

## **AN-2160 LM5066 Evaluation Board**

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### **1 Introduction**

The LM5066EVK evaluation board provides the design engineer with a fully functional intelligent monitoring and protection controller board designed for positive voltage systems. This application note describes the various functions of the board, how to test and evaluate it, and how to use the GUI design tool to change the components for a specific application. Use of the advanced telemetry and monitoring capabilities of this device requires the installation of the Intelligent Power Manager graphical user interface; however, the LM5066 is capable of acting as a hot-swap and protection circuit without any software installation. Please check the *LM5066 High Voltage System Power Management and Protection IC with PMBus* ([SNVS655](#)) data sheet for the latest software information.

### **2 PCB Features**

- Input voltage range: 36V to 60V
- Programmable current limit: set to 16.7A (CL = GND or HIGH-Z) or 8.7A (CL = VDD)
- $Q_1$  power limit: 70W (typical)
- UVLO thresholds: 36V (rising) and 32V (falling)
- OVLO thresholds: 60V (rising) and 56V (falling)
- PGD thresholds: 40V (rising) and 37V (falling)
- Insertion delay: 128 ms (typical)
- Fault time-out period: 8.2 ms
- Restart time: 1.4 seconds
- PCB size: 2.3" x 3.4"

### 3 Schematic

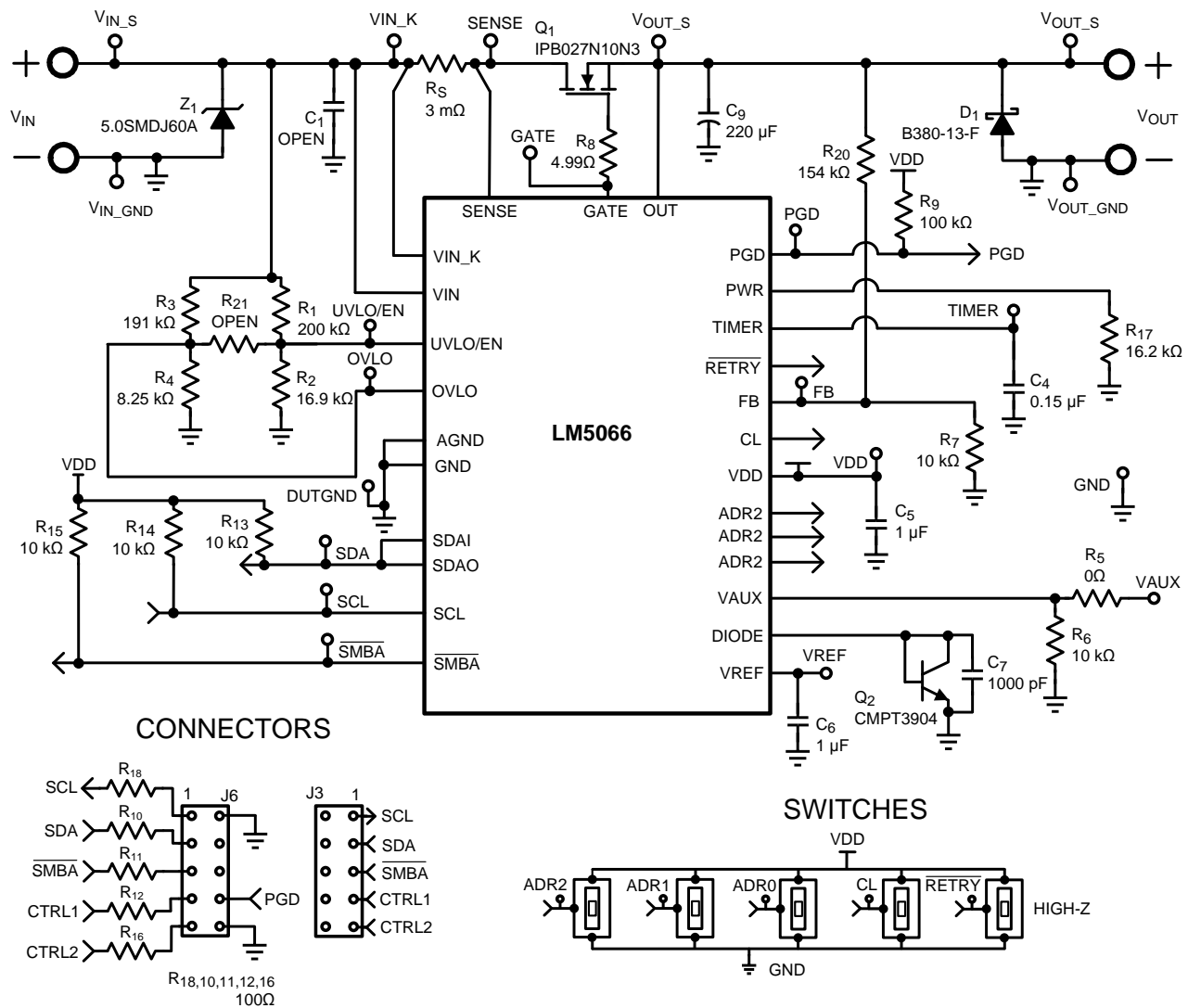


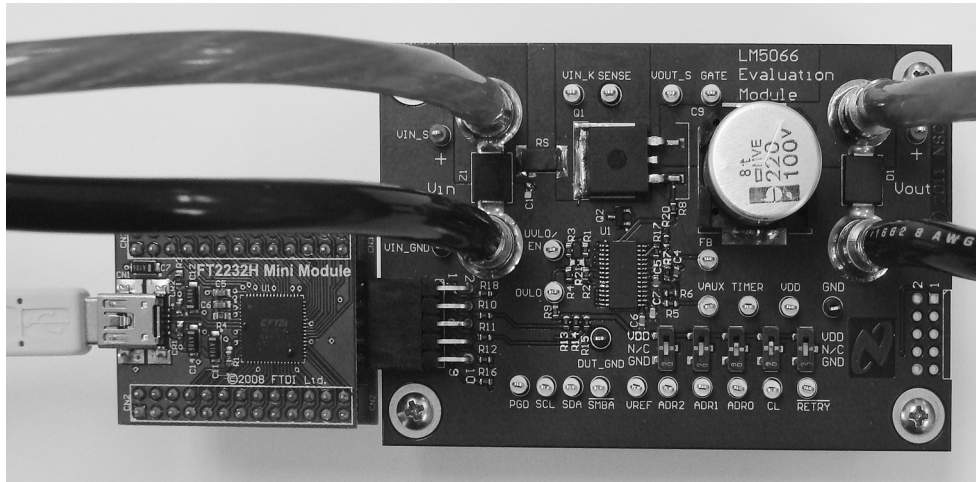
Figure 1. Evaluation Board Schematic

The schematic for the LM5066 evaluation board is shown in Figure 1. Connections to the PMBus™ interface are provided by J6. Banana connectors provide input and output connections. Pins ADR0, ADR1, and ADR2 are connected to switches that set the PMBus™ address of the device to one of 27 unique addresses. Pins RETRY and CL are also connected to switches, allowing for hardware programmability of the retry and current limit parameters, respectively. Test points are provided to connect to the input voltage, output voltage, VAUX, PGD, VREF, VDD, SENSE, GATE, FB, UVLO/EN, OVLO, SCL, SDA, SMBA and the TIMER pins.

## 4 Getting Started

The LM5066 evaluation kit hardware is shown in [Figure 2](#).

The LM5066EVK is supplied with the PMBus™ address set to 0x40 as dictated by the jumper configuration of the ADR0, ADR1, and ADR2 jumper connections.



**Figure 2. Connection Illustration**

The first step to evaluate the telemetry features of LM5066 is to install the GUI software. The software is included on a CD in the evaluation kit and is titled PMBManager-x.x.x-xxxxxxx.exe, where the x characters indicate the software version and build date. This file should be executed on a PC running Windows XP or later to install the software. Once the GUI software is installed the hardware should be configured as shown in [Figure 2](#).

## 5 Hardware Setup Steps

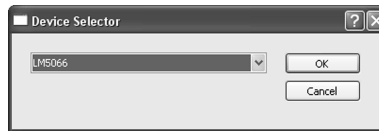
1. Connect the input supply to the VIN+ and VIN- banana plugs.
2. Connect the load to the VOUT+ and VOUT- banana plugs.
3. Connect the FTDI Dongle to the 10 pin connector on the left side of the board.
4. Connect the supplied mini USB cable from the FTDI dongle to an USB port on a PC.

When the FTDI dongle is connected for the first time the user will be prompted to install the device drivers. For the most current driver installation procedure refer to the README.TXT file in the installation directory.

For a hot swap circuit to function reliably, a low inductance connection to the input supply is recommended. Its purpose is to minimize voltage transients which occur when the load current changes or is shut off. If not careful, wiring inductance in the supply lines will generate a voltage transient at the input which can exceed the absolute maximum rating of the LM5066, resulting in its destruction. To protect against such voltage transients, TVS device Z1 is provided to clamp the voltage at the input to within safe operating limits. Likewise, Schottky diode D1 is provided on the output to clamp the output from going excessively negative during short circuit events.

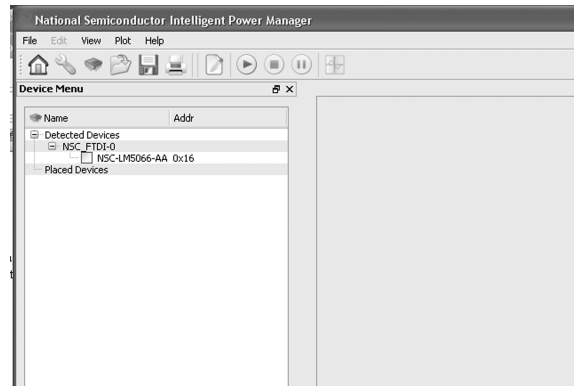
## 6 Device Evaluation

After configuring the hardware connections, apply an input voltage of 48V to the device. The current hardware configuration allows the LM5066 device to work from 36V to 60V input supply voltage; however, this guide will assume an input voltage of 48V. Launch the GUI by going to the Windows Start menu -> All Programs -> PMBManager-x.xxxxx -> PMBusManager. A pulldown menu should come up with a list of devices populated. Select the "LM5066" option as shown in [Figure 3](#).



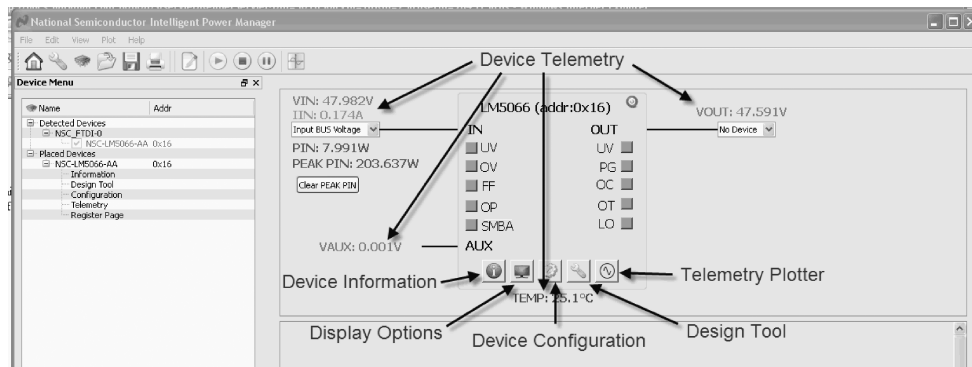
**Figure 3. Device Selector**

The device should be detected on the PMBus™ and the initial load screen should appear as shown in Figure 4.



**Figure 4. Initial GUI Screen**

If a device is not detected, an option is provided to rescan, ignore, or exit the GUI. If the hardware is intended to be connected, check the USB connection to the PCB, FTDI connection to the evaluation module, and verify that the power is present on the evaluation PCB by measuring the voltage between the  $V_{IN\_S}$  and  $V_{IN\_GND}$  test points. Ignoring the detection message allows use of the integrated design tool without the hardware connected.



**Figure 5. LM5066 Block Level Representation**

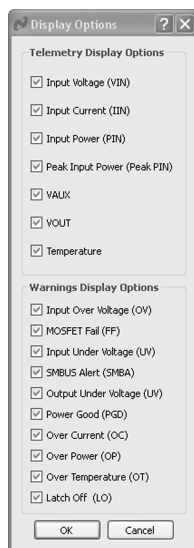
Click on the detected device ID (NSC-LM5066-AA) to display a block level representation of the device as shown in Figure 5. The block level view of the device provides a display of all the telemetry data as well as most of the faults and warnings supported by the device. The faults and warnings supported are generally associated with an invalid input or output condition.

The faults shown on the left side of the block representation are generally associated with the input. These include input under-voltage (UV), input over-voltage (OV), FET Fail (FF), and input over-power (OP). The SMBus alert status, SMBA, is also shown on the left side and will turn red during any warning or fault event. To facilitate the evaluation of the device, SMBus alerts are automatically cleared by the GUI.

The faults shown on the right side of the block representation are associated with the output. These include output over-voltage (OV), power good status (PGD), output over-current (OC), and over-temperature (OT). There is also an indicator if the output is in the latched off state (LO). The device will latch the output off after the number of user programmable retries is exceeded. To clear the latched off condition, the output can be toggled off and on by the red power button located in the top right of the LM5066 block representation.

To show a repetitive update of the device telemetry and status click on the Play button at the top of the screen. The Play button starts an active telemetry log of the gathered data. Clicking the Stop button stops the telemetry collection and allows for the log file to be viewed and saved. The pause button pauses both the displaying and logging of telemetry information.

To enable/disable specific telemetry, click the Display Options button on the block representation and choose the desired telemetry to display (see [Figure 6](#)).



**Figure 6. LM5066 Telemetry Display Options**

Note that turning off the various warning options does not mask the faults from issuing an SMBus alert - it just does not display them if they occur. The device is capable of masking various faults and this functionality can be setup in the device configuration panel.

## 7 GUI Event Log

A GUI event log is provided to keep track of GUI configuration changes and device fault events. To display the event log select View from the main menu bar and then View Event Log. The event log will appear on the left side of the main GUI window. The event log can be detached and expanded if desired by left clicking on the event log window and dragging window with the mouse to the desired location.

## 8 Plotting Telemetry Data

To enable telemetry data plots click on the sine wave button located on the LM5066 block representation. After enabling the telemetry, a prompt will appear requesting entry of the GUI sample rate, plot rate, and plot depth. For most cases the default rates and depths will be acceptable. The plotting tool allows the user to select the desired data to be plotted. Up to 2 different parameters may be plotted at the same time as shown in [Figure 7](#).

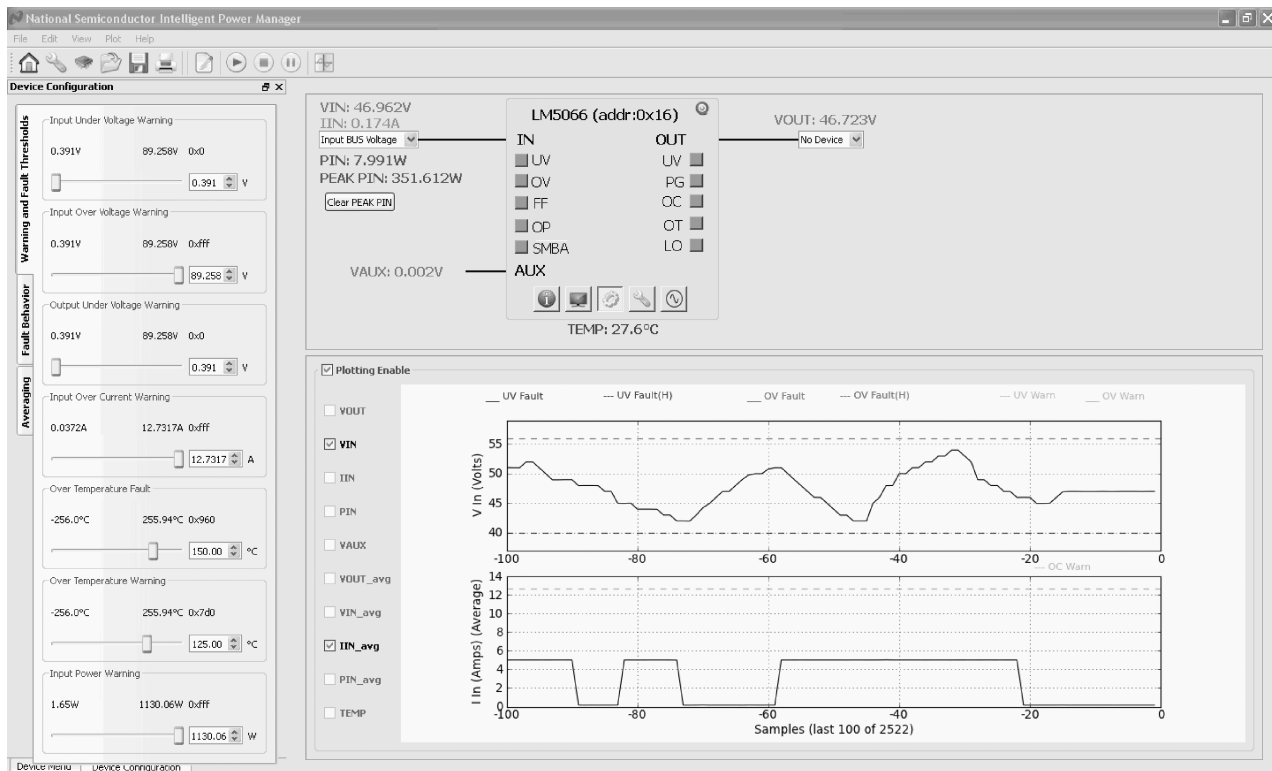


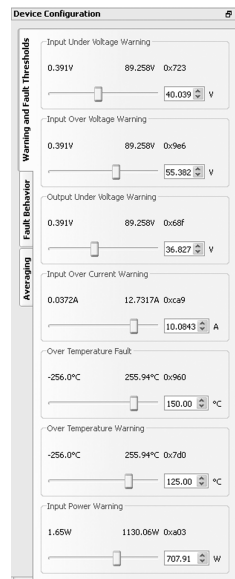
Figure 7. LM5066 GUI with Telemetry Plotting Tool Enabled

Telemetry data is plotted as a black line that continually updates as the device is queried. In addition to the telemetry data, the relevant warning and fault thresholds are also plotted. Warning thresholds are shown as orange lines while fault thresholds are shown in red and blue.

From the Plot menu option in the main menu bar, the user can disable the plotting grid as well as the warning and fault lines.

## 9 Configuring the LM5066 Device

Warning Thresholds, Temperature Fault Threshold, Protection Ranges, Fault Masking, and Averaging can be configured in the Device Configuration panel. This panel, shown in [Figure 8](#), is enabled by clicking the gear button shown on the LM5066 block representation.



**Figure 8. Device Configuration Panel**

The Warning and Fault Threshold tab allows configuration of the input under-voltage, input over-voltage, output under-voltage, input over-current, input power, and over temperature warnings. This tab also allows adjustment of the over-temperature fault threshold. Fault threshold for the input over- and under-voltage, current limit, power limit, and power good are set by the hardware design. Decimal values for the thresholds are shown in the text box located to the right of the slider bar. Above the decimal values setting is the value of the setting in hexadecimal, which can be useful when developing software for this device.

The fault behavior tab allows the user to set the device fault configuration and fault masking. The fault configuration section allows the user to set the number of retries, as well as the circuit breaker and current limit thresholds. The number of retries can be set by the `RETRY` pin to be infinite or latched off. Through software, the number of retries can be set to 0 (latch-off), 1, 2, 4, 8, 16 or infinite. The software settings are independent of the hardware settings; however, if the power is cycled the device will default to values dictated by the hardware. Current limit power-up values are also set by the hardware. The values for current limit can be set to either 26 mV (CL = VDD) or 50 mV (CL = GND). The circuit breaker threshold can also be set in software to either 1.9 times or 3.9 times the current limit value through the software. Fault masking is possible for many of the device fault conditions. Fault conditions allow masking of both the MOSFET response and the SMBus alert signal. Note that if a fault occurs repeatedly while the MOSFET is masked, damage to the MOSFET may result. This feature is allowed primarily for debug purposes. Faults that do not shut off the MOSFET, and only issue a SMBus alert, will also allow masking of the alert. Note the power-up default setting for the Power Good signal is to mask the SMBus alert, in order to ensure that SMBus alert is not asserted immediately after power-up.

For convenience, the Device Configuration Panel can be undocked by holding down the left mouse button while the cursor is at the top of the panel and dragging it to where you would like it to be placed.

## 10 Customizing the Design

The GUI assumes the hardware configuration is set to default LM5066 evaluation board configuration. If any of the components are changed, the device hardware configuration needs to be updated in the Design Tool section. To open the design tool, click the Wrench button located on the LM5066 block representation which will open the window displayed in [Figure 9](#).

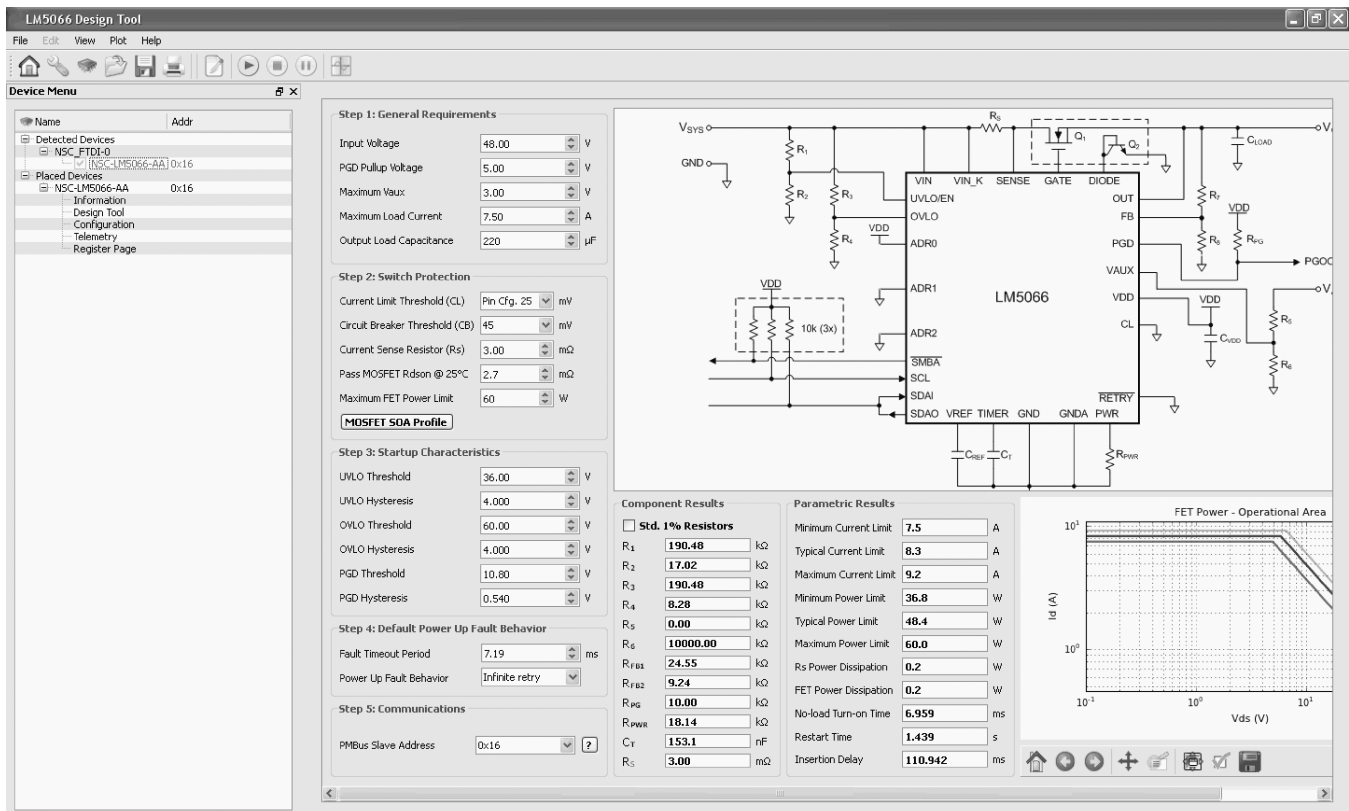


Figure 9. LM5066 Design Tool

Design inputs are keyed in on the left side following steps 1 through 5. General operating conditions should be entered in step 1 of the design tool. These inputs help set bounds on the startup time and application voltage ranges.

Step 2 allows the user to tailor the MOSFET protection features to be specific to the target application. Current limit is pin-configurable and software configurable, and circuit breaker is software-configurable. If CL switch is used to set the current limit, make sure the GUI selection matches the pin-configurable CL bit setting on the board. By clicking on the MOSFET SOA Profile button the user can select SOA data from several popular MOSFETs or enter the SOA data for the desired MOSFET. The resistor  $R_{PWR}$  can then be calculated to keep  $Q_1$  within its SOA profile.

Step 3 allows the user to select the under- and over-voltage lockout values (UVLO/OVLO), and power good (PGD) thresholds. Note that with the correct values for  $R_1 - R_4$ , and  $R_{FB1}$  and  $R_{FB2}$  installed, the LM5066 will indicate a fault condition when the input and/or output voltages are outside of their programmed range.

Step 4 allows the user to set the fault time-out period and the fault response. The fault time-out should be set to be below the MOSFET SOA data for a given time. For example, if a design is done to adhere to the 10 ms pulsed MOSFET SOA data, the desired fault time-out must be less than 10ms. The fault time-out time entered will set the value for  $C_T$ . It also sets the insertion delay and fault retry delay. The initial power up retry behavior is also selected in this design step. Make sure to change the  $\overline{RETRY}$  switch to match the design tool schematic when changing the default retry setting.

In Step 5 the user enters the desired PMBus address. Note changing the PMBus address of the device in step 5 does not change the device address, but shows how the address pins of the device need to be configured to achieve a desired address. Once the ADR pin switches are configured for a particular address, power to the device needs to be cycled and the GUI restarted in order for the new address to take affect.



When invalid or incorrect inputs are given to the design tool, text associated with the faulty input will turn red. Positioning the mouse cursor over the red text will give additional information about any design conflict.

Component and parametric results are shown to the right as well as the LM5066 safe operational area (SOA) chart. The SOA chart shows the minimum, typical, and maximum SOA protection areas for a given design. For a robust design, the SOA of the MOSFET used should be above the MAX protection SOA line for all operating areas.

Once a design is complete, the design should be saved by selecting the File menu, and then Save. Once the hardware is modified to match the design the GUI should be restarted and the hardware configuration file loaded right after the device is detected and placed. If the values in the design tool are different than the values on the board, erroneous telemetry and fault data will be reported by the GUI. To return to the block view of the device, press the Home button located at the far left in the menu bar.

The design tool is also useful to calculate the PMBus coefficients. With the correct value for current sense resistor ( $R_S$ ) the tool will calculate the correct coefficients to scale the raw telemetry data. The coefficients can be viewed by selecting View from the main menu bar, and then selecting the PMBus Coefficient Editor. When the PMBus Coefficient Editor is opened, press the Get All button to show the currently used coefficients.

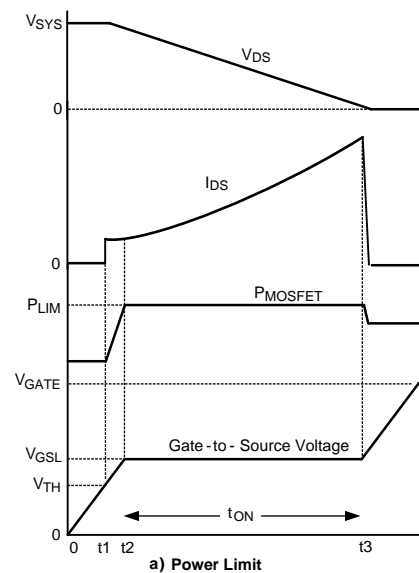
If desired the results presented by the design tool can be calculated by hand using the equations provided in the datasheet. However, note the design tool calculates parameters factoring in worst case tolerances, while the equations in the datasheet are based on typical thresholds.

## 11 Theory of Operation

The LM5066 provides intelligent control of the power to a load from a live power source. The three primary functions of the device are to limit in-rush current during turn-on, monitor the load current for faults during normal operation, and to provide system telemetry for the following parameters: Input Voltage ( $V_{IN}$ ), Input Current ( $I_{IN}$ ), Input Power ( $P_{IN}$ ), Output Voltage ( $V_{OUT}$ ), Auxilliary Voltage ( $V_{AUX}$ ), and Temperature. Additional functions include under- and over-voltage lock-outs (UVLO/OVLO) to ensure voltage is supplied to the load only when the system input voltage is within a specified range, power limiting of the series pass MOSFET ( $Q_1$ ) during turn-on, and a Power Good logic output (PGD) to indicate the output voltage status.

Upon applying the input voltage to the LM5066,  $Q_1$  is initially held off for the insertion delay (128 ms) to allow ringing and transients on the input to subside. At the end of the insertion delay, if the input voltage at  $V_{IN}$  is above the UVLO threshold,  $Q_1$  is turned on in a controlled manner to limit the in-rush current.

The LM5066 utilizes two methods to limit in-rush currents at startup. For the input voltage range and sense resistor on this board, the in-rush current will be limited by the MOSFET power limit method. The power limit method controls the input current such that a constant power is dissipated across  $Q_1$  during startup. At the onset of the startup period,  $V_{IN} = 48V$  and  $V_{OUT} = 0V$ .  $Q_1$ 's power dissipation is limited to a peak value set by  $R_{PWR}$  (70W) by monitoring its drain current (the voltage across  $R_S$ ) and its drain-to-source voltage. Their product is maintained constant by controlling the drain current as the drain-to-source voltage decreases (as the output voltage increases). This is shown in the constant power portion of [Figure 10](#) where the drain current is increasing to  $I_{LIM}$ .



**Figure 10. Power Up Using Power Limit**

If the power across  $Q_1$  does not exceed the programmed power limit, the LM5066 will also limit the drain current to the current limit value determined by the sense resistance and the selected current limit voltage threshold, 26 mV or 50 mV. The current limit will be maintained constant as the output voltage continues to increase. During the current limit period, the voltage at the TIMER pin will be rising. If the TIMER voltage reaches 3.9V before the current limit time has expired, the device will shut down and retry according to the programmed retry configuration. If the TIMER does not expire, the output voltage will rise and the drain current needed to charge the output capacitance will reduce. The output voltage will continue to rise towards the the input voltage ( $V_{DS}$  decreases to near zero), and the drain current then reduces to a value determined by the load.  $Q_1$ 's gate-to-source voltage then increases to its final value. The circuit is now in normal operation mode.

Monitoring of the load current for faults during normal operation is accomplished using the current limit circuit described above. If the load current increases to 8.67 Amps (26 mV across  $R_S$ ),  $Q_1$ 's gate is controlled to prevent the current from increasing further. When current limiting takes effect, the fault timer limits the duration of the fault. At the end of the fault time-out period  $Q_1$  is shut off, denying current to the load. The LM5066 then initiates a restart every 1.4 seconds. The restart consists of turning on  $Q_1$  and monitoring the load current to determine if the fault is still present. After the fault is removed, the circuit powers up to normal operation at the next restart. If the retry setting is changed to a limited number of retries, it will stop retrying after the programmed number of retries occur, and keep  $Q_1$  shut off until UVLO/EN is toggled, or the output is turned off, and then on via PMBus.

In a sudden overload condition (e.g. when the output is shorted to ground), it is possible the current could increase faster than the response time of the current limit circuit. In this case, the circuit breaker sensor shuts off  $Q_1$ 's gate rapidly when the voltage across  $R_S$  reaches 50 mV. When the current reduces to the current limit threshold, the current limit circuitry then takes over.

The PGD logic level output is low during turn-on and switches high when the output voltage at OUT is above 40V. PGD switches low when the voltage at OUT is below 37V. The high level voltage at PGD can be any appropriate voltage up to +80V and can be higher or lower than the voltages at VIN and OUT.

The UVLO thresholds are set by resistors R1 and R2, the OVLO thresholds are set by R3 and R4, and the PGD thresholds are set by resistors RFB1 and RFB2 ( $R_{20}$  and  $R_7$  on the board). Internal current sources at the UVLO, OVLO, and FB pins provide hysteresis for these thresholds.

## 12 Fault Detection & Restart

If the load current increases to the fault level (the current limit threshold of 8.67A), an internal current source charges the timing capacitor at the TIMER pin. When the voltage at the TIMER pin reaches 3.9V, the fault time-out period is complete and the LM5066 shuts off  $Q_1$ . The restart sequence then begins, consisting of seven cycles at the TIMER pin between 3.9V and 1.1V, as shown in Figure 11. When the voltage at the TIMER pin reaches 0.3V during the eighth high-to-low ramp,  $Q_1$  is turned on. If the fault is still present, the fault time-out period and the restart sequence repeat.

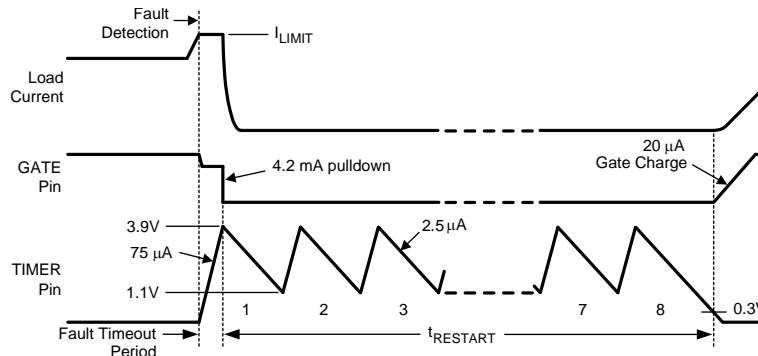


Figure 11. Fault Time-out and Restart Sequence

The waveform at the TIMER pin can be monitored at the TIMER test point. On this evaluation board, the initial fault time-out period is 8.2 ms and the restart time is 1.4 seconds.

## 13 UVLO and OVLO Input Voltage Threshold

Programming the UVLO threshold sets the minimum system voltage to enable  $Q_1$ . If  $V_{IN}$  is below the UVLO thresholds,  $Q_1$  is switched off, denying power to the load. Programmable hysteresis is adjustable by changing the value of R1.

The UVLO thresholds are set with two resistors (R1, R2) as shown in Figure 12 .

The OVLO threshold sets the maximum voltage that can be present on the input before the device turns off the series pass device. The OVLO threshold is set with the two resistors (R3, R4). The hysteresis voltage is set by the internal 21  $\mu$ A current source and the value of R3.

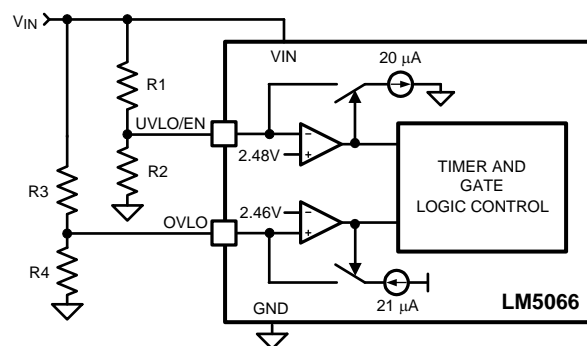
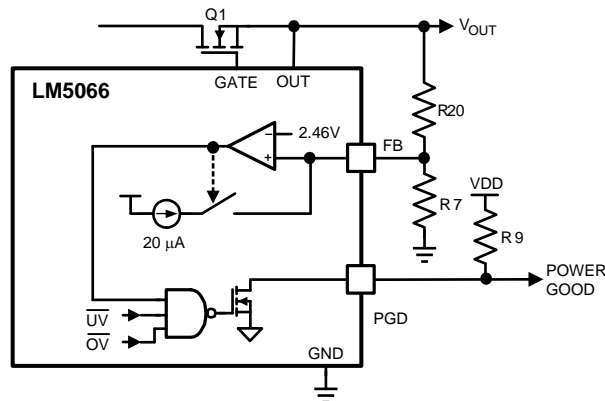


Figure 12. Programming the UVLO Threshold

## 14 PGD and FB Pins

During turn-on, the Power Good pin (PGD) will not be able to pull low until the voltage at VIN increases above  $\approx 1.6\text{V}$ . Pulling the PGD pin up to VDD will keep the PGD pin low during this region because VDD does not turn on until VIN increases above  $\approx 7\text{V}$ . When the voltage at the board's output pin increases above 40V (typ), PGD switches high. PGD switches low when the output voltage decreases below 37V (typ). Additionally, PGD switches low if the UVLO/EN pin is taken below its threshold regardless of the output voltage.

The output voltage threshold for the PGD pin is set with two resistors (RFB1, RFB2 on the GUI,  $R_{20}$  and  $R_7$  on the board) at the FB pin.



**Figure 13. Programming the PGD Threshold**

A pull-up voltage and pull-up resistor are required at PGD as shown in Figure 13. The pull-up voltage (VPGD) can be as high as 80V with transient capability to 100V and can be higher or lower than the voltages at VIN and OUT.

## 15 Shutdown

With the circuit in normal operation, the LM5066 can be shutdown by grounding the UVLO/EN pin or by clicking the ON/OFF button on the LM5066 block representation in the GUI.

## 16 Board Layout and Probing Cautions

Refer to the product datasheet for detailed layout guidelines. For most applications the layout of this evaluation module as detailed in the PC Board Layout section of this document should be sufficient to provide a working solution with accurate telemetry. The following should be kept in mind when the board is powered:

1. Use CAUTION when probing the circuit to prevent injury as well as possible damage to the circuit.
2. At maximum load current (16.7A), the wire size and length used to connect the power source and the load become very important. The wires connecting this evaluation board to the power source should be a heavy gauge and twisted together to minimize inductance in those leads. The same applies for the wires connecting this board to the load. This recommendation is made in order to minimize high voltage transients from occurring when the load current is shut off.
3. A 60V TVS diode located as close as possible to the LM5066 VIN and GND pins provides the critical function of clamping inevitable input voltage overshoot when  $Q_1$  turns off at high currents. If operation above 60V is required, the TVS will need to be replaced with a TVS rated at a higher standoff voltage. Always verify the TVS by performing a worst-case current limit at the maximum input voltage and monitoring the resulting input voltage surge. The TVS should be able to clamp the input below 100V in all cases.
4. The ground points for the UVLO/EN, OVLO and FB resistor networks are tied directly to a via where the LM5066 is connected to the ground plane. The ground for the temperature sensing transistor, Q2, is also tied back to the LM5066 ground.
5. Input capacitor, C1, local to the LM5066 is not populated due to the input current spike to charge this

capacitor. Populating C1 will result in reduced VIN voltage slew rates at the expense of increased inrush current during a hot insertion.

### 17 Performance Characteristics

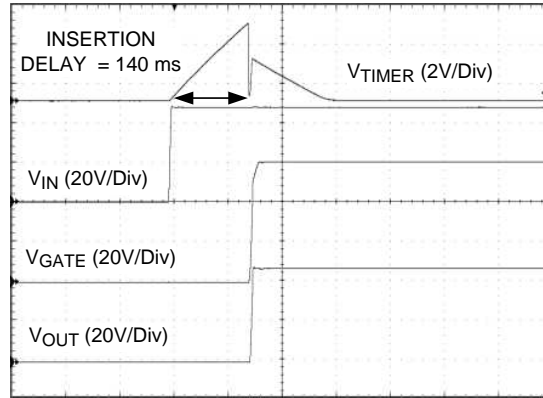


Figure 14. Insertion Time Delay (100 ms/DIV)

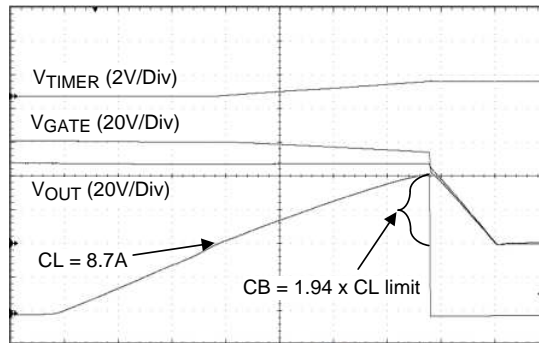


Figure 15. Circuit Breaker Response (500  $\mu$ s/DIV)

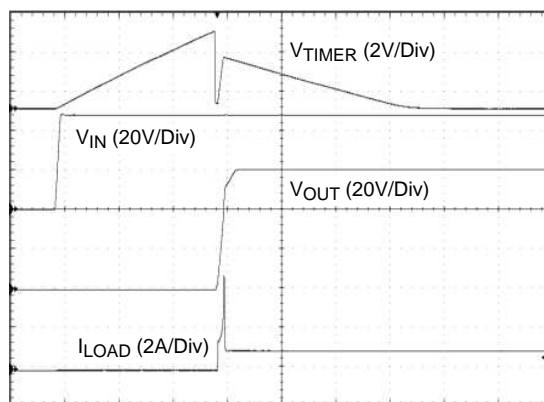


Figure 16. Turn-On Sequence into a 4 $\Omega$  Load (50 ms/DIV)

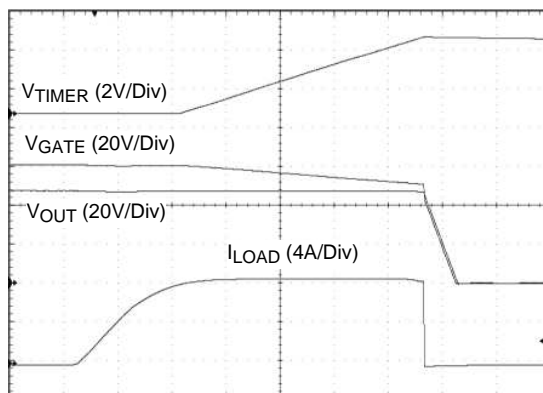


Figure 17. Initial Fault Timeout (2 ms/DIV)

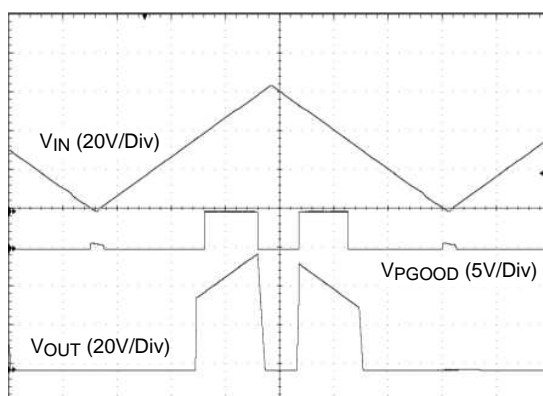


Figure 18. PGD Power up/Power down behavior (200 ms/DIV)

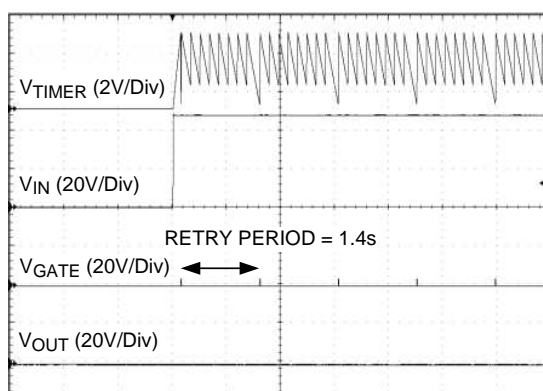
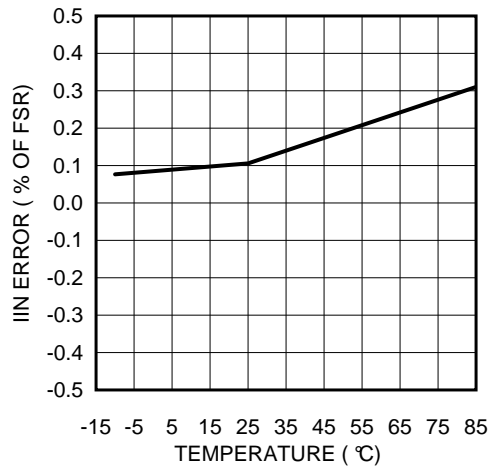
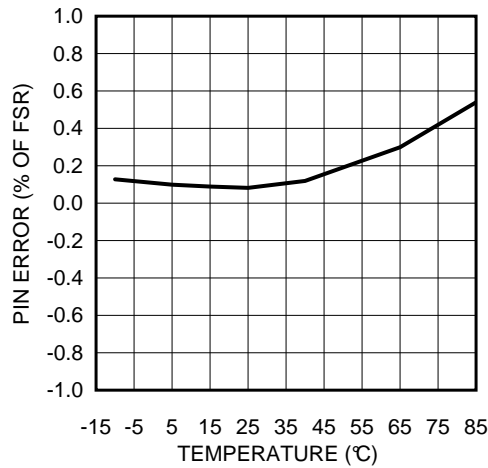


Figure 19. Restart Timing (1 s/DIV)



**Figure 20. IIN Error vs Temperature**



**Figure 21. PIN Error vs Temperature**

**18 Bill of Materials**

Designator	Value	Description	Manufacturer	Part Number	Qty.
U1		HOT SWAP CONTROLLER	Texas Instruments	LM5066	1
C4	0.15 $\mu$ F	CAP, CERM, 0.15 $\mu$ F, 10V, +/-10%, X7R, 0603	MuRata	GRM188R71A154KA01D	1
C5, C6	1 $\mu$ F	CAP, CERM, 1 $\mu$ F, 16V, +/-10%, X5R, 0603	Kemet	C0603C105K4PACTU	2
C7	1000 pF	CAP, CERM, 1000pF, 50V, +/-10%, X7R, 0603	TDK	C1608X7R1H102K	1
C9	220 $\mu$ F	CAP, AL, 220 $\mu$ F, 100V, +/-20%, SMD	Nippon Chemi-Con	EMVE101GDA221MLN0S	1
D1		Diode, Schottky, 80V, 3A, SMC	Diodes Inc.	B380-13-F	1
Q1		MOSFET N-CH 100V 120A TO263-3	Infineon Technologies	IPB027N10N3 G	1
Q2		Transistor, NPN, 40V, 0.2A, SOT-23	Central Semiconductor	CMPT3904 LEAD FREE	1
R1	200 k $\Omega$	RES, 200k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603200KFKEA	1
R3	191 k $\Omega$	RES, 191k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603191KFKEA	1
R2	16.9 k $\Omega$	RES, 16.9k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060316K9FKEA	1
R4	8.25 k $\Omega$	RES, 8.25k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06038K25FKEA	1
R5	0 $\Omega$	RES, 0 ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06030000Z0EA	1
R6,R7, R13, R14, R15	10.0 k $\Omega$	RES, 10.0k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060310K0FKEA	5
R8	4.99 $\Omega$	RES, 4.99 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06034R99FKEA	1
R9	100 k $\Omega$	RES, 100k ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW0603100KJNEA	1
R10, R11, R12, R16, R18	100 $\Omega$	RES, 100 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603100RFKEA	5
R17	16.2 k $\Omega$	RES, 16.2k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060316K2FKEA	1
R20	154 k $\Omega$	RES, 154k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603154KFKEA	1
RS	3 m $\Omega$	RES .003 OHM 1W 1% 2512 SMD	Vishay-Dale	WSL25123L000FEA	1
SW1, SW2, SW3, SW4, SW5		SWITCH SLIDE SPDT SMD J-LEAD 50 V, 100 mA	Copal	CJS-1201TA	5
Z1		DIODE TVS 60V 5000W 5% UNI SMD	Littlefuse	5.0SMDJ60A	1



19 PC Board Layout

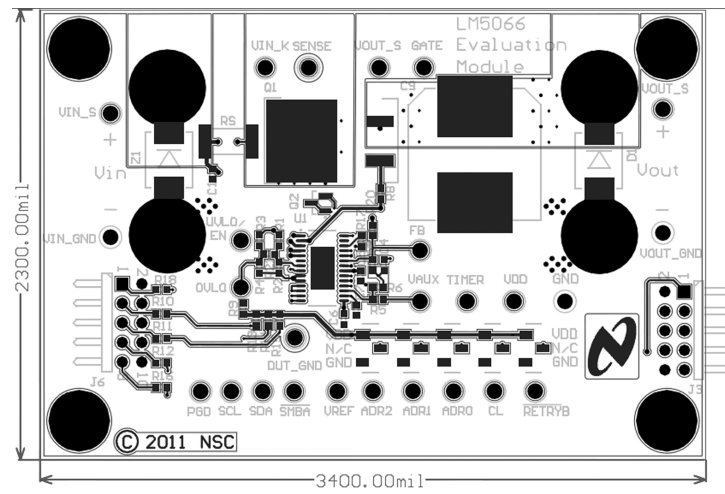


Figure 22. Board Top Layer (planes outlined in grey)

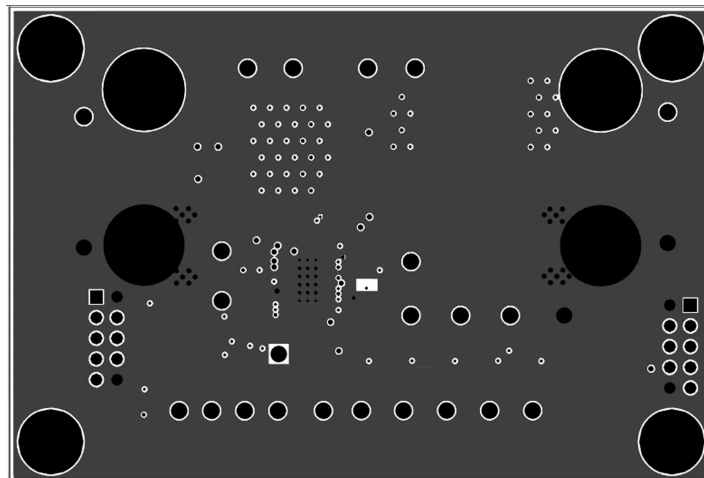


Figure 23. Board Mid Layer 1 (ground plane)

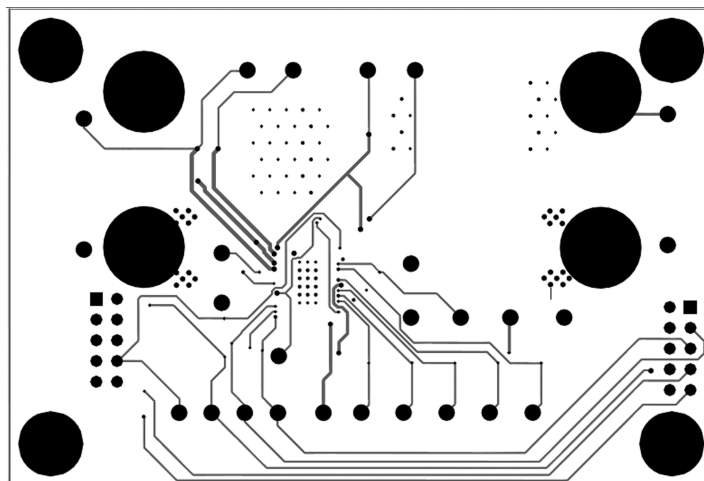
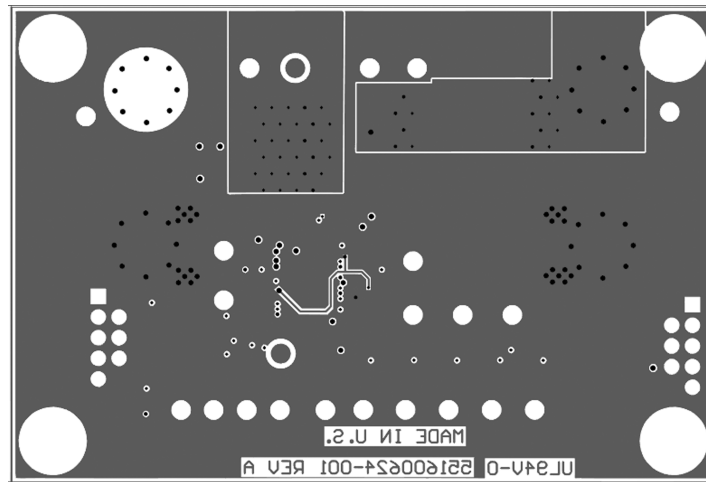


Figure 24. Board Mid Layer 2



**Figure 25. Board Bottom Layer (viewed from top)**

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1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.
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  - 2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
  - 2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.
  - 2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

### **WARNING**

**Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.**

**User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.**

**NOTE:**

**EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.**

### 3 Regulatory Notices:

#### 3.1 United States

##### 3.1.1 Notice applicable to EVMs not FCC-Approved:

**FCC NOTICE:** This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

##### 3.1.2 For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:

#### **CAUTION**

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

#### **FCC Interference Statement for Class A EVM devices**

*NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.*

#### **FCC Interference Statement for Class B EVM devices**

*NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:*

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

#### 3.2 Canada

##### 3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247

#### **Concerning EVMs Including Radio Transmitters:**

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

#### **Concernant les EVMs avec appareils radio:**

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

#### **Concerning EVMs Including Detachable Antennas:**

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

### Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

#### 3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see [http://www.tij.co.jp/lstds/ti\\_ja/general/eStore/notice\\_01.page](http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page) 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html>

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

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西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see [http://www.tij.co.jp/lstds/ti\\_ja/general/eStore/notice\\_02.page](http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_02.page)

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#### 3.4 European Union

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):*

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

- 
4. *EVM Use Restrictions and Warnings:*
    - 4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.
    - 4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.
    - 4.3 *Safety-Related Warnings and Restrictions:*
      - 4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user 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, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.
      - 4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.
    - 4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.
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