input bridge selected for the PD will normally depend on a cost-benefit analysis of the particular application. The cost and performance tradeoffs associated with the various input bridge options are further discussed in Bridging the Efficiency Gap in PoE Powered Device Designs .

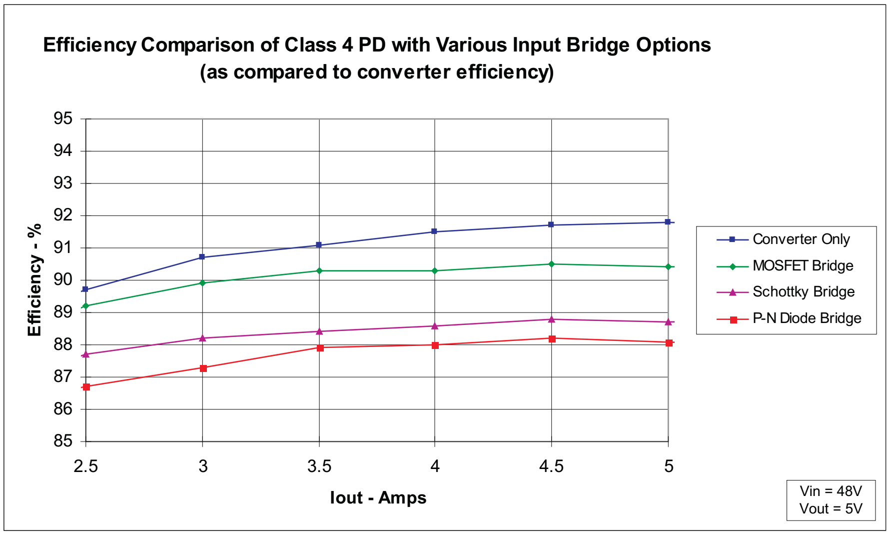

Figure 7. Overall Efficiency of the Class 4 PoE PD Demo Board for the Various Input Bridge Options

5 Considerations

The measurements provided in this report have assumed that the PD power is applied to the spare line pairs of the PI. For applications where the power is applied to the data line pairs of the PI, the added losses associated with type of data transformer used by the application will also need to be considered when determining the overall efficiency of the PD.

6 Summary

This report has presented a high efficiency Type 2, Class 4 PoE PD that uses the Texas Instruments TPS23754 PoE Interface/DC-DC controller in an active-clamp flyback topology. Use of the second gate drive and programmable dead-time features of the TPS23754 have been shown to produce converter efficiencies approaching 92%. The report has further examined the possibility of using of a MOSFET input bridge to obtain overall PD efficiencies of greater than 90%.

7 References

1. *IEEE 802.3at Draft 3.3 standard*, December 1, 2008
2. TPS23754: *High Power/High Efficiency PoE Interface and DC/DC Controller*, Datasheet SLVS885, Texas Instruments, January 2009
3. *Benefits of Adding an Active Clamp to a Synchronous Flyback Power Supply*, John Betten and Brian King, Texas Instruments, EDN December 14, 2006
4. *Boost Efficiency for Low-Cost Flyback Converters*, John Betten and Brian King, Texas Instruments, EDN April 3, 2008
5. *TPS23750 High Efficiency 5 V at 2.2 A PoE PD*, SLVU159, Texas Instruments, February 2007
6. *Bridging the Efficiency Gap in PoE Powered Device Designs*, Donald V. Comiskey, Texas Instruments, October 2008

8 List of Materials

Table 1. TPS23754 Demo Board List of Materials

COUNT	REF DES	DESCRIPTION	MFR	PART NUMBER
Main Board				
4	C1, C2, C3, C4	Capacitor, ceramic, 0.01 μF, 100 V, X7R, 10%, 0805	Std	Std
2	C5, C6	Capacitor, ceramic, 1000 pF, 2 kV, X7R, 10%, 1808	Johanson	202R29W102KV4E
1	C7	Capacitor, ceramic, 1000 pF, 100 V, X7R, 10%, 0805	Std	Std
1	C8	Capacitor, ceramic, 0.1 μF, 100 V, X7R, 10%, 0805	Murata	GCM21BR72A104K A37L
1	C9	Capacitor, aluminum, 47 μF, 63 V, 20%, 8mm x 10.2mm	Panasonic	EEV-FK1J470P
2	C10, C11	Capacitor, ceramic, 2.2 μF, 100 V, X7R, 10%, 1210	Murata	GRM32ER72A225K A35L
1	C12	Capacitor, ceramic, 10 μF, 16 V, X5R, 10%, 1206	Murata	GRM31CR61C106K C31L
1	C13	Capacitor, ceramic, 680 pF, 50 V, X7R, 10%, 0603	Std	Std
2	C14, C27	Capacitor, ceramic, 0.47 μF, 25 V, X7R, 10%, 0603	Murata	GRM188R71E474K A12D
1	C15	Capacitor, ceramic, 0.1 μF, 16 V, X7R, 10%, 0603	Std	Std
2	C16, C29	Capacitor, ceramic, 1 μF, 16 V, X5R, 10%, 0603	Std	Std
1	C17	Capacitor, ceramic, 22 μF, 16 V, X5R, 20%, 1206	Murata	GRM31CR61C226M E15L
1	C18	Capacitor, ceramic, 0.1 μF, 250 V, X7R, 10%, 1206	Murata	GRM31CR72E104K W03L
1	C19	Capacitor, ceramic, 3300 pF, 50 V, X7R, 10%, 0603	Std	Std
1	C20	Capacitor, ceramic, 0.022 μF, 16 V, X7R, 10%, 0603	Std	Std
1	C21	Capacitor, ceramic, 1500 pF, 50 V, X7R, 10%, 0805	Std	Std
4	C22, C23, C24, C25	Capacitor, ceramic, 100 μF, 6.3 V, X5R, 20%, 1210	Murata	GRM32ER60J107M E20L
1	C26	Capacitor, aluminum, 330 μF, 6.3 V, 20%, 8 mm x 6.2 mm	Panasonic	EEV-FK0J331P
1	C28	Capacitor, ceramic, 4700 pF, 2 kV, X7R, 10%, 1812	Murata	GR443DR73D472K W01L
0	C30	Not used, 0603		
1	C31	Capacitor, ceramic, 0.01 μF, 50 V, X7R, 10%, 0603	Std	Std
1	D1	Diode, TVS, 58 V 1 W, SMA	Diodes Inc.	SMAJ58A
3	D2, D3, D4	Diode, switching, 100 V, 200 mA, SOT-23	On Semi	MMBD914
2	D5, D6	Diode, dual series, 100 V, 200 mA, SOT-23	On Semi	MMBD7000
2	J1, J2	Connector, jack modular, 8 position, 0.705" x 0.820"	AMP	520252-4
2	J3, J4	Terminal block, 2 pin, 6 A, 3.5 mm, 0.27" x 0.25"	OST	ED555/2DS
2	L1, L2	Ferrite bead, 600 Ω, 1 A, 1206	Wurth	74279218
0	L3	Not used		
1	L4	Inductor, 3.3 μH, 1.1 A, 80 mΩ, 0.26" x 0.09"	Coilcraft	DO1608C-332MLB
1	Q1	MOSFET, N-Channel, 150 V, 3 A, 95 mΩ, PPAK	Vishay	Si7898DP
2	Q2, Q5	Transistor, PNP, 60 V, 800 mA, 350 mW, SOT-23	Fairchild	MMBT2907A
1	Q3	MOSFET, P-Channel, 150 V, 2.1 A, 1.2 Ω, 1212-8	Siliconix	Si7117DN
1	Q4	MOSFET, N-Channel, 30 V, 45 A, 3.8 mΩ, LFPAK	Renesas	HAT2166H
8	R1, R2, R3, R4, R5, R6, R7, R8	Resistor, chip, 75 Ω, 1/10 W, 1%, 0805	Std	Std
1	R9	Resistor, chip, 24.9 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R10	Resistor, chip, 63.4 Ω, 1/10 W, 1%, 0805	Std	Std

Table 1. TPS23754 Demo Board List of Materials (continued)

COUNT	REF DES	DESCRIPTION	MFR	PART NUMBER
1	R11	Resistor, chip, 17.4 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R12	Resistor, chip, 249 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R13	Resistor, chip, 68.1 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R14	Resistor, chip, 31.6 Ω, 1/16 W, 1%, 0603	Std	Std
1	R15	Resistor, chip, 10 Ω, 1/16 W, 1%, 0603	Std	Std
1	R16	Resistor, chip, 1 kΩ, 1/16 W, 1%, 0603	Std	Std
3	R17, R23, R27	Resistor, chip, 0 Ω, 1/16 W, 5%, 0603	Std	Std
1	R18	Resistor, chip, 60.4 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R19	Resistor, chip, 0.18 Ω, 1/4 W, 1%, 1206	Std	Std
1	R20	Resistor, chip, 499 Ω, 1/16 W, 1%, 0603	Std	Std
1	R21	Resistor, chip, 2 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R22	Resistor, chip, 10 Ω, 1/10 W, 1%, 0805	Std	Std
2	R24, R26	Resistor, chip, 10 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R25	Resistor, chip, 604 Ω, 1/16 W, 1%, 0603	Std	Std
1	R28	Resistor, chip, 49.9 Ω, 1/16 W, 1%, 0603	Std	Std
1	R29	Resistor, chip, 41.2 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R30	Resistor, chip, 13.7 kΩ, 1/16 W, 1%, 0603	Std	Std
1	T1	Transformer, PoE plus signal path, 0.695" x 0.620"	Coilcraft	ETH1-230L
1	T2	Transformer, PoE plus flyback, 5 V, 6 A, 30 W, 0.810" x 1.181"	Coilcraft	POE300F-50L or HA3817-AL
1	T3	Transformer, gate drive, 1:1, 0.354" x 0.339"	Pulse	PA0184NL
1	U1	PoE PD Interface and DC-DC controller, PWP	TI	TPS23754
1	U2	Photocoupler, 3750 V_{RMS}, 80% to 160% CTR, MF4	Vishay	TCMT1107
1	U3	Shunt regulator, 1.24 V, 1%, SOT-23-5	TI	TLV431ACDBVR
P-N Diode Input Bridge Plug-In Board Option				
8	D1, D2, D3, D4, D5, D6, D7, D8	Diode, P-N, 200 V, 1 A	Diodes Inc	ES1D-13-F
Schottky Diode Input Bridge Plug-In Board Option				
8	D1, D2, D3, D4, D5, D6, D7, D8	Diode, Schottky, 100 V, 1 A	Diodes Inc.	B1100-13-F
MOSFET Input Bridge Plug-In Board Option				
8	D1, D2, D3, D4, D5, D6, D7, D8	Zener diode, 15 V, 5%, 225 mW	On Semi	MMBZ5245BL
4	Q1, Q2, Q3, Q4	MOSFET, dual N and P-Channel, 100 V, 1.2 A	IR	IRF7350PbF
8	R1, R2, R3, R4, R5, R6, R7, R8	Resistor, chip, 200 kΩ, 1/10 W, 1%	Std	Std

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