User's Guide

LMP8646EB – Nov. 2011 – Revised Nov. 2011

LMP8646EB

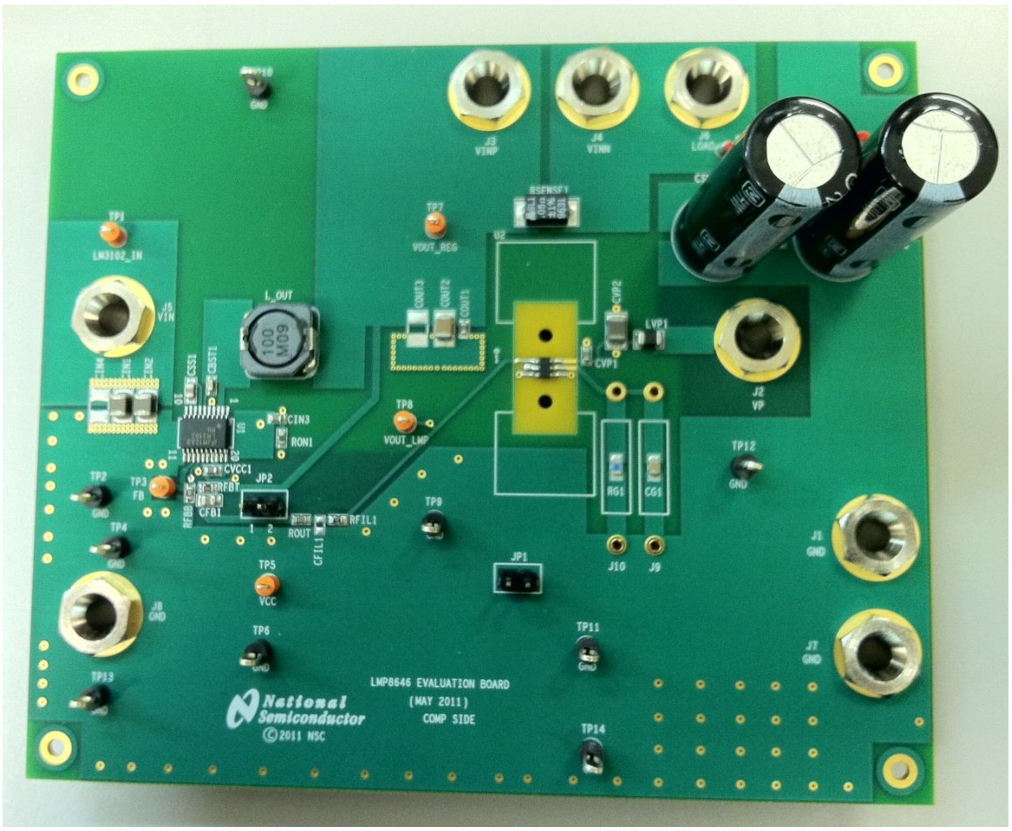

Figure 1 – LMP8646EB

The LMP8646 Evaluation Board (LMP8646EB) is designed to ease evaluation and design-in of Texas Instruments' LMP8646, a Precision Current Limiter. The LMP8646 is used to detect small differential voltages across a sense resistor in the presence of high input common mode voltages. On board with the current limiter is the LM3102, a Step Down Switching Regulator that is capable of supplying 2.5A to loads. This document describes super cap and resistive load applications utilizing the LM3102 voltage regulator and the LMP8646 precision current limiter. The document also provides the schematic, layout, and BOM for the LMP8646 evaluation board.

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1. EVM Overview

1.1. List of Features

The LMP8646 evaluation board consists of:

1. The LMP8646 precision current limiter and its supporting circuitries
2. Two super capacitors for the load
3. LM3102 voltage regulator and its circuitries
4. Sense resistor of 50 mOhm.

1.2. Equipment

1. LMP8646 evaluation board (NSID: LMP8646EB)
2. 2 Power supplies to source LM3102's VIN and LMP8646's V+
3. Multimeter
4. Oscilloscope
5. Current probe

1.3. Additional Resources

1. LM3102 Datasheet located at http://www.ti.com/product/lm3102
2. LM3102 Evaluation Board App Note located at http://www.ti.com/lit/snva248

2. Quick Start: Supercap Application

A supercap application requires a very high capacitive load to be charged. This example assumes the output capacitor is 3.3F with a limited load current at 1.5A. The LM3102 will provide the current to charge the supercap, and the LMP8646 will monitor this current to make sure it does not exceed the desired 1.5A value.

This is done by connecting the LMP8646 output to the feedback pin of the LM3102, as shown in **Figure 1**. This feedback voltage at the FB pin is compared to a 0.8V internal reference. Any voltage above this 0.8V means the output current is above the desired value of 1.5A, and the LM3102 will reduce its output current to maintain the desired 0.8V at the FB pin.

The following steps show the design procedures for this supercap application. The first step is to select the discrete components for the LM3102 by following the design steps described in its application note. Next, integrate the LMP8646 into the system and select the proper values for its gain, bandwidth, and output resistor. Lastly, capture the results and adjust the components to yield the desired performance.

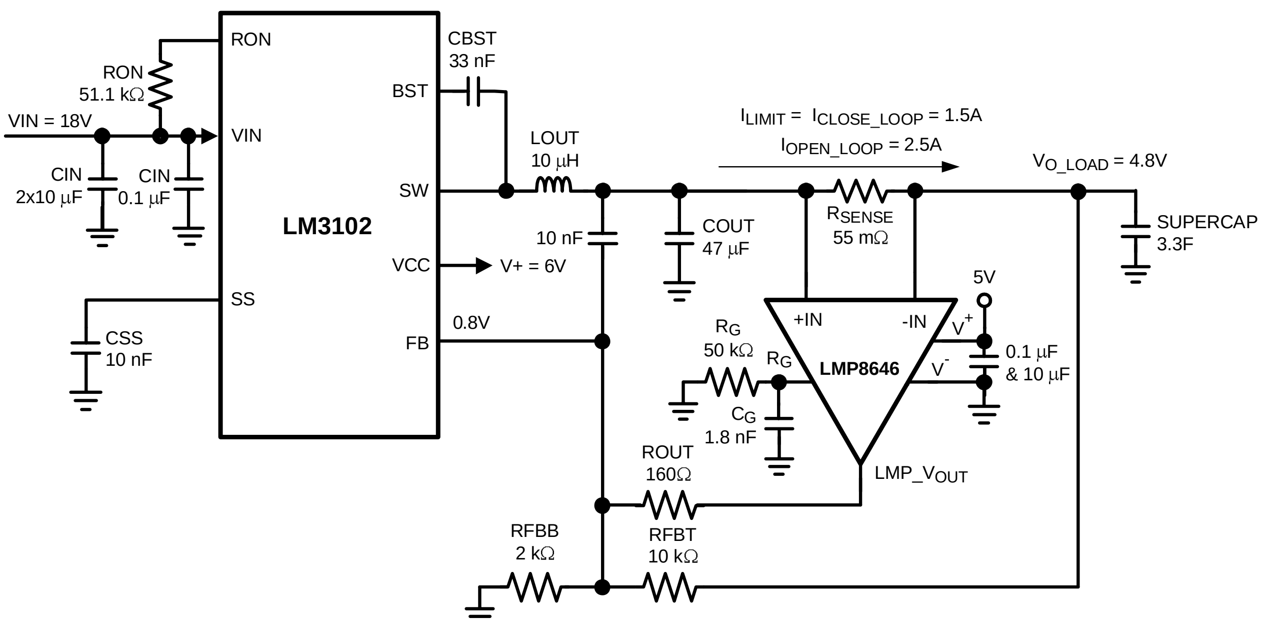

Figure 2 – Schematic for the SuperCap Application

1. **Step 1: Choose Components for the LM3102**

   Refer to the LM3102 evaluation board app note (AN-1646) located at http://www.ti.com/lit/snva248 to choose the appropriate components for the LM3102.

2. **Step 2: Choose the gain resistor, Rg, for LMP8646**

   If Rsense = 55 mOhm, then use the equation below to calculate the appropriate gain resistor, R_G, for an output current of 1.5A.

$$V_{OUT} = (R_{SENSE} I_{LIMIT})(Gain)$$
$$where\ Gain = \frac{R_G}{1/transconductance} = \frac{R_G}{1/200\mu A/V} = \frac{R_G}{5kOhm}$$
$$R_G = \frac{V_{OUT}\, 5kOhm}{R_{SENSE} I_{LIMIT}}$$
$$R_G = \frac{(0.8V)(5kOhm)}{(55\,mOhm)(1.5A)}$$
$$R_G \approx 50\,kOhm$$

Note: Refer to the "Selection of the Sense Resistor, R_{SENSE}" section of the LMP8646 datasheet to select your own R_{SENSE} if 55 mOhm is not desired.

3. **Step 3: Choose the Bandwidth Capacitance, C_G.**

The product of C_G and R_G determines the bandwidth for the LMP8646. Refer to the Typical Performance Characteristics plots of the LMP8646 datasheet to see the range for the LMP8646 bandwidth and gain. Since each application is very unique, the LMP8646 bandwidth capacitance, C_G, needs to be adjusted to fit the appropriate application.

Bench data has been collected for the supercap application with the LM3102 regulator. We found that this application works best for a bandwidth of 500 Hz to 3 kHz. Operating outside of this recommended bandwidth range might create an undesirable load current ringing. We recommend choosing a bandwidth that is in the middle of this range and using the following equation to find C_G:

$$Cg = \frac{1}{2\pi(R_G)(Bandwidth)}$$
$$Cg = \frac{1}{2\pi(50\,kOhm)(1.75\,kHz)}$$
$$Cg = 1.8\,nF$$

Once C_G is chosen, capture the output regulator current plot and adjust C_G to get the desired value. If adjusting C_G isn't enough, we also recommend adjusting the regulator's C_{OUT} to reduce the current ringing. We found that this application works best for a C_{OUT} value of 47 μF.

4. **Step 4: Calculate the Output Accuracy and Choose a Tolerable System Error**

Since the LMP8646 is a precision current limiter, the output current accuracy is extremely important. This accuracy is affected by the system error contributed by the LMP8646 device error and other errors contributed by the regulator and external resistances, such as R_{SENSE} and R_G. However, we cannot control for external errors, but we can predict the LMP8646 device error using the following equations:

$$\text{Output Accuracy} = \left|\frac{V_{OUT\_THEO} - V_{OUT\_CAL}}{V_{OUT\_THEO}}\right| \text{ x } 100(\%)$$

$$\text{where } V_{OUT\_THEO} = (V_{SENSE}) \text{ x } \frac{R_G}{1/Gm}$$

$$\text{and } V_{OUT\_CALC} = \frac{(V_{SENSE} + V_{OFFSET}) \text{ x } R_G}{1/[Gm\ (1 + Gm\_Accuracy)]}$$

a) Using the formula above, calculate for the LMP8646 output accuracy knowing that V_{SENSE} = (1.5A)(55 mOhm), R_G = 50 kOhm, V_{OFFSET} = 1 mV, and Gm_Accuracy = 2% (LMP8646 datasheet, electrical characteristics table).

$$V_{OUT\_THEO} = (1.5A)(55mOhm)\frac{50kOhm}{1/200\mu V} = 0.825V$$

$$V_{OUT\_CALC} = \frac{[(1.5A)(55mOhm) + 100mV](50kOhm)}{1/[200\mu V(1 + 2/100)]} = 0.852V$$

$$Output\ \ Accuracy = \left|\frac{0.825 - 0.852}{0.825}\right| x100 = 3.27\%$$

b) After figuring out the LMP8646 output accuracy, choose a tolerable system error or the output current accuracy that is bigger than the LMP8646 output accuracy. This tolerable system error will be labeled as I_{ERROR}, which has the equation I_{ERROR} = (I_{MAX} – I_{LIMIT})/I_{MAX} (%). In this example, we can choose I_{ERROR} = 5%. This value will be used to calculate for ROUT in the next step.

5. Step 5: Choose the output resistor, ROUT, for LMP8646

At startup, the capacitor is not charged yet and thus the output voltage of the LM3102 is very small ($V_{O\_3102\_MIN}$, see Figure 3). Therefore, at this point, the output current is at its maximum (I_{MAX}). When the output voltage is at its nominal, then the output current will settle to the desired target value. Because a large current error is not desired, ROUT needs to be chosen to stabilize the loop with minimal initial startup current error. Follow the equations and example below to choose the appropriate value for ROUT to minimize this initial error.

a) Target current I_{LIMIT}= 1.5A
In the previous example, we chose the maximum tolerable system error I_{ERROR} as 5%.
Now, let's calculate the maximum tolerable current, Imax:

$$I_{\max} = I_{LIMIT}(1 + I_{ERROR})$$

$$I_{\max} = (1.5A)\left(1 + \frac{5}{100}\right) = 1.575A$$

b) Calculate for ROUT, assuming that the minimum output voltage for the LM3102 is 0.6V (see figure 3).

$$I_{RFBB} = I_{RFBT} + I_{ROUT}$$

$$\frac{V_{FB}}{RFBB} = \frac{(V_{O\_3102\_min} - V_{FB})}{RFBT} + \frac{(V_{O\_8646} - V_{FB})}{ROUT}$$

$$\frac{V_{FB}}{RFBB} = \frac{(V_{O\_3102\_min} - V_{FB})}{RFBT} + \frac{(I_{max} R_{SENSE} G_{ain} - V_{FB})}{ROUT}$$

$$\frac{(I_{max} R_{SENSE} G_{ain} - V_{FB})}{ROUT} = \frac{V_{FB}}{RFBB} - \frac{(V_{O\_3102\_min} - V_{FB})}{RFBT}$$

$$ROUT = \frac{(I_{max} R_{SENSE} G_{ain} - V_{FB})}{\frac{V_{FB}}{RFBB} - \frac{(V_{O\_3102\_min} - V_{FB})}{RFBT}}$$

$$ROUT = \frac{[(1.575)(55mOhm)(10) - 0.8]}{\frac{0.8}{2k} - \frac{(0.6 - 0.8)}{10k}}$$

$$RFB3 = 157.74 \approx 160 \ ohm$$

This equation provides an initial value for ROUT. To get the desired results, ROUT should be adjusted. We recommend having an ROUT value of at least 50 ohm.

6. **Step 6: Adjusting Components –** capture the output current and output voltage plots and adjust the components as necessary. The most common components to adjust are Cg to minimize the current ripple and ROUT to decrease the current error.

   A plot for the load current (black), output voltage of the LM3102 (blue), voltage the feedback pin of the LM3102 (red), and switch frequency of the LM3102 (green), can be seen in figure 3.

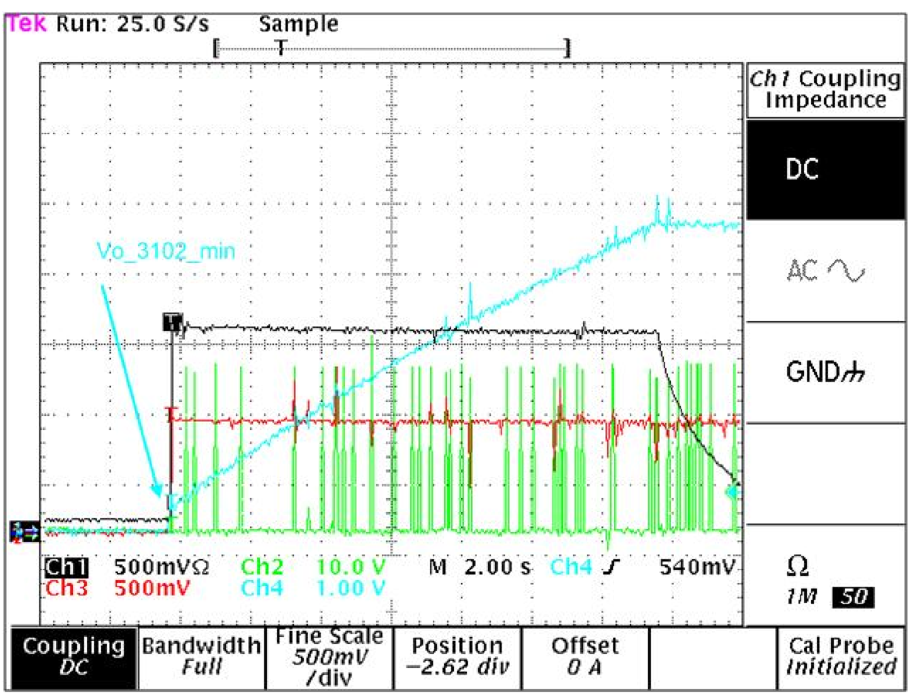

Figure 3 – Plot for the SuperCap Application

3. Quick Start: Resistive Load Application

Now, let's look at the design process for a resistive load application as seen in Figure 4. To see the current limiting capability of the LMP8646, the open-loop current must be greater than the close-loop current. An open-loop occurs when the LMP8646 output is not connected the LM3102's feedback pin. For this example, we will let the open-loop current to be 1.5A and the close-loop current, I_{LIMIT}, to be 1A.

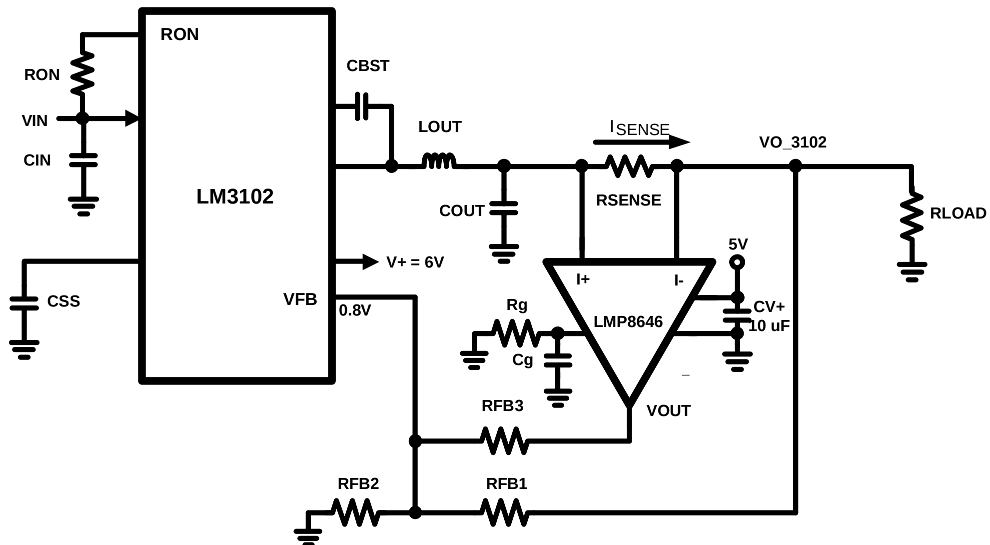

Figure 4 – Schematic for the Resistive Load Application

1. **Design Parameters:**
   - **a.** VIN_3102 = 8V to 42V, typical 18V
   - **b.** Vout_3102 = 3V
   - **c.** Rsense = 55 mOhm
   - **d.** Load resistance = 2 Ohm

2. **Step 1: Choose Components for the LM3102**

   Refer to the LM3102 evaluation board app note (AN-1646) located at http://www.ti.com/lit/snva248 to choose the appropriate components for the LM3102. For this application, we recommend increasing the input capacitance to 67 uF.

   For this example, the following LM3102 components are recommended:

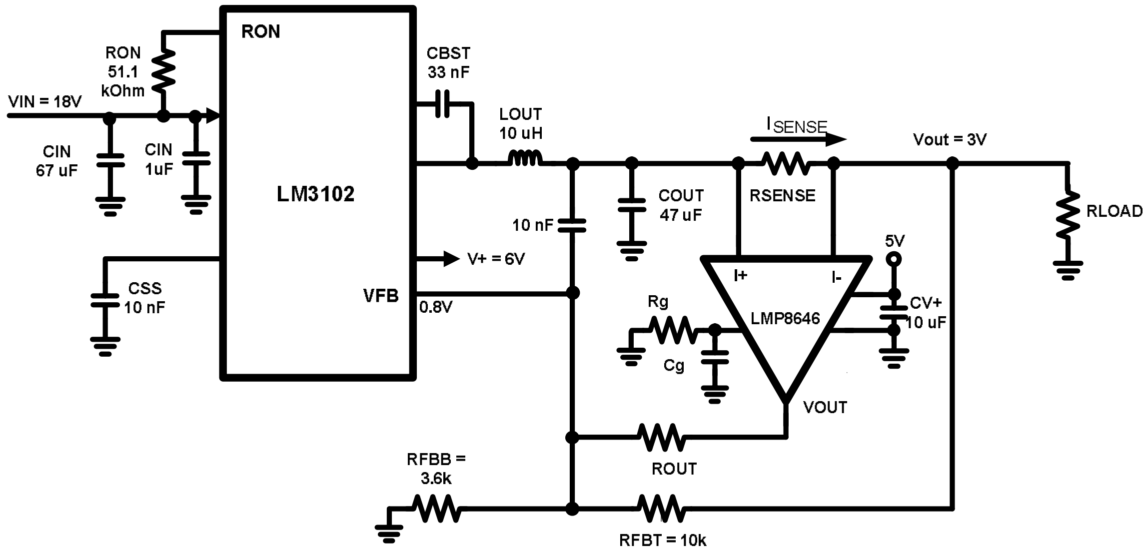

Figure 5 – Recommended Components for the LM3102

3. Step 2: Choose the gain resistor, Rg, for LMP8646

If Rsense = 55 mOhm, then use the equation below to calculate for the appropriate gain resistor, Rg, for a close-loop output current of 1A.

$$VFB = (I_{LIMIT})(R_{SENSE})(Gain_{LMP8646})$$

$$where\ Gain = \frac{R_G}{1/transconductance} = \frac{R_G}{1/200\mu A/V} = \frac{R_G}{5kOhm}$$

$$VFB = (I_{LIMIT})(R_{SENSE})\left(\frac{Rg}{5kOhm}\right)$$

$$Rg = \frac{(VFB)(5k)}{(I_{LIMIT})(R_{SENSE})}$$

$$Rg = \frac{(0.8V)(5k)}{(1A)(55mOhm)}$$

$$Rg = 73k\ Ohm$$

4. Step 3: Choose the Bandwidth Capacitance, Cg.

The product of Cg and Rg determines the bandwidth for the LMP8646. Because each application is very unique, the LMP8646 gain capacitance, Cg, needs to be adjusted to fit the appropriate application.

Bench data has been collected for the resistive load application. We found that this application works best for a bandwidth between 2 kHz to 30 kHz. If the bandwidth is not large enough, the LMP8646 will take a longer time to limit the output current.

For example, if Rg = 73 kOhm and the chosen bandwidth is 2 kHz, then the initial Cg value can be calculated as:

$$Cg = \frac{1}{2\pi(Rg)(Bandwidth)}$$

$$Cg = \frac{1}{2\pi(73\,kOhm)(2k\ Hz)}$$

$$Cg = 0.109\,nF$$

Once Cg is chosen, capture the output regulator current plot and adjust Cg to get the desired value.

5. **Step 4: Choose the output resistor, ROUT, for LMP8646**

For the resistive load application, we found that ROUT plays a very small role in the performance. ROUT was important in the supercap application because it affects the initial current error. Because current is directly proportional to voltage for a resistive load, the output current is not large at startup. In fact, the larger the ROUT, the longer it takes for the output voltage to reach its final value. In our example, we chose a value of 2 kOhm for ROUT.

6. **Step 5: Adjusting Components –** capture the output current and output voltage plots and adjust the components as necessary. The most common component to adjust is Cg for the bandwidth.

A plot for the load current (yellow), output voltage of the LM3102 (pink) can be seen in Figure 6.

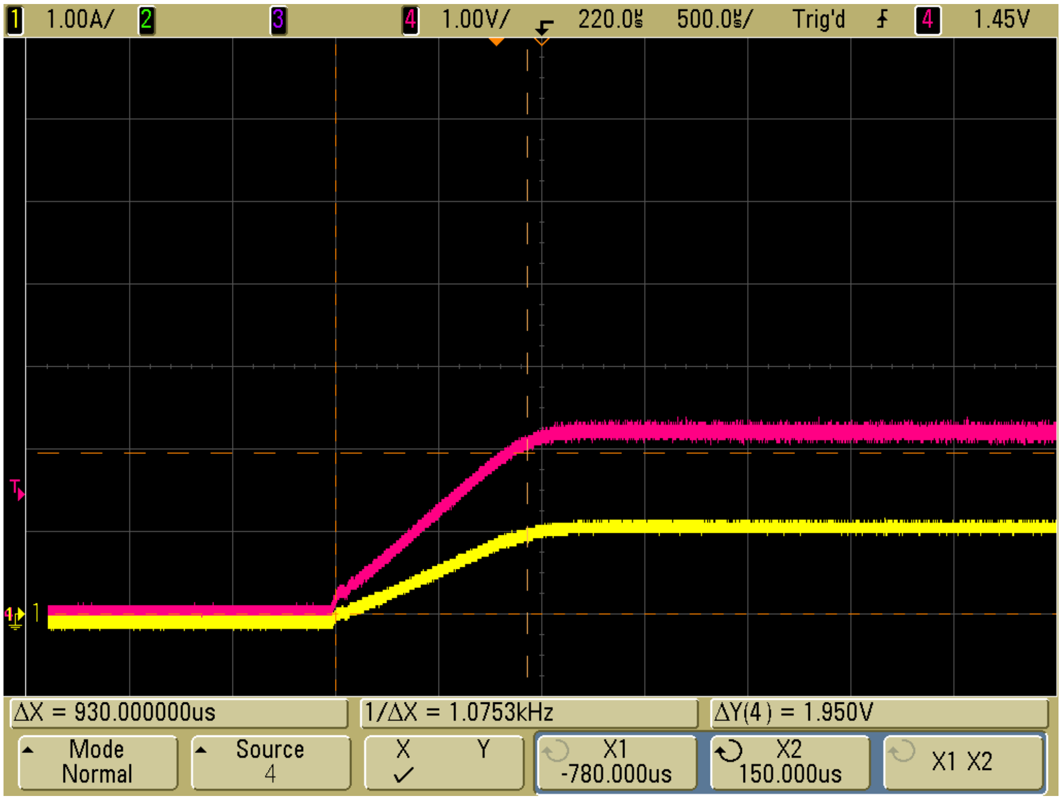

Figure 6 – Plots for the Resistive Load Application

4. Powering the LMP8646EB

Source V+ with an external voltage between 3.3V and 12V. Do this by connecting the external source to banana connector J2, VP, and J1, GND.

To activate the LM3102, source its VIN with external voltage of 4.5V to 42V. This can be done by connecting the external source to J5, VIN, and J8, GND.

5. Schematic

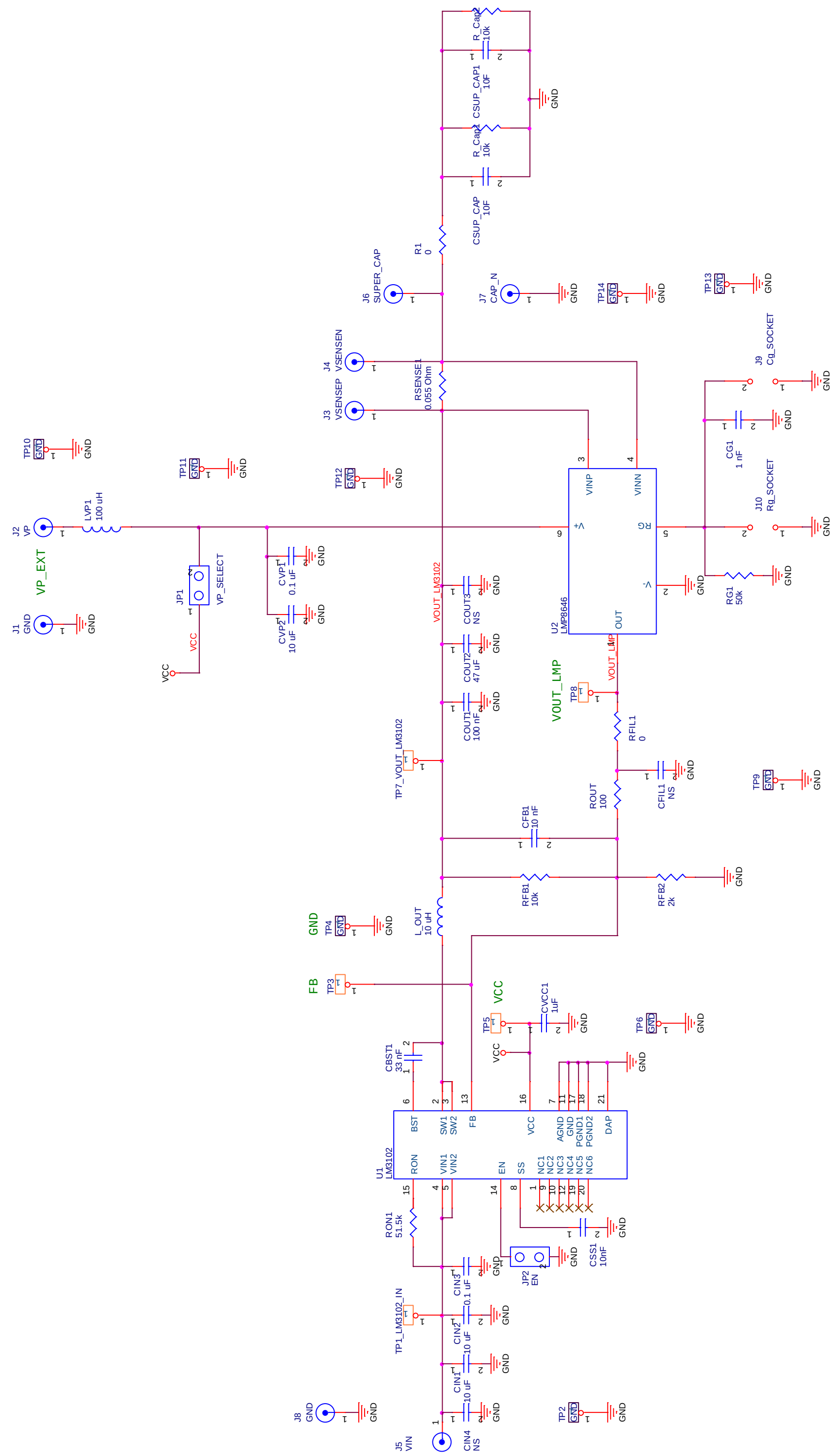

Figure 7 – Schematic

6. Layout

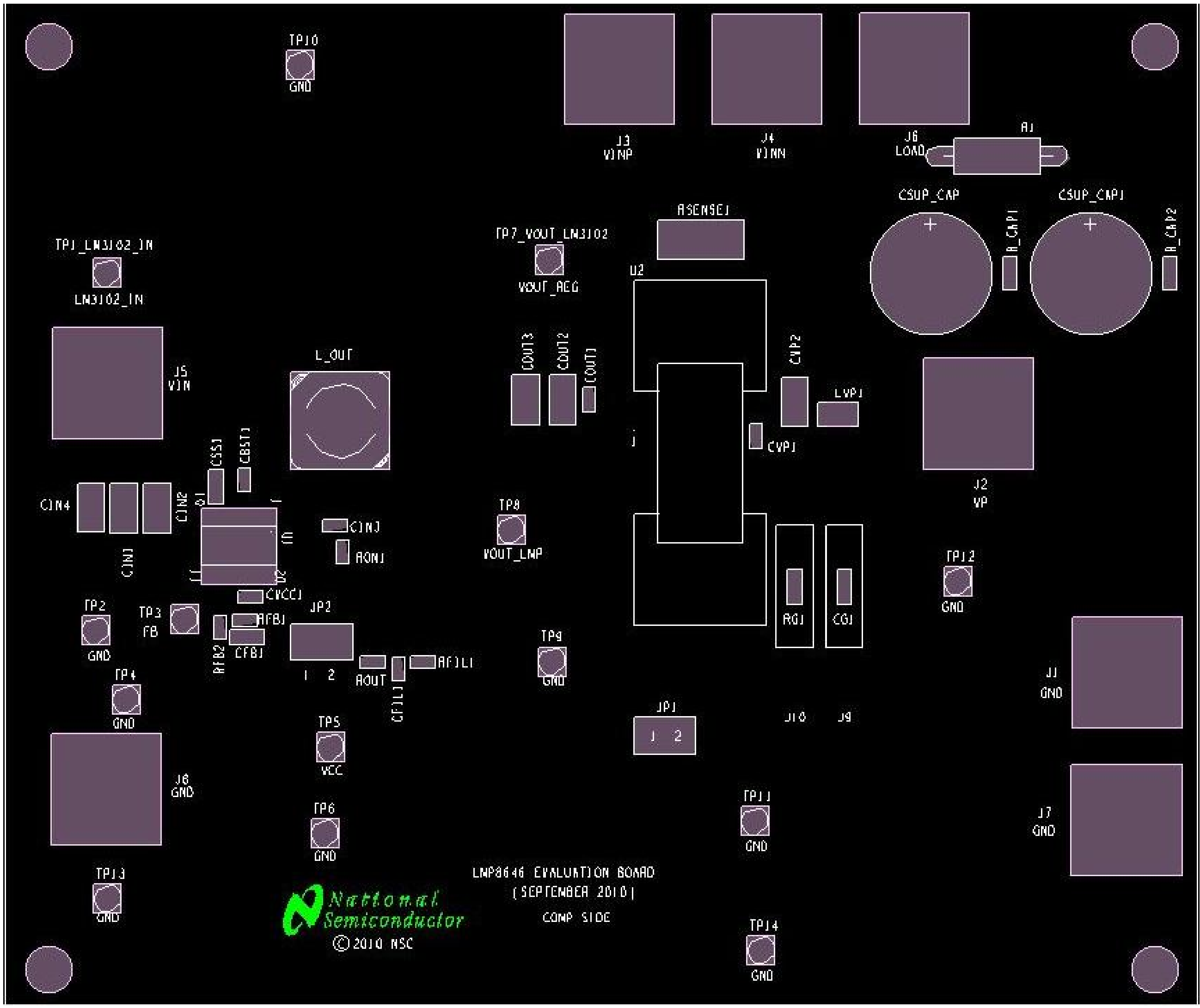

Figure 8 - Layout Top Layer

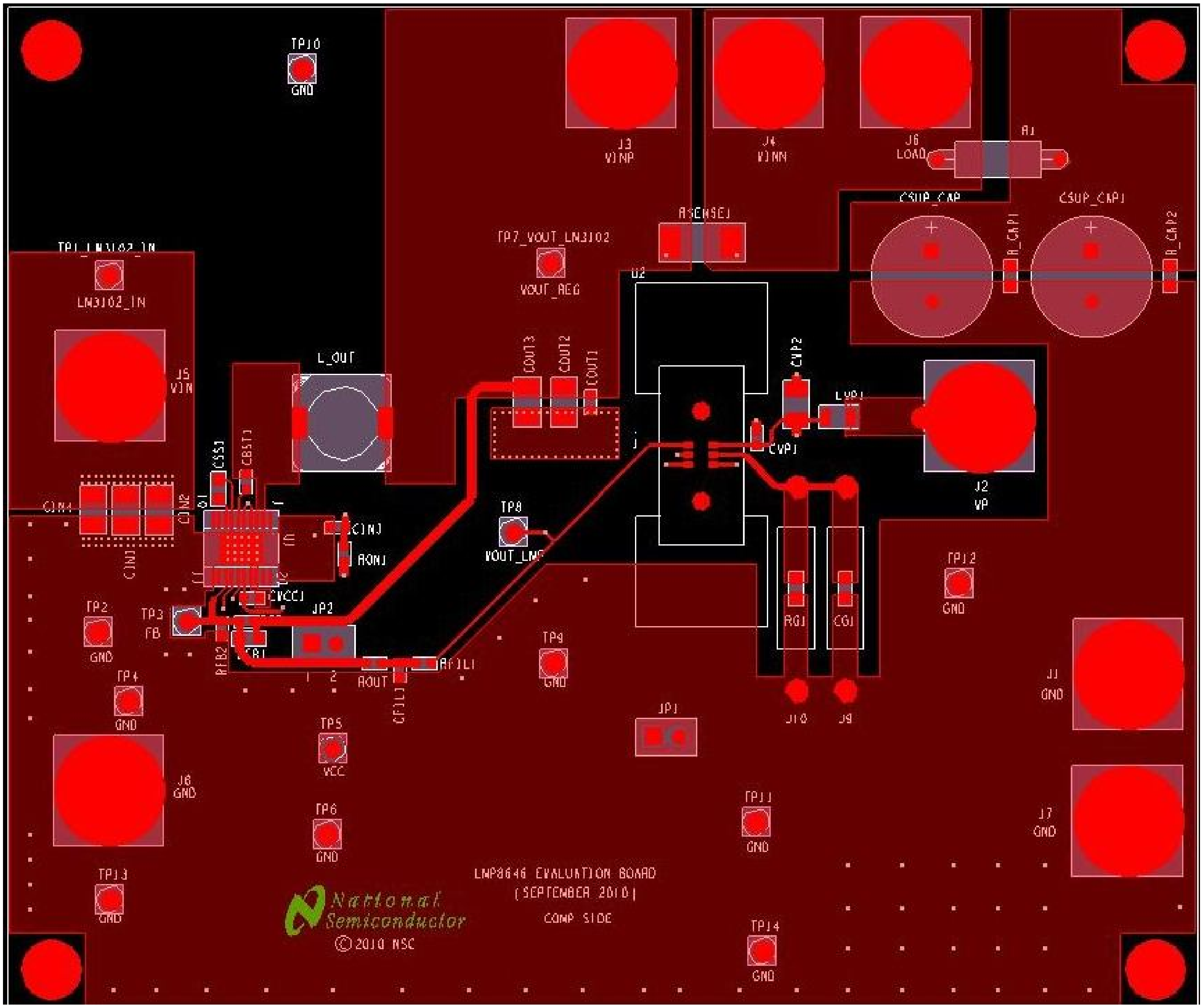

Figure 9 - Layout Top Layer

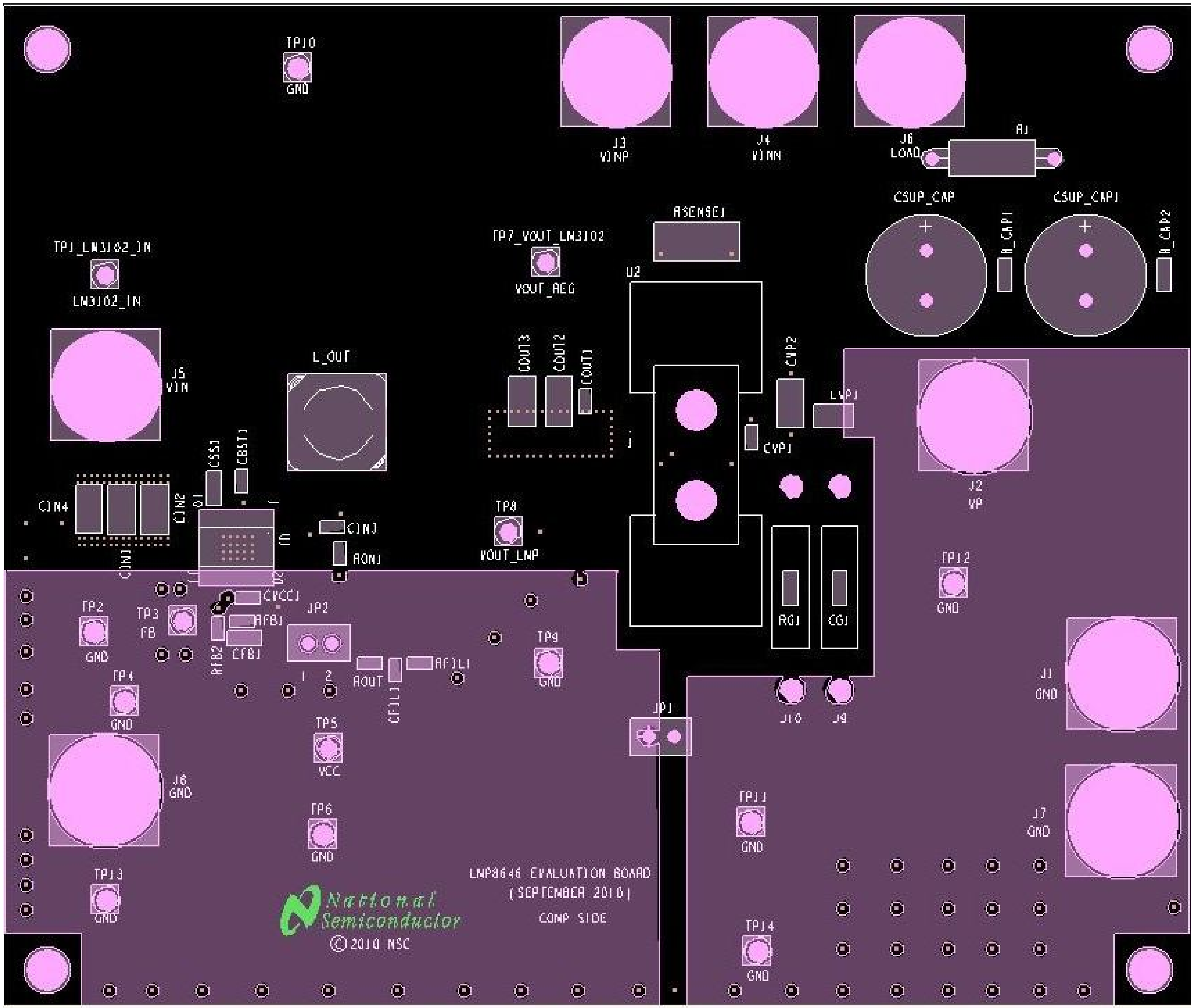

Figure 10 - Layout Layer #2: Power

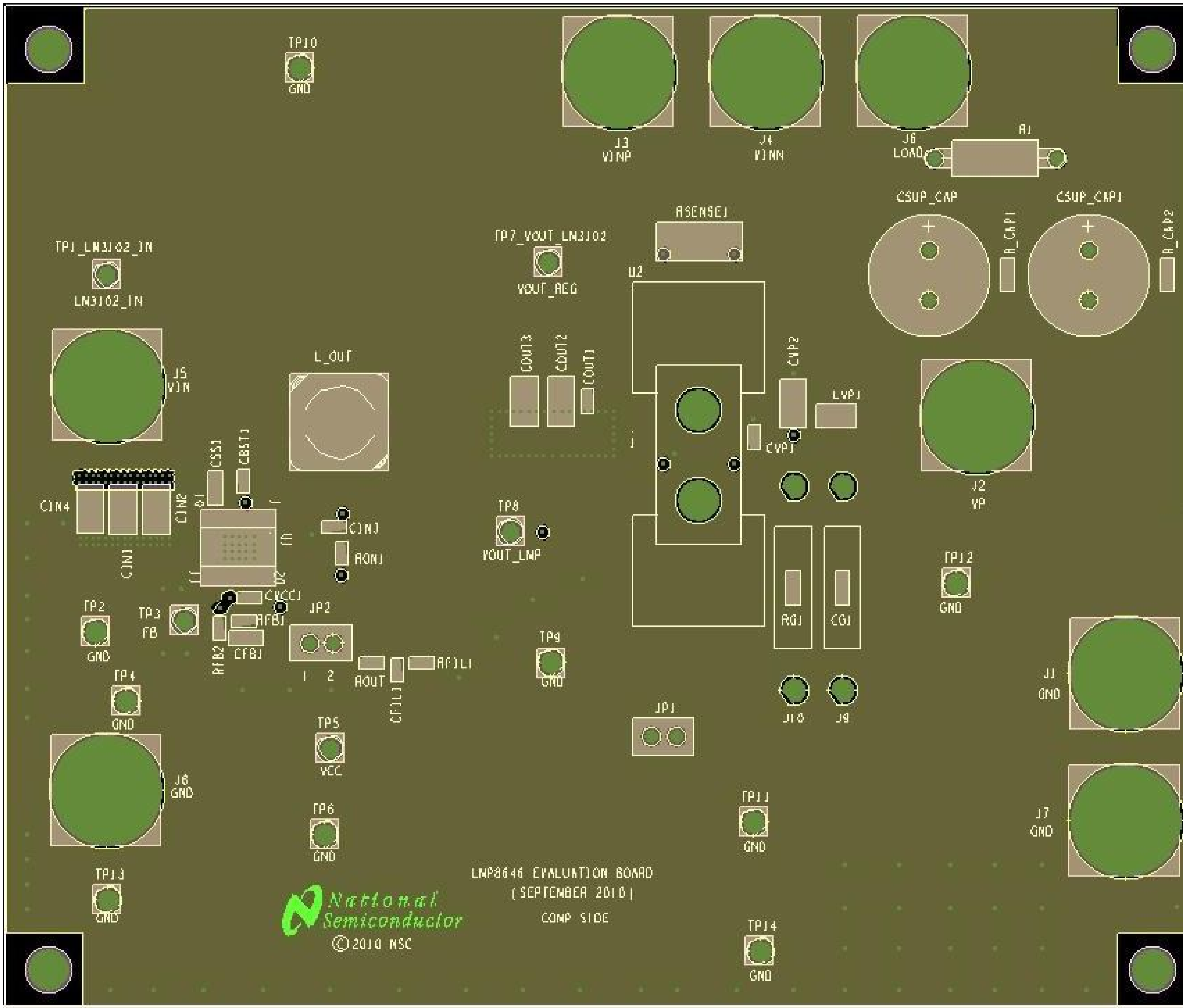

Figure 11 - Layout Layer #3: Ground

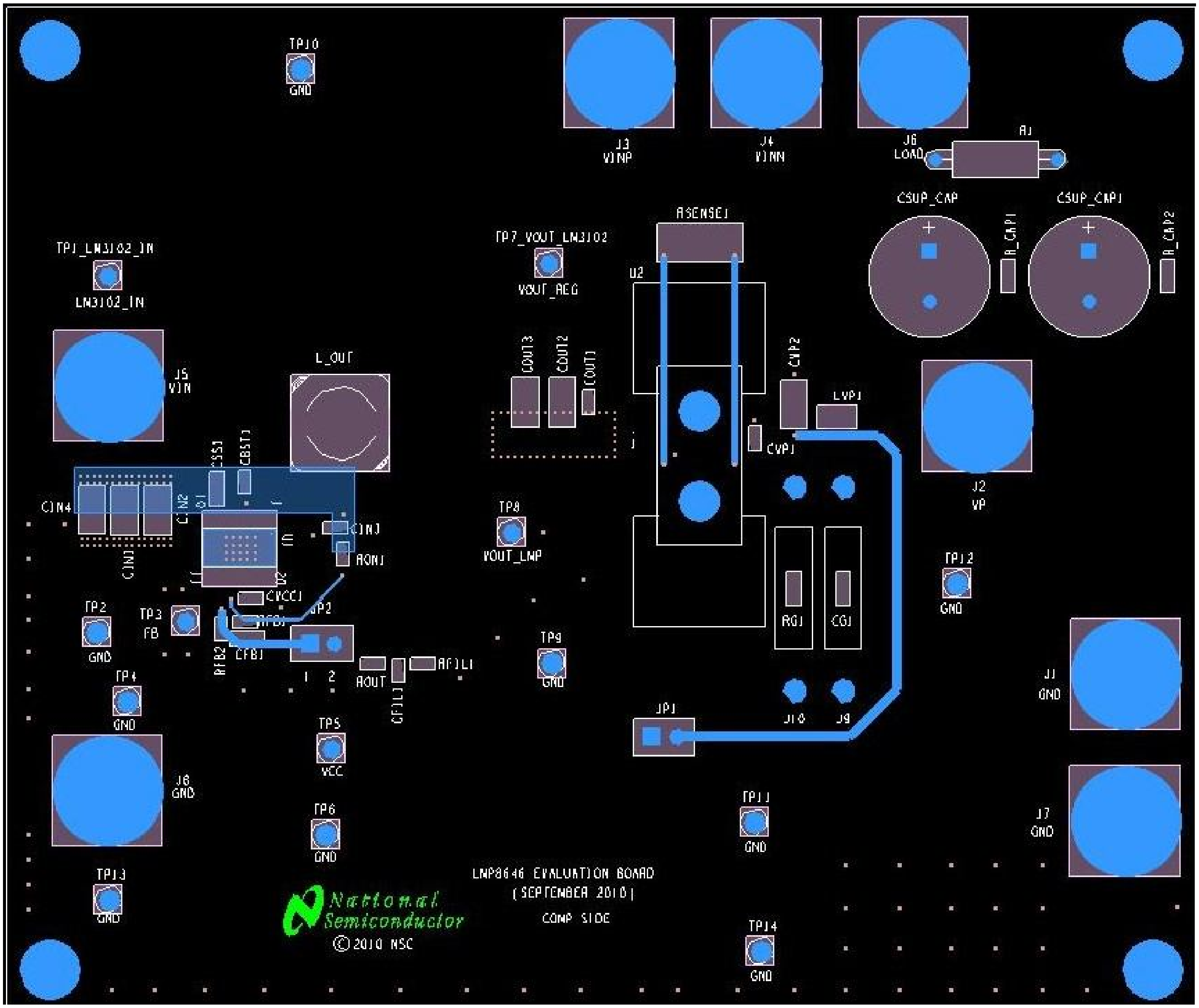

Figure 12 - Layout Bottom Layer

7. BOM

Item	Qnt	Reference	Value	Description	Package	Manufacturer	Manufacturer Part #
1	1	CBST1	33 nF	CAP CER 33000PF 25V 10% X7R 0603	603	Murata	GRM188R71E333KA01D
2	2	CSS1,CFB1	10nF	CAP CER 10000PF 50V 10% X7R 0805	805	Murata	GRM216R71H103KA01D
3	1	CFIL1	NS	CAP CER .1UF 25V 10% X7R 0603	603	Murata	GRM188R71E104KA01D
4	1	CG1	NS	CAP CER 100PF 50V C0G 5% 0805	805	TDK	C2012C0G1H101J
5	3	CIN1,VP2,CIN2	10 uF	CAP CER 10UF 50V Y5V 1210	1210	Murata	GRM32DF51H106ZA01L
6	2	VP1,CIN3	0.1 uF	CAP CERAMIC .1UF 50V X7R 0603	603	Panasonic	ECJ-1VB1H104K
7	1	COUT1	100 nF	CAP CER .1UF 25V 10% X7R 0603	603	Murata	GRM188R71E104KA01D
8	2	COUT2,COUT3	47 uF	CAP 47UF 6.3V CERAMIC X5R 1210	1210	Panasonic	ECJ-4YB0J476M
9	1	CSUP	SuperCap 10F	CAP 10F 2.3V GOLD HW RADIAL	Radial thu-hole	Panasonic	EEC-HW0D106
10	1	CVCC1	1uF	CAP CER 1.0UF 10V Y5V 0603	603	TDK	C1608Y5V1A105Z
11	1	JP1	VP_SELECT	CONN HEADER .100 SINGL STR 36POS	0.100"	Sullins Connector	PBC36SAAN
12	1	J1	GND	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
13	1	J2	VP_EXT	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
14	1	J3	VSENSEP	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
15	1	J4	VSENSEN	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
16	1	J5	VIN	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
17	1	J6	CAP_P	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
18	1	J7	CAP_N	CONN JACK BANANA UNINS PANEL MOU	Bulk	Emerson Network	108-0740-001
19	1	J8	Rg_SOCKET	PIN RECPT .032/.046 DIA 0328 SER	N/A	Mill-Max	0328-0-15-15-34-27-10-0
20	1	J9	Cg_SOCKET	PIN RECPT .032/.046 DIA 0328 SER	N/A	Mill-Max	0328-0-15-15-34-27-10-0
21	1	L_OUT	22 uH	INDUCTOR POWER 22UH 3.6A SMD		JW Miller	PM5022-220M-RC

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EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 3.3V to 5V and the output voltage range of 0V to 5V.
Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.
Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to theEVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.
During normal operation, some circuit components may have case temperatures greater than +30°C. The EVM is designed to operate properly with certain components above +85°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.