

# Current Sense Demo Board (SOIC) User's Guide

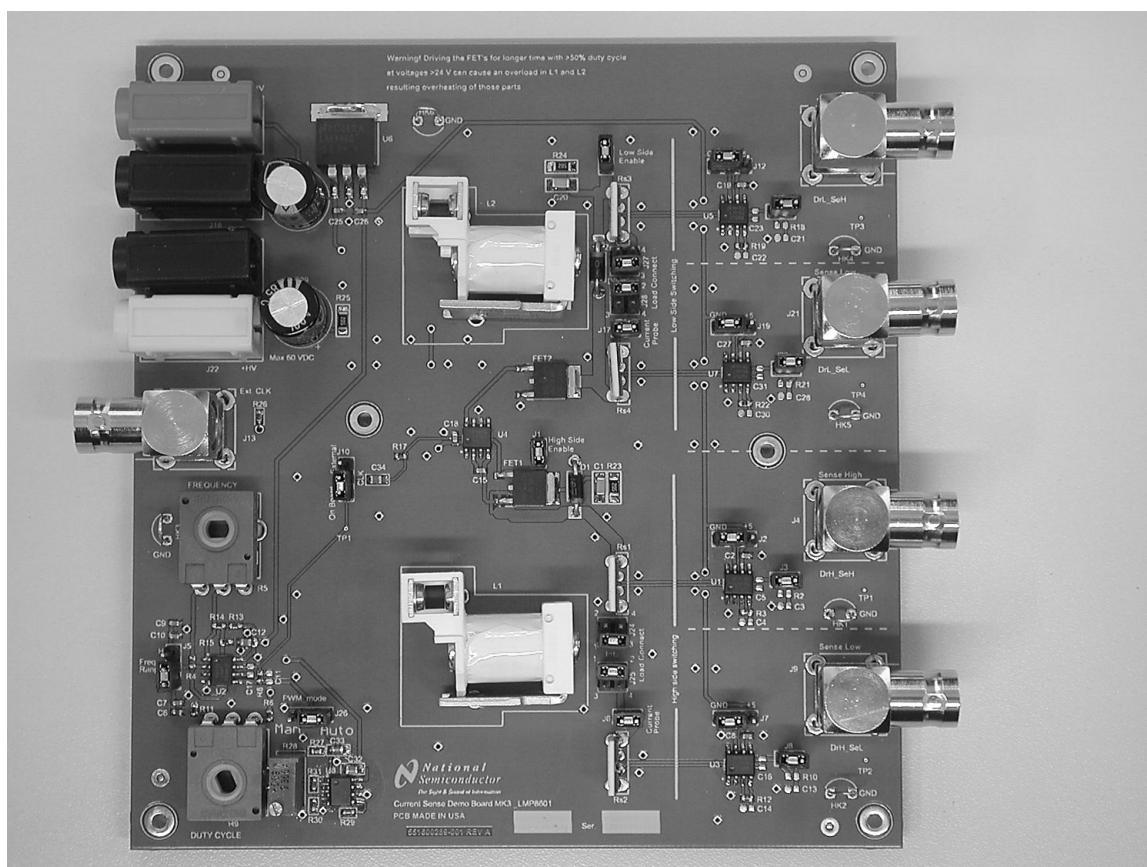
National Semiconductor  
Application Note 1923  
BeB Hennink  
April 29, 2009



## Introduction

The Current Sense Demo Board (SOIC) is designed to demonstrate four different current sense configurations for the National Semiconductor Current Sense Amplifiers in SOIC package. Among these parts are the LMP8601, LMP8602 and LMP8602 60V Common Mode, Bidirectional Precision Current Sensing Amplifier and the LMP8277 and LMP8278 High Common Mode 14x Gain Precision Current Sensing Amplifier. The board has four current sense Amplifiers mounted on the PCB together with a clock generator; FET switches, two inductive loads and surrounding compo-

nents ready for evaluation. This board offers high and low side sensing circuits for both high side and low side switched inductive loads. Both high and low side sensing signals are simultaneously available for measuring the current in the load offering the means for comparing performance simultaneously for both options. The board offers an on board clock oscillator to switch the FET's, which makes it possible to demonstrate the four configurations without the need for an external oscillator. The duty cycle of the clock oscillator can be varied, either by a potentiometer or automatically via the on board pulse width modulator.



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FIGURE 1. The Current Sense Demo Board

## General Description

The National Semiconductor Current Sense amplifiers are fixed gain precision amplifiers. The part amplifies and filters small differential signals in the presence of high common mode voltages. The input common mode voltage range is far beyond the supply rails. All these current sense parts are members of the Linear Monolithic Precision (LMP®) family and are ideal parts for unidirectional and for the LMP860X even bidirectional current sensing applications.

The parts all have a precise fixed gain varying from 14 V/V for the to 100 V/V, so there is an adequate gain available for most targeted applications to drive an ADC to its full scale value. The fixed gain is achieved in two separate stages, a pre-amplifier taking care of the wide common mode voltages and an output stage buffer amplifier. The connection between the two stages of the signal path is brought out on two pins to enable the possibility to create an additional filter network around the output buffer amplifier. These pins can also be used for alternative configurations with different gain as described in the applications section of the data sheet.

The mid-rail offset adjustment pin of the LMP860X enables the user to use these devices for bidirectional single supply voltage current sensing. The output signal is bidirectional and mid-rail referenced when this pin is connected to the positive supply rail. With the offset pin connected to ground, the output signal is unidirectional and ground-referenced.

The LMP8601Q incorporates enhanced manufacturing and support processes for the automotive market, including defect detection methodologies. Reliability qualification is compliant with the requirements and temperature grades defined in the AEC Q100 standard

Part no	Gain (V/V)	CMVR range		Temp range
		$V_S = 3V3$	$V_S = 5V$	
LMP8277	14	NA	-2V to 16V	-40°C to 125°C
LMP8278	14	NA	-2V to 40V	
LMP8603	20	-4V to 27V	-22V to 60V	-40°C to 125°C
LMP8602	50	-4V to 27V	-22V to 60V	
LMP8603	100	-4V to 27V	-22V to 60V	

For easier referencing from now on in this document the **LMP8601** will be used for all reference to the **current sense amplifiers mounted on this current sense demo board**. If one of the other National Semiconductor current sense amplifiers is mounted on the board, please read that part number instead of LMP8601 throughout rest of this document.

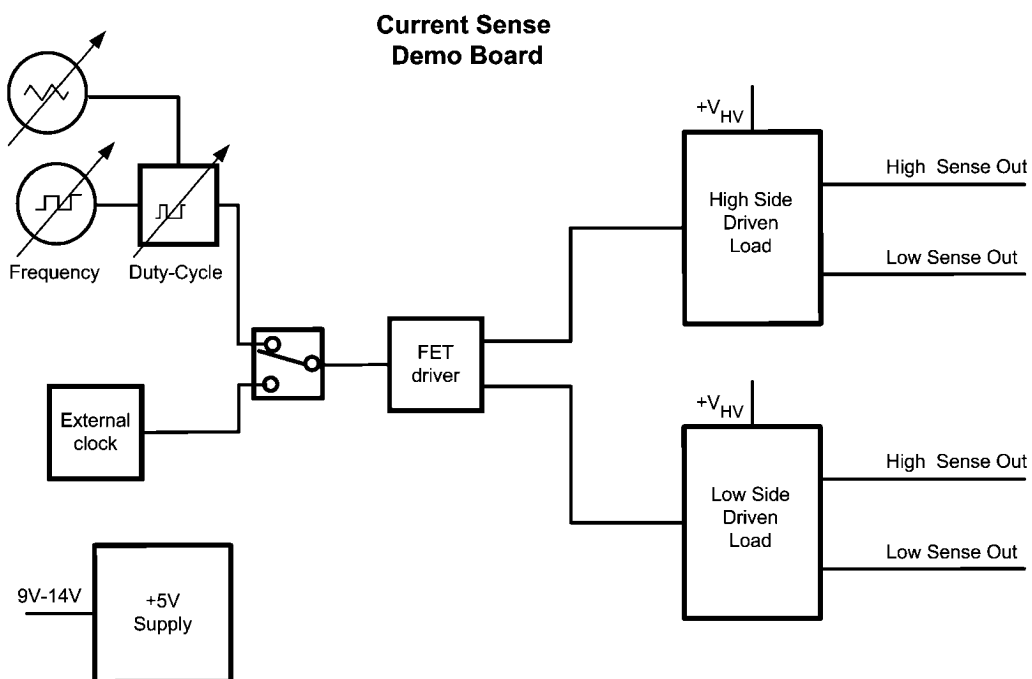
## The Current Sense Demo Board Features

With the Current Sense Demo Board is designed to show how the National Semiconductor current sense amplifiers operate in four different current sensing configurations.

1. Switch at the high side of the load and sensing resistor between load and switch
2. Switch at the high side of the load and sensing resistor between load and ground
3. Switch at the low side of the load and sensing resistor between load and high voltage supply
4. Switch at the low side of the load and sensing resistor between switch and load
5. On Board pulse width controllable oscillator for switching the FET's
6. ON Board PWM oscillator for automatic sweeping the duty cycle.

The FET switches switching the loads can be operated from an on board oscillator or an external oscillator.

The frequency of the on board square wave oscillator can be varied between 100Hz and 10kHz. The duty cycle of this oscillator can be swept automatically from about 10% to 90% duty cycle and the duty cycle can also be varied manually.



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**FIGURE 2. Block Schematic**

## Demo Board Operating Conditions

- Temperature Range  $0^{\circ}\text{C}$  to  $85^{\circ}\text{C}$
- Power Supply Voltage (DC)  $9\text{V} \leq V_{\text{supply}} \leq 14\text{V}$
- Load Supply Voltage (DC) (Note 1)  $0\text{V} \leq V_{\text{HV}} \leq 60\text{V}$

**Note 1:** The maximum load supply voltage is limited by the maximum input voltage range of the current sense amplifiers mounted on the demo board for U1, U3, U5 and U7.

**Note 2: Warning!** The inductive loads ( $L_1$  and  $L_2$ ) mounted on the demo board are a compromise used to emulate the switching behavior close to certain targeted application. The inductive loads are not capable of handling load conditions with duty cycles  $>50\%$  and load supply voltages  $>24\text{V}$  for longer time. Doing so will result in overheating of those components and possible damage.

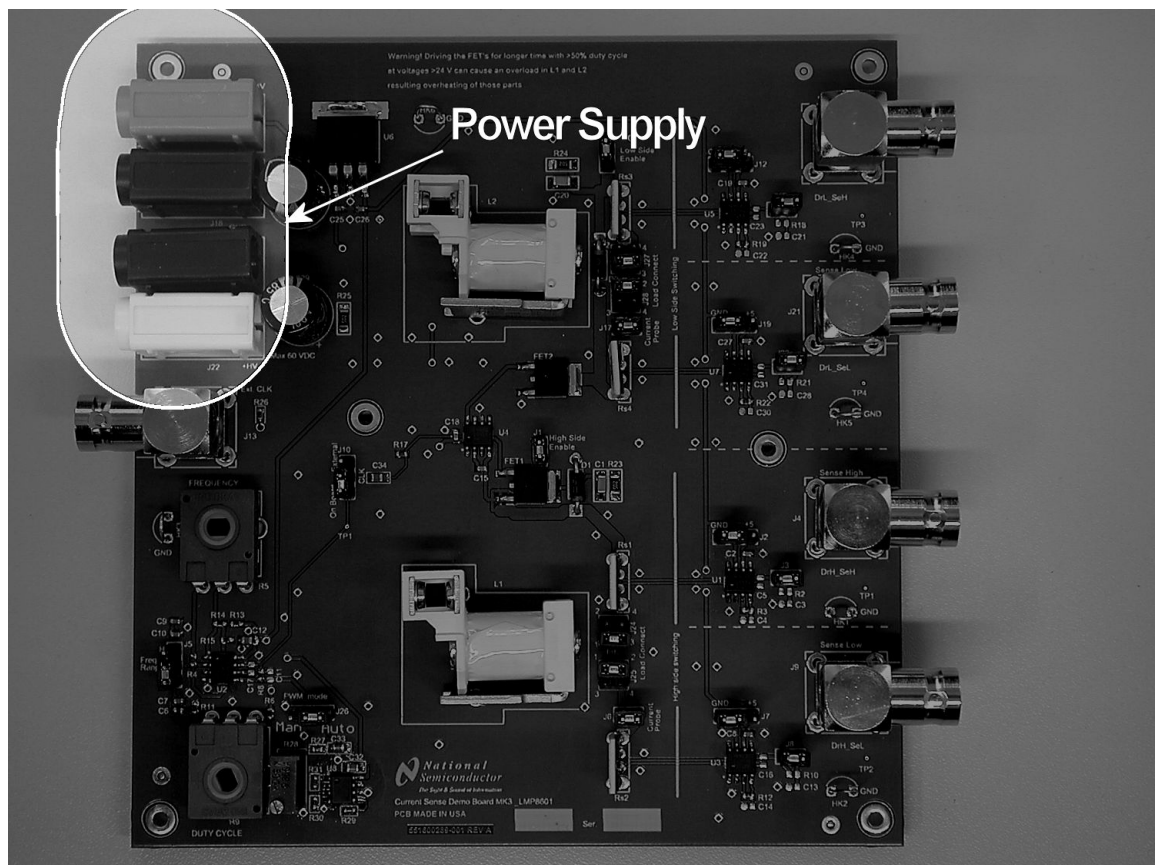
## Description of the Current Sense Demo Board Circuits

### POWER SUPPLY OF THE CURRENT SENSE DEMO BOARD

The Current Sense Demo Board requires two power supply voltages: One supply (marked +9 - 14V) is used to supply the on board oscillator, FET control circuit and the on board LMP8601 parts. This power supply voltage should be between 9V and 14 V<sub>DC</sub>. The required supply current for this supply will be below 50mA.

The second supply voltage (marked +HV) powers the switched loads. The maximum voltage on the +HV supply is limited by the current sense parts that are mounted on the PCB. For the LMP8601 the limit is 60 VDC maximum.

The two load circuits on the demo board can be enabled separately. Placing a jumper on J1 enables the high side switched load circuit. Placing a jumper on J11 enables the low side switched load circuit.



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FIGURE 3. Power Supply Connectors and Headers

## THE ON BOARD OSCILLATOR

For easy evaluation of the part and demonstration of the operation of the current sense amplifier parts, the LMP8601 Current Sense Amplifier Demo Board is equipped with an on board square wave oscillator. This is used for driving the on board FET switches. The schematic of the on board oscillator circuitry is shown in *Figure 4*. The frequency range can be selected to be in the range from 100Hz - 1kHz (jumper on J5 pin 1-2) or in the range from 1kHz - 10kHz (jumper on J5 pin 2-3). Within those ranges the frequency can be tuned with R5.

The on board oscillator supports two different modes of operation:

- A steady state where the duty cycle of the FET steering is controlled with potentiometer R9. (jumper on J26 Pin2-3)
- PWM mode where the duty cycle of the FET steering is controlled with an on board oscillator (jumper on J26 pin 1-2) which is continuously sweeping the duty cycle from high to low and back.

There is also an option to provide an external clock to the FET drivers via J13. For this mode of operation the jumper on J10 must be placed between pin 2 and 3. The levels of this signal must comply with CMOS 5 V logical levels

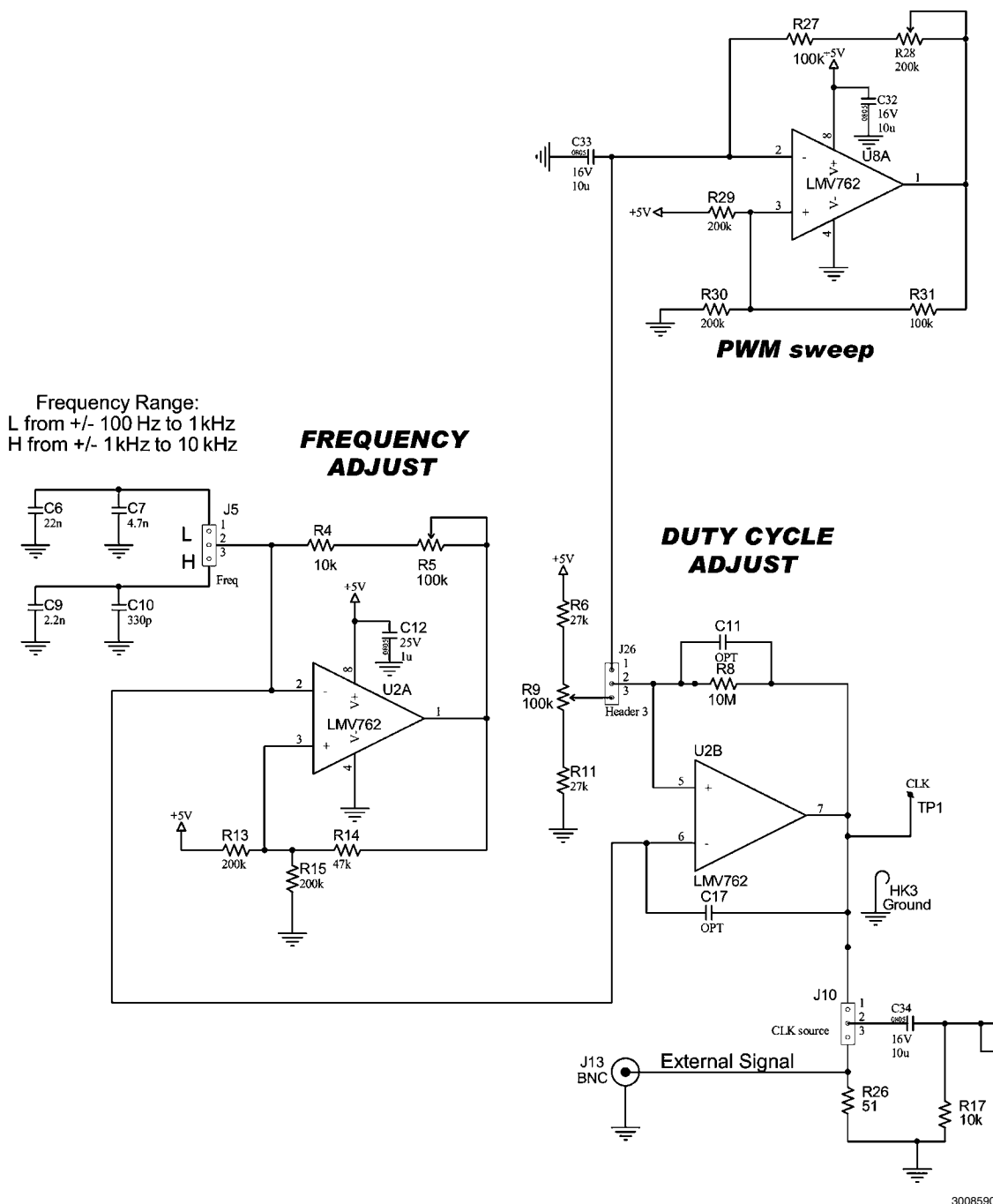
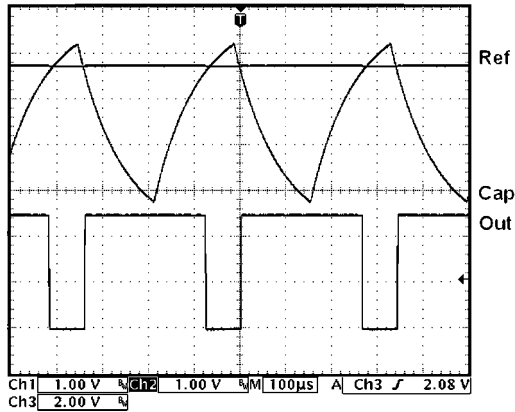


FIGURE 4. Schematic of the On Board Oscillator

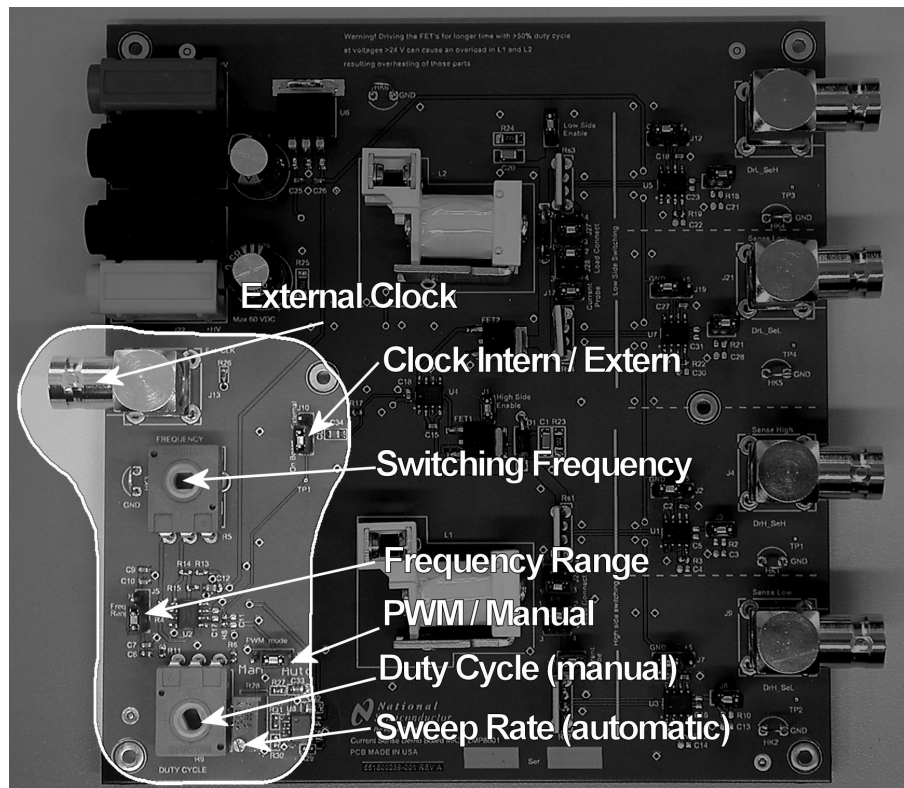
The on board oscillator is build around U2 a dual LMV762 Low voltage, Precision Comparator with Push Pull output. The Oscillator circuit consist of an a-stable multi vibrator build around U2A. This circuit generates a square wave voltage at the output of U2A and a saw tooth waveform at the capacitors at the (-)input. This capacitor voltage (Cap see figure Figure 5) is compared with an adjustable a reference voltage (Ref see figure Figure 5) in the comparator U2B. In this way the duty cycle of the output waveform of U2B can be controlled by varying the reference voltage at pin 5 of the comparator. Figure 5 shows the waveforms for this circuit.



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FIGURE 5. Oscillator Waveforms

#### Location Of The On Board Oscillator Controls



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FIGURE 6. Oscillator Controls

The automatic pulse width modulator sweep function is created by second low frequency oscillator (U8A) This circuit operates identical to the oscillator as described above with U2A.

With the jumper on J26 between pin 1 and 2, the reference voltage input for U2B which controls the duty cycle at the output of U2B is connected to C33. The signal at C33 is a slow varying sawtooth with a frequency below 1Hz. so in this configuration the pulse width of the oscillator is automatically swept up and down between about 10% and 90%.

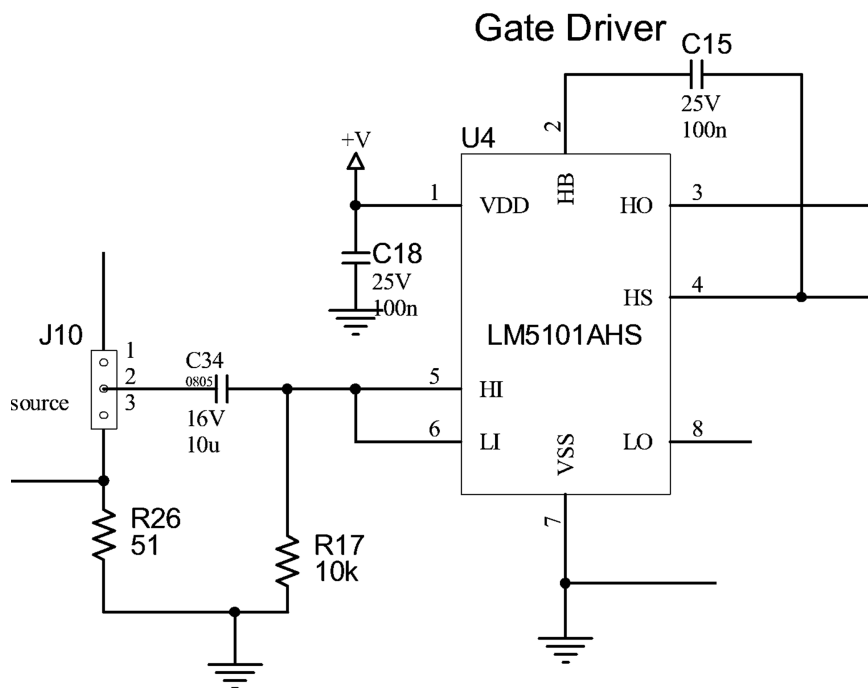
The sweep rate is controlled with R28

## FET DRIVER

The switching of the on board FET's is controlled with the LM5101 (U4). This is a high voltage gate driver that is designed to drive both the high side and the low side N-Channel MOSFETs in a synchronous buck or a half bridge configuration.

The Network C34, R17 driving the FET driver circuit U4 offers a protection when the clock signal is accidentally driven with

a constant 'high' level. This could burn out the inductors mounted on the PCB when the +HV supply is above 25V. With a steady 'high' drive signal the voltage over R17 will decay below the minimum high input level of the FET driver U4 and its output will go to the safe state where the FET's are switched off.



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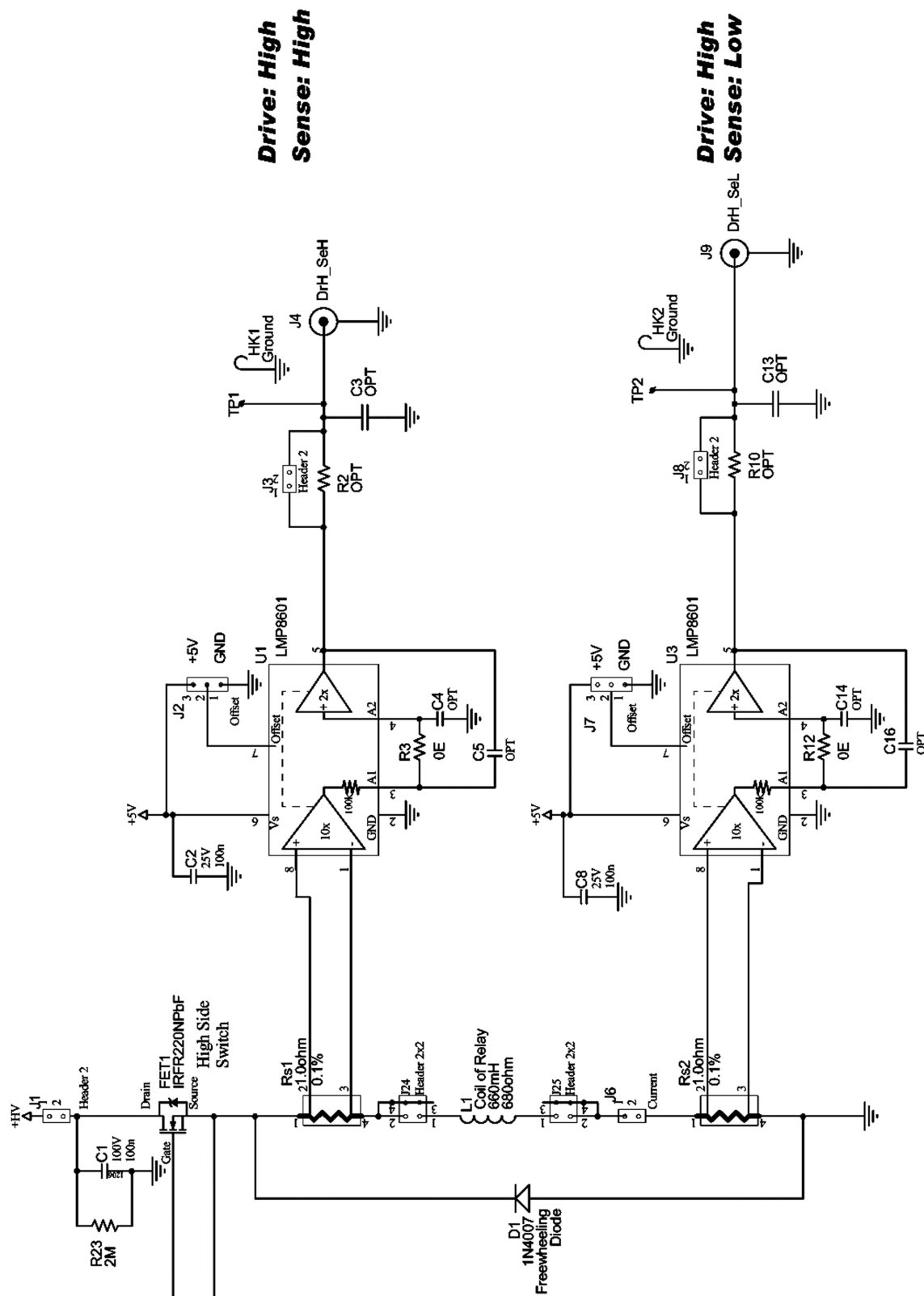
FIGURE 7. FET Driver Circuit

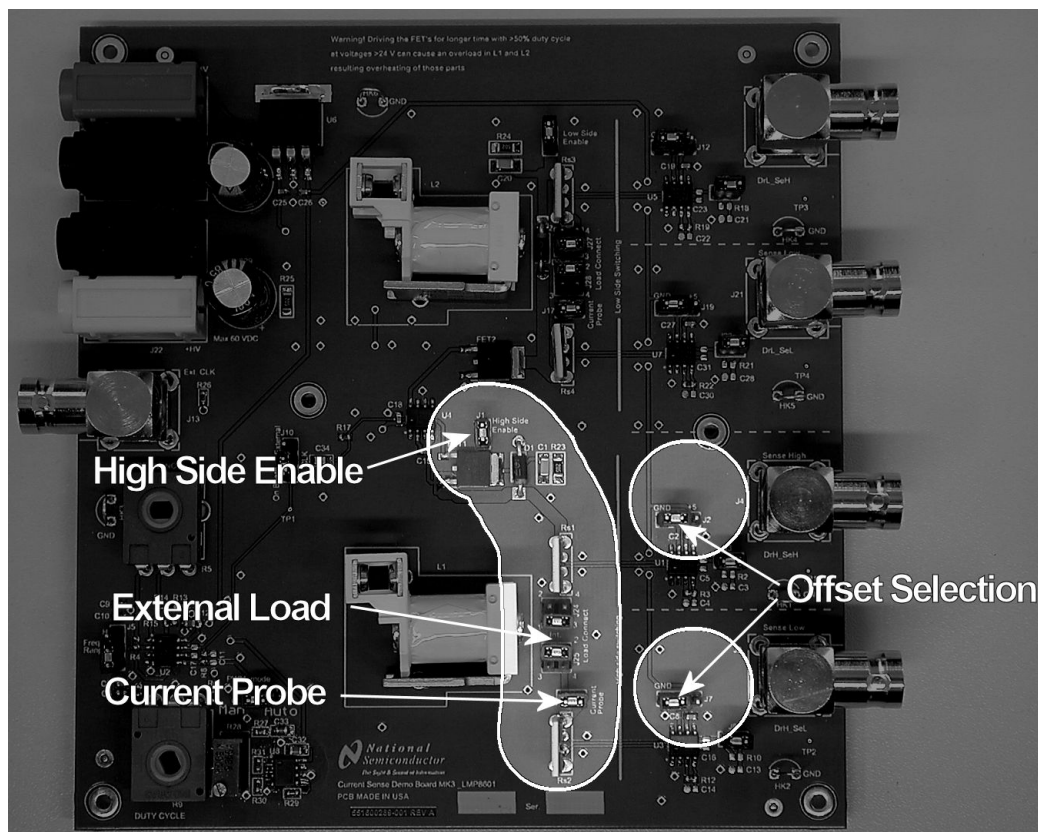
## HIGH SIDE SWITCHING APPLICATIONS

The Current Sense Amplifier Demo Board provides two example circuit applications where the load is switched with on and off with a FET. One is for an application where the load is connected to ground and the FET is switching the supply side of the load. In this circuit there are two current sense resistors provided connected to two LMP8601 amplifiers. One resistor RS1 is at the hot side of the load where large voltage transients will appear during switching of the FET. The other sensing resistor RS2 is connected in series with the ground side of the load.

The inductive load that is already mounted on the board is chosen such that the waveforms will match the targeted applications at a much lower current. It is possible to connect an of board load by removing the jumpers between pin 1 and 2 of headers J24 & J25 and placing a load between pin 2,3,4 of J24 and J25 for the high side switching circuit.

The impedance of this load must be such that all currents and voltages are within the safe ratings of the miscellaneous parts mounted on the demo board. (e.g. FET, Capacitors, Sense Resistors etc.)





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**FIGURE 9. Connectors and Jumpers for High Side Switching Application**

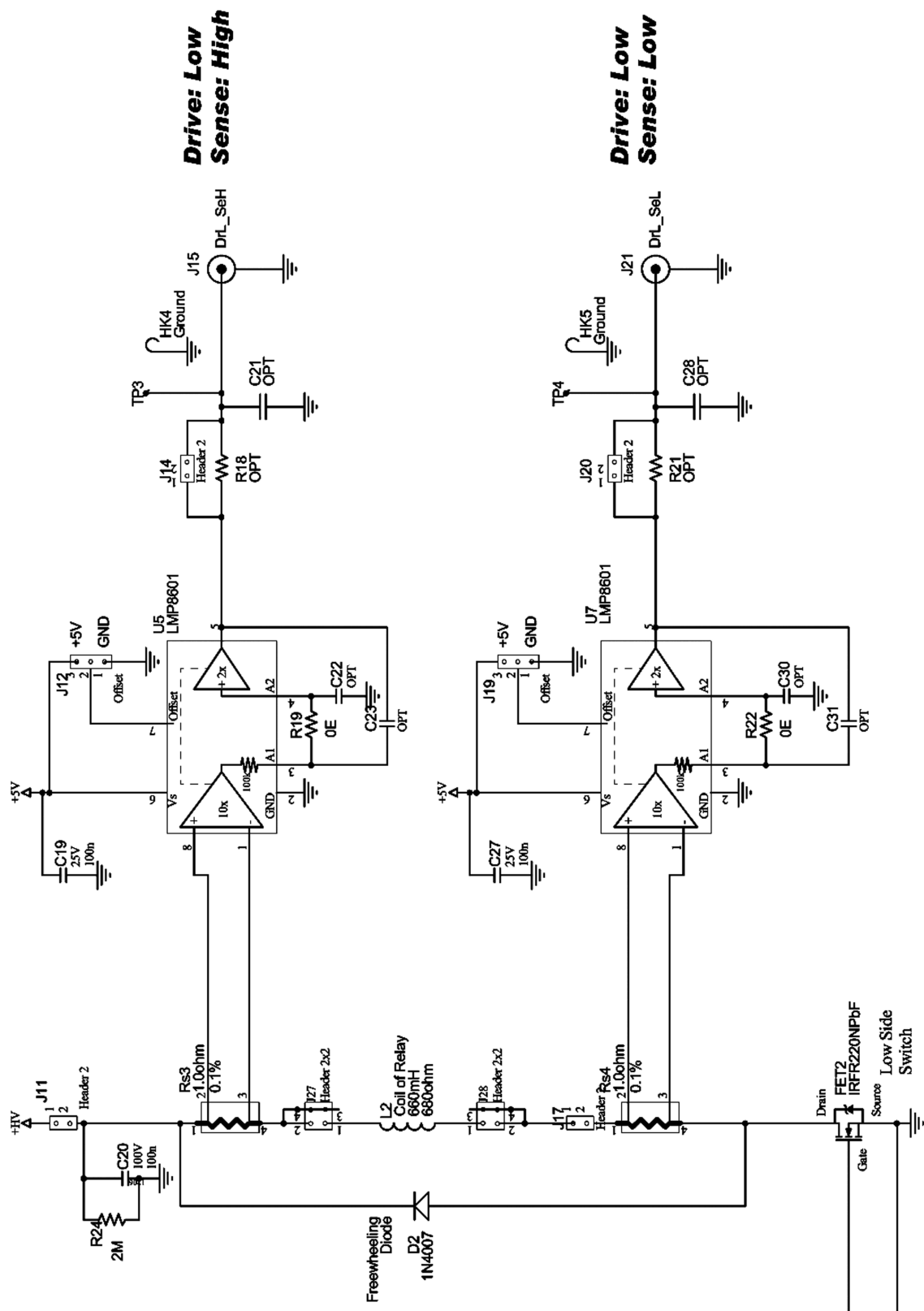
### LOW SIDE SWITCHING APPLICATIONS

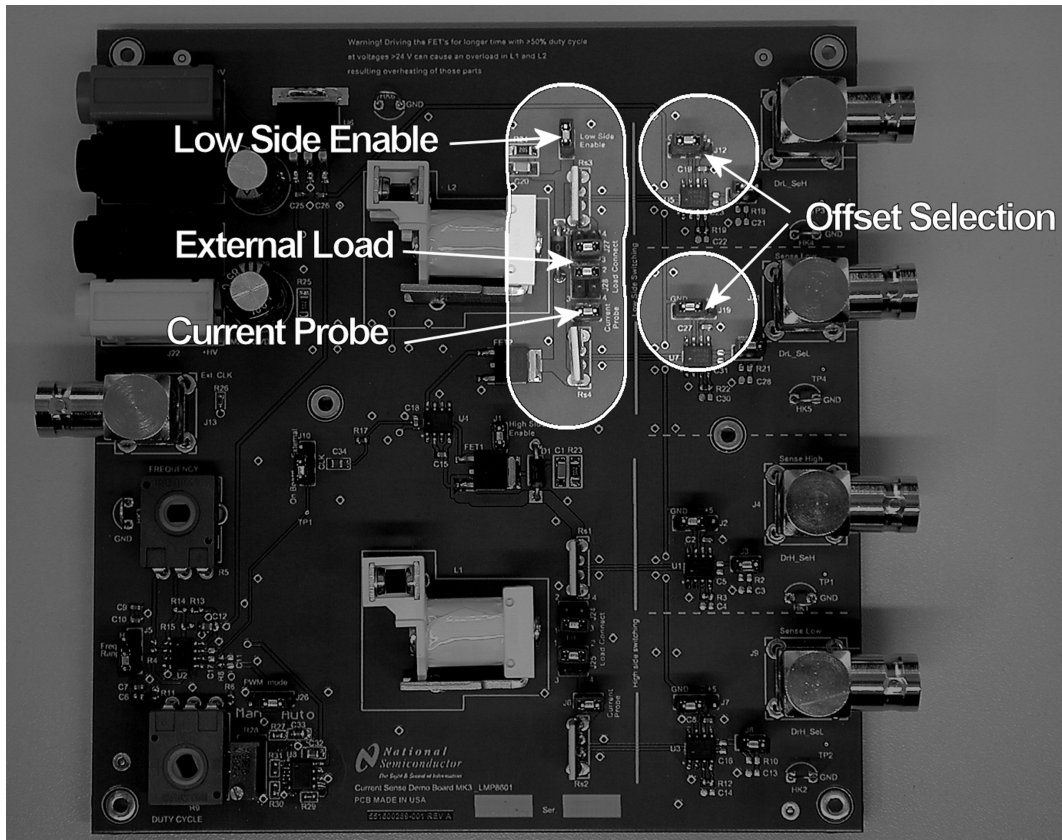
The low side switching application is a circuit where the load is connected to the +HV supply voltage and the FET is switching the low side of the load to GND. In this circuit there are two current sense resistors provided connected to two LMP8601 amplifiers. One resistor, RS3, is at the supply side of the load, while the second one, RS4, is at the low side of the load where large voltage transients will appear during switching of the FET.

The inductive load that is already mounted on the board is chosen such that the waveforms will match the targeted pri-

mary applications at a much lower current. It is possible to connect an off board load by removing the jumpers between pin 1 and 2 of headers J27 & J28 and placing a load between pin 2,3,4 of J27 and J28 for the high side switching circuit.

The impedance of this load must be such that all currents and voltages are within the safe ratings of the miscellaneous parts mounted on the demo board. (e.g. FET, Capacitors, Sense Resistors etc.)





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**FIGURE 11. Connectors and Jumpers for Low Side Switching Application**

## PCB Layout Guidelines

This section provides general practical guidelines for PCB layouts that use various power and ground traces. Designers should note that these are only "rule-of-thumb" recommendations and the actual results should be confirmed on the final layout.

### DIFFERENTIAL SIGNALS

Keep both signals coupled by routing them closely together and keep them of equal length. Keep all impedances in both

traces of the signal equal. Do not allow any other signal trace or ground between these differential traces

### POWER AND GROUND

Keep all ground returns close to the originating signals.

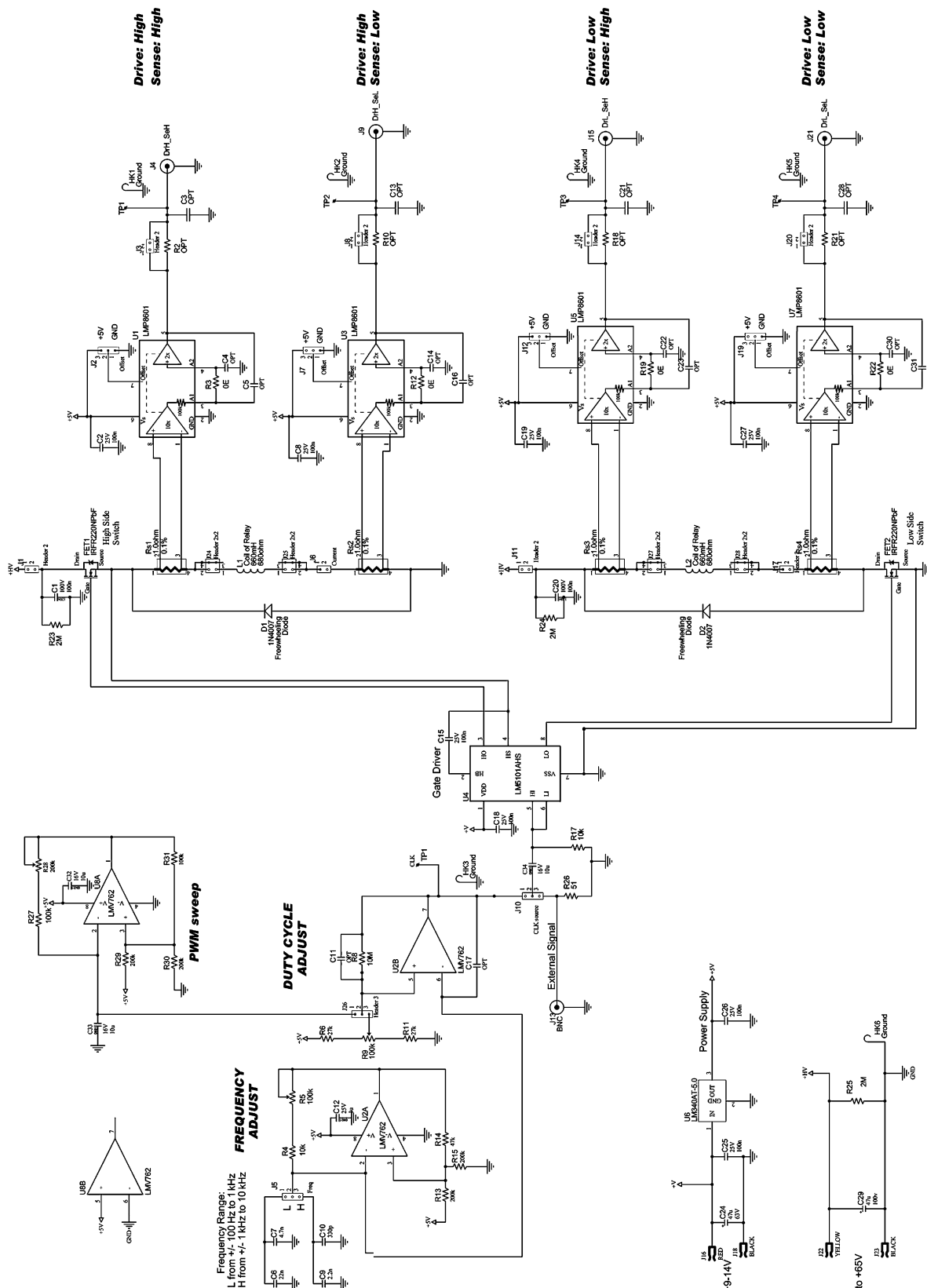
## Description of Headers and Connectors of the Current Sense Demo Board

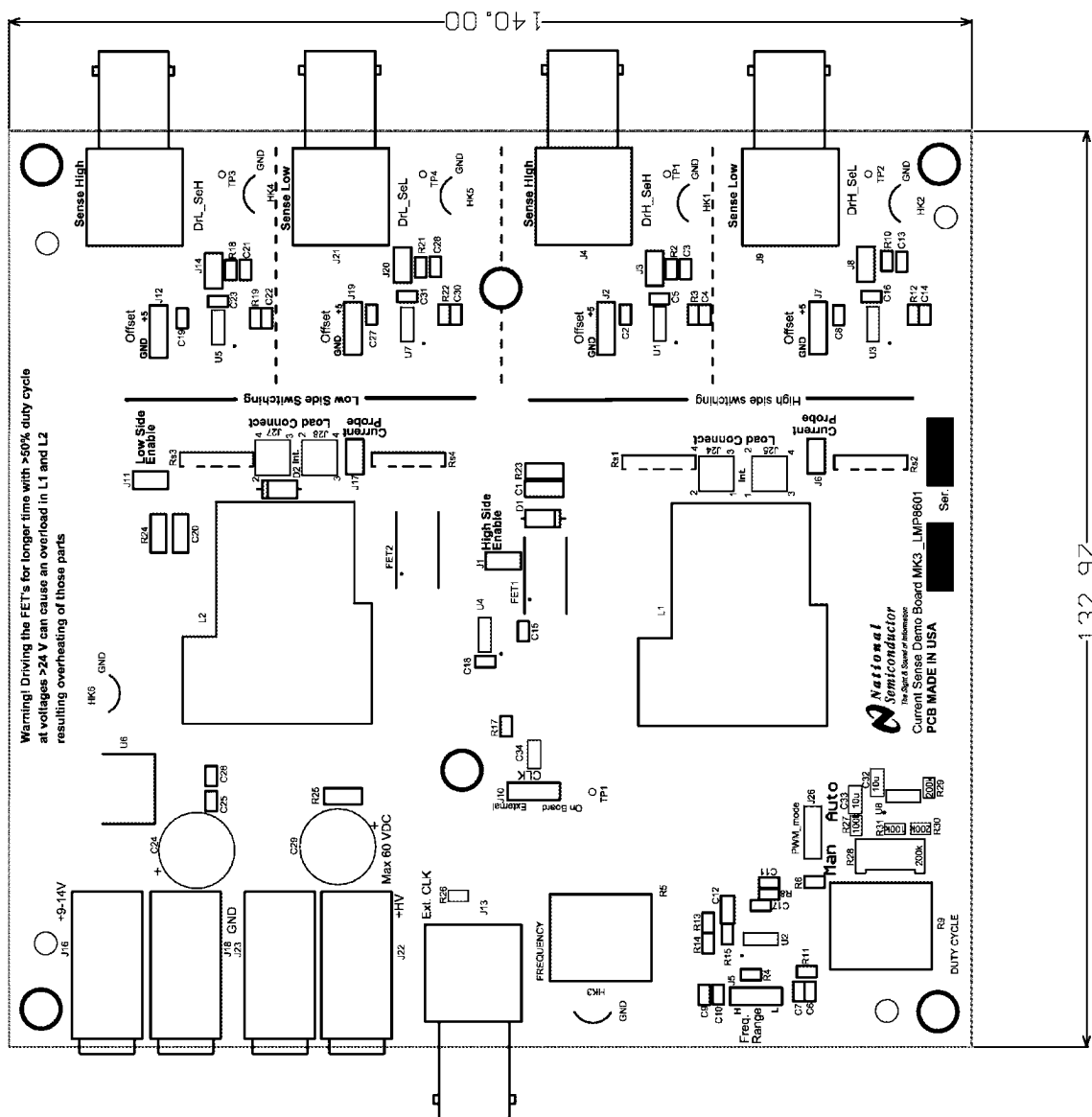
The Current Sense Demo Board provides many headers and connectors for connecting test equipment and controlling the settings of the board. The function that is controlled by the

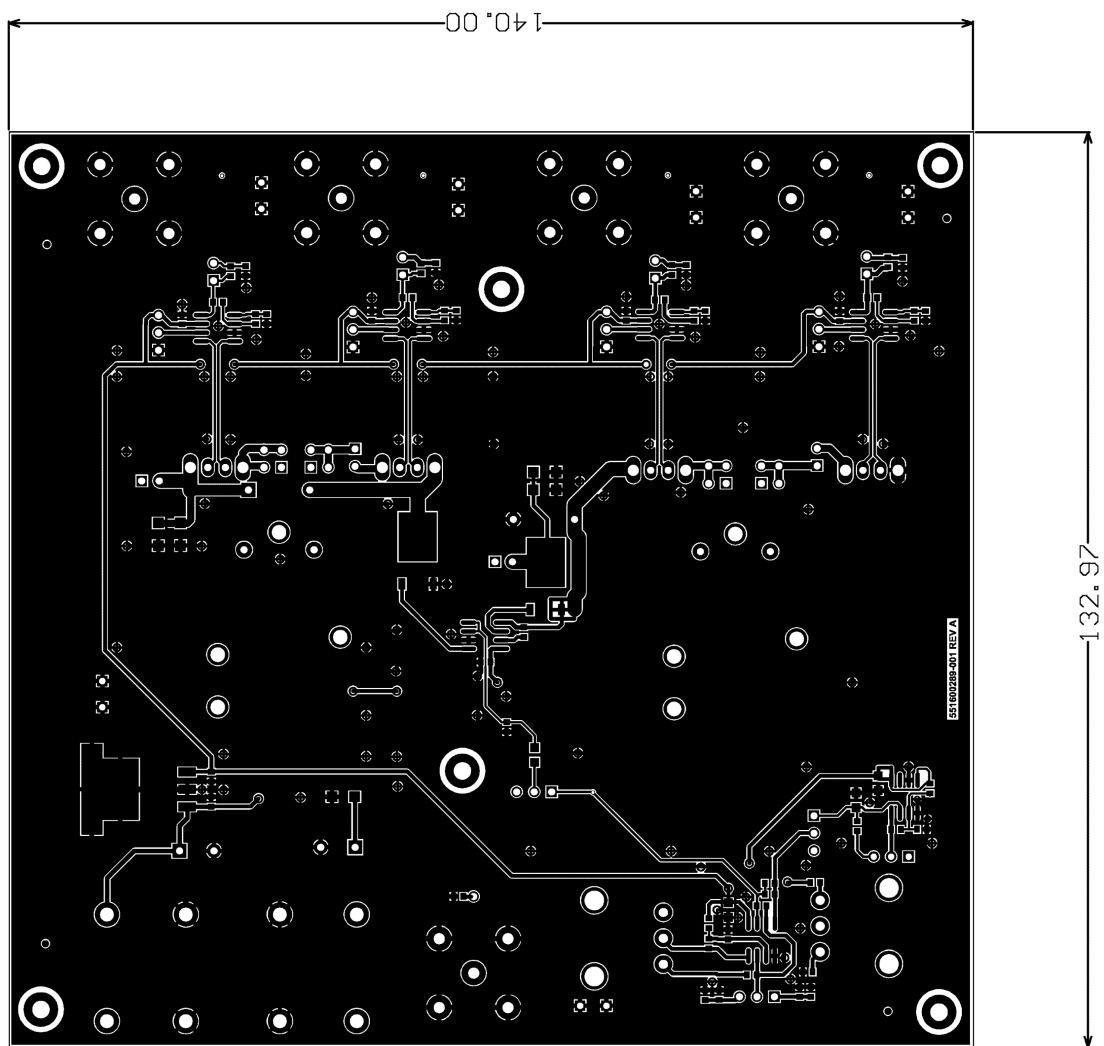
jumper on the Current Sense Demo Board (SOIC) is also indicated on the PCB in silk screen as shown in figure *Figure 12* (The name in parenthesis is as shown in the silk screen).

### Connector and Header Functions

Designator	Function or Use	Comment
J1	Enable High Side Switch load	Close to switch on
J2	Offset selection	1–2 Ground Referenced (unidirectional) 2–3 Mid rail offset (bi-directional)
J3,	Short for optional output filter	Normally shorted
J4	Output signal High sensing	connect to oscilloscope
J5	Selection of On board oscillator range	1–2 = 100Hz to 1 kHz 2–3 = 1 kHz to 10 kHz
J6	Header for connecting a current probe loop	Normally closed. Remove to connect current probe loop
J7	Offset selection	1–2 Ground Referenced (unidirectional) 2–3 Mid rail offset (bi-directional)
J8	Short for optional output filter	Normally shorted
J9	Output signal Low sensing	connect to oscilloscope
J10		
J11	Enable Low Side Switch load	Close to switch on
J12	Offset selection	1–2 Ground Referenced (unidirectional) 2–3 Mid rail offset (bi-directional)
J14,	Short for optional output filter	Normally shorted
J15	Output signal High sensing	connect to oscilloscope
J16	+ $V_{sup}$	Connect to + of 9–14V power supply
J17	Header for connecting a current probe loop	Normally closed. Remove to connect current probe loop
J18	GND ( $V_{sup}$ )	Connect to - of 9–14V power supply
J19	Offset selection	1–2 Ground Referenced (unidirectional) 2–3 Mid rail offset (bi-directional)
J20	Short for optional output filter	Normally shorted
J21	Output signal Low sensing	connect to oscilloscope
J22	+ ( $V_{HV}$ )	Connect to + of load power supply
J23	GND ( $V_{HV}$ )	Connect to - of load power supply
J24,J25	Load connect, high side switching	1–2 on board load External load between 2,3,4 of both headers
J26	PWM select	1–2 PWM mode 2–3 manual duty cycle control
J27,J28	Load connect, low side switching	1–2 on board load External load between 2,3,4 of both headers

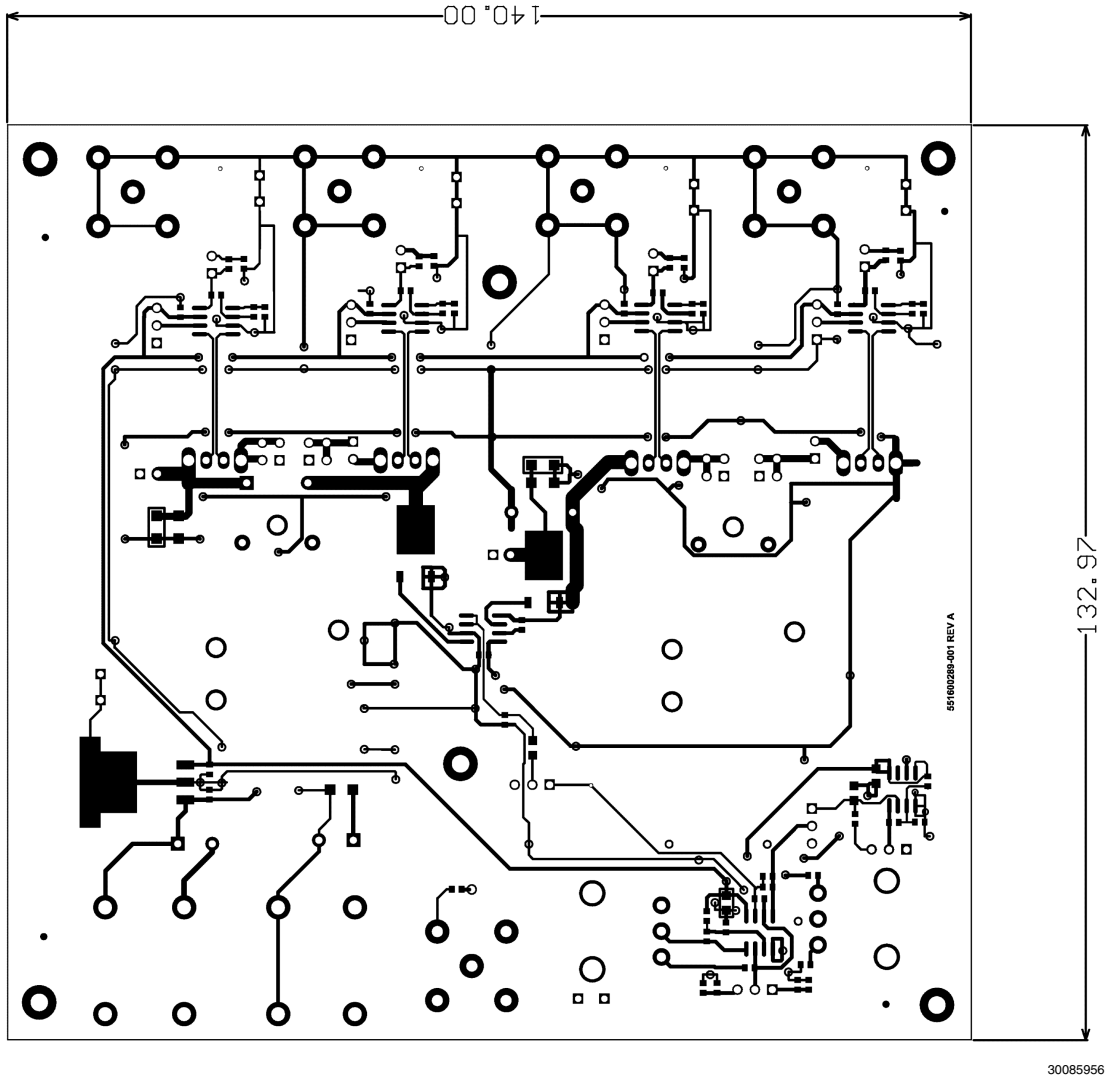






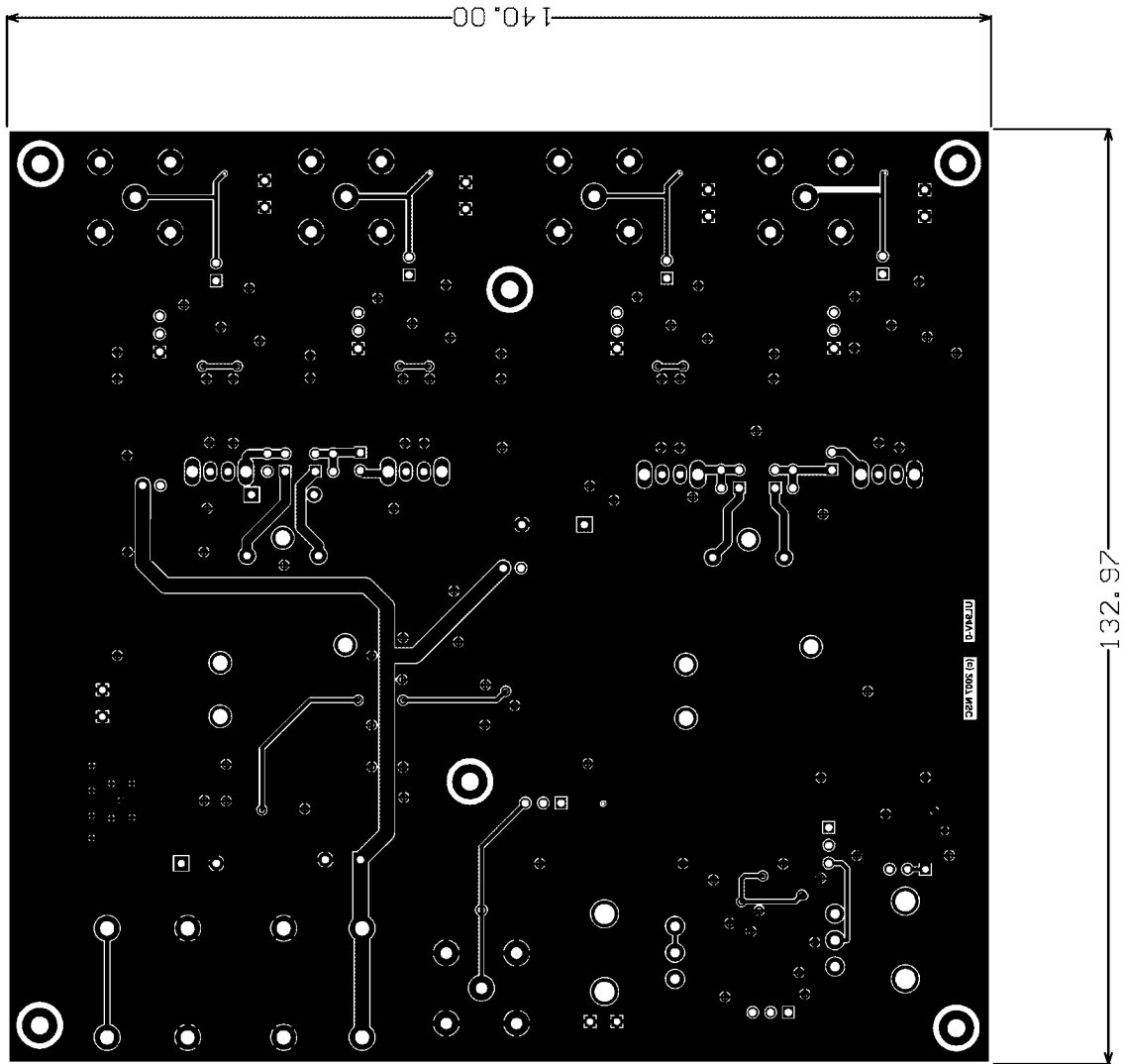
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FIGURE 13. Layout, Top Layer



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FIGURE 14. Layout, Top Layer, Traces No Copper Pour



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FIGURE 15. Layout, Bottom Layer

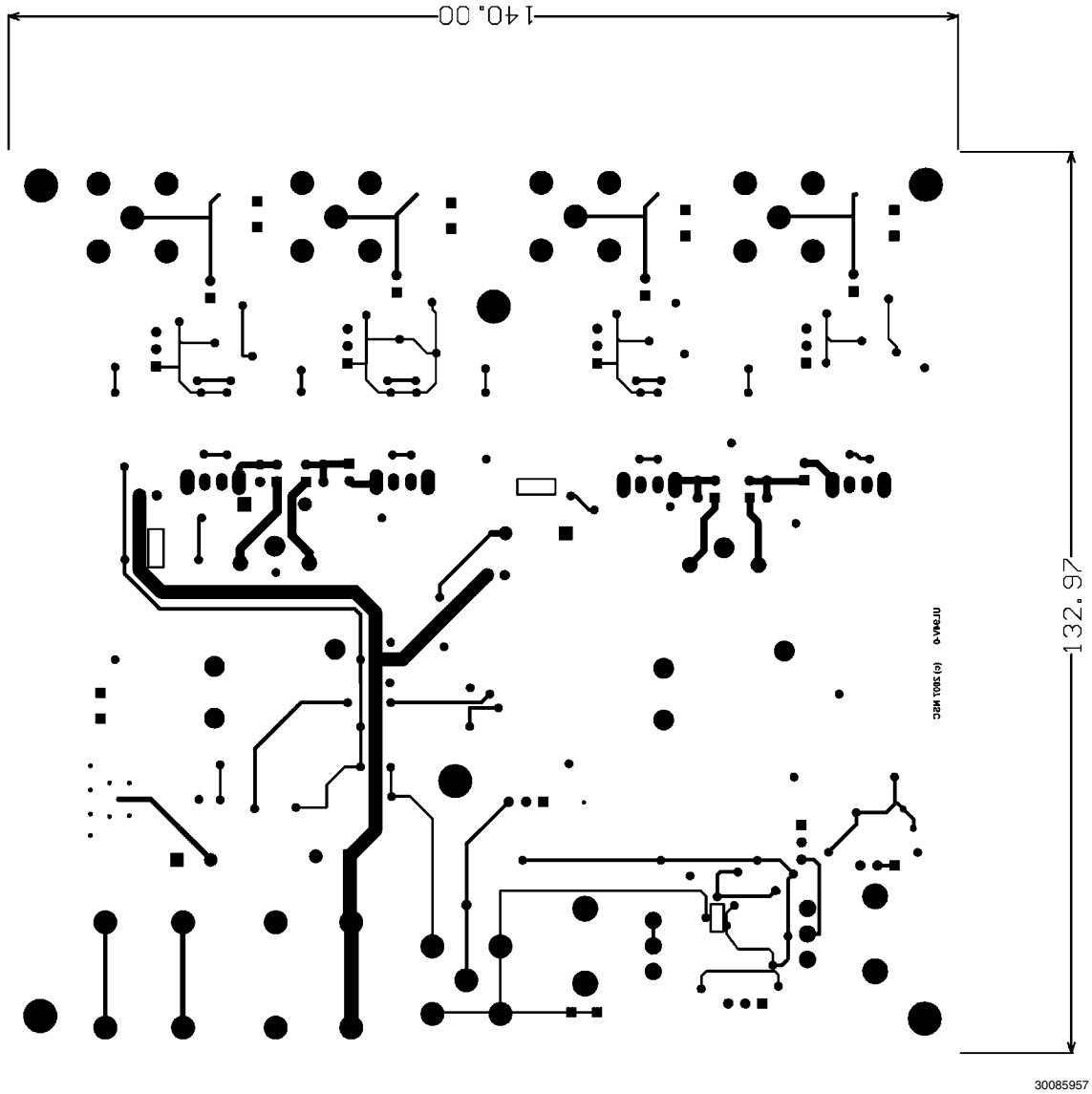


FIGURE 16. Layout, Bottom Layer, Traces No Copper Pour

## Notes

## Notes

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Interface	<a href="http://www.national.com/interface">www.national.com/interface</a>	Eval Boards	<a href="http://www.national.com/evalboards">www.national.com/evalboards</a>
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Power Management	<a href="http://www.national.com/power">www.national.com/power</a>	Green Compliance	<a href="http://www.national.com/quality/green">www.national.com/quality/green</a>
Switching Regulators	<a href="http://www.national.com/switchers">www.national.com/switchers</a>	Distributors	<a href="http://www.national.com/contacts">www.national.com/contacts</a>
LDOs	<a href="http://www.national.com/ldo">www.national.com/ldo</a>	Quality and Reliability	<a href="http://www.national.com/quality">www.national.com/quality</a>
LED Lighting	<a href="http://www.national.com/led">www.national.com/led</a>	Feedback/Support	<a href="http://www.national.com/feedback">www.national.com/feedback</a>
Voltage Reference	<a href="http://www.national.com/vref">www.national.com/vref</a>	Design Made Easy	<a href="http://www.national.com/easy">www.national.com/easy</a>
PowerWise® Solutions	<a href="http://www.national.com/powerwise">www.national.com/powerwise</a>	Solutions	<a href="http://www.national.com/solutions">www.national.com/solutions</a>
Serial Digital Interface (SDI)	<a href="http://www.national.com/sdi">www.national.com/sdi</a>	Mil/Aero	<a href="http://www.national.com/milaero">www.national.com/milaero</a>
Temperature Sensors	<a href="http://www.national.com/tempsensors">www.national.com/tempsensors</a>	SolarMagic™	<a href="http://www.national.com/solarmagic">www.national.com/solarmagic</a>
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