

# LM5041 Evaluation Board

National Semiconductor  
Application Note 1299  
Grant Smith  
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## 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 x 3.0 x 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  $< 40^{\circ}\text{C}$  and a minimum airflow of 200 CFM.

## Theory of Operation

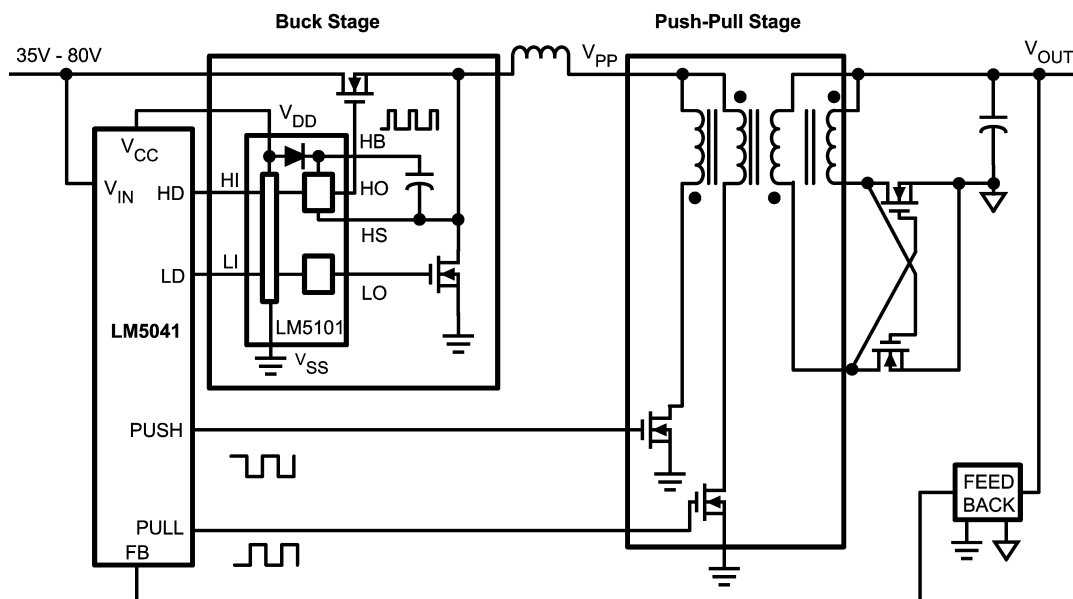
The current fed push-pull converter is a buck type converter consisting of a buck regulation stage followed by (cascaded

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.



Simplified Cascaded Push-Pull Converter

20083301

## 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.

### 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.

### 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 read-out of output current is desirable since the current is not subject to loss in the cables as voltage is.

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

## Loading

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.

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

### Air Flow

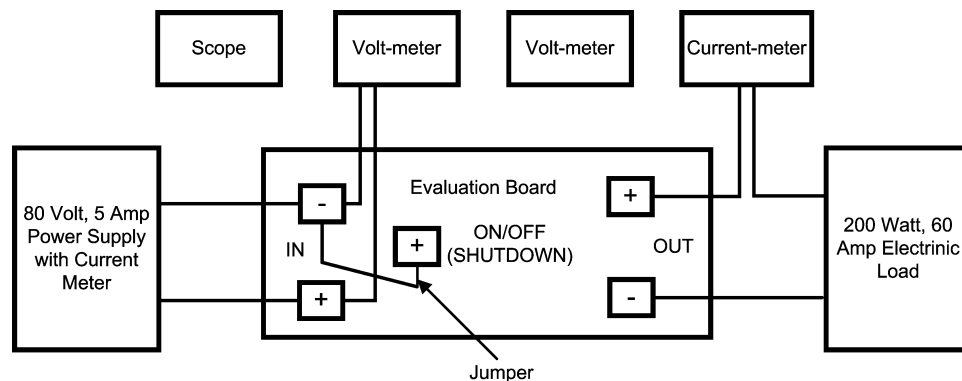
Full rated power should never be attempted without providing the specified 200 CFM of air flow over the UUT. This can be provided by a stand-alone fan.

### 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.



Typical Evaluation Setup

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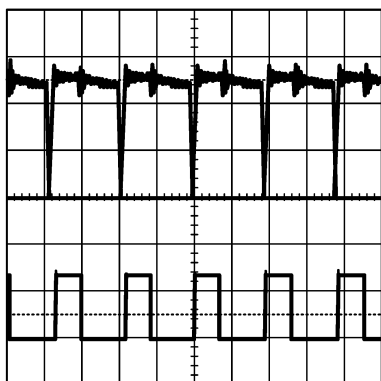
## Performance Characteristics

### 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 1* and *Figure 2* show typical turn-on waveforms at no load and at a load of 50A. Input voltage, output voltage and output current are shown.

### OUTPUT RIPPLE WAVEFORMS

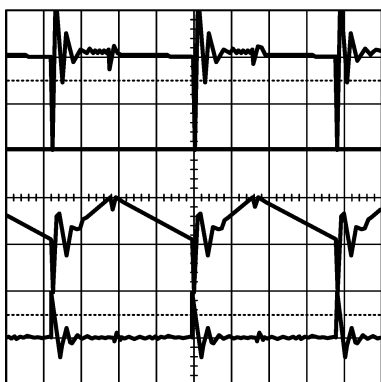
*Figure 3* shows output ripple for a load of 40A. The waveforms should be measured directly across the output capacitors using a short tip-type ground lead on the scope probe. Bandwidth limiting may also prove useful.



20083303

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

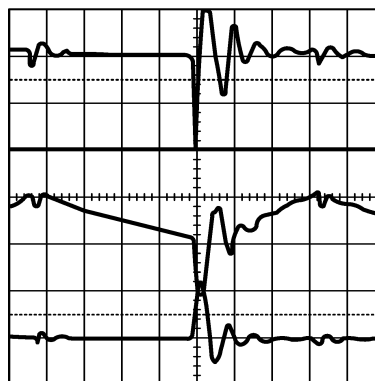
**FIGURE 1.**



20083304

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 2.**



20083305

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

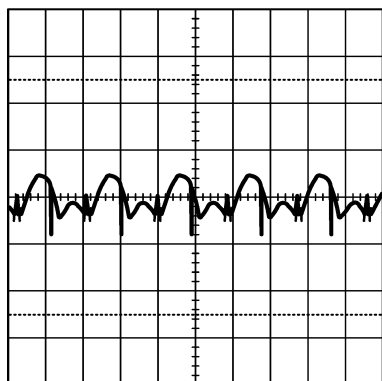
**FIGURE 3.**

*Figure 4* 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 5* and *Figure 6* 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 6* is identical to *Figure 5* 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.

## Performance Characteristics

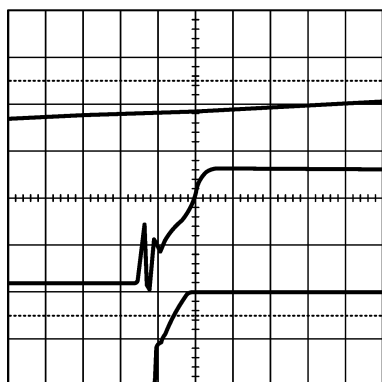
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20083306

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 = 2 $\mu$ s/div

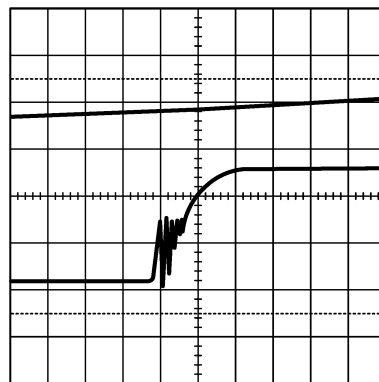
FIGURE 4.



20083307

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 = 1 $\mu$ s/div

FIGURE 5.



20083308

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 = 1 $\mu$ s/div

FIGURE 6.



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## Layout and Bill of Materials

The Bill of Materials is shown below and includes the manufacturer and part number. 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.

ITEM		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

# Layout and Bill of Materials (Continued)

ITEM		PART NUMBER	DESCRIPTION	VALUE
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	
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

## Layout and Bill of Materials (Continued)

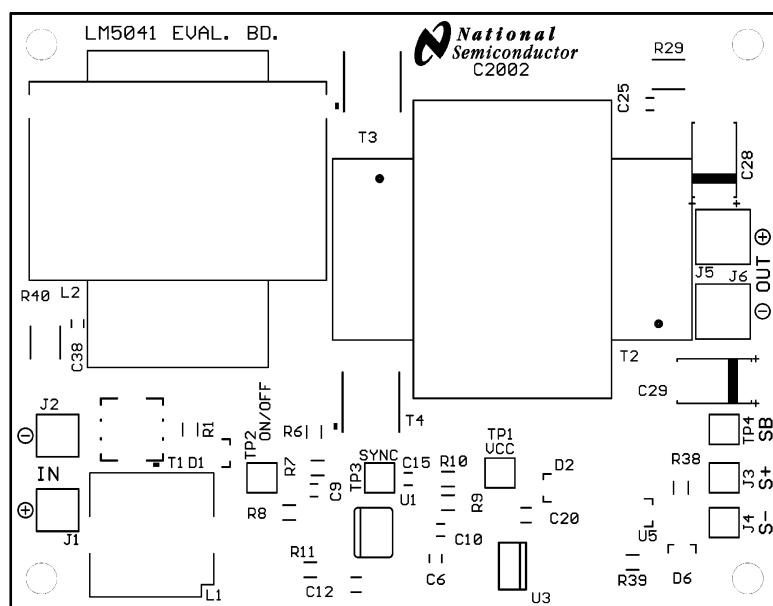
ITEM		PART NUMBER	DESCRIPTION	VALUE
Q	10	SI7858DP	FET, SILICONIX	12V, 3m
Q	11	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	12	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	13	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	14	ZXMN2A03E6	FET, ZETEX	20V, 55m
Q	15	CMPT591E-NSA	PNP, CENTRAL	60V, 1A
Q	16	CMPT591E-NSA	PNP, CENTRAL	60V, 1A
R	1	CRCW12061002F	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
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



## Layout and Bill of Materials (Continued)

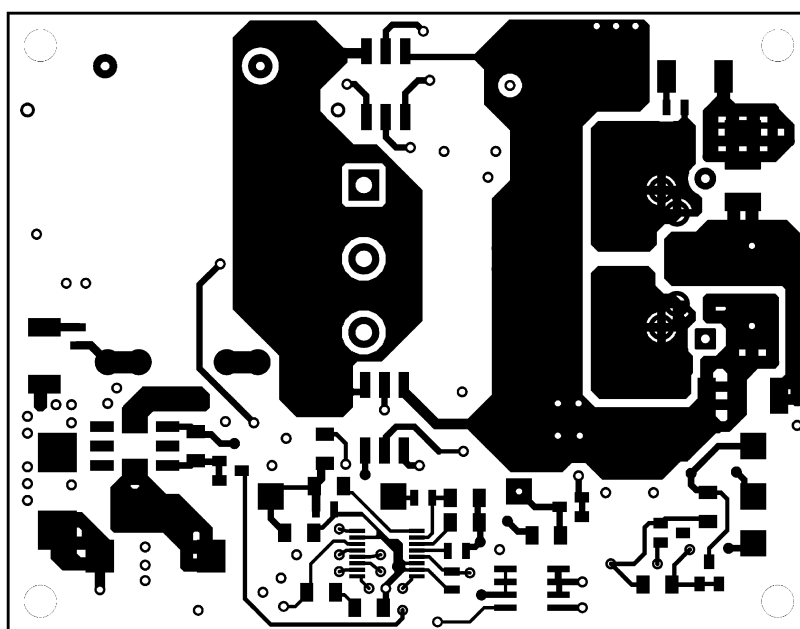
ITEM		PART NUMBER	DESCRIPTION	VALUE
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R	43	CRCW12061000F	RESISTOR	100
T	1	P8208T, Pulse	CURRENT XFR, PULSE ENG	100:1
T	2	A9786-A, Coilcraft	POWER XFR, COILCRAFT	
			EQ30, 3C94, 8T,8T,1T,1T,4T	
T	3	SM76925, Datatronic	ISOLATION XFR	1:1:1
T	4	SM76925, Datatronic	ISOLATION XFR	1:1:1
U	1	LM5041	CONTROLLER, NATIONAL	
U	2	LM5101	DUAL HV GATE DRIVER, NATIONAL	
U	3	MOCD207M	OPTO-COUPLER, QT OPTO	
U	4	LM6132AIM	OPAMP, NATIONAL	
U	5	LM4041CEM3-1.2	REFERENCE, NATIONAL	
			(4) 1/2 inch STANDOFFs #4	
				RB 01/21/04

## PCB Layouts



TOP SILKSCREEN

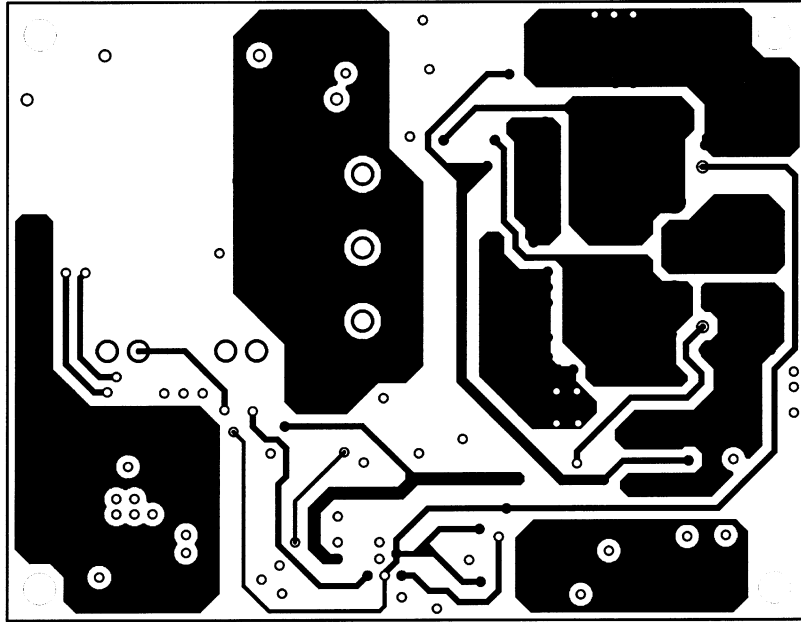
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TOP COPPER

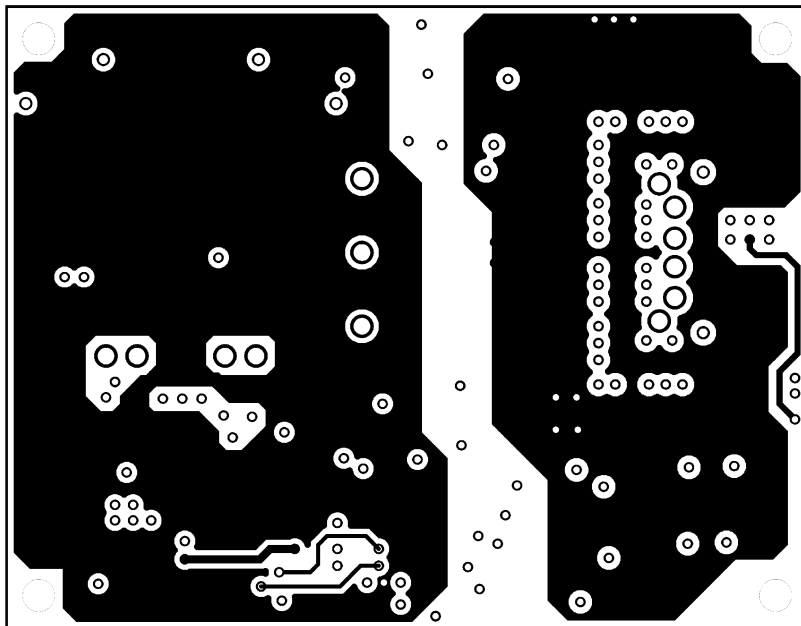
20083311

# PCB Layouts (Continued)



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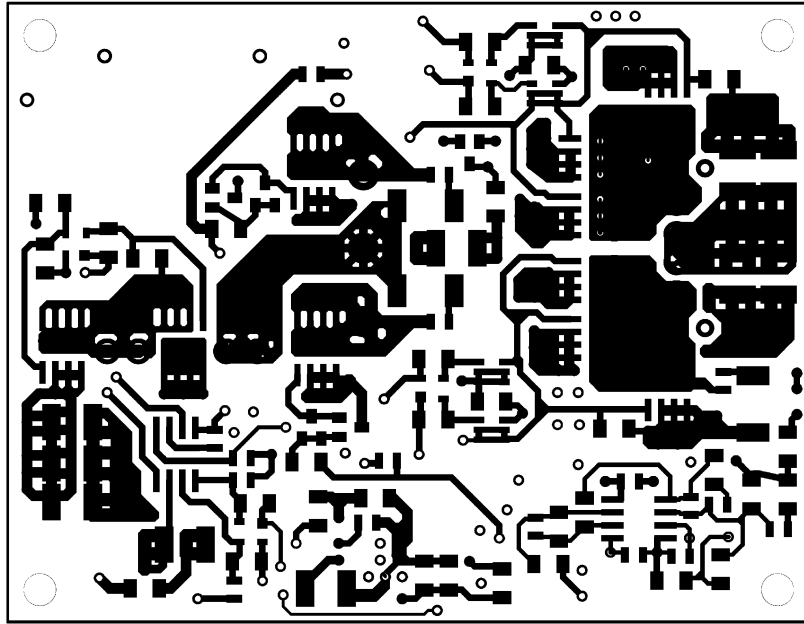
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MIDLAYER 2 COPPER

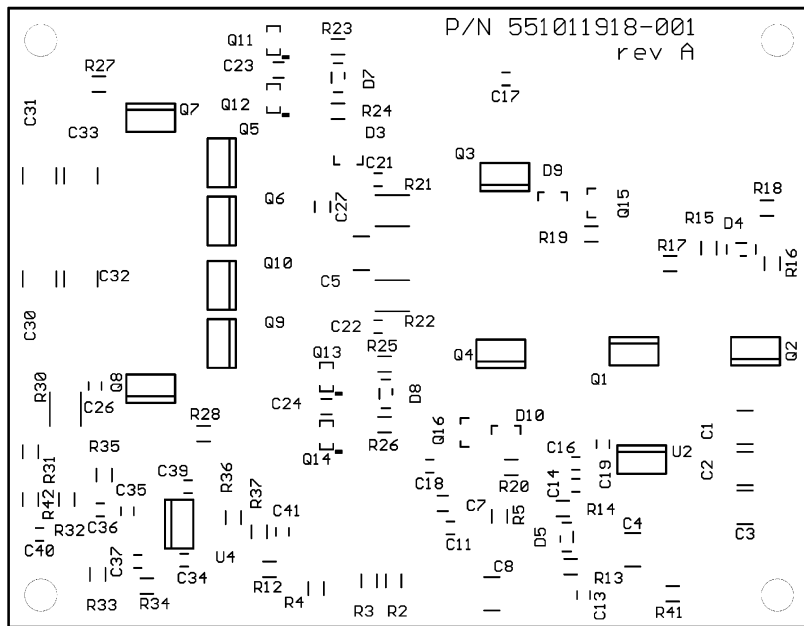
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## PCB Layouts (Continued)



BOTTOM COPPER

20083314



BOTTOM SILKSCREEN

20083315

## Notes

### LIFE SUPPORT POLICY

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1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

### BANNED SUBSTANCE COMPLIANCE

National Semiconductor certifies that the products and packing materials meet the provisions of the Customer Products Stewardship Specification (CSP-9-111C2) and the Banned Substances and Materials of Interest Specification (CSP-9-111S2) and contain no "Banned Substances" as defined in CSP-9-111S2.



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