25-W, High-Power PoE Using the TPS2376-H

This document describes the characteristics, operation, and use of reference design PR567A demonstrating high-power Power-over-Ethernet (PoE). Typical PoE applications consist of two parts: 1) power sourcing equipment (PSE) that injects power into the Ethernet Category 5 (CAT5) cable and 2) powered devices (PD) that connect to the CAT5 cable to receive power. This reference design demonstrates a complete PD solution including detection, classification, and current limiting required for many PoE applications and delivers an isolated 5 V at 5 A to the load.

The theory and general application of PoE is beyond the scope of this document; for a broader description, see the application material listed in the *Related Materials from Texas Instruments* section. This document includes a schematic diagram, a bill of materials, and PCB layout drawings for the PR567A reference design.

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1 Introduction

Traditionally, PoE has followed the IEEE 802.3af standard for specifying PD design and performance and includes a maximum power allotment of 15.4 W by the PSE. Due to resistive losses in the CAT5 cable, the power to the PD input is limited to approximately 13 W. Additionally, most applications require a power supply after the PD input that further reduces the system efficiency and limits actual power to the load at approximately 11 W. As the drive for more complex end-equipments increases, many end-equipments require more power than what the IEEE 802.3af standard allows. This evaluation board demonstrates how a PD can deliver up to 25 W to the load and can be interfaced to any PSE that follows detection and classification procedures defined by the IEEE 802.3af standard. For details on PD operation, see the Application Information section in the *TPS2375, IEEE 802.3af PoE Powered Device Controllers* data sheet (SLVS525). For details on PSE operation, see the Application Information section in the *TPS2384, Quad Integrated Power Sourcing Equipment Power Manager* data sheet (SLUS634).

Note that from a system-level perspective, the amount of power that can be delivered to the load depends on both the PD and PSE. This reference design is intended to demonstrate how a PD can deliver 25 W to the load. Because this PD reference design is intended for power levels greater than what the IEEE 802.3af specification allows, a PSE designed to meet the IEEE 802.3af standard will not be able to source enough power because it will go into current limit once the port current goes higher than 350 mA. For additional details, see the application report *High Power PoE Using TPS2375/77-1* (SLVA225).

The DC/DC power supply used in this evaluation board uses a continuous conduction mode synchronous flyback topology using the UCC3809-2 Economy Primary Side Controller. For details on this topology, see the application reports *Achieving High Efficiency with a Multi-Output CCM Flyback Supply Using Self-Driven Synchronous Rectifiers* (SLUP204) and *Reference Design: Isolated 50W Flyback Converter Using the UCC3809 Primary Side Controller* (SLUU096). For details on the UCC3809, see its data sheet (SLUS166).

1.1 Related Documentation From Texas Instruments

1. *TPS2376-H, IEEE 802.3af PoE High Power PD Controller* data sheet (SLVS646)
2. *UCC3809-2, Economy Primary Side Controller* data sheet (SLUS166)
3. *TPS2375, IEEE 802.3af PoE Powered Device Controllers* data sheet (SLVS525)
4. *TPS2384, Quad Integrated Power Sourcing Equipment Power Manager* data sheet (SLUS634)
5. *High Power PoE Using TPS2375/77-1* application report (SLVA225)
6. *Achieving High Efficiency with a Multi-Output CCM Flyback Supply Using Self-Driven Synchronous Rectifiers* application report (SLUP204)
7. *Reference Design: Isolated 50W Flyback Converter Using the UCC3809 Primary Side Controller* application report (SLUU096).

2 Performance

2.1 Electrical Specifications

Parameter	Condition	Min	Typ	Max	Unit
POWER INTERFACE					
Input voltage, Vin	Applied to the power pins of connectors J2 or J3	0		57	V
Operating voltage	After start-up	42		57	V
Input UVLO	Rising input voltage			40.5	V
	Falling input voltage	29			
Detection voltage		1.4		10.1	V
Classification voltage		10.2		23	V
Classification current		2.2	2.4	2.8	mA
DC/DC CONVERTER					
Output voltage	42 V < Vin < 57 V, Up to full load	4.75	5	5.25	V
Output current	42 V < Vin < 57 V			5	A
Output ripple voltage, peak-to-peak	Vin = 48 V, Load = 5 A		50		mV
Efficiency, end-to-end	Vin = 48 V, Load = 3 A		83%		
Switching frequency		270		330	kHz

2.2 Test Results

The test results for this EVM at T_A = 25°C follow.

Figure 1 shows the 5-V output voltage start-up waveform at J4 (Bottom, 2V/DIV) after the application of 48 Vdc at J3 (Top, 20V/DIV). The output at J4 was loaded to 0 A (50ms/DIV).

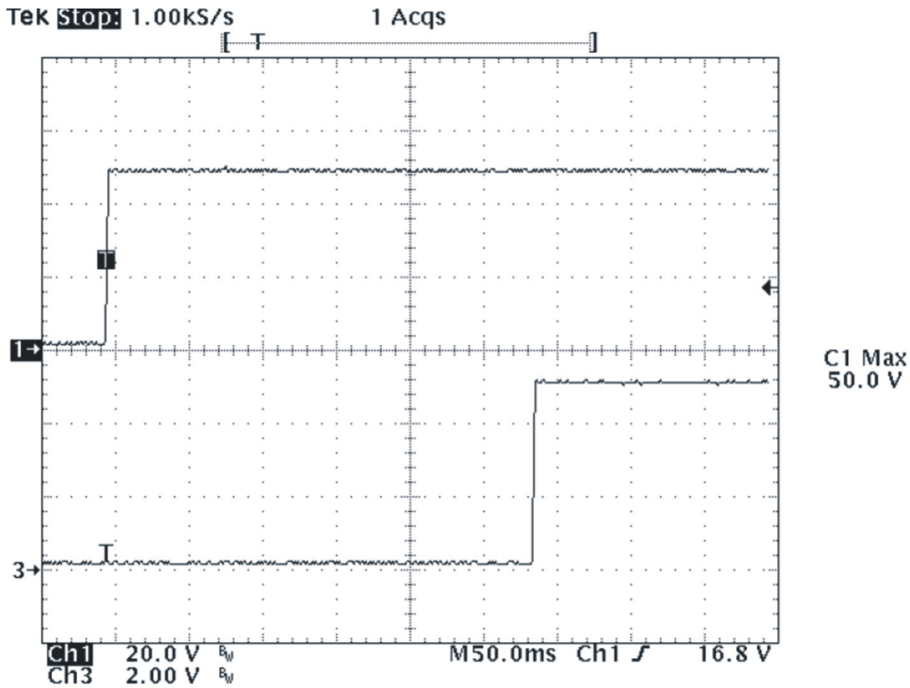


Figure 1. 5-V Output Start-up

Figure 2 shows the waveform at TP13 on the drain of the primary-side FET (Top, 50V/DIV) and the 5-V output ripple voltage at J4 (Bottom, 50mV/DIV). The images were taken with the output loaded to 5 A at J4 and the input voltage set to 48 Vdc at J3 (2µs/DIV).

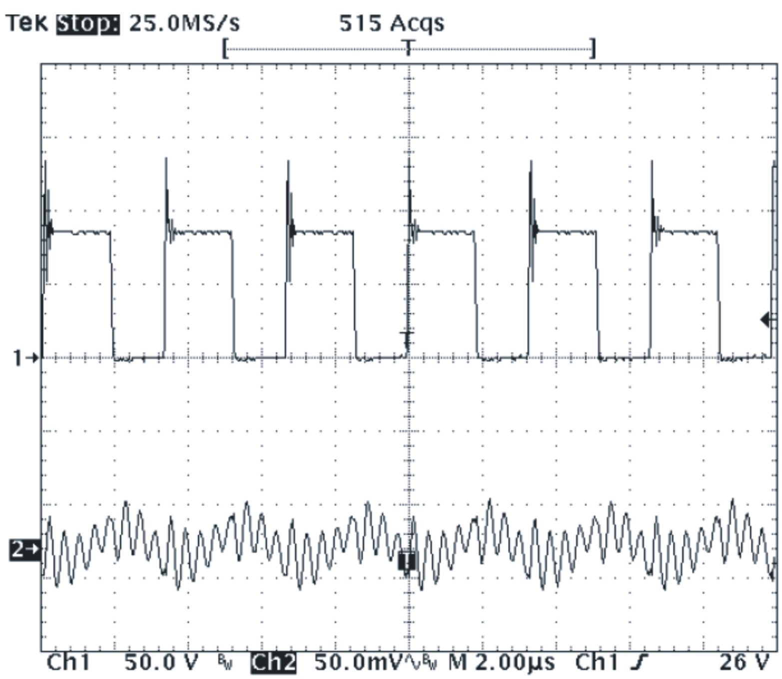


Figure 2. Switching Waveform and Output Ripple Voltage

The converter efficiency and regulation over load are shown in Figure 3. Two conditions are shown:

1. 48 V is applied at J2.
2. 48 V is applied at J3.

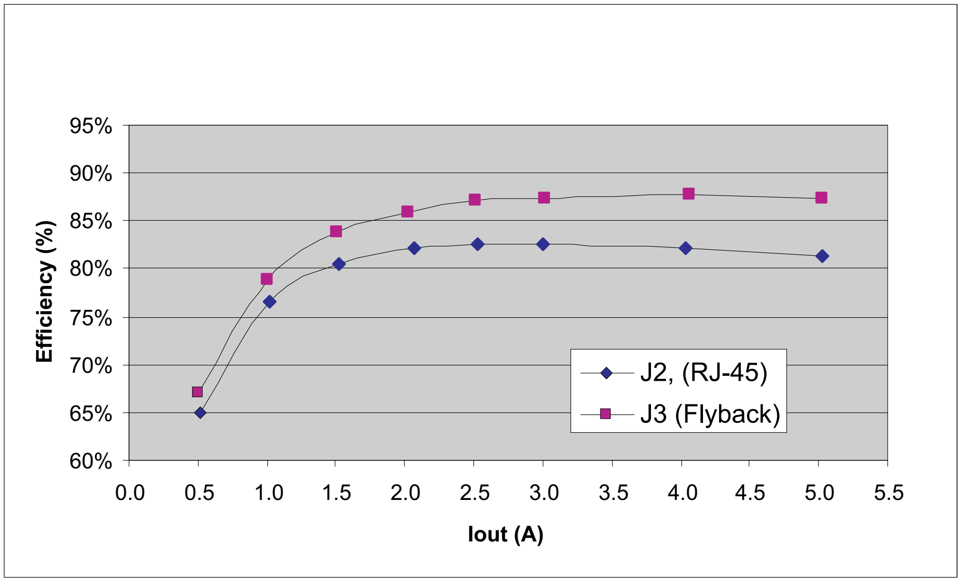


Figure 3. PR567A Efficiency, Vin = 48 V

To avoid current limiting at the TPS2376-H PD, a current booster circuit composed of Q1, Q2, R15, and R19 is used to create a secondary return path for the input current. Figure 4 shows the current distribution between the two paths. Detailed explanation on this circuit is provided in the application report *High-Power PoE Using TPS2375/77-1* (SLVA225).

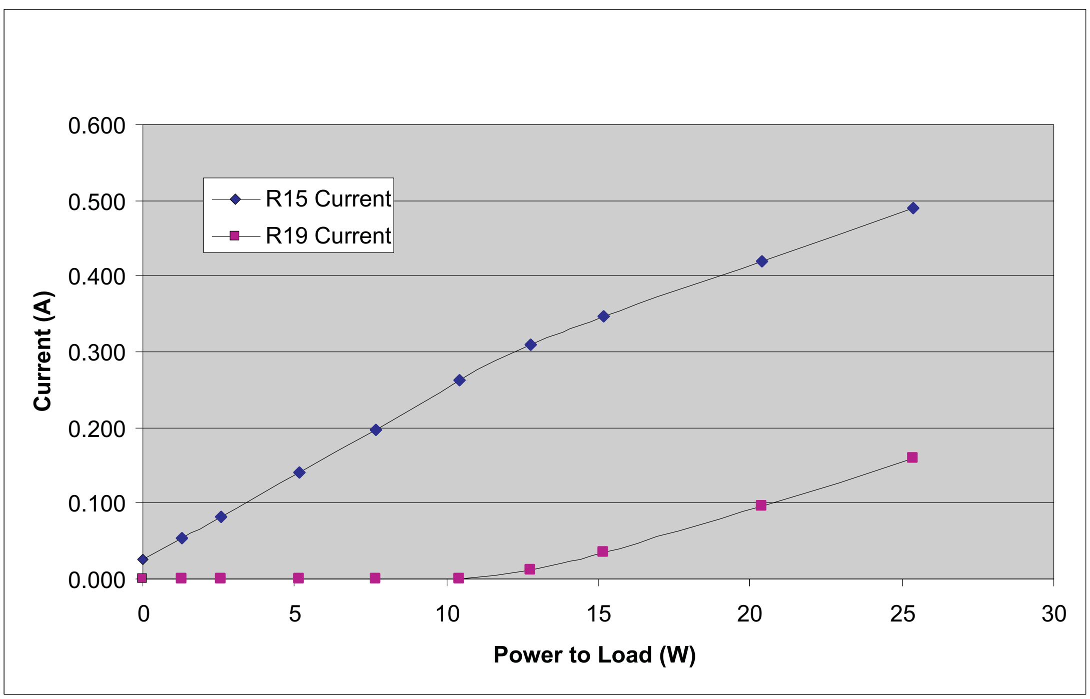


Figure 4. Q1/Q2 Current Distribution, Voltage at RJ-45 = 48 V

The plot in Figure 5 shows the loop gain and phase margin with input voltage set to 48 V at J3. The output was loaded to 5 A at J4 with bandwidth of ~3.19 kHz and phase margin of ~75.3 degrees.

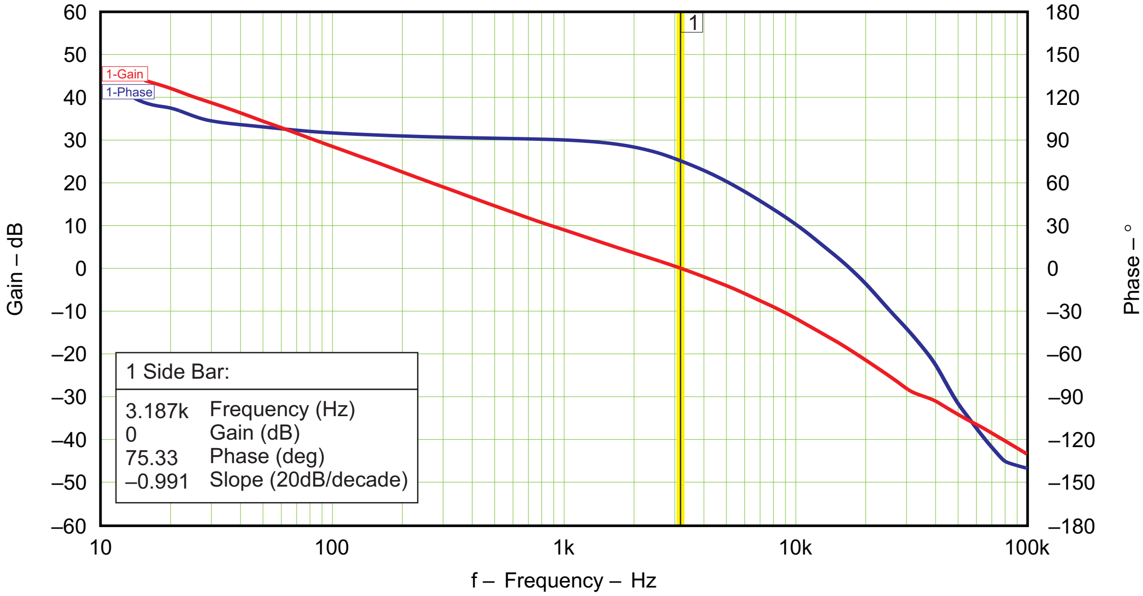


Figure 5. Loop Response

3 Board Layout

This section provides the PR567A board layout and illustrations.

3.1 Layout

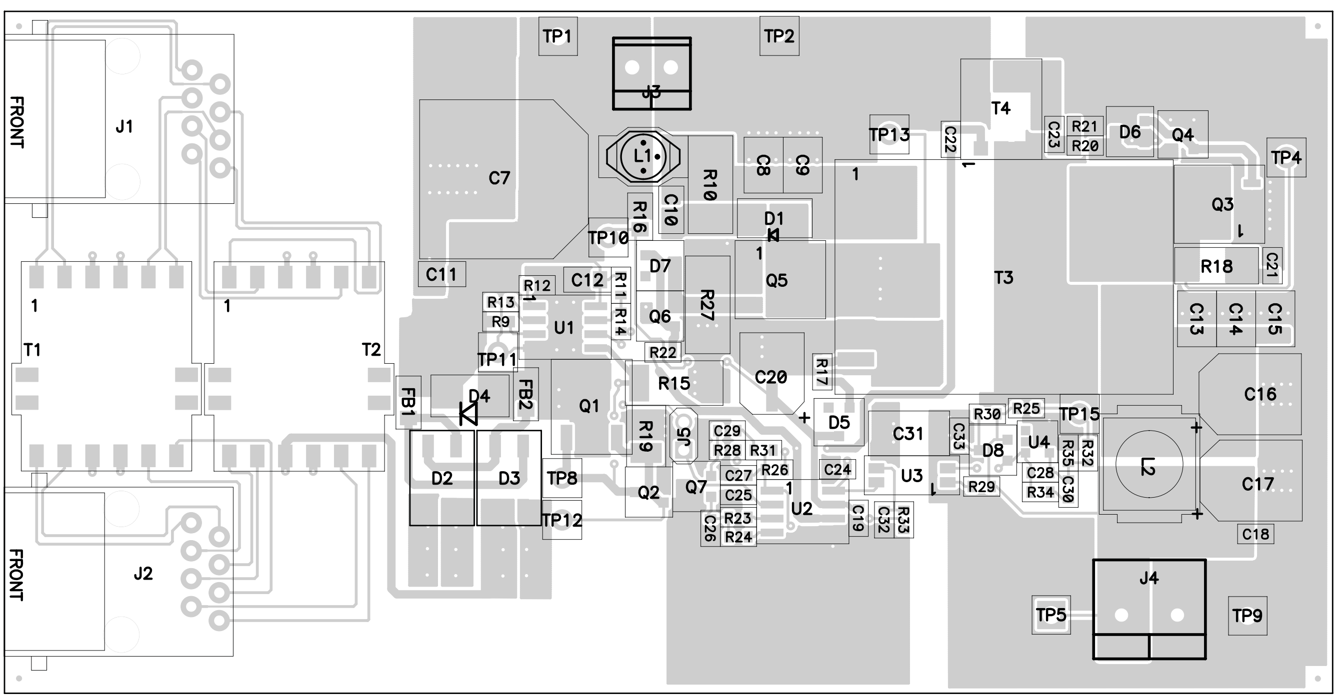


Figure 6. Top-Side Layout

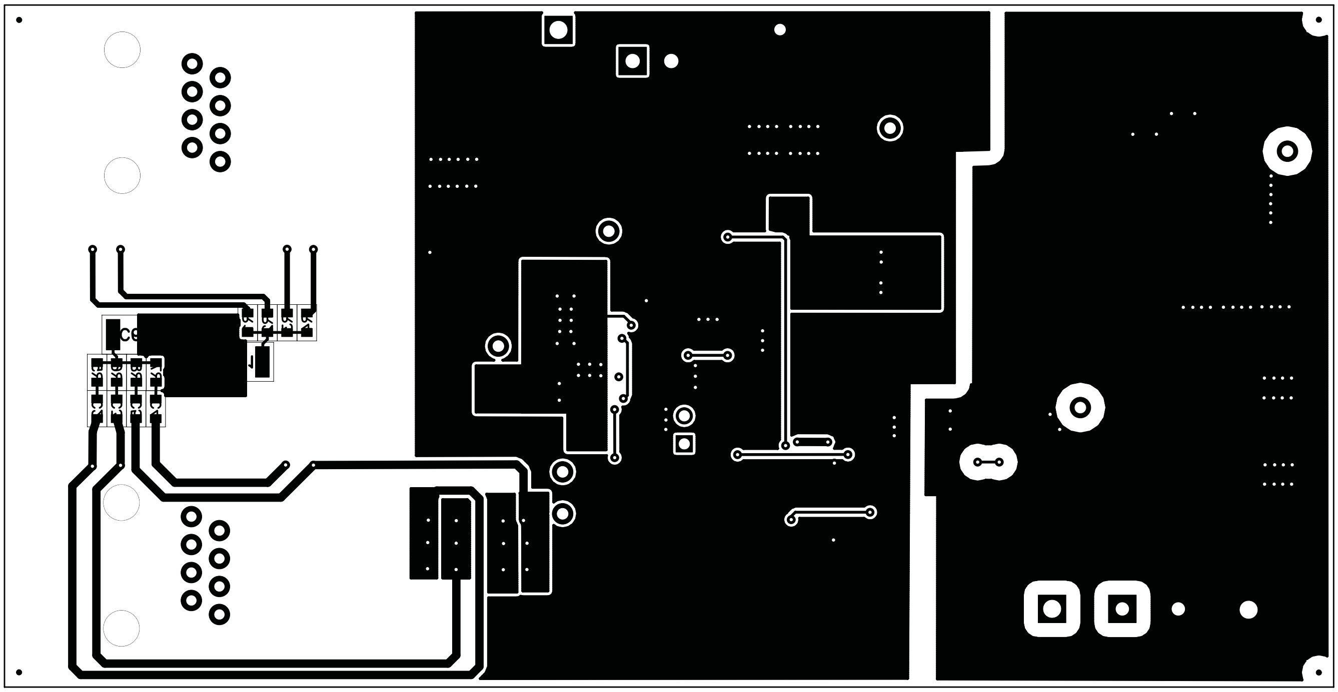


Figure 7. Bottom-Side Layout

3.2 Layout Considerations

The layout of the PoE front end must use good practice for power and EMI/ESD. A basic set of recommendations include:

- The parts placement must be driven by the power flow in a point-to-point manner such as RJ-45 → Ethernet transformer → diode bridges → TVS and 0.1-µF capacitor → TPS2376-H → bulk capacitor → DC/DC power supply.
- There should not be any crossovers of signals from one part of the flow to another.
- All leads should be as short as possible with wide power traces and paired signal and return.
- Spacing consistent with safety standards like IEC60950 must be observed between the 48-V input voltage rails and between the input and an isolated converter output
- The TPS2376-H should be referenced to a local ground plane Vss. The UCC3809-2 should be referenced to a local ground plane RTN.
- Large copper fills and traces should be used on SMT power-dissipating devices, and wide traces or overlay copper fills should be used in the power path.

Converter layout benefits from basic rules such as:

1. Minimize trace length.
2. Pair signals to reduce emissions and noise, especially the paths that carry high-current pulses which include the power semiconductors and magnetics.
3. Where possible, use vertical pairing.
4. Use the ground plane for the switching currents carefully.
5. Keep the high-current and high-voltage switching away from low-level sensing circuits including those outside the power supply.
6. Pay special attention to spacing around the high-voltage sections of the converter.

4 Schematic and Bill of Materials

This section provides the PR567A schematic and bill of materials.

4.1 Bill of Materials

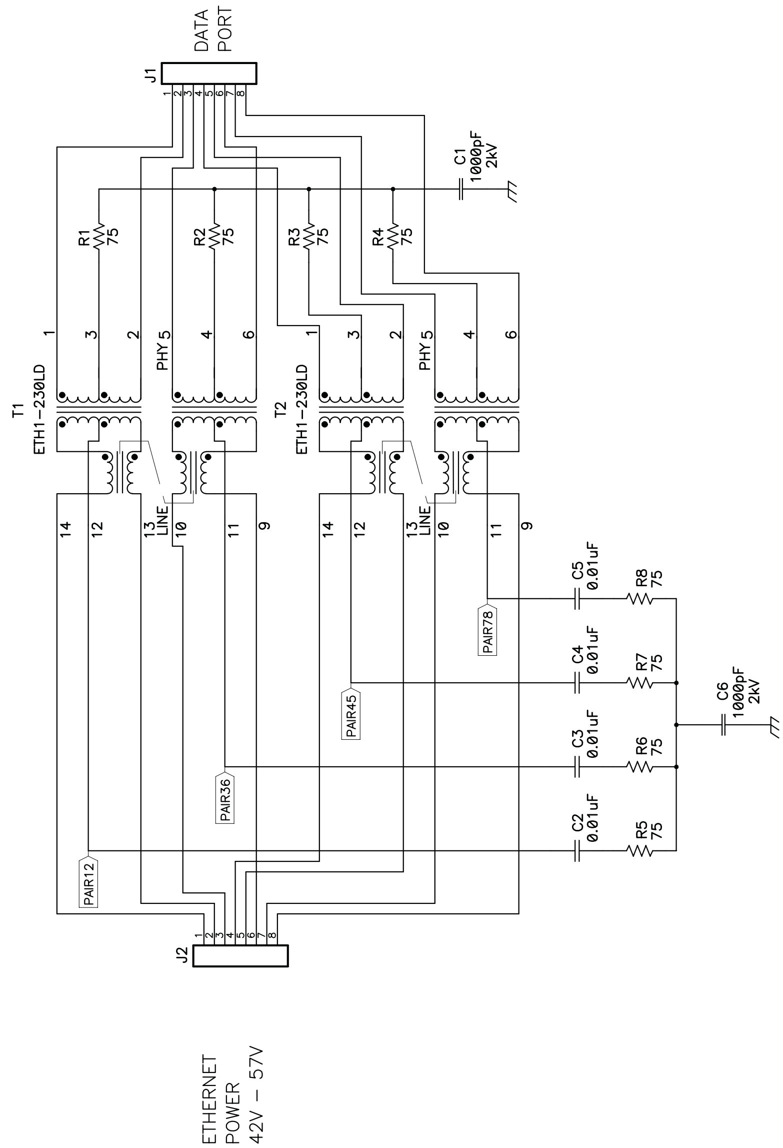
Count	RefDes	Value	Description	Size	Part Number	MFR
2	C1, C6	1000pF	Capacitor, ceramic, 2kV, X7R, 10%	1210	Std	TDK
3	C10–C12	0.1µF	Capacitor, ceramic, 100V, X7R, 10%	0805	Std	TDK
3	C13–C15	47µF	Capacitor, ceramic, 10V, X5R, 15%	1210	Std	TDK
2	C16, C17	220µF	Capacitor, Aluminum, 6.3V, ±20%	0.260×0.276 inch	EEVFK0J221P	Panasonic
3	C18, C24, C33	1µF	Capacitor, ceramic, 16V, X7R, 10%	0603	Std	TDK
1	C19	0.22µF	Capacitor, ceramic, 25V, X7R, 10%	0603	Std	TDK
4	C2–C5	0.01µF	Capacitor, ceramic, 100V, X7R, 10%	0603	Std	TDK
1	C20	22µF	Capacitor, Aluminum, 25V, ±20%	0.201×0.262 inch	EEVFK1E220R	Panasonic
1	C21	1000pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
2	C22, C23	0.47µF	Capacitor, Ceramic, 25V, X7R, 10%	0805	Std	TDK
1	C25	0.01µF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C26	270pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C27	100pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C28	DNP	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C29	0.1µF	Capacitor, Ceramic, 25V, X7R, 10%	0603	Std	TDK
1	C30	1200pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C31	2200pF	Capacitor, Ceramic, 2kV, X7R, 10%	1812	Std	TDK
1	C32	0.082µF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	TDK
1	C7	47µF	Capacitor, Aluminum, 100V, 20%	0.543 × 0.543	EEVFK2A470Q	Panasonic
2	C8, C9	1µF	Capacitor, Ceramic, 100V, X7R, 10%	1210	Std	TDK
1	D1	MURA120	Diode, Rectifier, 1A, 200V	SMA	MURA120	On Semi
2	D2, D3	HD01-T	Bridge Rectifier, 400V, 0.8A, Glass Passivated, SMD	MINI DIP4	HD01	Diodes, Inc
1	D4	SMAJ58A	Diode, SMT TVS 400W, 4.3-A, 58-V	SMA	SMAJ58A	Diodes, Inc
2	D5, D7	BAS16	Diode, Switching, 150-mA, 75-V, 350mW	SOT23	BAS16	Vishay
2	D6, D8	BAV99	Diode, Dual Ultra Fast, Series, 200-mA, 70-V	SOT23	BAV99	Fairchild
2	FB1, FB2	MI0805J102R-10	Bead, Ferrite, SMT, 1.1Ω, 1A	0805	MI0805J102R-10	Steward
2	J1, J2	520252	Connector, Jack, Modular, 8 POS	0.705×0.820 inch	520252	AMP
1	J3	ED1514	Terminal Block, 2-pin, 6-A, 3,5mm	0.27×0.25 inch	ED1514	OST
1	J4	ED1609-ND	Terminal Block, 2-pin, 15-A, 5,1mm	0.40×0.35 inch	ED1609	OST
1	L1	3.3µH	Inductor, SMT, 2A, 80mΩ	0.26×0.09 inch	DO1608-332	Coilcraft
1	L2	0.33µH	Inductor, SMT, 6.26A, 7.4mΩ	0.300 sq"	DR74-R33	Coiltronics
1	Q1	BCP53T1	Bipolar, PNP, 100-V, 1.5-A, 1.5-W	SOT-223	BCP53T1	On Semi
1	Q2	MMBT2907ALT1	Transistor, PNP, -60V, –600mA, 225-W	SOT23	MMBT2907ALT	On Semi
1	Q3	Si7848DP	MOSFET, NChannel, 60V, 15.8 A, 11mΩ PWRPAK	S0-8	Si7848DP	Vishay
3	Q4, Q6, Q7	MMBT3906	Bipolar, PNP, 40-V, 200-mA, 225-mW	SOT23	MMBT3906LT1	On Semi
1	Q5	Si7450DP	MOSFET, NChannel, 200V, 5.3A, 90mΩ PWRPAK	S0-8	Si7450DP	Vishay
8	R1–R8	75	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R10	15K	Resistor, Chip, 1W, 1%	2512	Std	Stdi
1	R11	909K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R12	357K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R13	4.42K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R14	61.9K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R15	2.2	Resistor, Chip, 1W, 5% 2512 Std Std		Std	Std
1	R16	30.1K	Resistor, Chip, 1/10W, 1%	0805	Std	Std

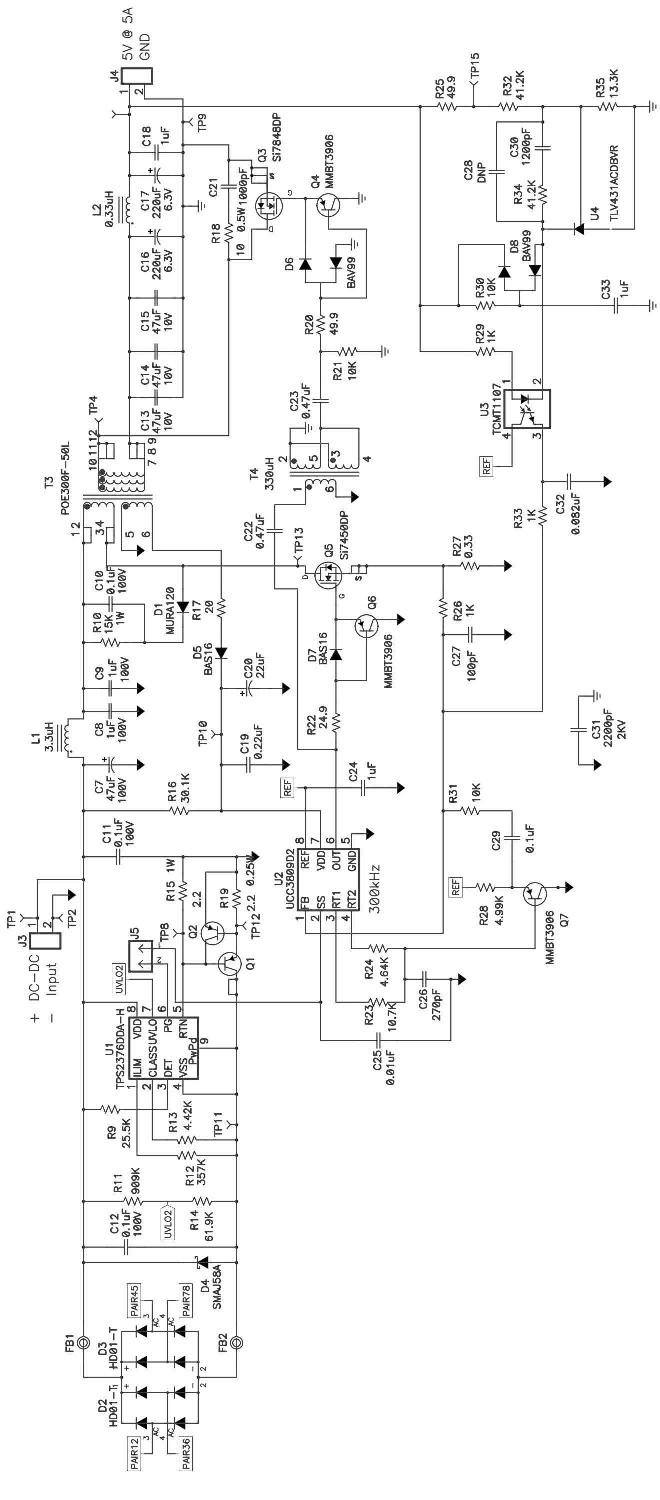
Count	RefDes	Value	Description	Size	Part Number	MFR
1	R17	20	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R18	10	Resistor, Chip, 1/2W, 1%	2010	Std	Std
1	R19	2.2	Resistor, Chip, 1/4W, 1%	1210	Std	Std
2	R20, R25	49.9	Resistor, Chip, 1/16W, 1%	0603	Std	Std
3	R21, R30, R31	10K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R22	24.9	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R23	10.7K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R24	4.64K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
3	R26, R29, R33	1K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R27	0.33	Resistor, Chip, 1W, 1%	2512	Std	Std
1	R28	4.99K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R32, R34	41.2K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R35	13.3K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R9	25.5K	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	T1, T2	ETH1-230LD	XFMR, Mid-Power PoE Magnetics	S0 14 Wide	ETH1-230LD	Coilcraft
1	T3	POE300F-50L	Transformer, SMT For PoE/PD, 2.6A	0.810×1.181 inch	POE300F-50L	Coilcraft
1	T4	330µH	Transformer, Driver, 330µH Ip, 1500V isolation	0.210×0.210 inch	P0926	Pulse
3	TP1, TP5, TP9	5012	Test Point, White, Thru Hole	0.125×0.125 inch	5012	Keystone
1	J5		Header 1×2 100mils	TH	TH	Std
2	TP2, TP11	5001	Test Point, Black, Thru Hole Color Keyed	0.100×0.100 inch	5001	Keystone
6	TP4, TP8, TP10, TP12, TP13, TP15	5000	Test Point, Red, Thru Hole Color Keyed	0.100×0.100 inch	5000	Keystone
1	U1	TPS2376DDA-H	IC, IEEE 802.3af Power Device Controller	S0-8 PowerPAD	TPS2376DDA-H	TI
1	U2	UCC3809D2	IC, Economy Primary-Side Controller, 15-V Startup	SO8	UCC3809D-2	TI
1	U3	TCMT1107	TCMT1107 IC, Photocoupler	MF4	TCMT1107	Vishay
1	U4	TLV431ACDBVR	IC, Shunt Regulator, 1.24-V ref, 6-V, 10-mA, 1%	SOT23-5	TLV431ACDBVR	TI
1	N/A	N/A	PCB, 2-Layer, 4.750" × 2.440" × 0.062"		PR567A	Any
1	N/A	N/A	Shunt		STC02SYANS	Sullins

Notes: 1 These assemblies are ESD sensitive, ESD precautions shall be observed.

2. These assemblies must be clean and free from flux and all contaminants. Use of no clean flux is not acceptable.
3. These assemblies must comply with workmanship standards IPC-A610 Class 2.
4. Reference designators marked with an asterisk (**) cannot be substituted. All components can be substituted with equivalent MFG's components.

4.2 Schematic





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