User's Guide
SNVA074A – May 2004 – Revised May 2013

AN-1299 LM5041 Evaluation Board

1 Introduction

The LM5041 evaluation board is designed to provide the design engineer with a fully functional current fed push-pull power converter to evaluate the LM5041 controller, and also the LM5101 buck stage gate driver, in a typical environment. Another name often used for the current fed push-pull is a “Cascaded” topology.

The performance of the evaluation board is as follows:

- Input range: 35V to 80V
- Output voltage: 2.5V
- Output current: 0 to 50A
- Measured efficiency: 89% at 50A, 91% at 20A
- Board size: 2.3 × 3.0 × 0.5 inches
- Load Regulation: 0.1%
- Line Regulation: 0.1%
- Line UVLO, Current Limit

The printed circuit board consists of 4 layers of 3 ounce copper on FR4 material with a total thickness of 0.050 inches. Soldermask has been omitted from some areas to facilitate cooling. The unit is designed for continuous operation at rated load at < 40°C and a minimum airflow of 200 CFM.

2 Theory of Operation

The current fed push-pull converter is a buck type converter consisting of a buck regulation stage followed by (cascaded by) a push-pull isolation stage that also provides voltage reduction in the transformer. The buck stage is synchronous, the upper and lower MOSFETS are both N-channel, which are driven by the LM5101 high voltage buck stage driver. The signals to the driver are provided by the LM5041, which drives the push-pull stage directly.

The push-pull stage is fed directly from the buck inductor current. The push-pull duty cycles actually overlap slightly so that there is always a current path for the buck inductor. One cycle of the buck regulator is provided for each of the push and pull switching events providing proper flux balance in the transformer.

Operating the transformer with both primary windings active during the brief overlap time does not present a problem to either the current source or the transformer. When both windings are active the magnetomotive force of the transformer breaks down and the impedance at the VPP node decreases toward zero. At that time, the inductor source current divides evenly between the primary windings. Some losses are avoided in the current fed push-pull topology since switching losses require the presence of both voltage and current.

The output stage uses synchronous rectification to avoid consuming a large percentage of the 2.5 volt output by the forward voltage drop of a typical Schottky rectifier.

Feedback from the output is processed by an amplifier and reference and then coupled back to the LM5041 controller through an optocoupler.

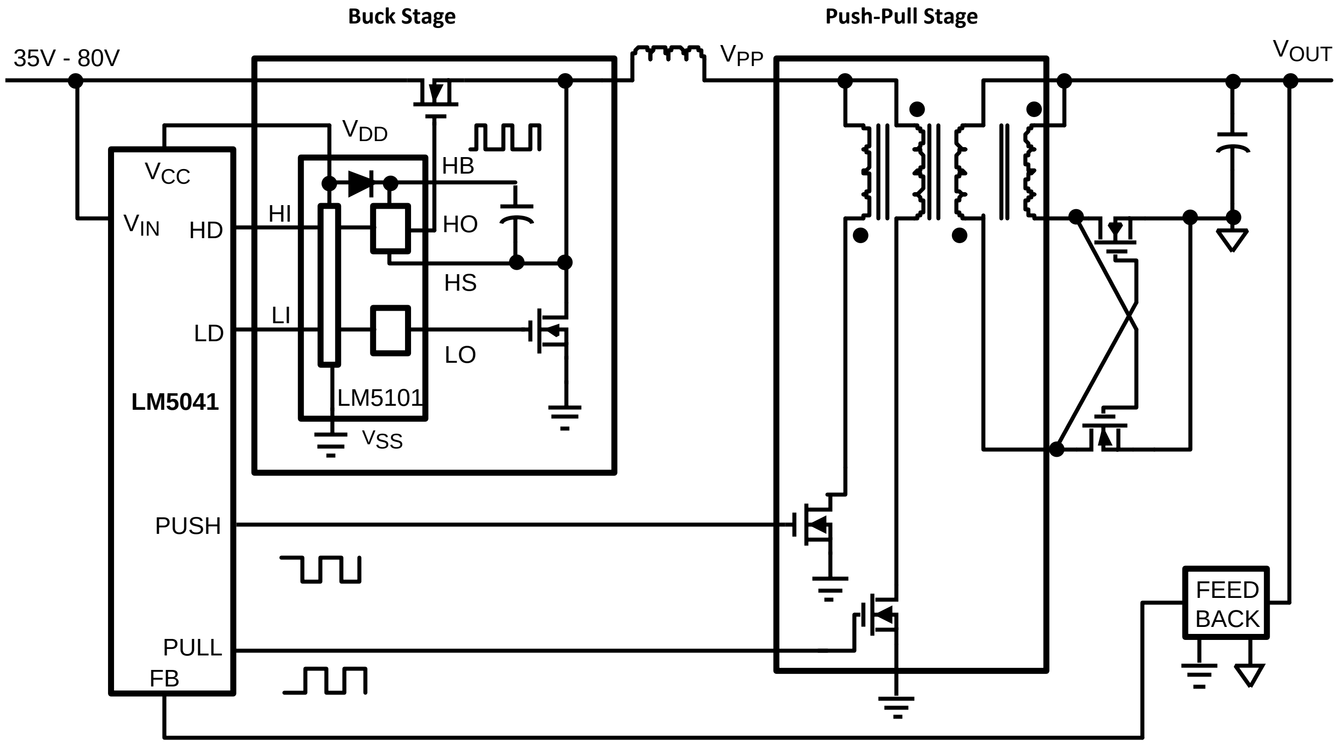


Figure 1. Simplified Cascaded Push-Pull Converter

3 Powering and Loading Considerations

When applying power to the LM5041 evaluation board certain precautions need to be followed. 125W is a considerable amount of continuous power. A failure or mistake can present itself in a very alarming manner. A few simple rules can easily prevent any startling surprises.

4 Proper Connections

When operated at low input voltages the UUT can draw over 4A of current at full load. The maximum rated output current for the evaluation board is 50A. Be sure to choose the correct connector and wire size when attaching the source supply and the load. Monitor the current into and out of the UUT (evaluation board or unit under test). Monitor the voltage directly at the output terminals of the UUT. The voltage drop across the load connecting wires will give inaccurate measurements. For accurate efficiency measurements, the same precautions should be taken, attaching a meter directly at the UUT input terminals.

5 Source Power

The evaluation board can be viewed as a constant power load. At low input line voltage (35V) the input current can exceed 4A, while at high input line voltage the input current will be approximately 1.8A. Therefore to fully test the LM5041 evaluation board a DC power supply capable of at least 80V and 5A is required. The power supply must have adjustments for both voltage and current. An accurate readout of output current is desirable since the current is not subject to loss in the cables as in the voltage.

The power supply and cabling must present a low impedance to the UUT. Insufficient cabling or a high impedance power supply will droop during power supply application with the UUT inrush current. If large enough, this droop will cause a chattering condition upon power up. This chattering condition is an interaction with the UUT undervoltage lockout, the cabling impedance and the inrush current.

6 Loading

WARNING

The high temperatures reached by even the most adequately rated resistors may burn you or melt your benchtop.

An appropriate electronic load specified down to 2.0V is desirable. The resistance of a maximum load is 0.050Ω. You need thick cables! Consult a wire chart if needed. If resistor banks are used there are certain precautions to be taken. The wattage and current ratings must be adequate for a 50A, 125W supply. Monitor both current and voltage at all times.

7 Air Flow

Full rated power should never be attempted without providing the specified 200 CFM of air flow over the UUT. This can be provided by a stand-alone fan.

8 Powering Up

Using the shutdown pin provided will allow powering up the source supply with the current level set low. It is suggested that the load be kept quite nominal during the first power up. Set the current limit of the source supply to provide about 1 1/2 times the wattage of the load. As you remove the connection from the shutdown pin to ground, immediately check for 2.5 volts at the output.

A most common occurrence, that will prove unnerving, is when the current limit set on the source supply is insufficient for the load. The result is similar to having the high source impedance referred to earlier. The interaction of the source supply folding back and the UUT going into undervoltage shutdown will start an oscillation, or chatter, that may have highly undesirable consequences.

A quick efficiency check is the best way to confirm that everything is operating properly. If something is a miss you can be reasonably sure that it will affect the efficiency adversely. Few parameters can be incorrect in a switching power supply without creating losses and potentially damaging heat.

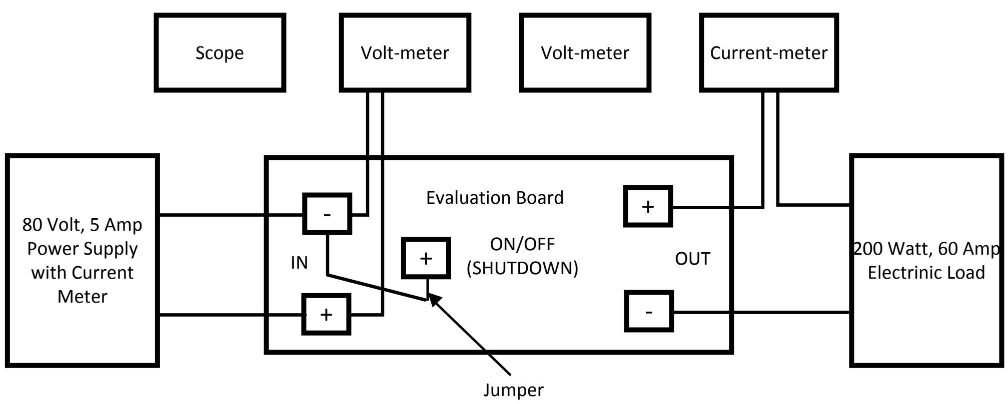


Figure 2. Typical Evaluation Setup

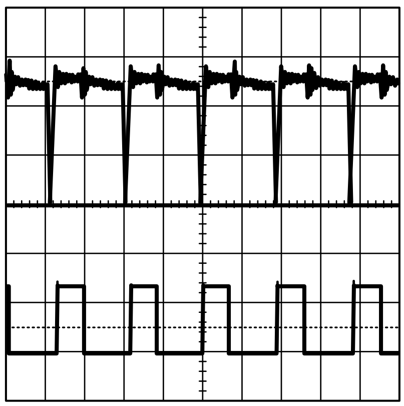
9 Performance Characteristics

9.1 Turn-on Waveforms

When applying power to the LM5041 evaluation board a certain sequence of events must occur. Soft-start capacitor values and other components allow for a minimal output voltage for a short time until the feedback loop can stabilize without overshoot. Figure 3 and Figure 4 show typical turn-on waveforms at no load and at a load of 50A. Input voltage, output voltage and output current are shown.

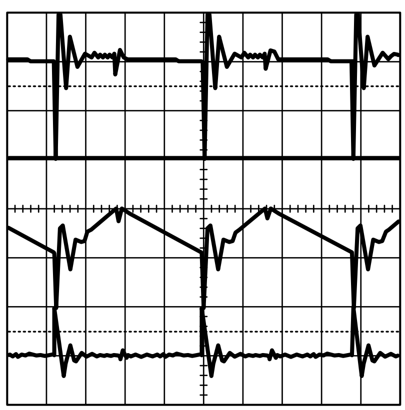
9.2 Output Ripple Waveforms

Figure 5 shows output ripple for a load of 40A. The waveforms should be measured directly across the output capacitors using a short tip-type ground lead on the scope probe. Bandwidth limiting may also prove useful.



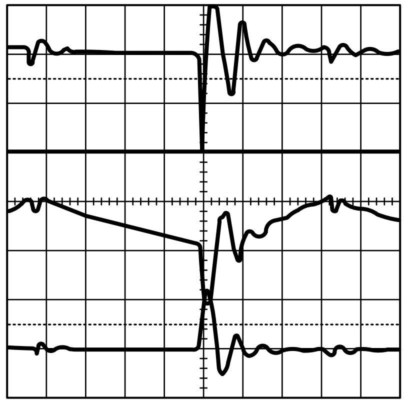
Trace 1: Input Voltage, no load Volts/div = 10.0V
Trace 2: Output Voltage, no load Volts/div = 1.0V
Trace 3: Output Current, no load Amps/div = 20.0A
Horizontal Resolution = 1µs/div

Figure 3. Typical Turn-on Waveform at No Load



Trace 1: Input Voltage, no loadVolts/div = 10.0V
Trace 2: Output Voltage, no load Volts/div = 1.0V
Trace 3: Output Current, no load Amps/div = 20.0A
Horizontal Resolution = 1µs/div

Figure 4. Typical Turn-on Waveform at a Load of 50A

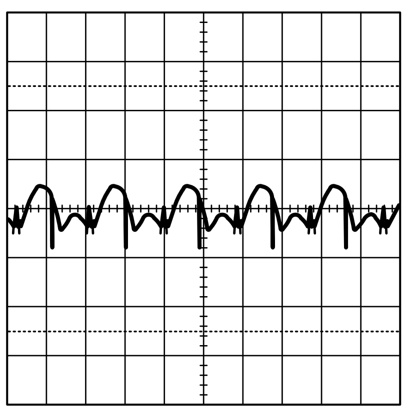


Conditions: Input Voltage = 48VDC
Output Current = 40A
Bandwidth Limit = 25MHz
Measured Ripple = 90mV pp
Trace 1: Output Ripple Voltage Volts/div = 50mV
Horizontal Resolution = 5µs/div

Figure 5. Output Ripple for a Load of 40A.

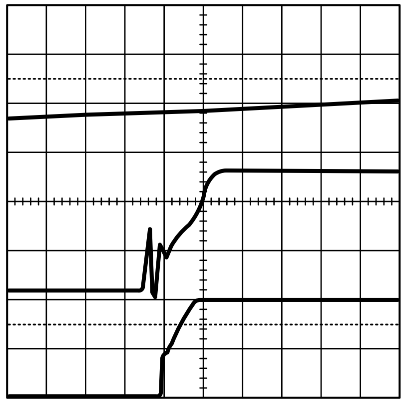
Figure 6 shows typical waveforms seen at the buck stage switching node at the input to L2 inductor, trace 3. It also shows the typical waveforms at the push-pull terminals of the main transformer, traces 1 and 2. The input voltage was 60VDC and the load current was 20.0A.

Figure 7 and Figure 8 show the typical waveforms seen when measuring the drain-source voltage and current of the push-pull MOSFETS. The upper two traces are the drain-source voltages and the lower two traces are the corresponding drain-source currents. The input voltage was 48VDC and the load current was 20.0A. Figure 8 is identical to Figure 7 except for the expanded time scale. The current waveforms show the characteristic ramp imparted by the buck stage which is responsible for regulation of the output voltage.



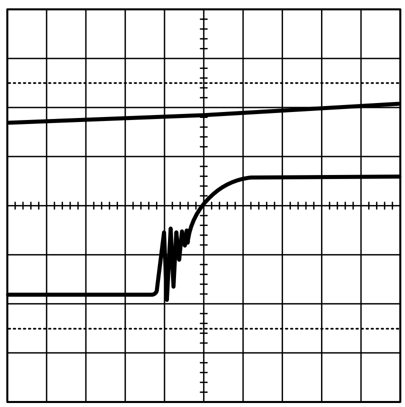
Trace 1: Push-pull at transformer,Side A, load = 20.0A Volts/div = 20.0V
Trace 2: Push-pull at transformer,Side B, load = 20.0A Volts/div = 20.0V
Trace 3: Buck Stage Switching Node, Load = 20.0A Volts/div = 50.0V
Horizontal Resolution = 2µs/div

Figure 6. Typical Waveforms seen at the Buck Stage Switching Node



Trace 1: Push-pull Mosfet drain-source voltage, side A, load = 20.0A Volts/div = 20.0V
Trace 2: Same as trace 1, side B
Trace 3: Push-pull Mosfet drain-source current, side B, load = 20.0A Amps/div = 1.0A
Trace 4: Same as trace 3, side A
Horizontal Resolution = 1µs/div

Figure 7. Typical Waveforms



Trace 1: Push-pull Mosfet drain-source voltage, side A, load = 20.0A Volts/div = 20.0V
Trace 2: Same as trace 1, side B
Trace 3: Push-pull Mosfet drain-source current, side B, load = 20.0A Amps/div = 1.0A
Trace 4: Same as trace 3, side A
Horizontal Resolution = 1µs/div

Figure 8. Typical Waveforms

10 Bill of Materials

The Bill of Materials is listed in Table 1 and includes the manufacturer and part number.

Table 1. Bill of Materials

Item	Qty	Part Number	Description	Value
C	1	C4532X7R2A225M	CAPACITOR, CER, TDK	2.2µ, 100V
C	2	C4532X7R2A225M	CAPACITOR, CER, TDK	2.2µ, 100V
C	3	C4532X7R2A225M	CAPACITOR, CER, TDK	2.2µ, 100V
C	4	C4532X7R2A225M	CAPACITOR, CER, TDK	2.2µ, 100V
C	5	C4532X7R3A103K	CAPACITOR, CER, TDK	0.01µ, 1000V
C	6	C0805C471J5GAC	CAPACITOR, CER, KEMET	470p, 50V
C	7	C3216X7R2E104K	CAPACITOR, CER, TDK	0.1µ, 250V
C	8	C4532X7R1E156M	CAPACITOR, CER, TDK	15µ, 25V
C	9	C2012X7R2A103K	CAPACITOR, CER, TDK	0.01µ, 100V
C	10	C2012X7R2E472K	CAPACITOR, CER, TDK	4700p,250V
C	11	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	12	C3216X7R2E104K	CAPACITOR, CER, TDK	0.1µ, 250V
C	13	C0805C101J1GAC	CAPACITOR, CER, KEMET	100p, 100V
C	14	C0805C101J1GAC	CAPACITOR, CER, KEMET	100p, 100V
C	15	C0805C101J1GAC	CAPACITOR, CER, KEMET	100p, 100V
C	16	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	17	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	18	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	19	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	20	C3216X7R1H334K	CAPACITOR, CER, TDK	0.33µ, 50V
C	21	PCC1986CT-ND	CAPACITOR, CER, PANASONIC	1500p, 100V
C	22	PCC1986CT-ND	CAPACITOR, CER, PANASONIC	1500p, 100V
C	23	C3216X7R1H334K	CAPACITOR, CER, TDK	0.33µ, 50V
C	24	C3216X7R1H334K	CAPACITOR, CER, TDK	0.33µ, 50V
C	25	C0805C471J5GAC	CAPACITOR, CER, KEMET	470p, 50V
C	26	C0805C471J5GAC	CAPACITOR, CER, KEMET	470p, 50V
C	27	C3216X7R1H334K	CAPACITOR, CER, TDK	0.33µ, 50V
C	28	T520D337M006AS4350	CAPACITOR,TANT,KEMET	330µ, 6.3V
C	29	T520D337M006AS4350	CAPACITOR,TANT,KEMET	330µ, 6.3V
C	30	C4532X7S0G686M	CAPACITOR, CER, TDK	68µ, 4V
C	31	C4532X7S0G686M	CAPACITOR, CER, TDK	68µ, 4V
C	32	C4532X7S0G686M	CAPACITOR, CER, TDK	68µ, 4V
C	33	C4532X7S0G686M	CAPACITOR, CER, TDK	68µ, 4V
C	34	C2012X7R2A102K	CAPACITOR, CER, TDK	1000p, 100V
C	35	C0805C221J5GAC	CAPACITOR, CER, KEMET	220p, 50V
C	36	C2012X7R2A103K	CAPACITOR, CER, TDK	0.01µ, 100V
C	37	C2012X7R1H104K	CAPACITOR, CER, TDK	0.1µ, 50V
C	38	PCC1996CT-ND	CAPACITOR, CER, PANASONIC	680p, 200V
C	39	C2012X7R1H104K	CAPACITOR, CER, TDK	0.01µ, 50V
C	40	C0805C331J5GAC	CAPACITOR, CER, KEMET	330p, 50V
C	41	C2012X7R2A102K	CAPACITOR, CER, TDK	1000p, 100V
C	42	C1206223K5RAC	CAPACITOR, CER, KEMET	0.022µ, 50V
D	1	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	2	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	3	CMPSH-3C-NSA	DIODE, SIGNAL, CENTRAL	

Table 1. Bill of Materials (continued)

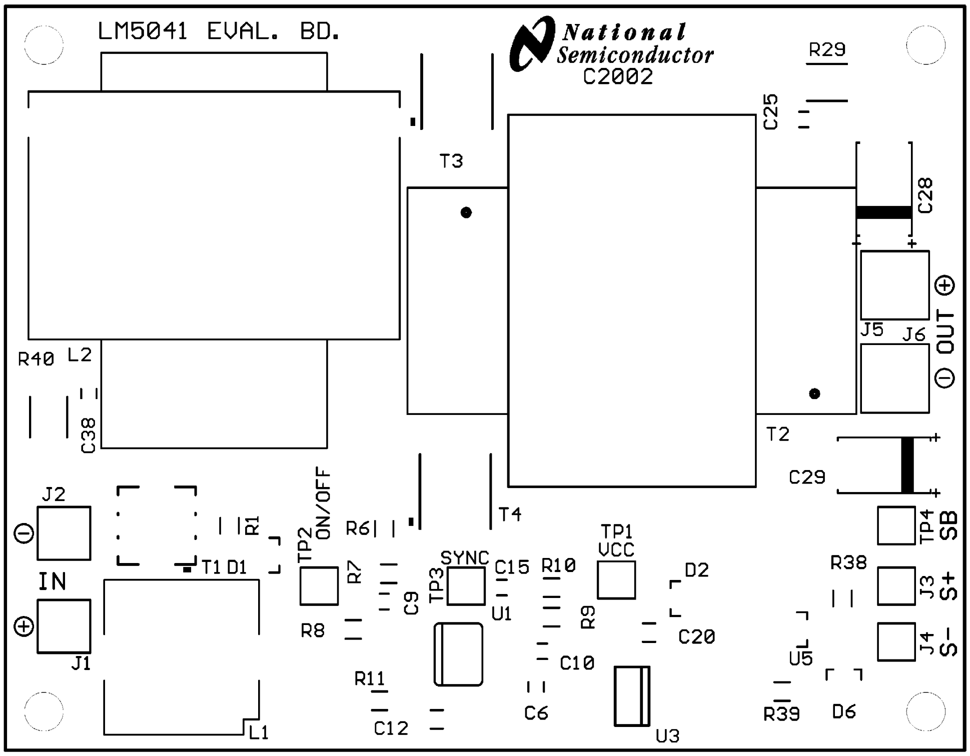
Item	Qty	Part Number	Description	Value
D	4	BAS56-NSA	DIODE, SIGNAL, CENTRAL	
D	5	BAS56-NSA	DIODE, SIGNAL, CENTRAL	
D	6	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	7	BAS56-NSA	DIODE, SIGNAL, CENTRAL	
D	8	BAS56-NSA	DIODE, SIGNAL, CENTRAL	
D	9	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	10	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	11	CMPD2838-NSA	DIODE, SIGNAL, CENTRAL	
D	12	CMPD6001S-NSA	DIODE, SIGNAL, CENTRAL	
D	13	CRH01CT-ND	DIODE, SIGNAL, TOSHIBA	
L	1	SLF12575-100M5R4	INPUT CHOKE, TDK	10µH, 5A
L	2	A9787-A, Coilcraft	PRIMARY CHOKE	60µH, 7.5A
			EQ30, Gapped for Al=400, 12Turns, 3C92 material	
Q	1	SI7456DP	FET, SILICONIX	100V, 25m
Q	2	SI7456DP	FET, SILICONIX	100V, 25m
Q	3	SI7852DP	FET, SILICONIX	80V, 17m
Q	4	SI7852DP	FET, SILICONIX	80V, 17m
Q	5	SI7858DP	FET, SILICONIX	12V, 3m
Q	6	SI7858DP	FET, SILICONIX	12V, 3m
Q	7	SI7858DP	FET, SILICONIX	12V, 3m
Q	8	SI7858DP	FET, SILICONIX	12V, 3m
Q	9	SI7858DP	FET, SILICONIX	12V, 3m
Q	10	SI7858DP	FET, SILICONIX	12V, 3m
Q	11	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	12	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	13	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	14	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	15	CMPT591E-NSA	PNP, CENTRAL	60V, 1A
Q	16	CMPT591E-NSA	PNP, CENTRAL	60V, 1A
R	1	CRCW12061002F	RESISTOR	10K
R	2	CRCW120610R0F	RESISTOR	10
R	3	CRCW120620R0F	RESISTOR	20
R	4	CRCW12062000F	RESISTOR	200
R	5	CRCW120649R9F	RESISTOR	49.9
R	6	CRCW12061003F	RESISTOR	100K
R	7	CRCW12061001F	RESISTOR	1K
R	8	CRCW12068061F	RESISTOR	8.06K
R	9	CRCW12061652F	RESISTOR	16.5K
R	10	CRCW12062372F	RESISTOR	23.7K
R	11	CRCW12062001F	RESISTOR	2K
R	12	CRCW12064990F	RESISTOR	499
R	13	CRCW12067500F	RESISTOR	750
R	14	CRCW12067500F	RESISTOR	750
R	15	CRCW12065R1J	RESISTOR	5.1
R	16	CRCW12065R1J	RESISTOR	5.1
R	17	CRCW12061002F	RESISTOR	10K
R	18	CRCW12061002F	RESISTOR	10K

Table 1. Bill of Materials (continued)

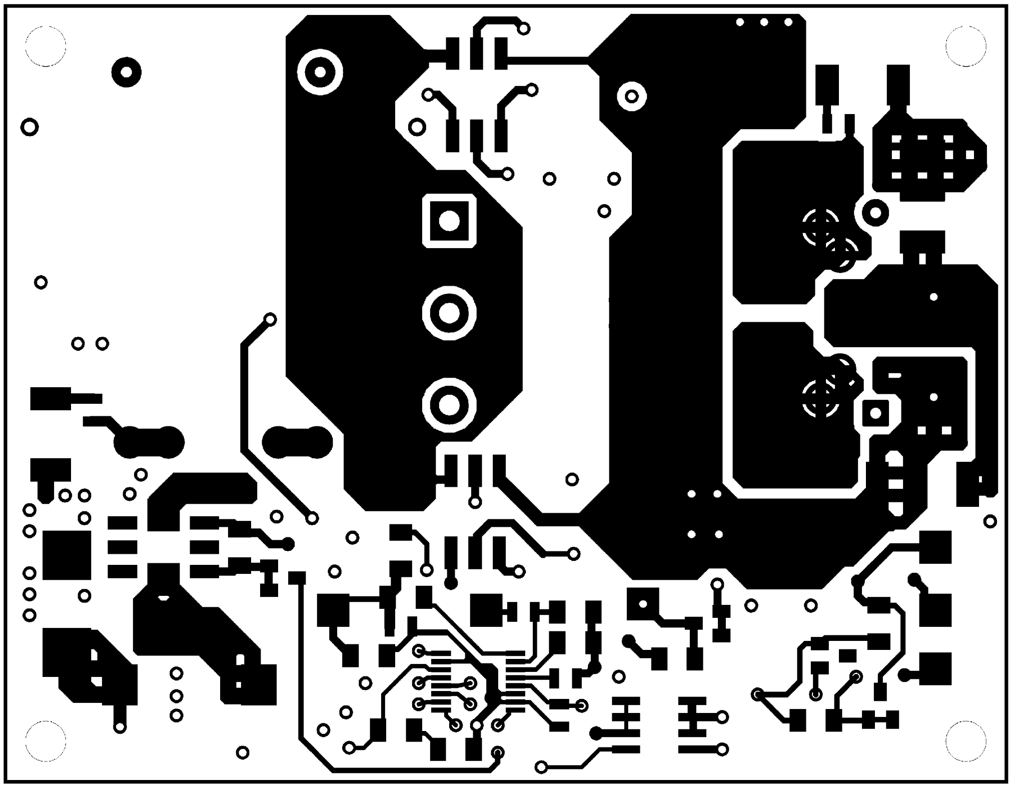
Item	Qty	Part Number	Description	Value
R	19	CRCW12065R1J	RESISTOR	5.1
R	20	CRCW12065R1J	RESISTOR	5.1
R	21	CRCW2512100J	RESISTOR	10, 1W
R	22	CRCW2512100J	RESISTOR	10, 1W
R	23	CRCW120610R0F	RESISTOR	10
R	24	CRCW120610R0F	RESISTOR	10
R	25	CRCW120610R0F	RESISTOR	10
R	26	CRCW120610R0F	RESISTOR	10
R	27	CRCW12061002F	RESISTOR	10K
R	28	CRCW12061002F	RESISTOR	10K
R	29	CRCW2512100J	RESISTOR	10, 1W
R	30	CRCW2512100J	RESISTOR	10, 1W
R	31	CRCW120610R0F	RESISTOR	10
R	32	CRCW12062102F	RESISTOR	21K
R	33	CRCW12062002F	RESISTOR	20K
R	34	CRCW120610R0F	RESISTOR	10
R	35	CRCW12062002F	RESISTOR	20K
R	36	CRCW12064991F	RESISTOR	4.99K
R	37	CRCW12064991F	RESISTOR	4.99K
R	38	CRCW12061002F	RESISTOR	10K
R	39	CRCW12062002F	RESISTOR	20K
R	40	CRCW2512100J	RESISTOR	10, 1W
R	41	CRCW120610R0F	RESISTOR	10
R	42	CRCW12064991F	RESISTOR	4.99K
R	43	CRCW12061000F	RESISTOR	100
T	1	P8208T, Pulse	CURRENT XFR, PULSE ENG	100:1
T	2	A9786-A, Coilcraft	POWER XFR, COILCRAFT	
			EQ30, 3C94, 8T,8T,1T,1T,4T	
T	3	SM76925, Datatronic	ISOLATION XFR	1:1:1
T	4	SM76925, Datatronic	ISOLATION XFR	1:1:1
U	1	LM5041	CONTROLLER, TEXAS INSTRUMENTS	
U	2	LM5101	DUAL HV GATE DRIVER, TEXAS INSTRUMENTS	
U	3	MOCD207M	OPTO-COUPLER, QT OPTO	
U	4	LM6132	OPAMP, TEXAS INSTRUMENTS	
U	5	LM4041	REFERENCE, TEXAS INSTRUMENTS	
			(4) 1/2 inch STANDOFFs #4	
				RB 01/21/04

11 PCB Layouts

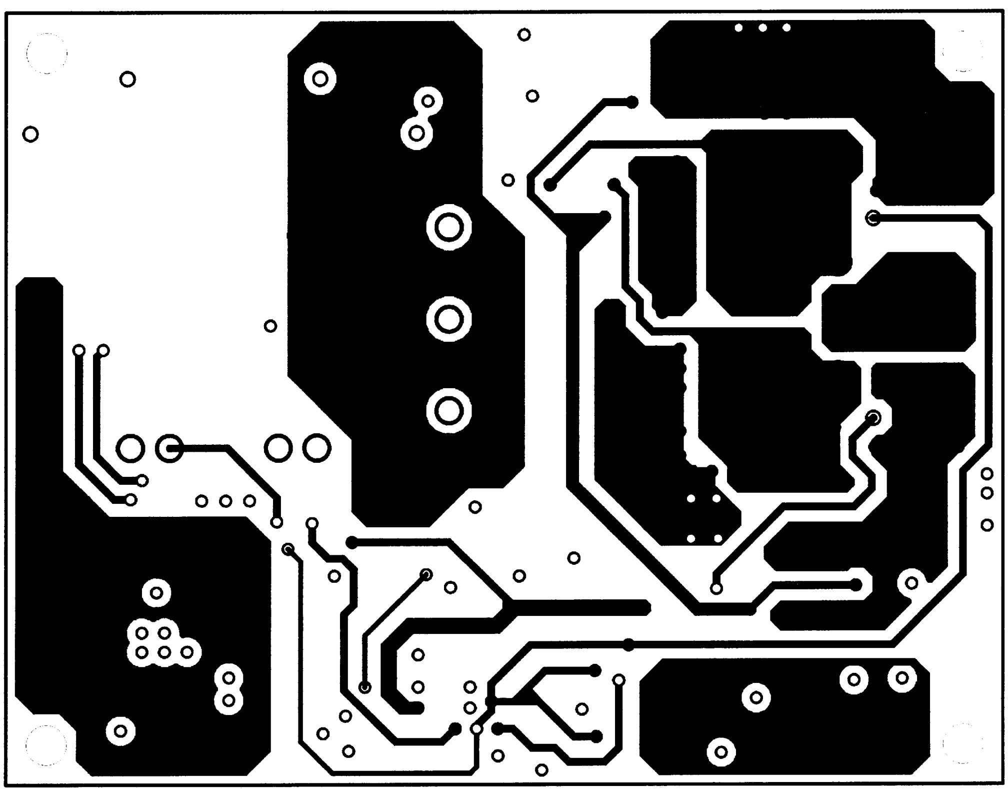
The layers of the printed circuit board are shown in top down order. View is from the top down except for the bottom silkscreen which is shown viewed from the bottom. Scale is approximately X1.5. The printed circuit board consists of 4 layers of 3 ounce copper on FR4 material with a total thickness of 0.050 inches.



TOP SILKSCREEN



TOP COPPER



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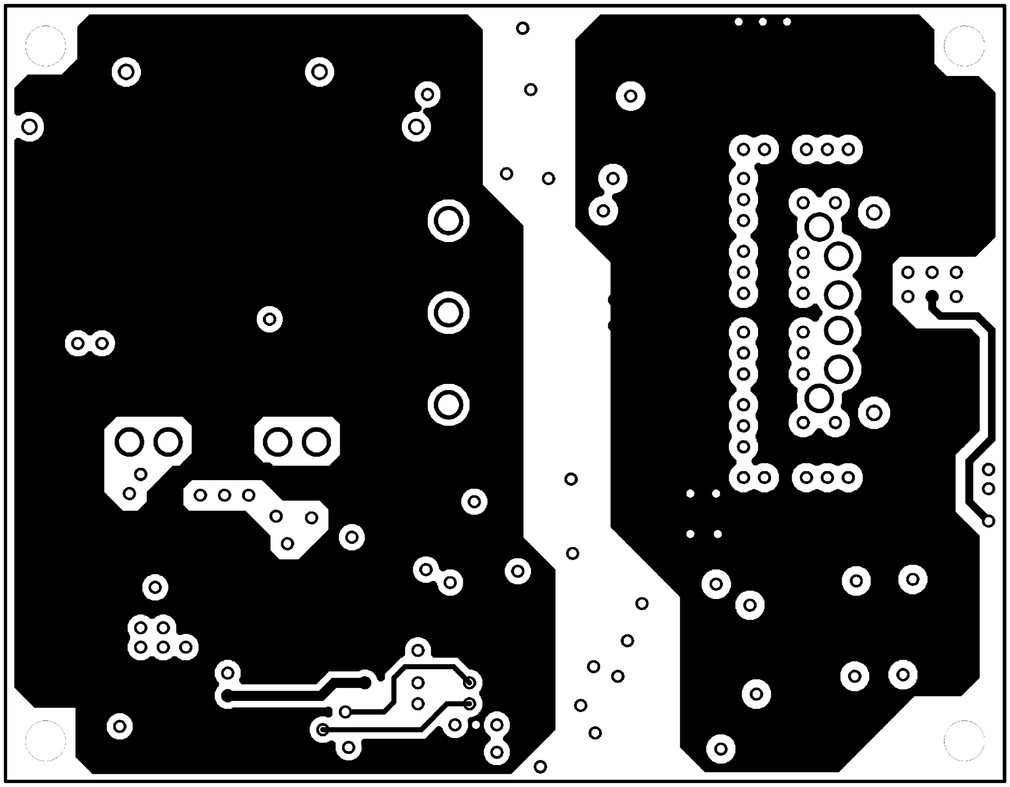

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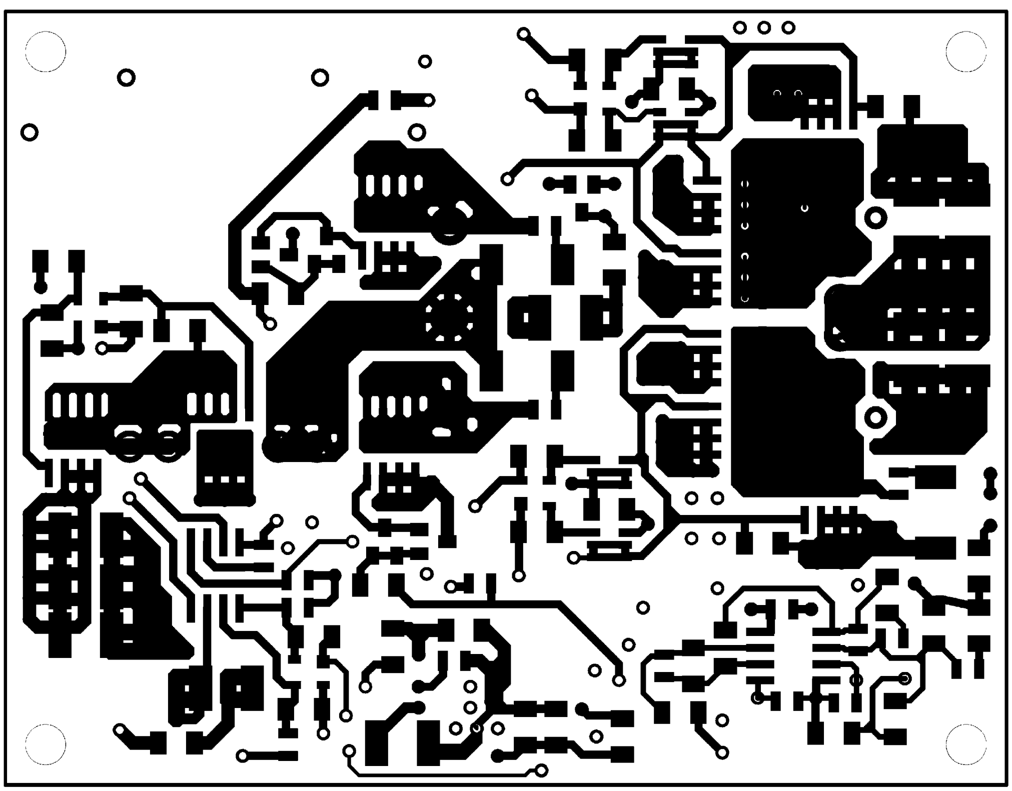
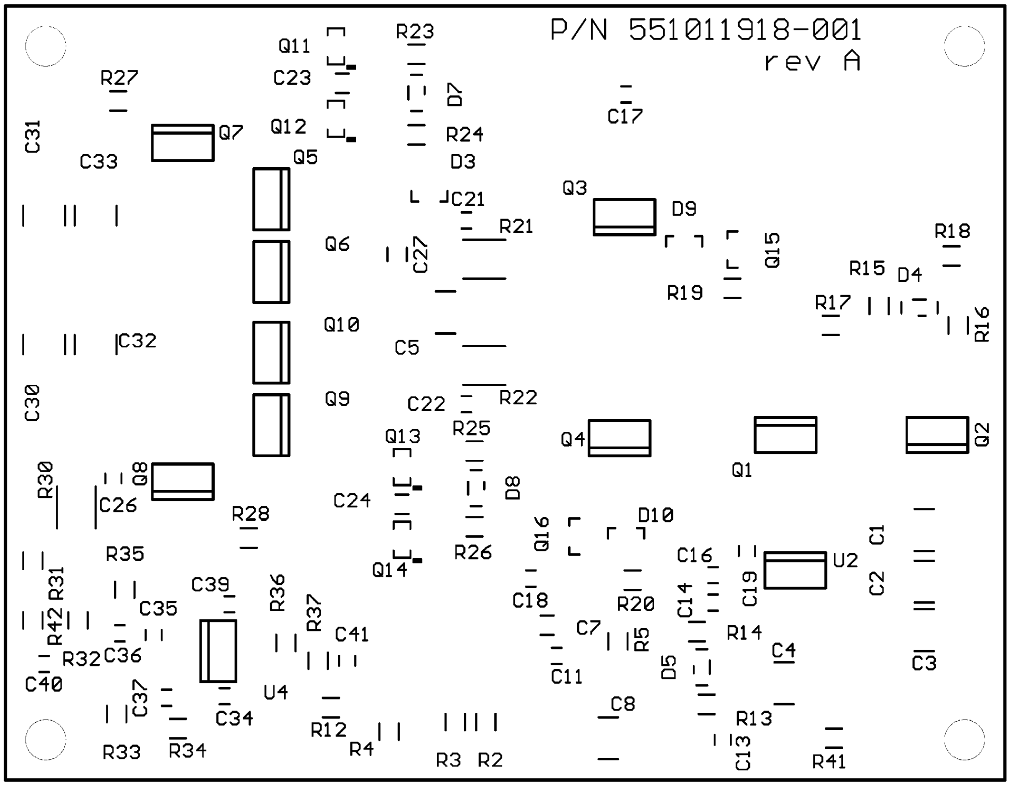


BOTTOM COPPER



BOTTOM SILKSCREEN

12 Application Circuit

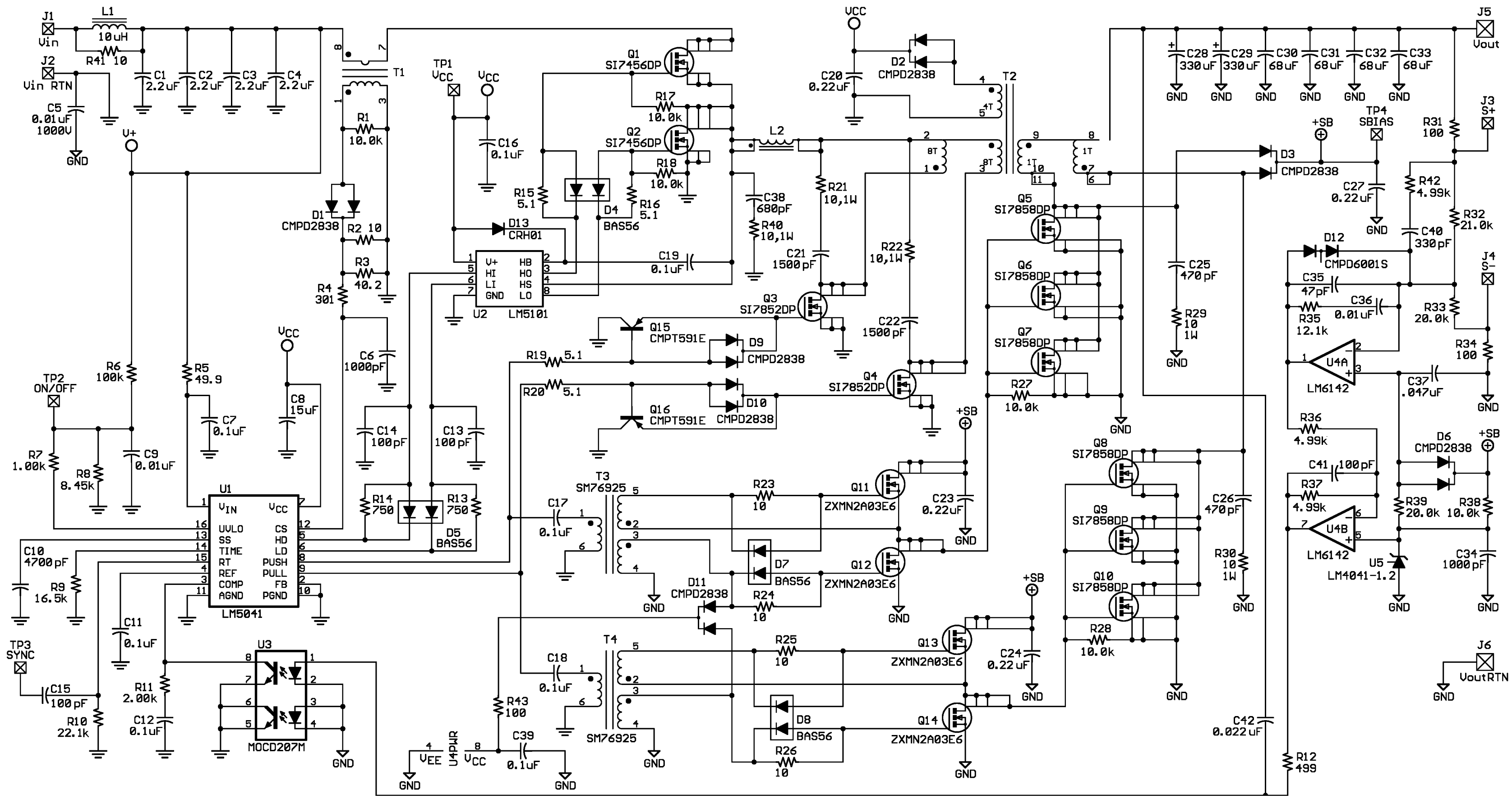


Figure 9. Application Circuit: Input 35V to 80V, Output 2.5V, 50A

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

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