

AN-2131 LM21215A-1 Evaluation Board

1 Introduction

This evaluation board provides a solution to examine the high efficiency LM21215A-1 buck switching 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 reference. This device also features a clock synchronization input that allows the switching frequency to be synchronized to an external clock source. The 300 kHz to 1.5 MHz frequency synchronization range enables the user to minimize the power stage component size, while still allowing for high efficiency. The LM21215A-1 is capable of down converting from an input voltage between 2.95V and 5.5V. Fault protection features include current limit, output power good, and output over-voltage protection. The dual function soft-start/tracking pin can be used to control the startup response of the LM21215A-1, and the precision enable pin can be used to easily sequence the LM21215A-1 in applications with sequencing requirements.

The LM21215A-1 evaluation board has been optimized to work from 2.95V to 5.5V, achieving a balance between overall solution size and regulator efficiency. The evaluation board measures just over 2" x 2" on a four layer PCB, and exhibits a junction-to-ambient thermal impedance (θ_{JA}) of 24°C/W with no air flow. The power stage and compensation components of the LM21215A-1 evaluation board have been optimized for an input voltage of 5V, but for testing purposes, the input can be varied across the entire operating range. The output voltage of the evaluation board is nominally 1.2V, but this voltage can be easily changed to any voltage between 0.6V and V_{IN} by modifying the feedback resistor network.

2 Evaluation Board Schematic

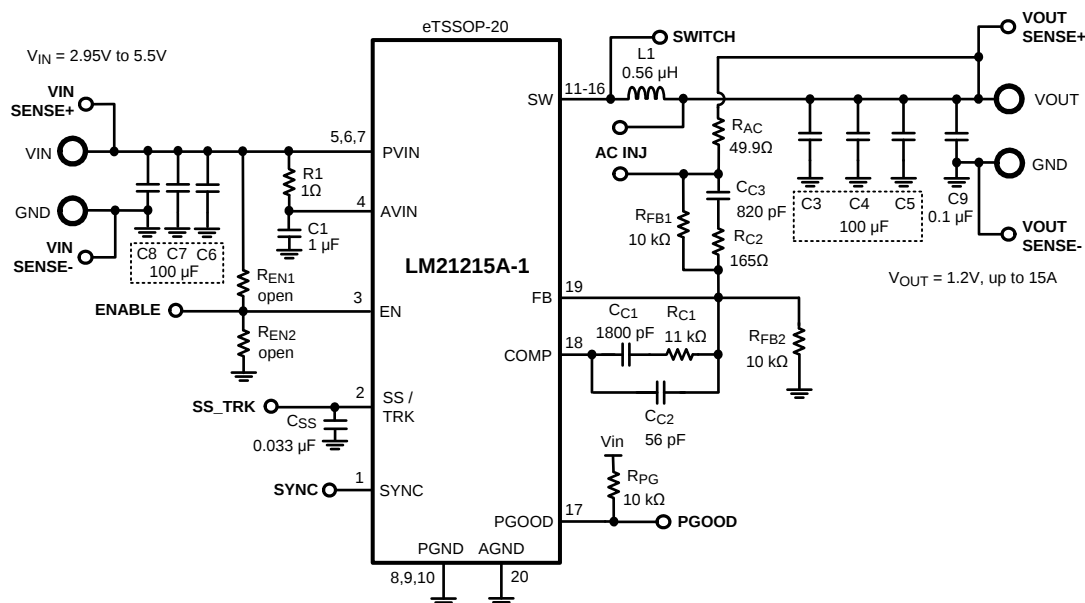


Figure 1. Evaluation Board Schematic

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3 Powering and Loading Considerations

Read this entire section prior to attempting to power the evaluation board.

3.1 Quick Setup Procedure

Step 1: Set the input source current limit to 10A. Turn off the input source. Connect the positive output of the input source to V_{IN} and the negative output to the corresponding GND.

Step 2: Connect the load (with 15A capability) to V_{OUT} for the positive connection and GND for the negative connection.

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

Step 4: Set the input source voltage to 5V. The load voltage should be in regulation with a nominal 1.2V output.

Step 5: Slowly increase the load while monitoring the load voltage at V_{OUT} . It should remain in regulation with a nominal 1.2V output as the load is increased up to 15A.

Step 6: Slowly sweep the input source voltage from 2.95V to 5.5V. The load voltage should remain in regulation with a nominal 1.2V output. If desired, the output of the device can be disabled by connecting the ENABLE pin to GND.

Step 7: The frequency of operation can be varied as desired by connecting a 2.0V square-wave positive signal between SYNC and GND.

3.2 Powering Up

It is suggested that the load power be kept low during the first power up. Once the device is powered up, immediately check for 1.2V at the output.

A quick efficiency check is the best way to confirm that everything is operating properly. If something is amiss you can be reasonably sure that it will affect the efficiency adversely. Few parameters can be incorrect in a switching power supply without creating losses and potentially damaging heat.

Some voltage supplies can exhibit severe voltage overshoot during high current transients. If a supply overshoots above 6.0V, damage to the LM21215A-1 can occur. For these supplies, a large capacitor across the terminals of the supply (1000 μ F) can alleviate this problem.

3.3 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.

4 Connection Descriptions

Table 1. Connection Descriptions

Terminal Silkscreen	Description
VIN	This terminal is the input voltage to the device. The evaluation board will operate over the input voltage range of 2.95V to 5.5V.
GND	These terminals are the ground connections to the device. The input power ground should be connected next to the input V_{IN} connection, and the output power ground next to the V_{OUT} 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 device. This terminal 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 1.2V will disable the device.
SS/TRK	This terminal provides access to the SS/TRK pin of the device. Connections to this terminal 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 device. This pin is pulled up through a 10 k Ω pull-up resistor to V_{IN} .

Table 1. Connection Descriptions (continued)

Terminal Silkscreen	Description
AC INJ	This terminal block allows the user to insert an AC injection signal across a 49.9Ω resistor for open-loop gain bode measurements. A jumper shorts out 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 device. The LM21215A-1 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.

5 Component Selection

This section provides a walk-through of the design process of the LM21215A-1 evaluation board. Unless otherwise indicated, all equations assume units of amps (A) for current, farads (F) for capacitance, henries (H) for inductance, and volts (V) for voltages.

5.1 Input Capacitors: C1, C2, C3

The required RMS current rating of the input capacitor for a buck regulator can be estimated by the following equation:

$$I_{CIN(RMS)} = I_{OUT} \sqrt{D(1-D)} \quad (1)$$

The variable D refers to the duty cycle, and can be approximated by:

$$D = \frac{V_{OUT}}{V_{IN}} \quad (2)$$

From this equation, it follows that the maximum $I_{CIN(RMS)}$ requirement will occur at a full 15A load current with the system operating at 50% duty cycle. Under this condition, the maximum $I_{CIN(RMS)}$ is given by:

$$I_{CIN(RMS)} = 15A \sqrt{0.5 \times 0.5} = 7.5A \quad (3)$$

Ceramic capacitors feature a very large I_{RMS} rating in a small footprint, making a ceramic capacitor ideal for this application.

The input capacitors also keep the input stable during load transient conditions. If the input capacitance is too low, the input can drop below the UVLO threshold and cause the device to disable the output. This may result in repetitive dropout and re-enable oscillation, or "motorboating". To give the user the ability to operate with a low V_{IN} voltage, three 100 μF ceramic capacitors were used on the input.

5.2 Inductor: L1

The value of the inductor was selected to allow the device to achieve a 5V to 1.2V conversion at 500kHz to provide a peak to peak ripple current of 3.2A, which is about 21% of the maximum output current. To have an optimized design, generally the peak to peak inductor ripple current should be kept to within 20% to 40% of the rated output current for a given input voltage, output voltage and operating frequency. The peak to peak inductor ripple current can be calculated by the equation:

$$\Delta I_{P-P} = \frac{(V_{IN} - V_{OUT}) \times D}{L \times f_{SW}} \quad (4)$$

Once an inductance value is calculated, an actual inductor needs to be selected based on a trade-off between physical size, efficiency, and current carrying capability. For the LM21215A-1 evaluation board, a Vishay IHLP4040DZERR56M01 inductor offers a good balance between efficiency (1.8 mΩ DCR) and size.

5.3 Output Capacitors: C3, C4, C5, C9

The value of the output capacitor in a buck regulator influences the voltage ripple that will be present on the output voltage as well as the large signal output voltage response to a load transient. Given the peak-to-peak inductor current ripple (ΔI_{P-P}) the output voltage ripple can be approximated by the equation:

$$\Delta V_{OUT} = \Delta I_{P-P} \times \left[R_{ESR} + \frac{1}{8 \times f_{SW} \times C_{OUT}} \right] \quad (5)$$

The variable R_{ESR} above refers to the ESR of the output capacitor. As can be seen in Equation 5, the ripple voltage on the output can be divided into two parts, one of which is attributed to the AC ripple current flowing through the ESR of the output capacitor and another due to the AC ripple current actually charging and discharging the output capacitor. The output capacitor also has an effect on the amount of droop that is seen on the output voltage in response to a load transient event.

For the evaluation board, three 100 μ F ceramic capacitors were selected to provide good transient and DC performance. Ceramic capacitors give the lowest R_{ESR} of any standard capacitor chemistries, resulting in the lowest output ripple for the given ripple current. Ceramic capacitors (especially high capacitance, small package multi-layer types, or MLCC) lose their capacitance as the DC voltage is increased. For this configuration, the actual capacitance value was approximated to be 50 μ F per capacitor, or 150 μ F total. This is lower than measured capacitance values for 1.2V, but will allow the user to change the output voltage up to 3.3V and maintain stability.

5.4 Soft-Start Capacitor: C_{SS}

A soft-start capacitor can be used to control the startup time of the LM21215A-1 voltage regulator. The startup time of the regulator when using a soft-start capacitor can be estimated by the following equation:

$$t_{SS} = \frac{0.6V \times C_{SS}}{I_{SS}} \quad (6)$$

For the LM21215A-1, I_{SS} is nominally 5 μ A. For the evaluation board, the soft-start time has been designed to be roughly 10 ms, resulting in a C_{SS} capacitor value of 33 nF.

5.5 Compensation Components: C_{C1}, C_{C2}, C_{C3}, R_{C1}, R_{C2}

These components are used in conjunction with the error amplifier to create a type 3 voltage-mode compensation network. The analysis of type 3 compensation is outside the scope of this document, but an example of the step-by-step procedure to generate compensation component values is given. The parameters needed for the compensation values are given in the following table.

Parameter	Value
V_{IN}	5.0V
V_{OUT}	1.2V
I_{OUT}	15A
$f_{CROSSOVER}$	100 kHz
L	0.56 μ H
R_{DCR}	1.8 m Ω
C_O	150 μ F
R_{ESR}	1.0 m Ω
ΔV_{RAMP}	0.95V
f_{SW}	500 kHz

where ΔV_{RAMP} is the oscillator peak-to-peak ramp voltage (nominally 0.8 V, however, 0.95V is used here to cover a broad frequency and input voltage combination range), $f_{CROSSOVER}$ is the frequency at which the open-loop gain is a magnitude of 1, R_{DCR} is the effective DC resistance of the inductor, R_{ESR} is the effective resistance of the output capacitor, and C_O is the effective output capacitance at the programmed output voltage. It is recommended that $f_{CROSSOVER}$ not exceed one-fifth of the switching frequency. The output capacitance, C_O , depends on capacitor chemistry and bias voltage. For Multi-Layer Ceramic Capacitors

(MLCC), the total capacitance will degrade as the DC bias voltage is increased. Measuring the actual capacitance value for the output capacitors at the output voltage is recommended to accurately calculate the compensation network. Note that it is more conservative, from a stability standpoint, to err on the side of a smaller output capacitance value in the compensation calculations rather than a larger, as this will result in a lower bandwidth but increased phase margin.

First, the value of R_{FB1} should be chosen. A typical value is 10k Ω . From this, the value of R_{C1} can be calculated to set the mid-band gain so that the desired crossover frequency is achieved.

$$\begin{aligned} R_{C1} &= \frac{f_{CROSSOVER}}{f_{LC}} \cdot \frac{\Delta V_{RAMP}}{V_{IN}} \cdot R_{FB1} \\ &= \frac{100 \text{ kHz}}{17.4 \text{ kHz}} \cdot \frac{0.95 \text{ V}}{5.0 \text{ V}} \cdot 10 \text{ k}\Omega \\ &= 10.9 \text{ k}\Omega \end{aligned} \quad (7)$$

Next, the value of C_{C1} can be calculated by placing a zero at half of the LC double pole frequency.

$$\begin{aligned} C_{C1} &= \frac{1}{\pi f_{LC} R_{C1}} \\ &= 1.67 \text{ nF} \end{aligned} \quad (8)$$

Now the value of C_{C2} can be calculated to place a pole at half of the switching frequency.

$$\begin{aligned} C_{C2} &= \frac{C_{C1}}{\pi f_{SW} R_{C1} C_{C1} - 1} \\ &= 61 \text{ pF} \end{aligned} \quad (9)$$

R_{C2} can then be calculated to set the second zero at the LC double pole frequency.

$$\begin{aligned} R_{C2} &= \frac{R_{FB1} f_{LC}}{f_{ESR} - f_{LC}} \\ &= 166\Omega \end{aligned} \quad (10)$$

Last, C_{C3} can be calculated to place a pole at the same frequency as the zero created by the output capacitor ESR.

$$\begin{aligned} C_{C3} &= \frac{1}{2\pi f_{ESR} R_{C2}} \\ &= 898 \text{ pF} \end{aligned} \quad (11)$$

The standard values used for the above calculations are given in the Bill of Materials ([Section 7](#)).

5.6 Feedback Resistors: R_{FB1} , R_{FB2} , and R_{AC}

The resistors labeled R_{FB1} and R_{FB2} create a voltage divider from V_{OUT} to the feedback pin that is used to set the output of the voltage regulator. Nominally, the output of the LM21215A-1 evaluation board is set to 1.2V, giving resistor values of $R_{FB1} = R_{FB2} = 10\text{k}\Omega$. If a different output voltage is required, the value of R_{FB2} can be adjusted according to the equation:

$$R_{FB1} = \left(\frac{V_{OUT}}{0.6} - 1 \right) \times R_{FB2} \quad (12)$$

R_{FB1} does not need to be changed from its value of 10k Ω . Resistor R_{AC} has a value of 49.9 Ω and is provided as an injection point for loop stability measurements, as well as, a way to further tweak the output voltage accuracy to account for resistor tolerance values differing from ideal calculated values. The jumper is used to short out R_{AC} when not needed.

5.7 Programmable UVLO: R_{EN1} and R_{EN2}

The resistors labeled R_{EN1} and R_{EN2} create a voltage divider from V_{IN} to the enable pin that can be used to enable the device above a programmed V_{IN} , effectively creating a programmable UVLO voltage above the device's internal UVLO (nominally 2.7V). To allow evaluation of the device down to 2.95V, these components are not installed. To change the turn-on threshold of the device a 10 k Ω resistor is recommended for R_{EN1} and the value of R_{EN2} can be calculated using the equation:

$$R_{EN1} = \left(\frac{V_{TO}}{1.35} - 1 \right) \times R_{EN2} \quad (13)$$

where V_{TO} is the desired V_{IN} voltage at which the device will enable.

6 Performance Characteristics

Figure 2 shows the conversion efficiency versus output current for a 5V input voltage for 500kHz, 1MHz, and 1.5MHz f_{SW} .

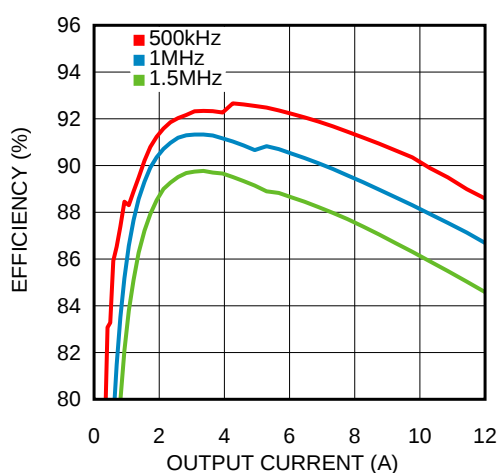


Figure 2. Conversion Efficiency Versus Output Current

A soft-start sequence occurs when applying power to the LM21215A-1 evaluation board. Figure 3 shows the output voltage during a typical start-up sequence.

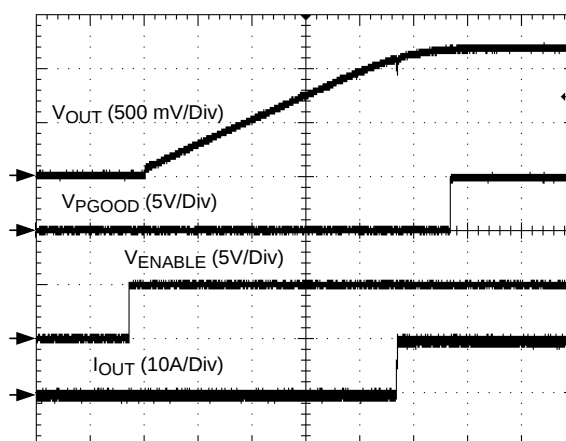


Figure 3. Startup Waveform (200 μ s/DIV)

Figure 4 shows the output voltage ripple. This measurement was taken with the scope probe tip placed on the output capacitor C9 VOUT connection and the scope probe ground "barrel" wired to the GND connection of C9. The scope bandwidth is set to 20 MHz.

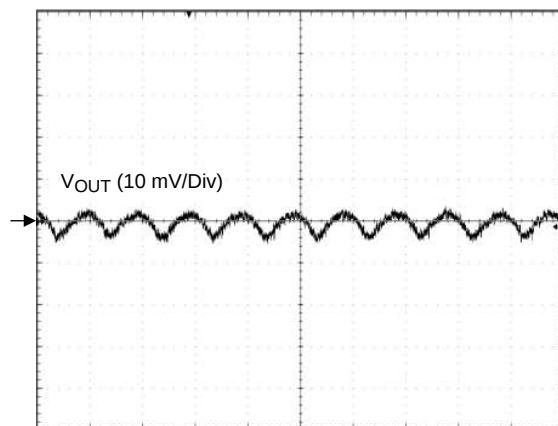


Figure 4. Output Ripple Waveform (1 μ s/DIV)

Figure 5 shows the typical SW pin voltage while synchronizing to an external source.

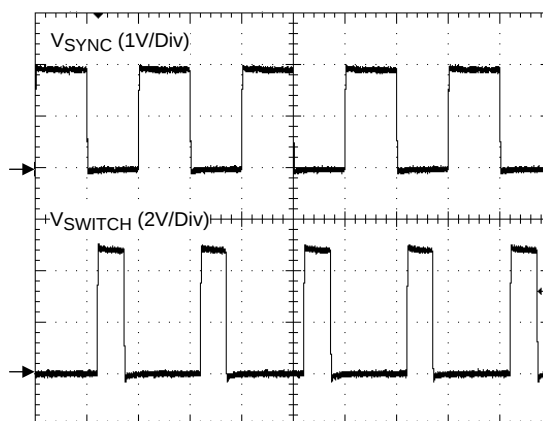


Figure 5. Primary Switch Node Waveform (1 μ s/DIV)

Figure 6 shows the V_{OUT} deviation for a 3A to 15A output current transient condition.

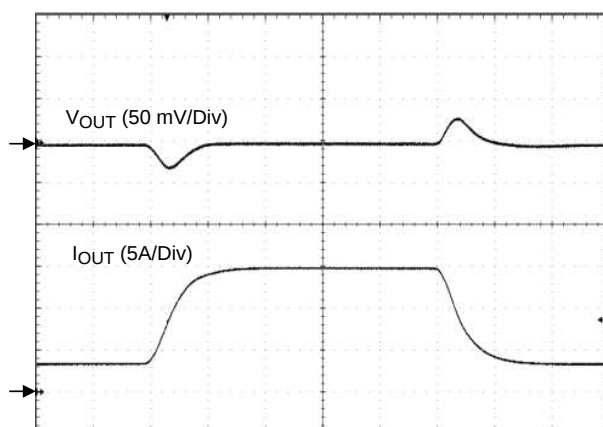


Figure 6. V_{OUT} Transient Response (40 μ s/DIV)

Figure 7 shows the open loop bode response generated by inserting a stimulus signal across R_{AC} and using a network analyzer to plot the gain and phase.

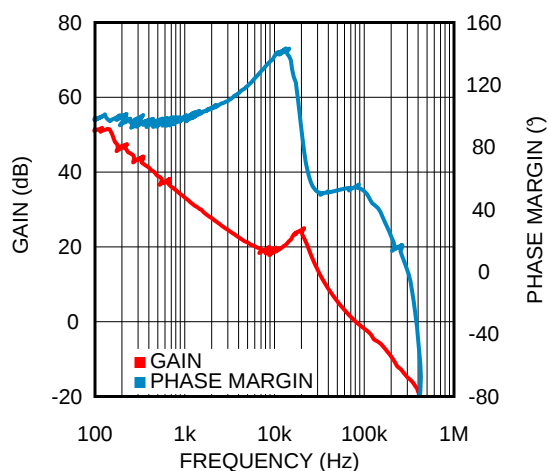


Figure 7. Open Loop Bode Response

7 Bill of Materials

Table 2. Bill of Materials

Item	Description	Vendor	Part Number	Qty
AC INJ	Header, TH, 100mil, 2 × 1, Gold plated, 230 mil above insulator	Samtec Inc.	TSW-102-07-G-S	1
C1	CAP, CERM, 1 uF, 10V, +/-10%, X7R, 0603	MuRata	GRM188R71A105KA61D	1
C3, C4, C5, C6, C7, C8	CAP, CERM, 100 uF, 6.3V, +/-20%, X5R, 1206	MuRata	GRM31CR60J107ME39L	6
C9	CAP, CERM, 0.1 uF, 50V, +/-10%, X7R, 0603	TDK	C1608X7R1H104K	1
C _{C1}	CAP, CERM, 1800pF, 50V, +/-5%, C0G/NP0, 0603	MuRata	GRM1885C1H182JA01D	1
C _{C2}	CAP, CERM, 56pF, 50V, +/-5%, C0G/NP0, 0603	MuRata	GRM1885C1H560JA01D	1
C _{C3}	CAP, CERM, 820 pF, 50V, +/-5%, C0G/NP0, 0603	MuRata	GRM1885C1H821JA01D	1
C _{SS}	CAP, CERM, 0.033 uF, 16V, +/-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	RES, 1.0 ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06031R00JNEA	1
R _{AC}	RES, 49.9 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060349R9FKEA	1
R _{C1}	RES, 11.0k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060311K0FKEA	1
R _{C2}	RES, 165 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603165RFKEA	1
R _{FB1} , R _{FB2} , R _{PG}	RES, 10 kohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060310K0JKEA	3
SH-J1	Shunt, 100mil, Gold plated, Black	Samtec Inc.	SNT-100-BK-G	1
U1	15A Buck DC/DC Converter	Texas Instruments	LM21215	1

Figure 8. Top Layer (Copper planes outlined in grey)

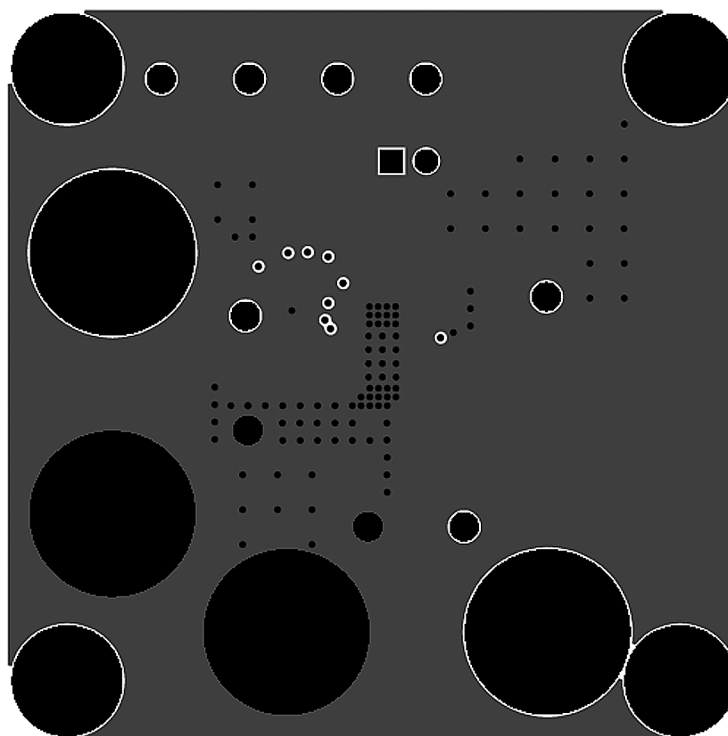


Figure 9. Mid Layer1

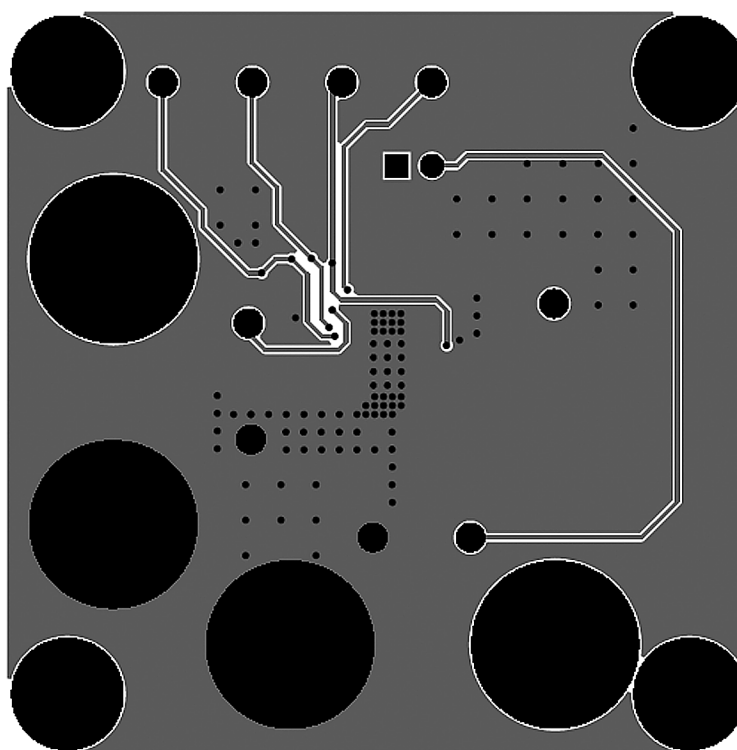


Figure 10. Mid Layer2

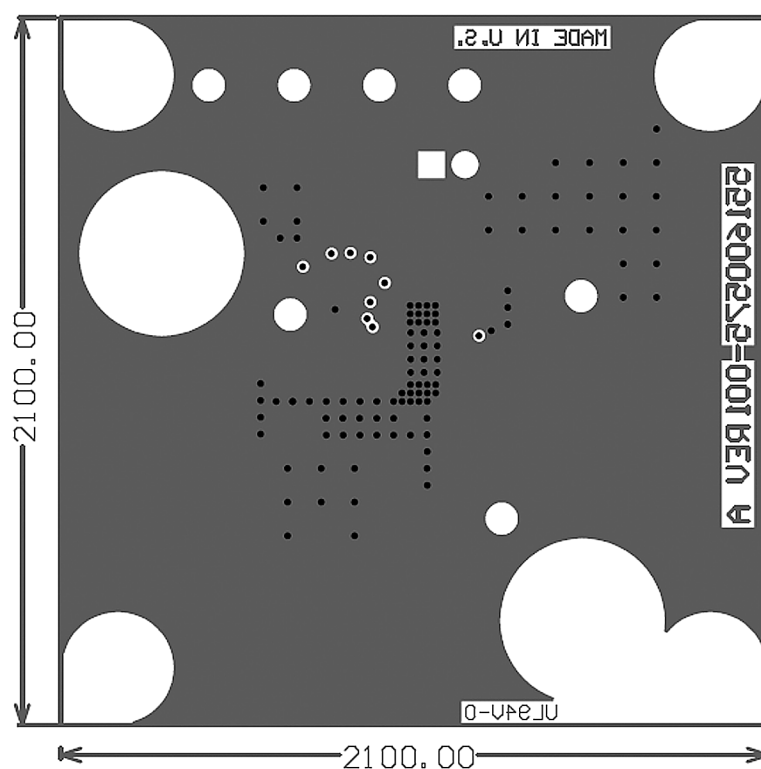


Figure 11. Bottom Layer

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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 instructions, 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/sds/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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1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
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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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/sds/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.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

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