

LM10011 Evaluation Module

1 Introduction

This application report describes the various functions of the LM10011 evaluation module, how to test and evaluate it, and how to use the GUI design tool to change the components for a specific application. Please check the *LM10011 GUI Installer* ([SNVC071](#)) for the latest software and the *6/4-Bit VID Programmable Current DAC for Point of Load Regulators with Adjustable Start-Up Current* ([SNVS822](#)). For more information on the LM21215A-1 and its operation, please check the *LM21215A-1 15A High Efficiency Synchronous Buck Regulator with Frequency Synchronization* ([SNOSB87](#)) and the *AN-2131 LM21215A-1 Evaluation Board User's Guide* ([SNVA477](#)).

The LM10011 is a precision, digitally programmable device used to control the output voltage of a DC/DC converter. The LM10011 outputs a DC current proportional to a 6-bit or 4-bit input word. The current DAC output is intended to connect to the feedback node of a buck converter in order to adjust the converter output voltage to a desired range and resolution. As the 6-bit or 4-bit word counts up, the output voltage is adjusted higher based on the setting of the feedback resistors in the buck converter.

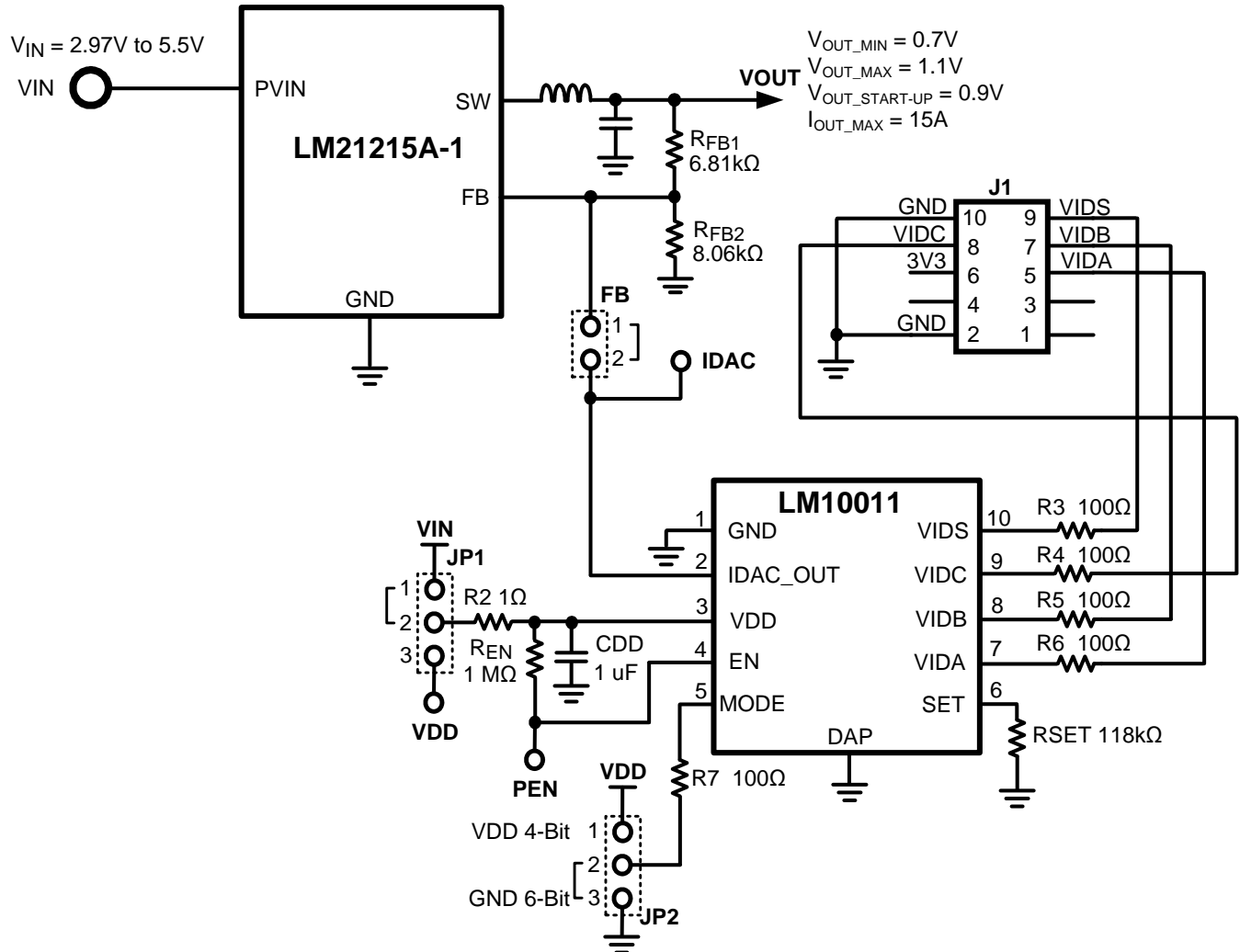
The LM10011 evaluation module provides the power design engineer with a low voltage high current point-of-load solution with an adjustable output voltage using the LM10011 VID controlled current DAC, an LM21215A-1 15A integrated buck regulator, and a companion GUI software. The GUI software along with included hardware are used to assist in the design and understanding of how to implement the LM10011. The GUI can be used to change the output voltage of the on-board POL based on direct user input. It is also able to assist the power designer in selecting the correct external components needed for any given application.

2 PCB Features

- Input voltage range: 2.97V to 5.5V
- V_{OUT} at start-up: 0.9V
- Programmable output voltage: 0.7V to 1.1V (adjustable)
- Over current protection: 17A
- PCB Size: 2.2" x 2.8"
- USB connection through communications dongle
- Software control with graphical user interface

3 Evaluation Module Introduction

The evaluation module provides a VID interface to test the LM10011 and its control of an LM21215A-1 buck regulator. The LM21215A-1 is capable of driving up to 15A of continuous load current with excellent output voltage accuracy due to its $\pm 1\%$ internal voltage reference and high gain error amplifier. The LM21215A-1 also features a clock synchronization input (SYNC), precision enable pin (ENABLE), a power good output (PGOOD), and a soft-start and track pin (SS_TRK) (as labeled on the PCB). The input voltage can be operated from 2.97V to 5.5V. On power-up, the output voltage defaults to 0.9V. The evaluation board allows for control of the LM21215A-1 output voltage from 0.7V to 1.1V in 6.4mV steps through the 4-pin VID interface of the LM10011. A 10-pin header is included to communicate with the LM10011. A USB communications dongle is provided along with software to control the output voltage through a graphical user interface (GUI) and a USB port.

4 Simplified Schematic

Figure 1. Simplified Schematic

5 Theory of Operation

The LM10011 can be thought of as a D/A converter, converting the VID codes to analog outputs. In this device, the output is a current DAC (IDAC_OUT), which is connected to the feedback node of a slave regulator. Therefore, all VID data words are decoded into a 6-bit current DAC output. The impedance of the feedback node at DC appears as the top feedback resistor. This is because the control loop of the slave regulator effectively maintains a constant current and voltage through and across the bottom feedback resistor. Therefore, as more current is sourced into the feedback node, less current is needed from RFB1 and the output voltage is reduced. See Figure 2.

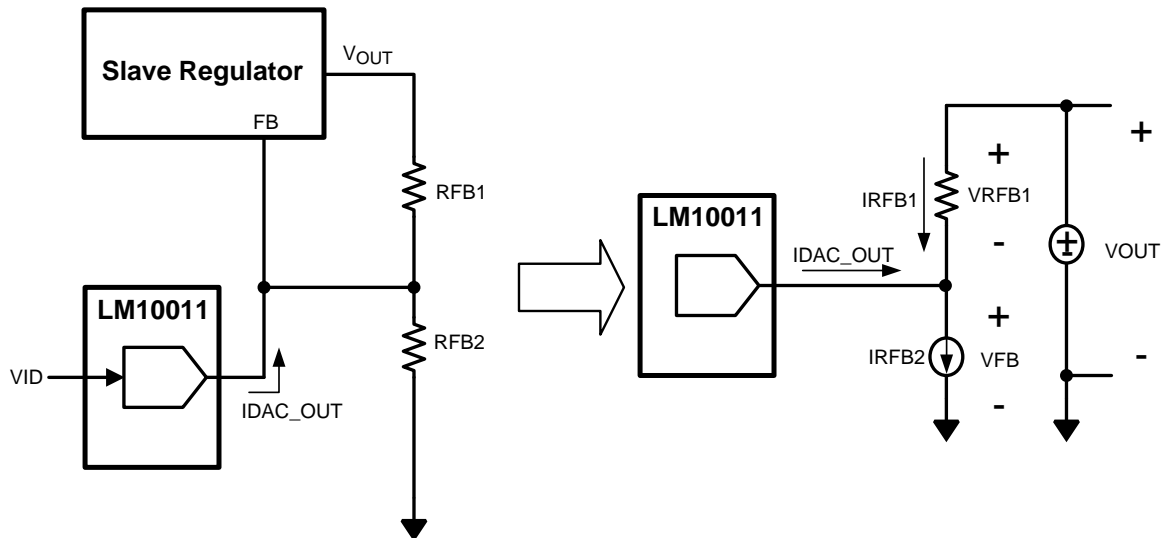


Figure 2. Current Injection into the Feedback Node

Looking at Figure 2, the following equation defines V_{OUT} for a given regulator (valid for $V_{OUT} > V_{FB}$, V_{FB} = voltage at FB pin):

$$V_{OUT} = V_{FB} \times \left(1 + \frac{R_{FB1}}{R_{FB2}} \right) - IDAC_OUT \times R_{FB1} \quad (1)$$

For the LM21215A-1, V_{FB} is 600mV. For the LM10011, the IDAC_OUT maximum current is 59.2µA, with 64 settings at a resolution of 940nA, adjustable with the 6-bit VID word. Note that as the VID codes count up, the output current (IDAC_OUT) counts down starting from the highest current. This allows for V_{OUT} to increment up with the VID code. For a more in-depth analysis of the circuit, see the LM10011 datasheet.

Table 1 shows the codes and some of the resultant values of IDAC_OUT current and corresponding regulator output voltage for the default resistor values on the evaluation board.

Table 1. VID Codes with IDAC Current and Regulator Voltage for the Evaluation Board

VID Code	IDAC Current (µA)	Regulator Voltage (V)
000000b	59.2	0.704
000001b	58.3	0.710
000010b	57.4	0.716
000011b	56.4	0.723
:	:	:
111100b	2.87	1.087
111101b	1.93	1.094
111110b	1.00	1.100
111111b	0.06	1.107

6 Power-Up Procedures

CAUTION

Read the entire power-up procedures prior to applying power to the evaluation board.

The LM10011 evaluation kit hardware is shown in Figure 3. The board offers a connection for the system input voltage on the left side and a connection for the load on the bottom. To the right of the LM10011 evaluation module is a communications dongle. It is connected to the board through the 10 pin right angle header and is used to communicate with the LM10011. A USB cable connects the dongle to a USB port on the computer for software control.

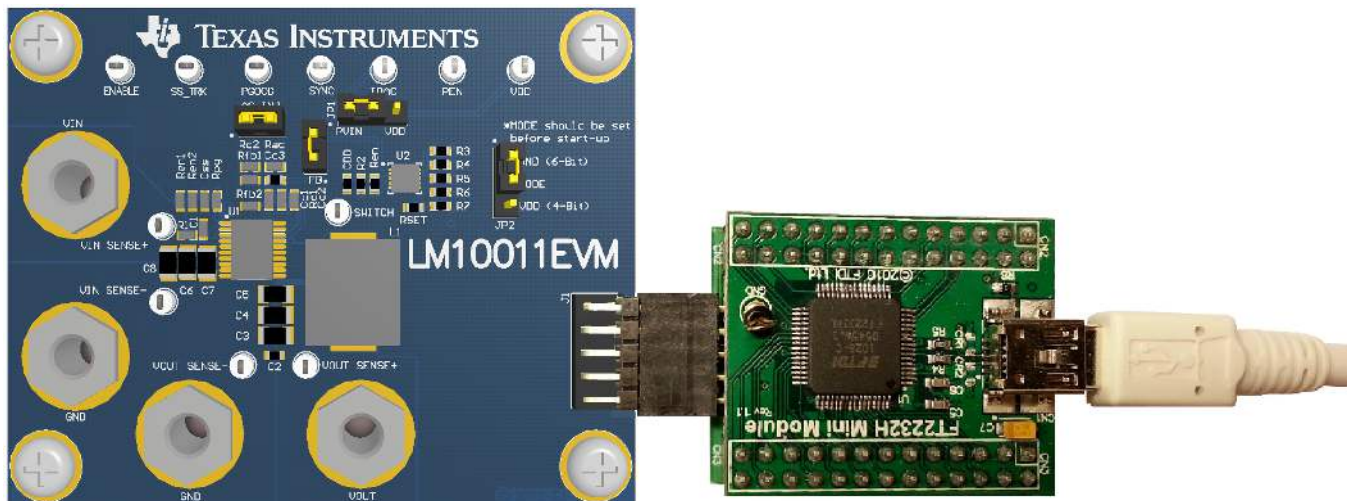


Figure 3. LM10011 Evaluation Kit Hardware

6.1 Quick Setup Procedure

Step 1: Before connecting the input power supply, set the output of the power supply to current limit at 10A and output voltage two any voltage between 2.97V and 5.5V. Disable the power supply output. Connect the positive output (+) of the power supply to VIN and the negative output (-) to the corresponding GND. **Be sure to disable the output of the power supply before connecting it to the evaluation board. Minimize the inductance between the power supply and the evaluation board to mitigate any voltage spikes that may occur.**

Step 2: Connect the load (with 15A capability) positive (+) input to VOUT and negative (-) input to the corresponding GND on the evaluation board.

Step 3: The ENABLE pin should be left open for normal operation.

Step 4: Activate the output of the power supply. The load voltage should be in regulation with a nominal 0.9V output.

Step 5: Slowly increase the load while monitoring the load voltage at VOUT SENSE. It should remain in regulation with a nominal 0.9V output as the load is increased up to 15A.

Step 6: Slowly sweep the input source voltage from 2.97V to 5.5V (DO NOT EXCEED 5.5V). The load voltage should remain in regulation with a nominal 0.9V output. If desired, the output of the device can be disabled by connecting the ENABLE pin to GND.

Step 7: The LM21215A-1 switching frequency can be varied by connecting a 2.0V clock signal between SYNC and GND.

6.2 Over-Current Protection

The evaluation board is configured with over-current protection. This function is completely contained in the LM21215A-1. The peak current is limited to approximately 17A.

6.3 Quick Setup for Software Control

Once the LM10011 evaluation board is setup and the LM21215A-1 is determined to be correctly regulating the output voltage, the software can be installed and communication can then be established with the LM10011. In the evaluation board kit, there should be a CD with all the necessary executable files to install the LM10011 GUI. If there is no CD, the software can be found in the *LM10011 GUI Installer (SNVC071)*.

The installation files should be executed on a PC running Windows XP or later.

7 Connection Descriptions

Terminal Silkscreen	Description
VIN	This terminal is the input voltage to the evaluation board. The evaluation board will operate over the input voltage range of 2.97V to 5.5V.
GND	These terminals are the ground connections to the device. The input power ground should be connected next to the input VIN connection, and the output power ground next to the VOUT connection.
VOUT	This terminal connects to the output voltage of the power supply and should be connected to the load.
ENABLE	This terminal connects to the enable pin of the LM21215A-1. ENABLE can be left floating or driven externally. If left floating, a 2 μ A current source will pull the pin high, thereby enabling the device. If driven externally, a voltage typically less than 1.24V will disable the LM21215A-1 and above 1.35V will enable the LM21215A-1.
SS/TRK	This terminal provides access to the SS/TRK pin of the LM21215A-1. Connections to SS/TRK are not needed for most applications. The feedback pin of the device will track the voltage on the SS/TRK pin if it is driven with an external voltage source that is below the 0.6V reference.
PGOOD	This terminal connects to the power good output of the LM21215A-1. This pin is pulled up through a 10k Ω pull-up resistor to VIN.
AC INJ	This terminal block allows the user to insert an AC injection signal across a 49.9 Ω resistor for open loop gain bode measurements. A jumper shorts this resistor when it is not needed.
SWITCH	This terminal allows easy probing of the switch node. Do not apply any external voltage source to this pin.
SYNC	This terminal connects to the SYNC pin of the LM21215A-1. The regulator can synchronize the SWITCH pin to a SYNC signal with a frequency between 300kHz and 1.5MHz. If this pin is left open, the switching frequency will default to 500kHz.
VIN_SENSE+, VIN_SENSE-, VOUT_SENSE+, VOUT_SENSE-	These terminals allow a sense connection on the board for accurate V_{IN} and V_{OUT} measurements, respectively.
IDAC	This terminal connects to the LM10011 IDAC output (IDAC_OUT).
PEN	This terminal connects to the enable (EN) pin of the LM10011. EN can be left floating or driven externally. If left floating, a 2 μ A current source will pull the LM10011 EN pin high, thereby enabling the LM10011. If driven externally, a voltage typically less than 1.24V will disable the LM10011 and above 1.34V will enable the LM10011.
FB	This jumper connects the LM10011 output to the feedback node of the LM21215A-1. If the LM10011 is used to control the output voltage, then this jumper is required. If the LM10011 is to be evaluated alone, then the IDAC_OUT current can be observed at the IDAC connection by removing the jumper.
J1	This terminal block is used to connect the LM10011 evaluation board with the communications dongle.
JP1	This terminal block controls the source of power for the LM10011. If a jumper is connected between pins 1 and 2, then the LM10011 supply comes from PVIN. If the jumper is connected from pins 2 and 3, then the LM10011 derives power from an external connection to VDD.
JP2	This terminal block controls the mode of the LM10011. To put the LM10011 into 4-Bit mode, set the terminal block to VDD. For 6-Bit mode, set the terminal block to GND.
VDD	This terminal can be used as an alternate power source for the LM10011 though terminal block JP1.

8 Evaluation Board

The evaluation board shows how the LM10011 is used to control the LM21215A-1. However, the LM10011 can operate independently without the LM21215A-1 by jumpering pins 2 and 3 on JP1 and applying the supply voltage through the VDD test point. The IDAC_OUT output current can be observed at the IDAC test point with the jumper removed from FB.

Additionally, the output voltage range of the evaluation board can be adjusted by replacing the R_{FB1} and R_{FB2} feedback resistors on the board. However, a change in the feedback resistors may change the compensation network for the LM21215A-1 and this may require adjustments in values for C_{C1} , C_{C2} , C_{C3} , R_{C1} , and R_{C2} . For further guidance with component selection, please see the LM21215A-1 datasheet and evaluation board user's guide.

9 LM10011 Control and Design Software

The LM10011 evaluation board comes with a communications dongle and software to control the output voltage (software can also be found on the LM10011 Texas Instruments Product Folder online). This section describes software features and modes of operation. The software has a built-in calculator to determine the feedback resistor values for a given range and resolution of operation. This is only used when the user decides to remove the existing default resistor feedback values and determines the LM21215A-1's compensation is correct for the new feedback resistors. The default or updated values are used to calculate expected output voltages of the point of load regulator. After installing the Texas Instruments VID GUI, open it by going to Start>Programs>Texas Instruments LM1001X_GUI-0.8.1-xxxx-xxxx>LM1001X_GUI. Figure 4 shows the initial screen.

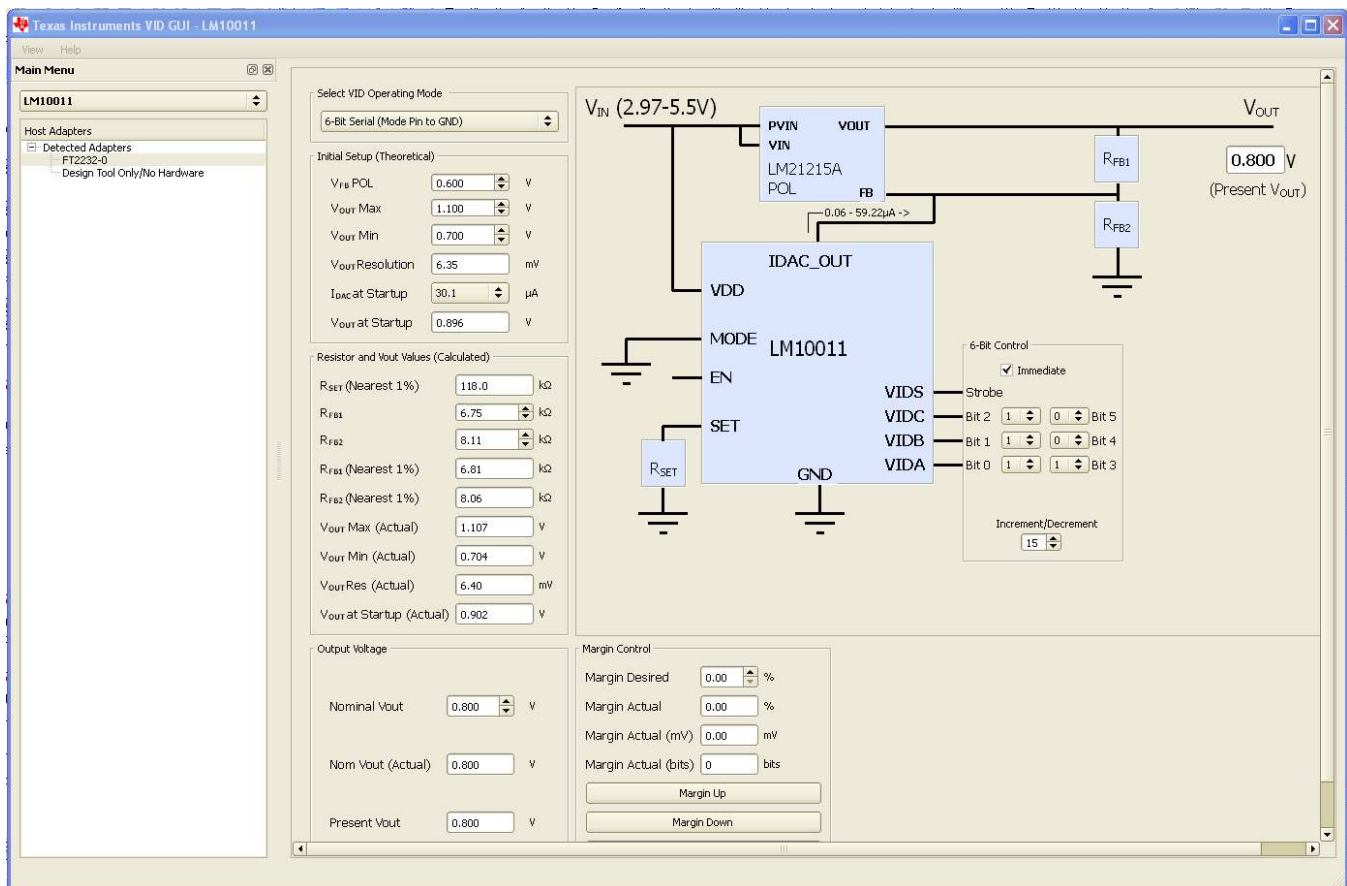


Figure 4. LM10011 Initial Screen

Select the device connected to the USB dongle, in this case, the LM10011 as shown in [Figure 5](#).



Figure 5. Select Device Menu

Once the device is selected, the Host Adapter list will show. The Host Adapter list will display any FT2232 USB dongles connected to the computer. Select the USB dongle that corresponds to the one connected to the LM10011 evaluation board. This is shown in [Figure 6](#).

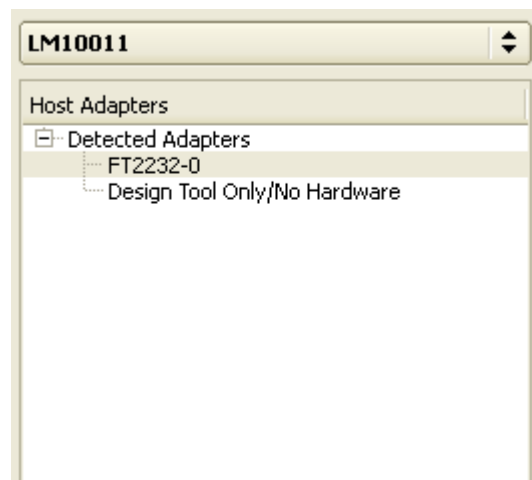


Figure 6. Host Adapter List

The Host Adapter list also shows an option for "Design Tool Only /No Hardware". Select this option if you only want to use the design tool without the LM10011 connected to the computer. This allows the user to use all of the design features of the GUI without the need for the actual hardware.

9.1 Main Window

Once the device is selected the main window should look like the screenshot in Figure 7.

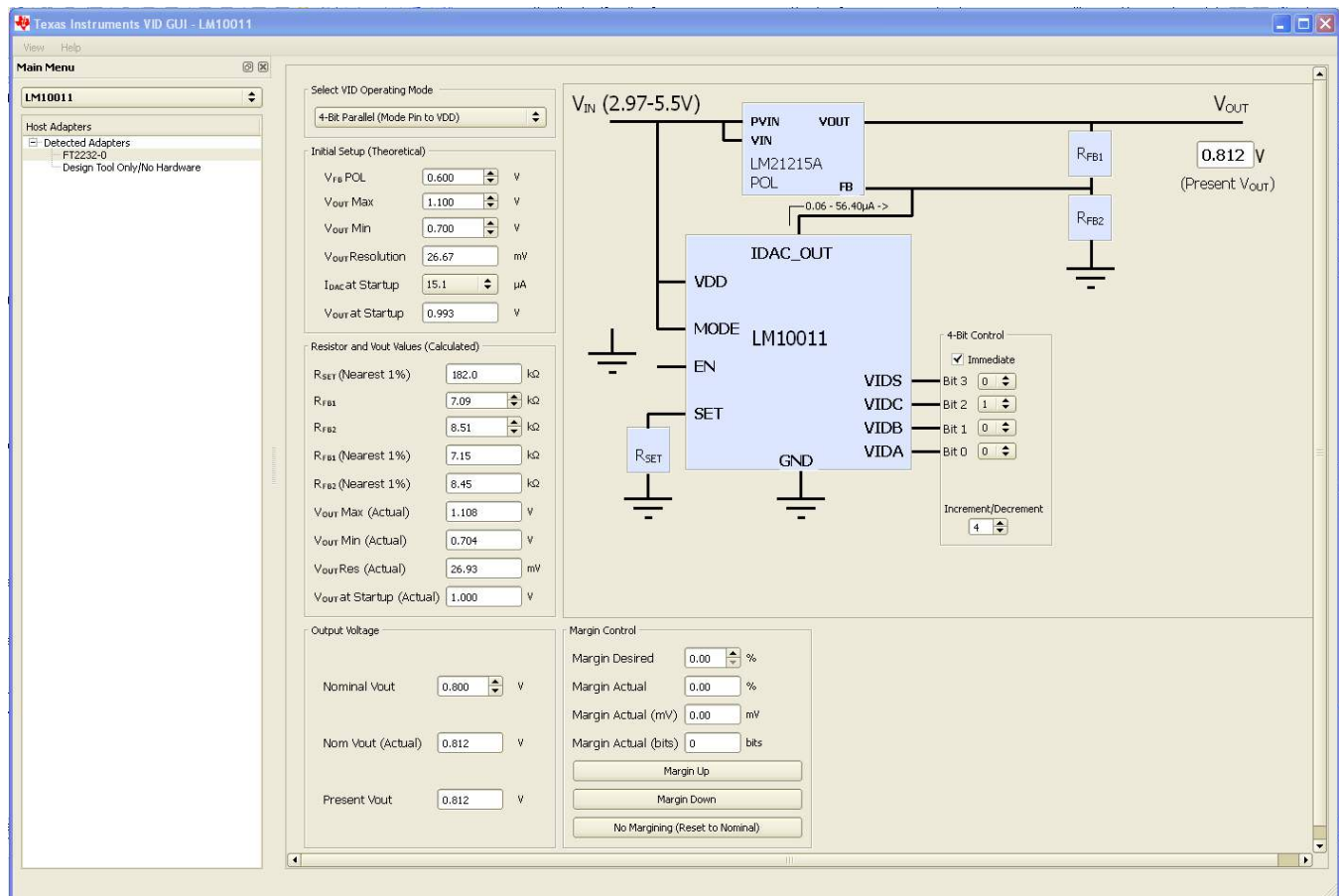


Figure 7. Main Window

The main window consists of six different items:

- **Select VID Operating Mode:** This section allows the user to switch between 4-Bit and 6-Bit communication mode. The mode jumper must be manually positioned on the actual evaluation board if the mode is toggled.
- **Initial Setup:** The Initial Setup section allows the user to enter the design inputs based on the application requirements of the VID enabled POL. The default values in this section represent the values used in on the evaluation module.
- **Resistor and Vout Values (Calculated):** R_{FB1} and R_{FB2} components along with output voltage parameters in the Resistor and Vout Values section are the resulting values calculated using the user inputs in the Initial Setup section.
- **Output Voltage:** Use the Output Voltage section to change the nominal output voltage directly.
- **Margin Control:** The user can set the exact margining value in the Margin Control section. The user can then use the "Margin Up" and "Margin Down" buttons to adjust the output voltage up or down depending on the value in the Margin Desired box. The percent of margining is based on the value in the Nom Vout (Actual) box in the Output Voltage section.
- **Block Level Schematic:** The LM10011 GUI shows a block level schematic. This schematic displays the present value of the POL output and allows the user to control the VID codes directly.

9.2 Select VID Operating Mode

When the user first starts the GUI, the software assumes the LM10011 evaluation board is in 6-Bit mode. The software and hardware must both be operating in the same mode for the GUI to properly communicate to the evaluation board. The evaluation board has a "MODE" jumper that must be set to the correct mode before powering the board. The software has a "Select VID Operating Mode" section, [Figure 8](#), with a listbox giving the user the option to select between 4-Bit communication and 6-Bit communication.

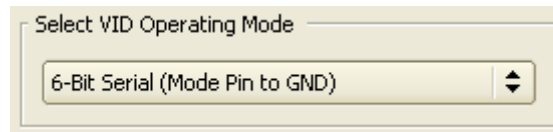


Figure 8. Select VID Operating Mode Section

9.3 Initial Setup

The Initial Setup section, [Figure 9](#), allows the user to enter the design inputs based on the application requirements of the VID enabled POL. The default values in this section represent the values used on the evaluation module.

The inputs include any box with spin buttons (indicated by up and down arrows) . Boxes without spin buttons are design outputs.

When starting a design, the user must input the nominal feedback voltage of the POL in use in the VFB POL box. In the case of the LM21215A-1, this is 0.600V. The desired maximum and minimum output voltage is entered into the VOUT MAX and VOUT MIN boxes respectively. Doing this sets the effective VID range were each step resolution is defined in the VOUT Resolution box. To set a nominal start-up voltage, select an IDAC_OUT current from the available currents in the IDAC at Startup list box. The Vout at Start-up box will display what the corresponding start-up voltage is.

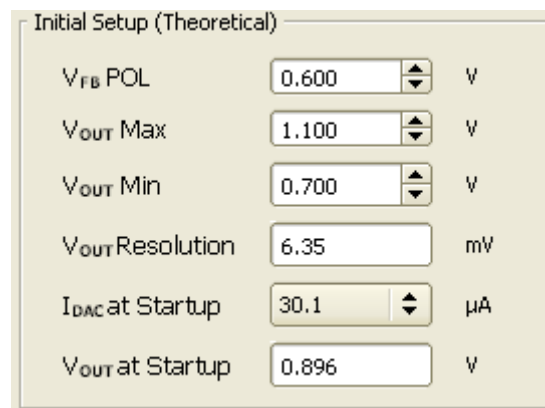


Figure 9. Initial Setup (Theoretical) Section

9.4 Resistor and Vout Values (Calculated)

The components listed in the Resistor and Vout Values section, [Figure 10](#), are calculated by the inputs in the Initial Setup section. The Resistor and Vout Values section will provide the user with the standard components needed to make a working design. The component designators are reflected in the schematic to the right of this section.

The first component in the Resistor and Vout Values section is the RSET resistor. This resistor is chosen based on the input in the IDAC at Startup box. This resistor will match the resistors listed in the electrical characteristics table in the LM10011 datasheet.

The feedback resistors RFB1 and RFB2 are calculated based on the VOUT MIN and VOUT MAX range set in the Initial Setup section. The values in the RFB1 and RFB2 spin boxes represent calculated theoretical values and can be changed manually at the users discretion if needed. The RFB1 and RFB2 (Nearest 1%) values represent standard E96 1% resistor values available on the market.

Using the nearest 1% RFB1 and RFB2 resistor values, the actual VOUT MIN and VOUT MAX along with the VOUT resolution and initial startup voltage is calculated. This gives the user a more realistic preview of what they can expect to see at the output of the POL under VID control using standard size resistors.

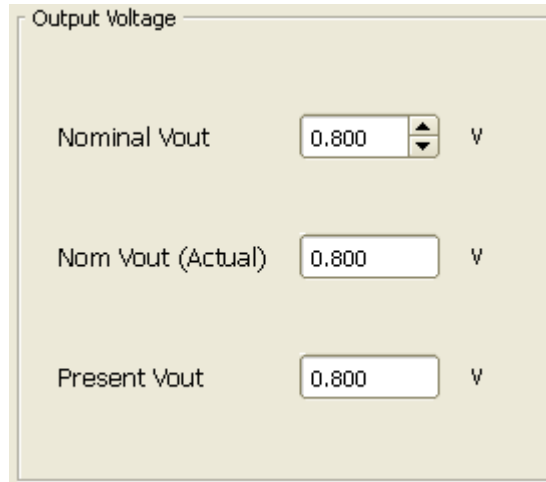
Resistor and Vout Values (Calculated)	
R _{SET} (Nearest 1%)	118.0 kΩ
R _{F B1}	6.75 kΩ
R _{F B2}	8.11 kΩ
R _{F B1} (Nearest 1%)	6.81 kΩ
R _{F B2} (Nearest 1%)	8.06 kΩ
V _{OUT} Max (Actual)	1.107 V
V _{OUT} Min (Actual)	0.704 V
V _{OUT} Res (Actual)	6.40 mV
V _{OUT} at Startup (Actual)	0.902 V

Figure 10. Resistor and Vout Values (Calculated) Section

9.5 Output Voltage

After modifying the evaluation board with the new design values, the user can then use the GUI to change the output voltage. The Output Voltage section, [Figure 11](#), allows the user to change the output voltage to any voltage within the range specified by VOUT MIN and VOUT MAX in the Resistor and Vout Values (Calculated) section. Enter the desired VOUT in the Nominal Vout spin box. The closest available Nominal VOUT will be chosen in the NOM VOUT (Actual) Section.

The Present Vout box will show what the current state of the output voltage is. The value in this box will match the "(Present VOUT)" box in the schematic. This value will change on the users margining input.



The screenshot shows a GUI window titled "Output Voltage" with three rows of controls:

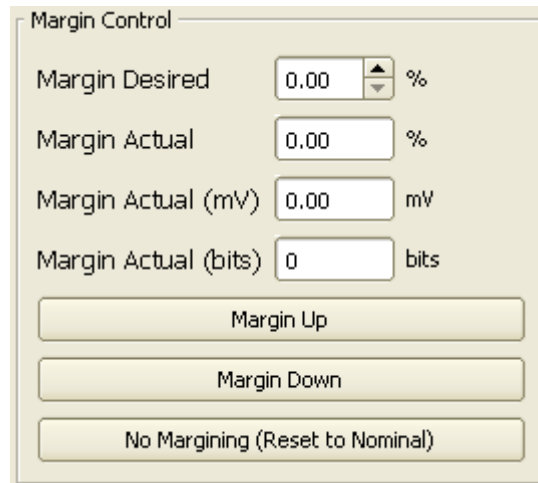
- Nominal Vout:** A spin box containing the value "0.800" followed by a "V" unit indicator.
- Nom Vout (Actual):** A text box containing the value "0.800" followed by a "V" unit indicator.
- Present Vout:** A text box containing the value "0.800" followed by a "V" unit indicator.

Figure 11. Output Voltage Section

9.6 Margin Control

The main application of the LM10011 VID current DAC is voltage margining. The Margin Control section, [Figure 12](#), allows the user to set a desired margin weight and adjust the output voltage up or down based on the desired margin weight.

Enter the desired margin weight in the Margin Desired box as a percentage of the Nominal Vout (Actual) box in the Output Voltage section. The Margin Actual (%) and Margin Actual (mV) boxes will show what the actual margining value is based on the VID controller codes and RFB1 and RFB2 values. Margin Actual (bits) shows the number of bits the LM10011 will step for each press of the Margin Down and Margin Up buttons. After the user has set the margin value, the output voltage can be increased or decreased by the margin value by pressing the margin up and margin down buttons.



Margin Control

Margin Desired %

Margin Actual %

Margin Actual (mV) mV

Margin Actual (bits) bits

Margin Up

Margin Down

No Margining (Reset to Nominal)

Figure 12. Margin Control Section

9.7 Block Level Schematic

The included block level schematic shown in Figure 13 shows the present output voltage of the evaluation board and the current bit setting.

The 6-Bit/4-Bit Control box allows the user to directly enter a VID code. The VID code of the current margining output will be displayed in this box as well if the Margin Up/Down buttons are toggled. Use the step spin box to step a single code value up or down. Check the immediate box to allow realtime control of the output voltage through direct toggling of the VID bits.

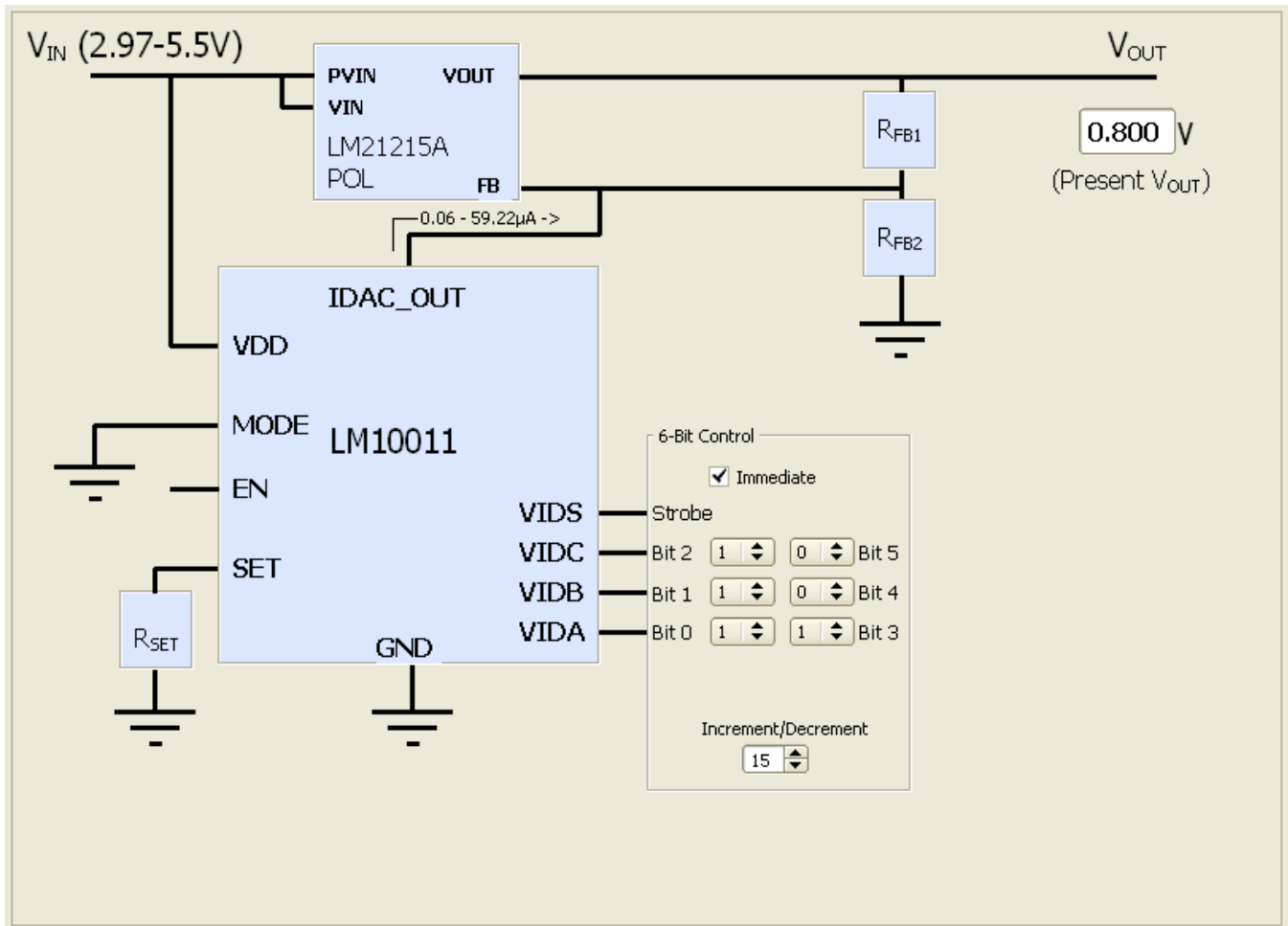


Figure 13. Block Level Schematic

10 Full Evaluation Board Schematic

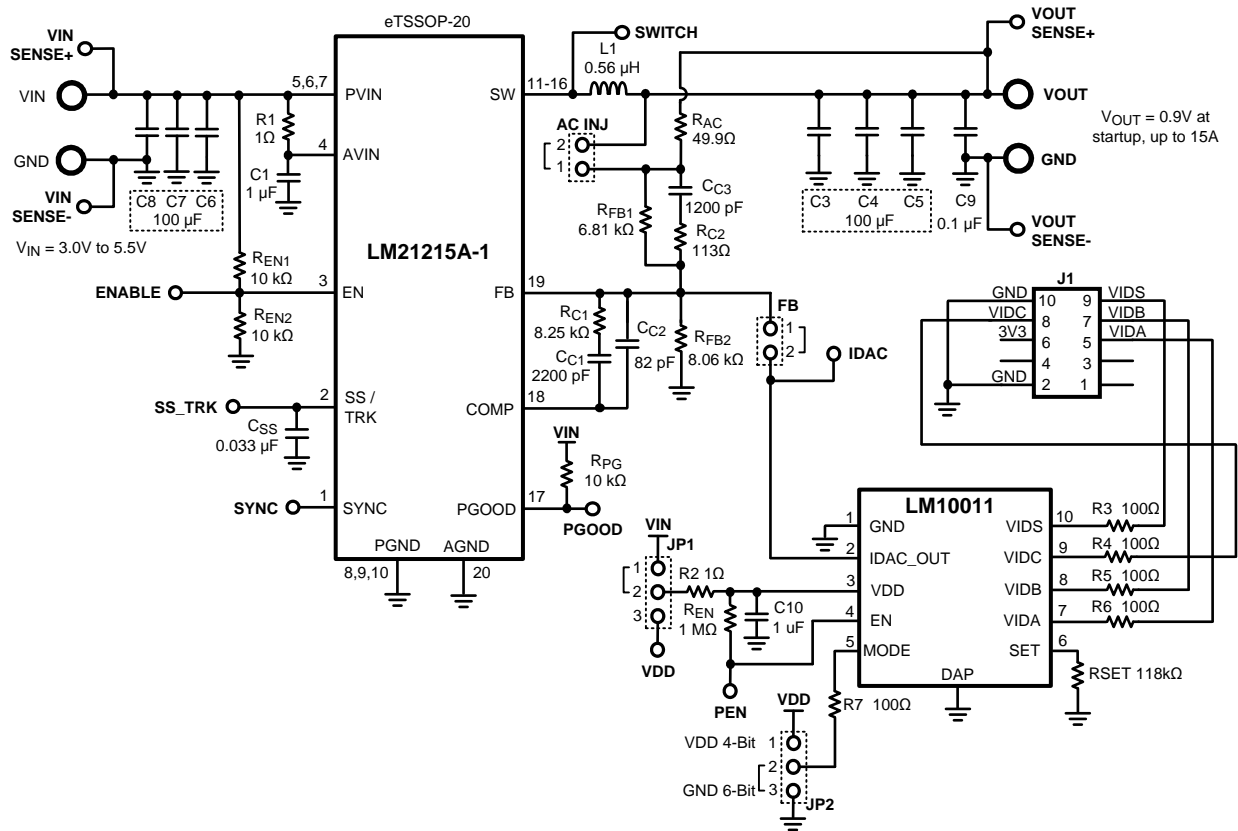


Figure 14. LM21215A-1 and the LM10011

11 Bill of Materials

The Bill of Materials is listed in [Table 2](#), including the manufacturer and part number.

Table 2. Bill of Materials

ID	Description	Vendor	Part Number	Qty
AC INJ, FB	Header, TH, 100mil, 2x1, Gold plated, 230 mil above insulator	Samtec Inc.	TSW-102-07-G-S	2
JP2, JP1	Header, TH, 100mil, 3x1, Gold plated, 230 mil above insulator	Samtec Inc.	TSW-103-07-G-S	2
J1	Header, 5-Pin, Dual row, Right Angle, Printed Circuit Board	Samtec Inc.	TSW-105-08-L-D-RA	1
C1, C10	CAP, CERM, 1 uF, 10V, $\pm 10\%$, X7R, 0603	MuRata	GRM188R71A105KA61D	2
C3, C4, C5, C6, C7, C8	CAP, CERM, 100 uF, 6.3V, $\pm 20\%$, X5R, 1206	MuRata	GRM31CR60J107ME39L	6
C9	CAP, CERM, 0.1 uF, 50V, $\pm 10\%$, X7R, 0603	TDK	C1608X7R1H104K	1
C _{C1}	CAP, CERM, 2200 pF, 50V, $\pm 5\%$, C0G/NP0, 0603	MuRata	GRM1885C1H222JA01D	1
C _{C2}	CAP, CERM, 82 pF, 50V, $\pm 5\%$, C0G/NP0, 0603	MuRata	GRM1885C1H820JA01D	1
C _{C3}	CAP, CERM, 1200 pF, 50V, $\pm 5\%$, C0G/NP0, 0603	MuRata	GRM1885C1H122JA01D	1
C _{SS}	CAP, CERM, 0.033 uF, 16V, $\pm 10\%$, X7R, 0603	MuRata	GRM188R71C333KA01D	1
GND_FI, GND_FO, VIN_F, VOUT_F	Standard Banana Jack, Uninsulated, 15A	Johnson Components	108-0740-001	4
L1	Inductor, Shielded Drum Core, Powdered Iron, 560nH, 27.5A, 0.0018 ohm, SMD	Vishay-Dale	IHLP4040DZERR56M01	1
R1, R2	RES, 1.0 ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06031R00JNEA	2
R3, R4, R5, R6, R7	RES, 100 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603100RFKEA	4
RSET	RES, 118 kohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603118kFKEA	1
R _{EN}	RES, 1M ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06031M00JNEA	1
R _{AC}	RES, 49.9 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060349R9FKEA	1
R _{C1}	RES, 8.25k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06038K25FKEA	1
R _{C2}	RES, 113 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603113RFKEA	1
R _{FB1}	RES, 6.81k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06036K81FKEA	1
R _{FB2}	RES, 8.06k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06038K06FKEA	1
R _{EN1} , R _{EN2} , R _{PG}	RES, 10 kohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW060310K0JNEA	3
SH-J1, SH-J2, SH-J3	Shunt, 100mil, Gold plated, Black	Samtec Inc.	SNT-100-BK-G	3
U1	15A Buck DC/DC Converter	Texas Instruments	LM21215	1
U2	VID Voltage Programmer for Point of Load Regulator	Texas Instruments	LM10011	1
ENABLE, GND_SI, GND_SO, IDAC, PEN, PGOOD, SS_TRK, SWITCH, SYNC, VDD, VIN_S, VOUT_S	Test Point, TH, Miniature, White	Keystone Electronics	5002	12
H1, H2, H3, H4	Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	B & F Fastener Supply	NY PMS 440 0025 PH	4
H5, H6, H7, H8	Standoff, Hex, 0.5"L #4-40 Nylon	Keystone Electronics	1902C	4

12 PCB Layout

The PCB was manufactured with 2oz. copper outer layers, and 1oz. copper inner layers. Twenty 8 mil diameter vias placed underneath the device, along with additional vias placed throughout the ground plane around the device, help improve the thermal dissipation of the board.

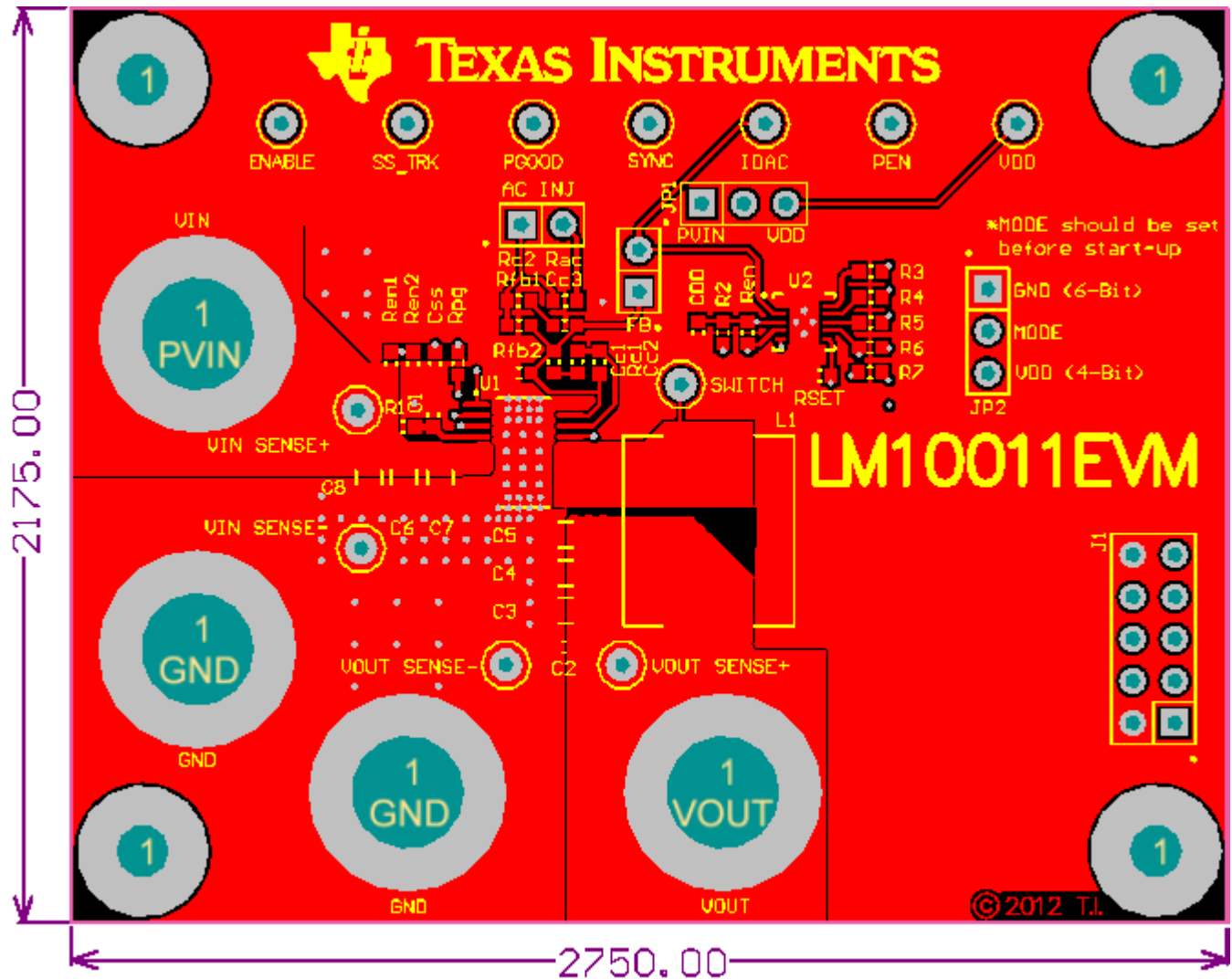


Figure 15. Top Layer

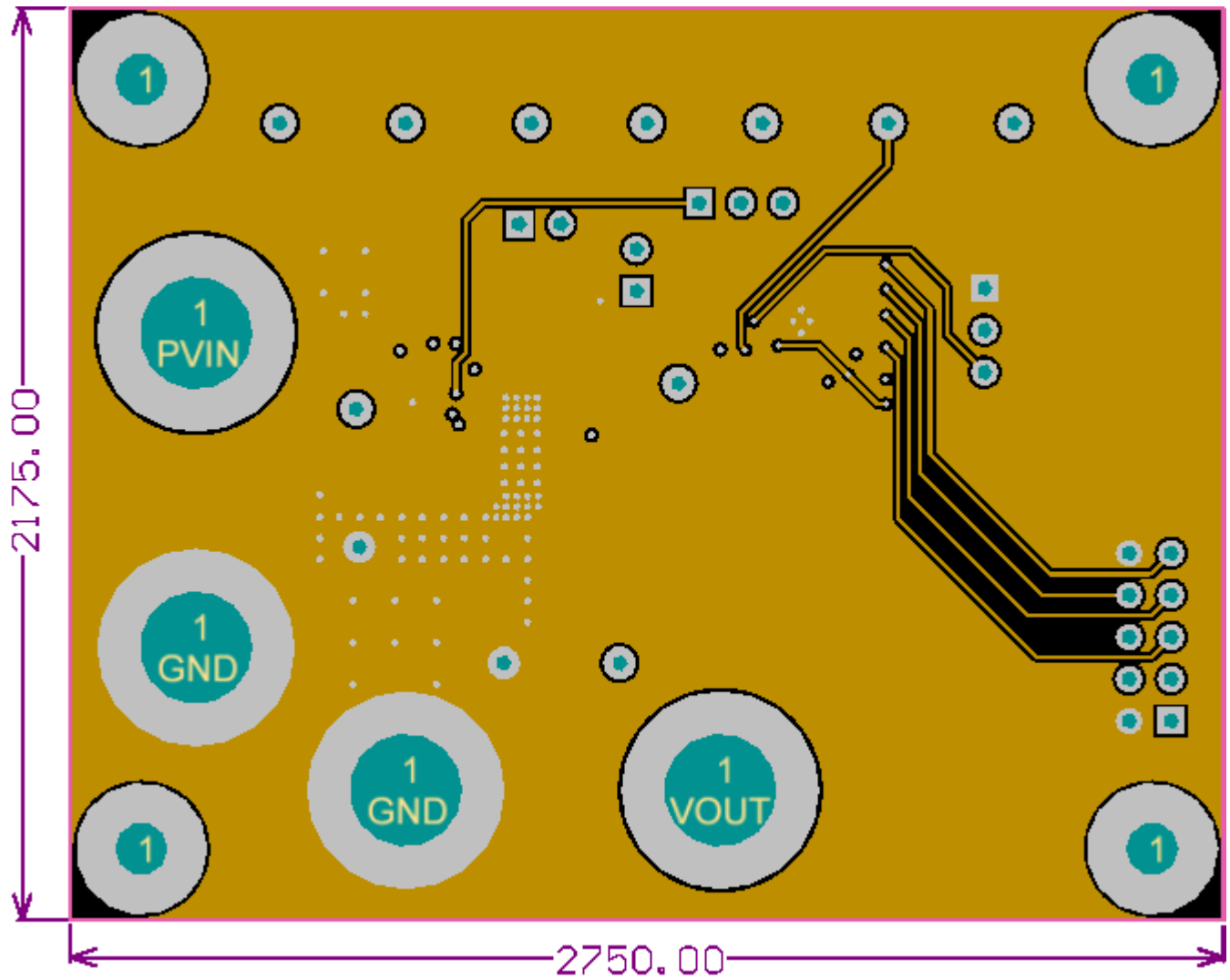


Figure 16. Mid Layer1

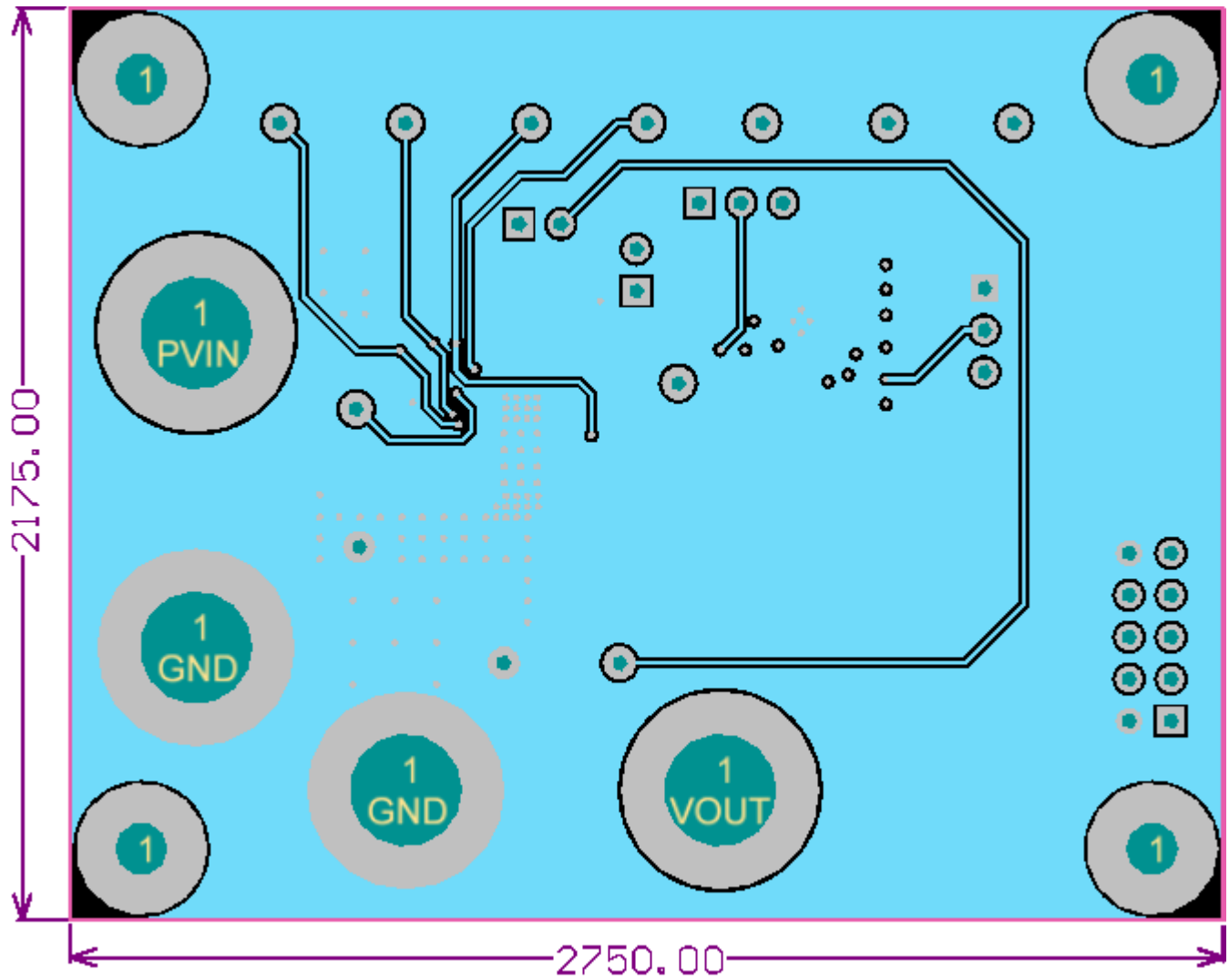


Figure 17. Mid Layer2

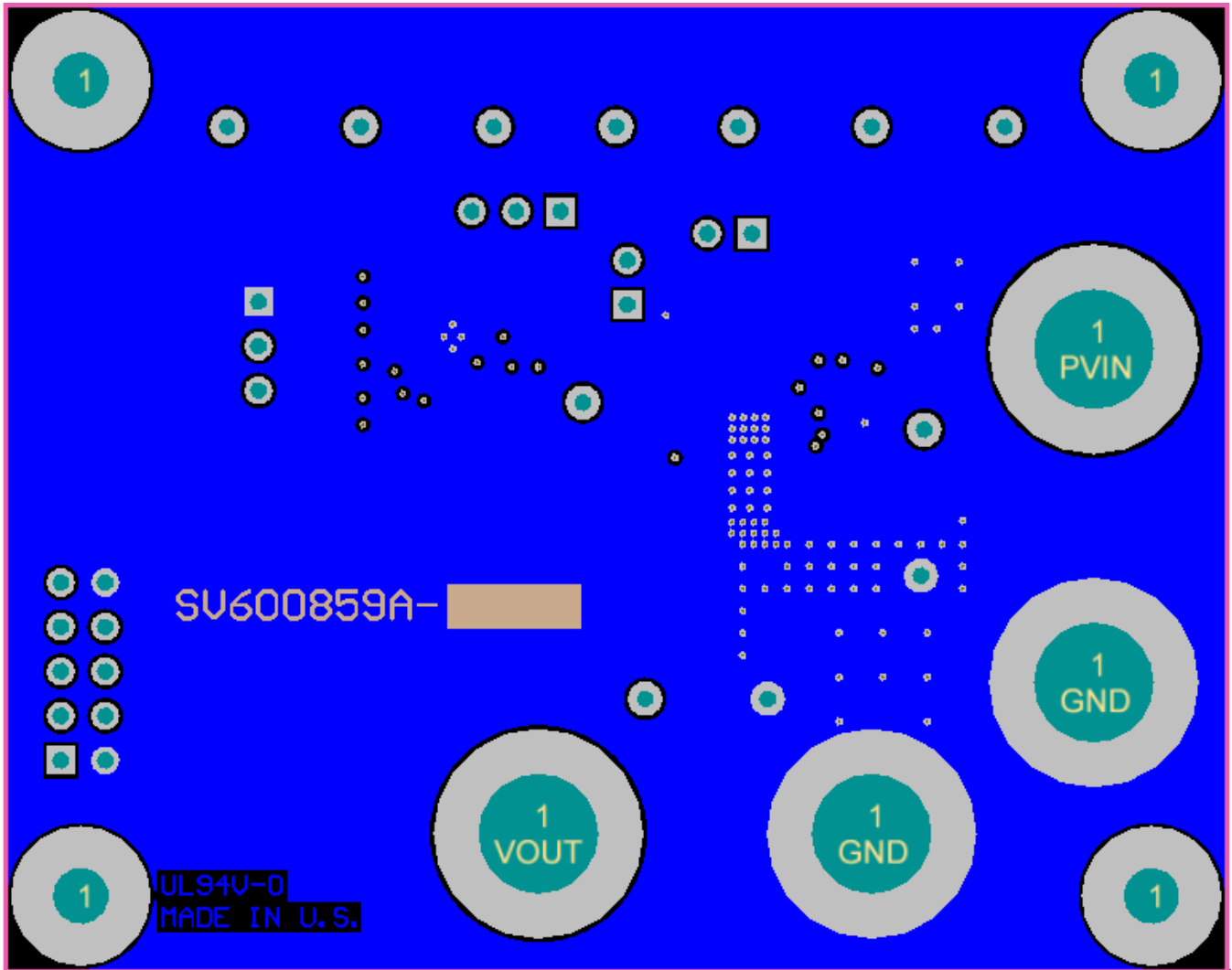


Figure 18. Bottom Layer (Rear View)

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