

LTC3372EUK

4-Channel 8A Configurable Buck Plus Low I_Q High Voltage Buck Supply

DESCRIPTION

Demonstration circuit 2419A features the [LTC®3372](#) in a multi-output step-down converter. The controller portion of the LTC3372 drives a high output voltage (HV) buck converter which has an input voltage range of 6V to 60V. Its output voltage (V_{OUT_HV}) is nominally 5V but can be configured for either 5V or 3.3V with the V_{OUTPRG} pin. V_{OUT_HV} supplies power to the configurable buck regulator. This regulator provides four low voltage (LV) outputs labelled V_{OUT1-4} . These outputs are 1.2V/2A, 1.8V/2A, 2.5V/2A and 3.3V/2A respectively. When V_{OUT_HV} is configured for 5V, it can supply 6A to the external loads with full load on V_{OUT1-4} . With no load on V_{OUT1-4} , V_{OUT_HV} can supply 10A to the external loads. See Figure 3 for the Block Diagram.

The LV buck regulator consists of eight power stages that can be arranged in up to four channels. The LV regulator on the DC2419A is setup for four channels of two power stages each. With modifications, the LV buck regulator can be setup for eight different configurations. See the LV Regulator Configuration section for more details.

If V_{OUT_HV} is programmed for 3.3V, then V_{OUT4} which provides 3.3V/2A will be in dropout. This rail will require an external input voltage to stay in regulation. See the LV Regulator Configuration section for more details.

The LV rails operate at 2MHz and the HV converter operates at one-sixth this frequency or 333kHz. The high frequency of the LV rails allows the use of 4mm × 4mm inductors. The power stage for the HV converter consists of 60V avalanche rated MOSFETs and a 2.2μH 10mm × 10mm inductor. A 4mΩ discrete sense resistor is used to sense current.

The low I_Q current of the LTC3372 provides high efficiency at light loads. When the V_{OUT_HV} is supplying the nominal 5V, its Burst Mode® efficiency with 1mA load is 90.3% for a 12V input, see Figure 9. When the HV converter is off, it only draws 27μA from a 12V input.

Other features of the board include:

- Selectable light load operating modes of:
 - FCM
 - Pulse-skipping (HV) and Burst Mode operation (LV)
 - Burst Mode operation
- PLLIN pin to synchronize the LV regulators over a 1MHz to 3MHz range (166kHz to 500kHz for the HV converter)
- Watch dog circuit
- TEMP pin to monitor the junction temperature of the LTC3372
- PGOOD pin for the HV converter and $\overline{RST}$ pin for the LV regulators

The LTC3372 data sheet provides a complete description of the IC operation and application information. The data sheet must be read in conjunction with the quick start guide.

Design files for this circuit board are available at <http://www.analog.com/DC2419A>

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PERFORMANCE SUMMARY Specifications are at $T_A = 25^\circ\text{C}$

Table 1. Performance Summary for the HV Converter ($T_A = 25^\circ\text{C}$), No Airflow

PARAMETER	CONDITION	VALUE
Minimum Input Voltage (V_{IN})		6V
Maximum Input Voltage (V_{IN})		60V
Output Voltage (V_{OUT_HV})	$I_{OUT_HV} = 0\text{A to } 10\text{A}$, No load on V_{OUT1-4} V_{OUTPRG} Tied High	$5\text{V} \pm 2\%$
Output Voltage (V_{OUT_HV})	$I_{OUT_HV} = 0\text{A to } 10\text{A}$, No load on V_{OUT1-4} V_{OUTPRG} Tied Low	$3.3\text{V} \pm 2\%$
$I_{OUT(MAX)}$ for V_{OUT_HV}	$V_{IN} = 6\text{V to } 60\text{V}$, $V_{OUT_HV} = 5\text{V or } 3.3\text{V}$ No Load on V_{OUT1-4}	10A
Nominal Switching Frequency		333kHz
Efficiency See Figures 7 to 10	$V_{OUT_HV} = 5\text{V}$, $V_{IN} = 12\text{V}$, $I_{OUT_HV} = 10\text{A}$ $V_{OUT_HV} = 5\text{V}$, $V_{IN} = 48\text{V}$, $I_{OUT_HV} = 10\text{A}$	94.6% Typical 90.6% Typical

Table 2. Performance Summary for the LV Regulators ($T_A = 25^\circ\text{C}$), No Airflow

PARAMETER	CONDITION	VALUE
Minimum Input Voltage (V_{IN_LV})*		2.25V
Maximum Input Voltage (V_{IN_LV})*		5.5V
Output Voltage V_{OUT1}	$I_{OUT1} = 0\text{A to } 2\text{A}$, $V_{IN_LV} = 5\text{V or } 3.3\text{V}$	$1.2\text{V} \pm 1\%$
Output Voltage V_{OUT2}	$I_{OUT2} = 0\text{A to } 2\text{A}$, $V_{IN_LV} = 5\text{V or } 3.3\text{V}$	$1.8\text{V} \pm 2\%$
Output Voltage V_{OUT3}	$I_{OUT3} = 0\text{A to } 2\text{A}$, $V_{IN_LV} = 5\text{V or } 3.3\text{V}$	$2.5\text{V} \pm 3\%$
Output Voltage V_{OUT4}	$I_{OUT4} = 0\text{A to } 2\text{A}$, $V_{IN_LV} = 5\text{V Only}$	$3.3\text{V} \pm 3\%$
Nominal Switching Frequency		2MHz
Efficiency See Figures 11 to 14	$V_{OUT1} = 1.2\text{V}$, $I_{OUT1} = 2\text{A}$, $V_{IN_LV} = 5\text{V}$	79.7% Typical
	$V_{OUT2} = 1.8\text{V}$, $I_{OUT2} = 2\text{A}$, $V_{IN_LV} = 5\text{V}$	84.7% Typical
	$V_{OUT3} = 2.5\text{V}$, $I_{OUT3} = 2\text{A}$, $V_{IN_LV} = 5\text{V}$	88.0% Typical
	$V_{OUT4} = 3.3\text{V}$, $I_{OUT4} = 2\text{A}$, $V_{IN_LV} = 5\text{V}$	90.4% Typical

* V_{IN_LV} and V_{OUT_HV} share the same net on the demo board.

QUICK START PROCEDURE

The evaluation setup for demonstration circuit 2419A is straight forward. Refer to the diagram shown in Figure 1.

Next, follow the procedure below:

- 1) With power off, connect the input supply, load and meters as shown in Figure 1. Preset the loads to 0A and V_{IN} supply to be 0V.
- 2) Place the RUN jumper in the ON position and EN1 to EN4 in the off position. Make sure V_{OUTPRG} is in the 5V position and the PULLUP PWR jumper is in the INTV_{CC} position.
- 3) Set the input voltage to 12V.
- 4) Check V_{OUT_HV} . The output voltage should be within the regulation limits shown in the performance summary table for the HV converter.
- 5) Apply 10A load and re-measure V_{OUT_HV} . It should be within the same regulation limits.
- 6) Make sure the PULLUP PWR jumper is in the INTV_{CC} position. This will ensure the EN pins for the LV regulators can be pulled high for the steps that follow.

QUICK START PROCEDURE

- 7) Place EN1 in the ON position.
- 8) Measure V_{OUT1} . It should be within the regulation limits shown in the performance summary table for the low voltage regulators.
- 9) Apply 2A load to V_{OUT1} . It should be within the same regulation limits.
- 10) Repeat steps 7 to 9 for V_{OUT2-4} .
- 11) With 2A load each on V_{OUT1-4} and 6A load on V_{OUT_HV} , measure the input current flowing into V_{IN} at an input voltage of 12V. It should be less than 4.58A.
- 12) After the basic performance has been verified, the other aspects of performance can be measured and observed.

OUTPUT RIPPLE MEASUREMENT

When measuring the output voltage or input voltage ripple, be sure to place the probe directly across an output or input capacitor. Figure 2 shows one example. Leads

are soldered to either side of the capacitor. The probe's ground ring makes contact with the return lead and the probe tip makes contact with the other lead.

AIRFLOW REQUIREMENTS

When V_{OUT_HV} is 5V, the demo board can operate with no airflow at room temperature ambient with full load on all outputs for input voltages up to 60V.

When V_{OUT_HV} is 3.3V, airflow will be required with full load on all outputs and high input voltages due to losses in the INTV_{CC} LDO. Here are some guidelines to follow:

$V_{IN} = 12V$: no airflow

$V_{IN} = 36V$: 200 LFM airflow

$V_{IN} = 48V$: 400 LFM airflow

LV REGULATOR CONFIGURATION

The LV regulator section consists of eight power stages labeled A to H which can be arranged in up to four channels. Each stage consists of a PMOS top FET and NMOS bottom FET and can supply 1A each. The stages are paralleled by tying their input voltages together and SW nodes together. When paralleled, the combined stages can supply $N \times 1A$, where N is the number of parallel stages. Up to four stages can be paralleled.

The LV regulators on the demo board are setup for the 2-2-2-2 configuration. 2-2-2-2 means four channels with two stages each. As indicated, the switch nodes are tied in pairs: SWA and B, SWC and D, SWE and F and SWG and H. Modifying the LV regulation section involves these steps:

- 1) Cutting and jumping the SW traces. The SW pairs mentioned above are all separable. A SW trace in one pair can be tied to a SW trace in another pair by making a cut and jump. Use 28 AWG or similar size wire. Make the cuts and jumps close to the SW pins. To facilitate this, openings in the solder mask were placed over the SW traces next to the SW pins.
- 2) Setting the configuration bits. Pins C1 to C3 are the configuration bits. By tying these pins high or low, different configurations can be programmed. Refer to Table 1 in the data sheet for the complete list of configurations.

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LV REGULATOR CONFIGURATION

3) If a channel is not used, then tie its FB pin and EN pin to ground. Also remove the inductor.

The V_{IN} pin for each stage is tied to the output of the HV converter with $0m\Omega$ jumpers.

Figure 4 and Figure 5 show how to setup the board for two different configurations.

Refer to the Applications Information section of the data sheet for guidance on selecting the output capacitors and inductors when adding or removing a power stage to or from a channel.

For a few cases an external supply may be required for the LV regulators. This could happen for the following reasons:

- The HV converter is fed from a supply which does not have sufficient power.

- An external load is drawing too much current from the HV converter.

- A LV regulator needs more headroom.

To supply a LV regulator channel with an external supply, follow these steps:

- Remove the $0m\Omega$ copper jumper tying V_{IN_LV} to the channel's input pins. V_{IN_LV} and V_{OUT_HV} share the same net.
- Place a small bulk capacitor from the input to ground for damping.
- Connect the external supply across this capacitor.

See Figure 6 for more details

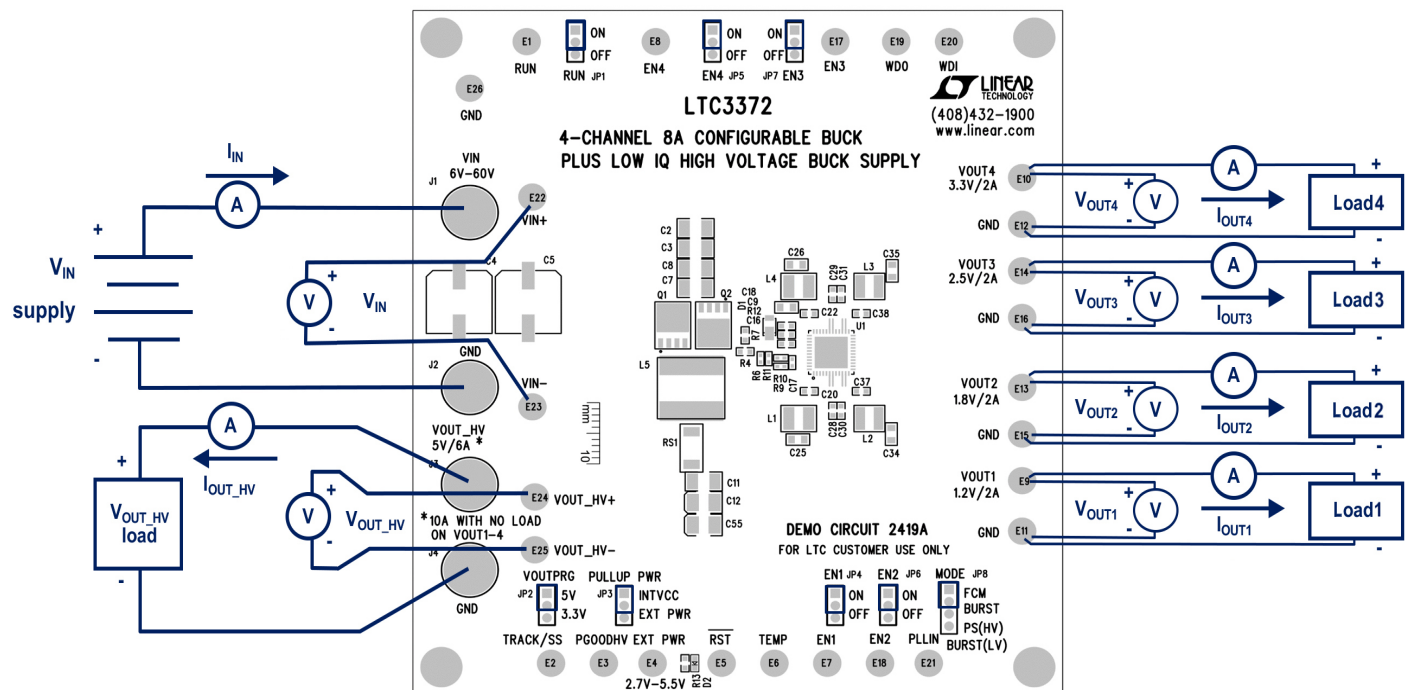


Figure 1. Proper Measurement Setup of the DC2419A

QUICK START PROCEDURE

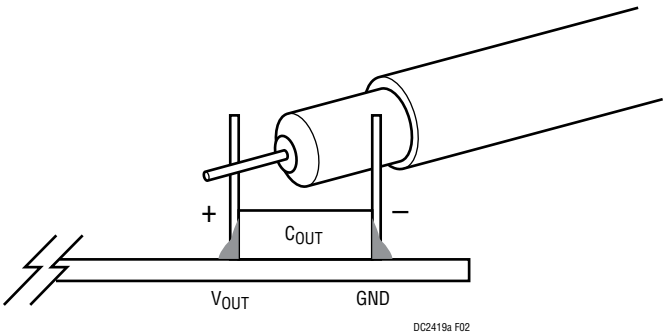


Figure 2. Measuring Output Voltage Ripple

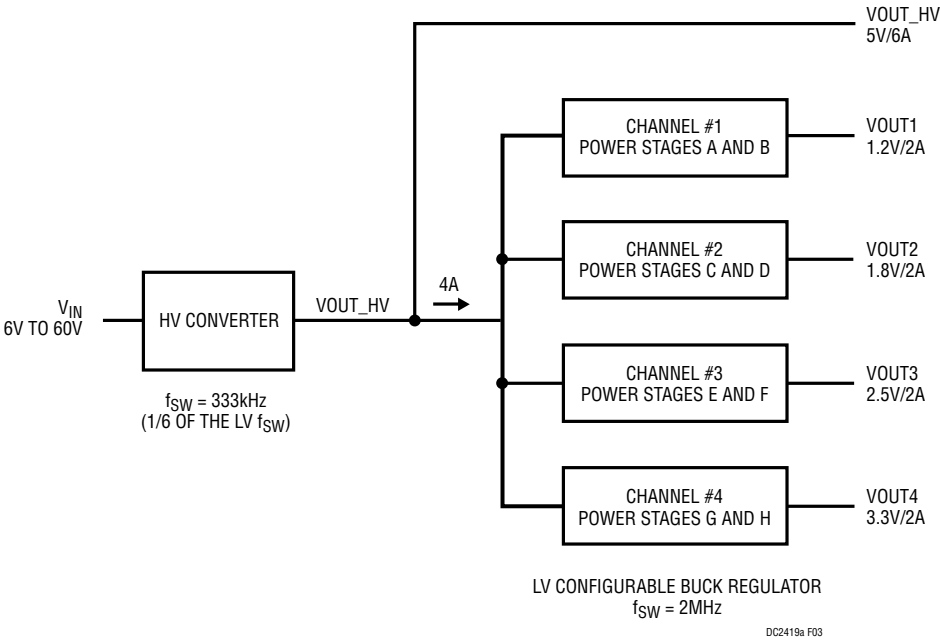
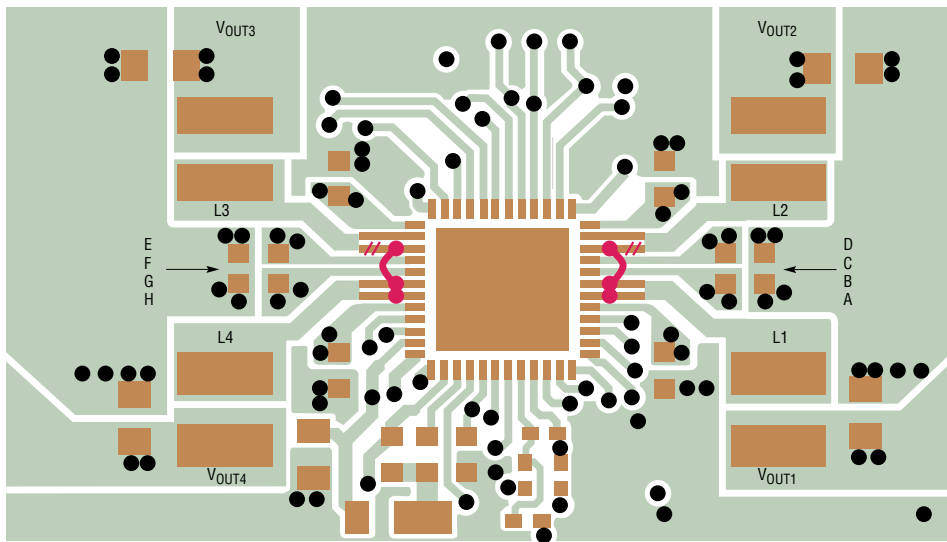


Figure 3. DC2419A Block Diagram

QUICK START PROCEDURE



// = CUT

WITH THIS CONFIGURATION, CHANNELS 1 AND 4 PROVIDE 3A OUTPUTS WHILE CHANNELS 2 AND 3 PROVIDE 1A OUTPUTS. THE FOOTPRINTS OF L1 AND L4 CAN BE STUFFED WITH 5mm x 5mm INDUCTORS TO ALLOW HIGHER CURRENT DEVICES TO BE USED. ORIGINAL DESIGN USES 4mm x 4mm INDUCTORS.

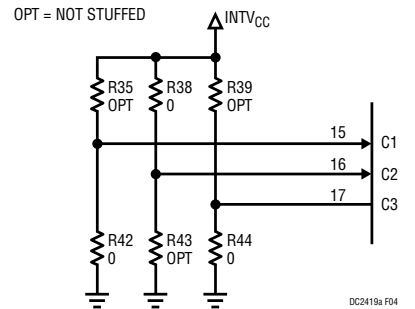
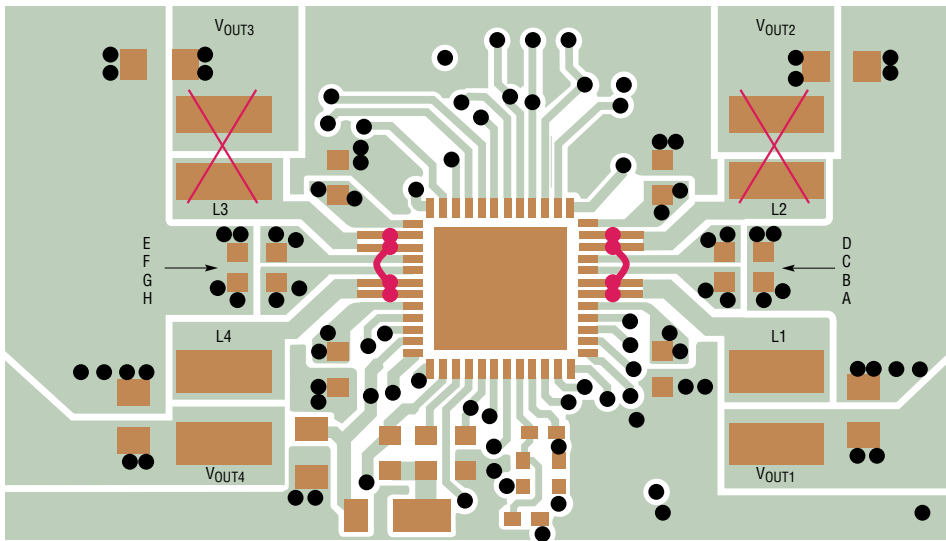


Figure 4. DC2419A Setup for the ABC-D-E-FGH Configuration



WITH THIS CONFIGURATION, BOTH CHANNELS 1 AND 4 PROVIDE 4A OUTPUTS. CHANNELS 2 AND 3 ARE NOT USED. THE FOOTPRINTS OF L1 AND L4 CAN BE STUFFED WITH 5mm x 5mm INDUCTORS TO ALLOW HIGHER CURRENT DEVICES TO BE USED. ORIGINAL DESIGN USES 4mm x 4mm INDUCTORS.

NOTE:
TIE THE EN AND FB
PINS OF CHANNELS 2 AND 3
TO GND SINCE THEY
ARE NOT BEING USED.

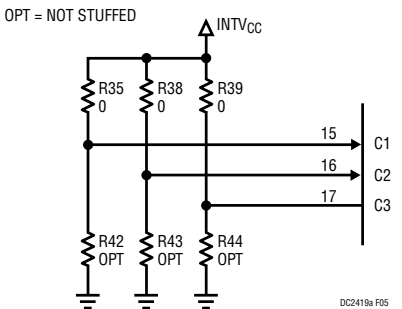
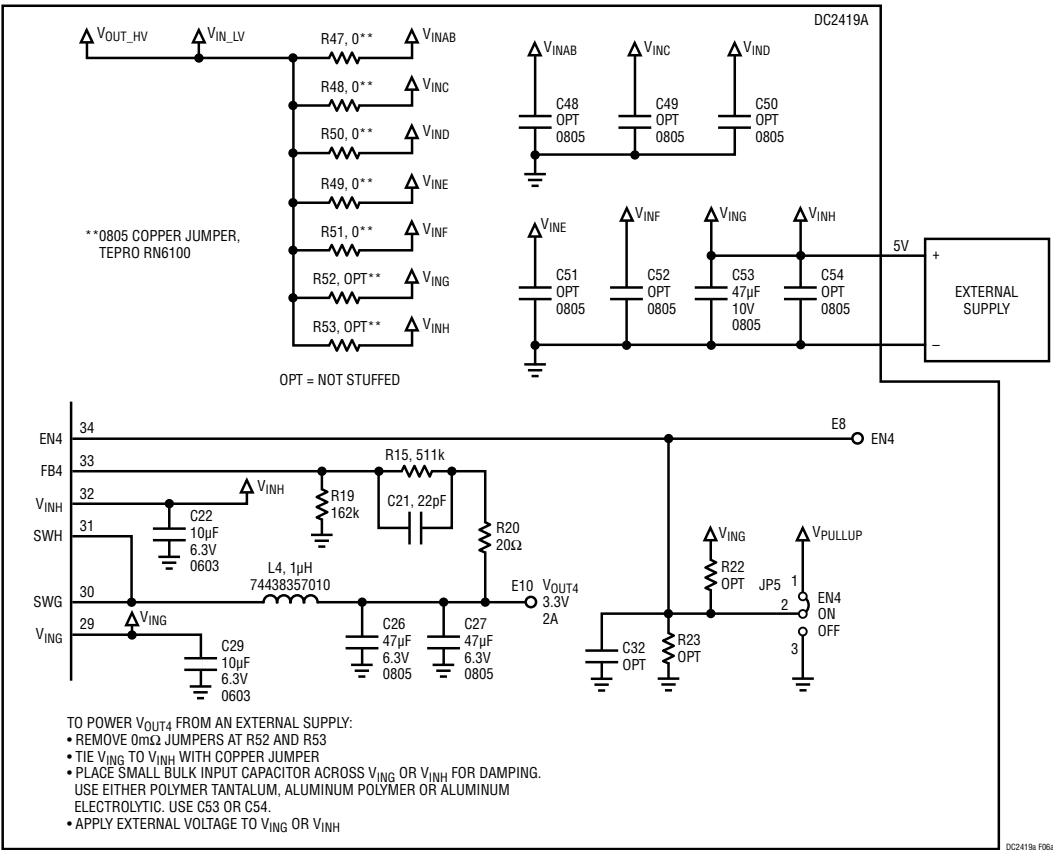
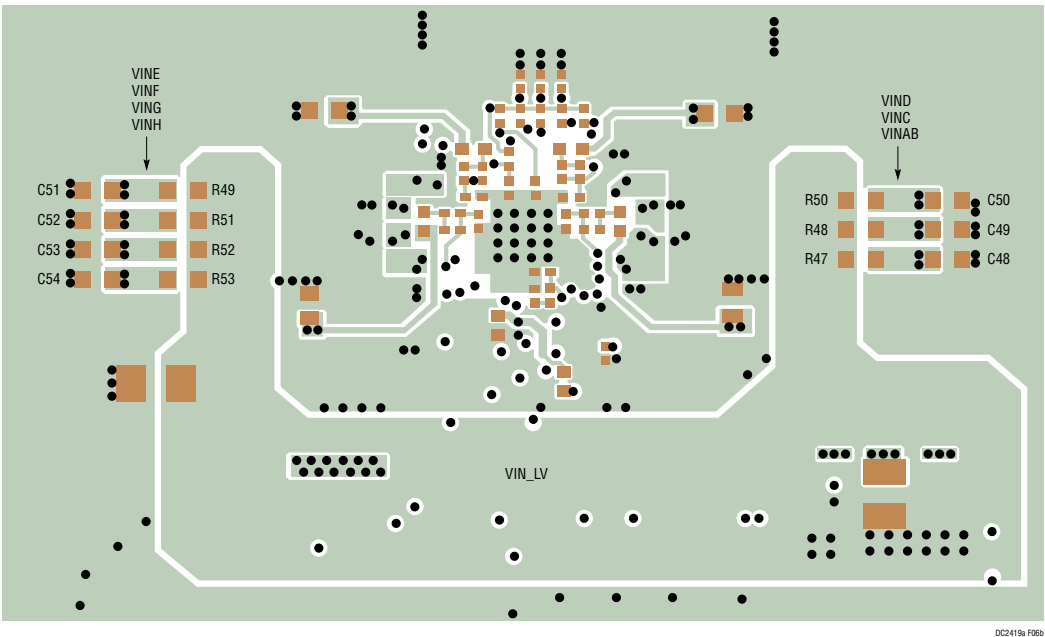


Figure 5. DC2419A Setup for the ABCD-EFGH Configuration

QUICK START PROCEDURE



(a) Example: Supplying the 3.3V, 2A Rail with an External Voltage



(b) Location of the V_{IN_LV} Jumpers and the Optional LV Input Capacitors

Figure 6. How to Connect an External Supply to the Input of a LV Rail

QUICK START PROCEDURE

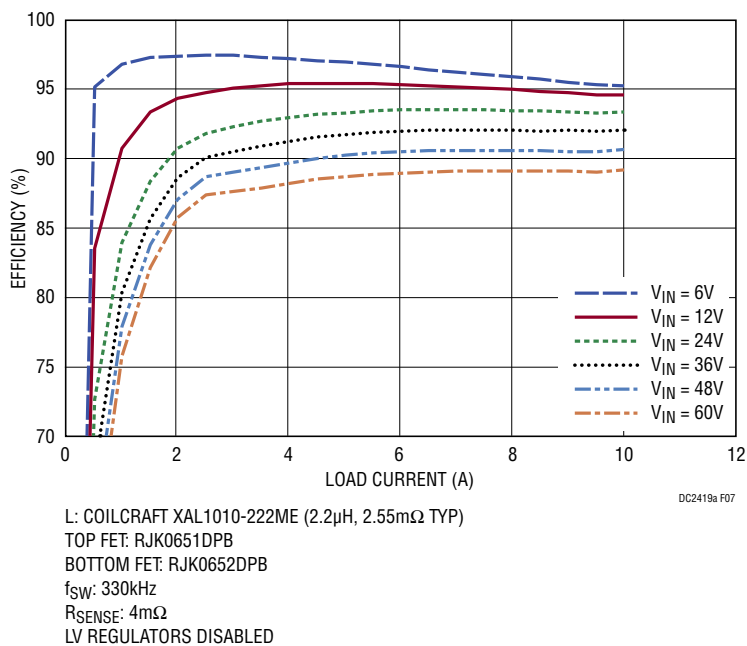


Figure 7. Efficiency of the HV Converter in FCM, $V_{OUT_HV} = 5V$

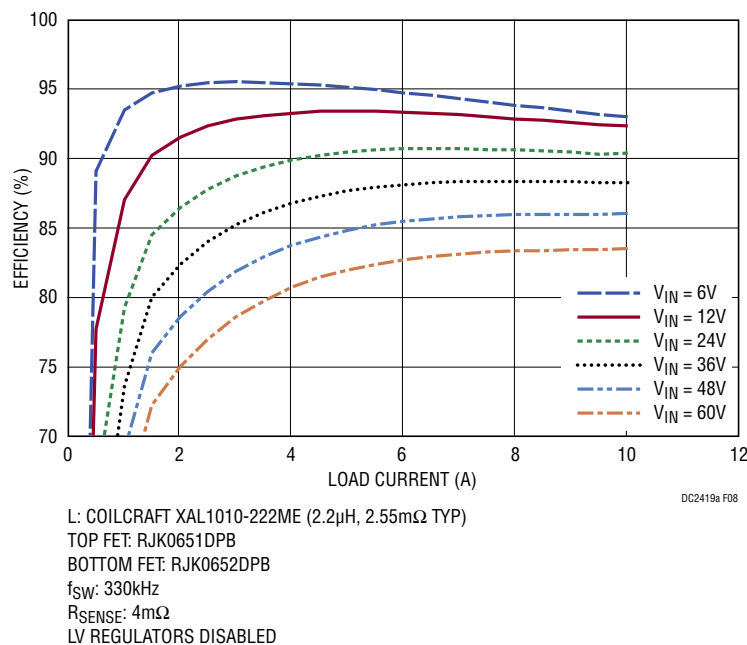


Figure 8. Efficiency of the HV Converter in FCM, $V_{OUT_HV} = 3.3V$

QUICK START PROCEDURE

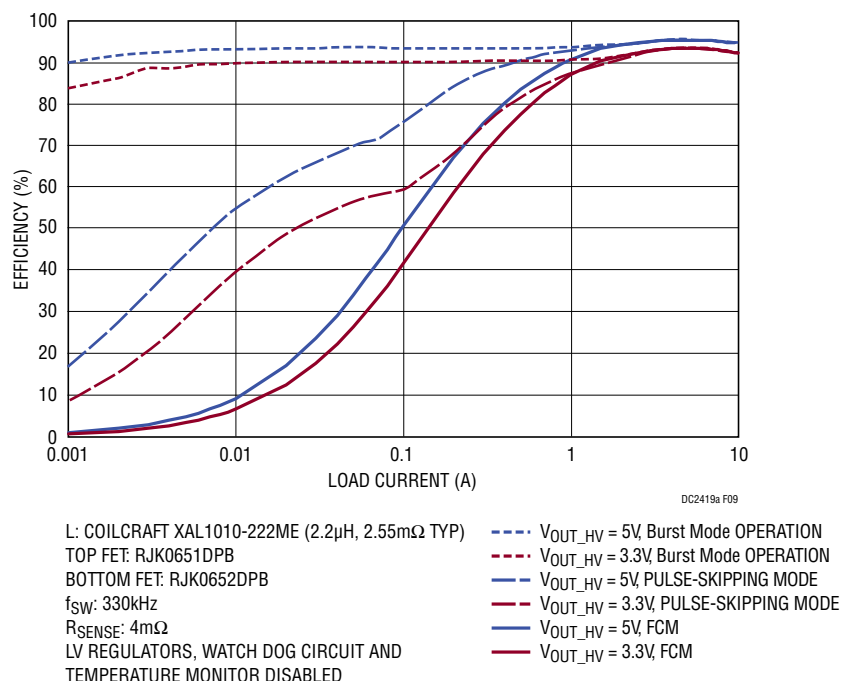


Figure 9. Efficiency of the HV Converter in FCM, Pulse-Skipping and Burst Mode Operation, $V_{IN} = 12V$

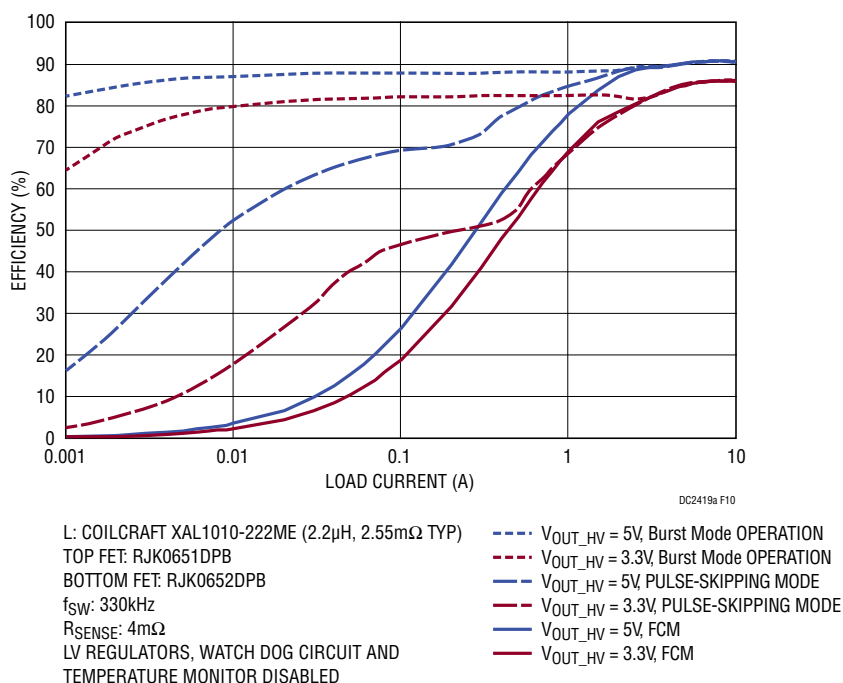


Figure 10. Efficiency of the HV Converter in FCM, Pulse-Skipping and Burst Mode Operation, $V_{IN} = 48V$

QUICK START PROCEDURE

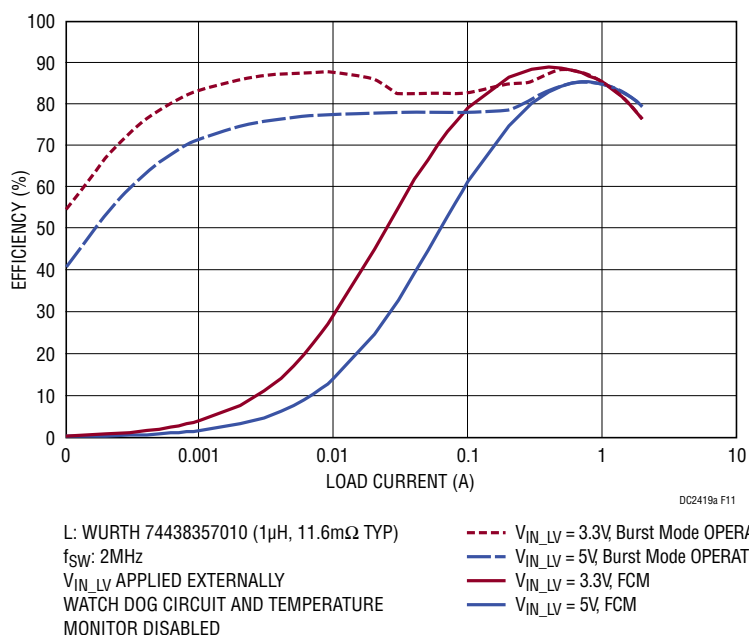


Figure 11. Efficiency of the 1.2V, 2A LV Rail (V_{OUT1})

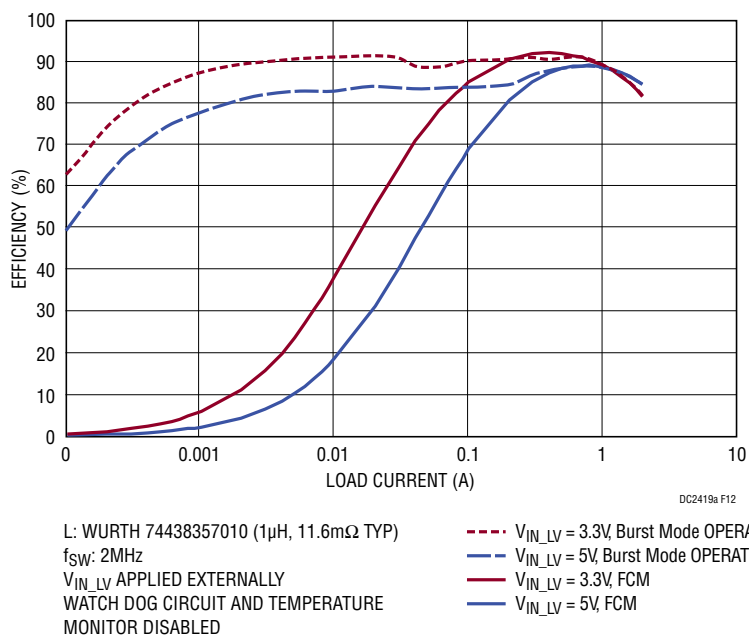


Figure 12. Efficiency of the 1.8V, 2A LV Rail (V_{OUT2})

QUICK START PROCEDURE

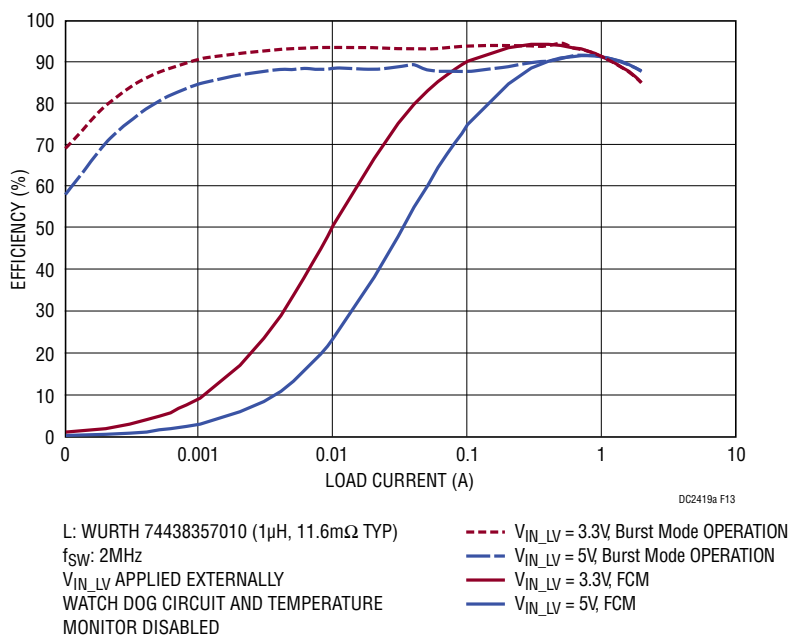


Figure 13. Efficiency of the 2.5V, 2A LV Rail (V_{OUT3})

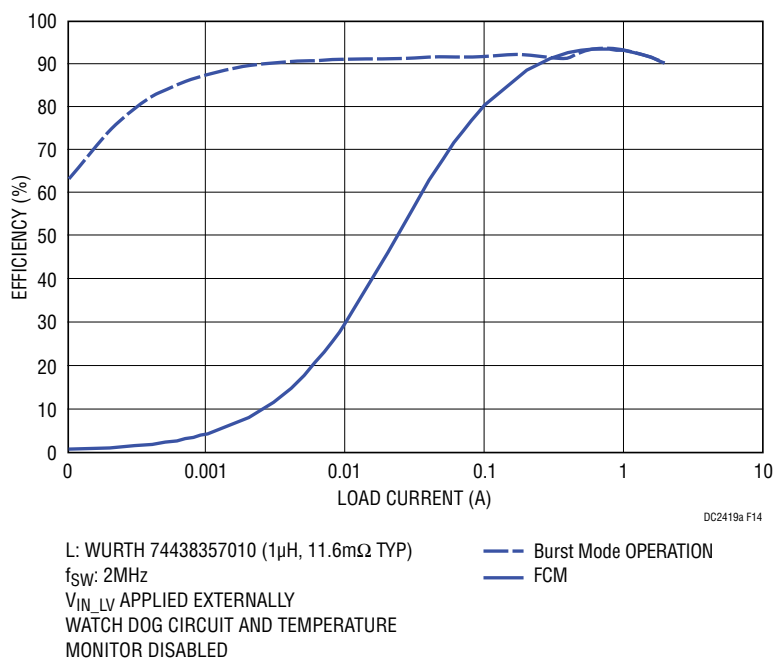
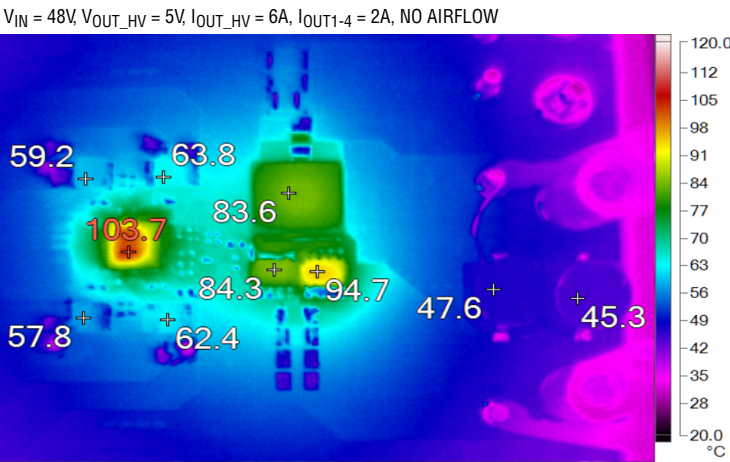
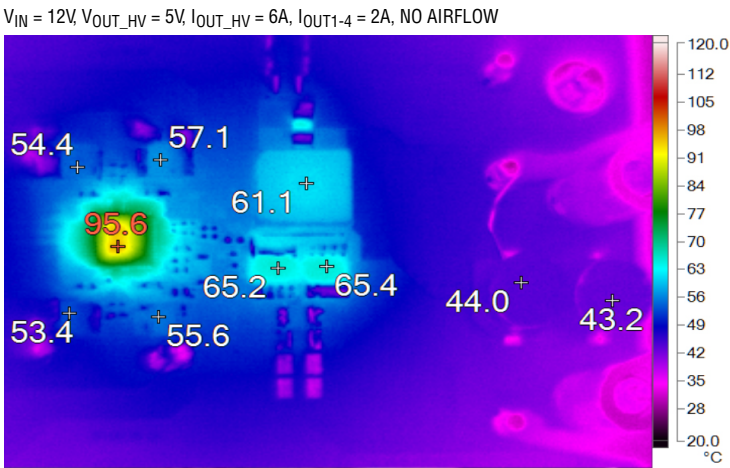


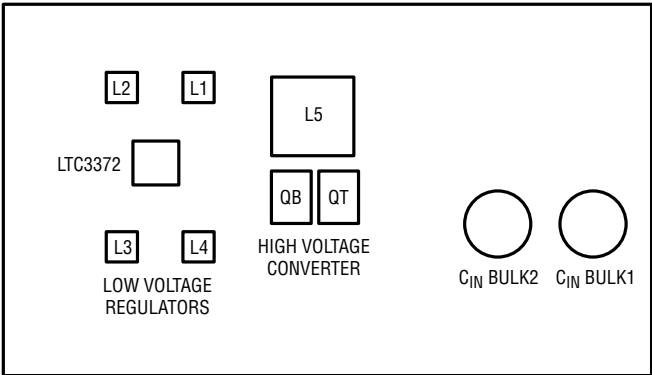
Figure 14. Efficiency of the 3.3V, 2A LV Rail (V_{OUT4}), $V_{IN_LU} = 5V$

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QUICK START PROCEDURE



LOCATION OF COMPONENTS MEASURED



CIRCUIT COMPONENTS AND SETUP

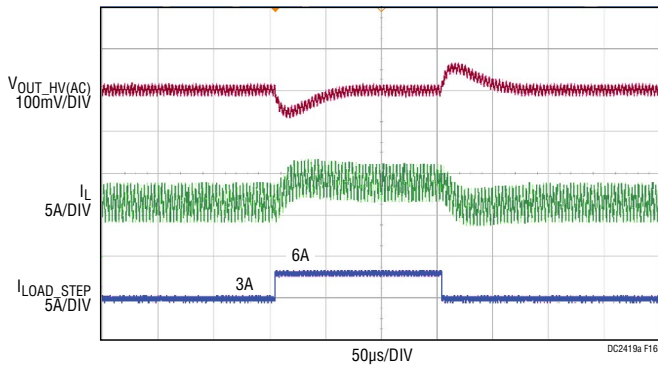
LV REGULATORS:
 V_{OUT1-4} : 1.2V/2A, 1.8V/2A, 2.5V/2A, 3.3V/2A
L1-4: WURTH 74438357010 (1 μ H, 11.6m Ω TYP)
 f_{SW} : 2MHz

HV CONVERTER:
L5: COILCRAFT XAL1010-222ME (2.2 μ H, 2.55m Ω TYP)
TOP FET: RJK0651DPB
BOTTOM FET: RJK0652DPB
 f_{SW} : 330kHz
 R_{SENSE} : 4m Ω

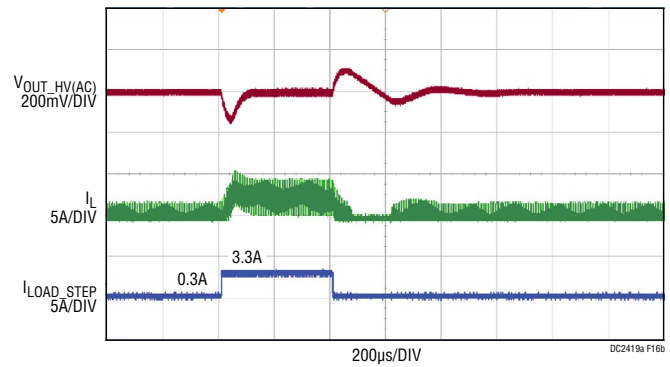
DC2419 F015

Figure 15. Thermal Image of the DC2419A Demo Board with Full Load on All Rails

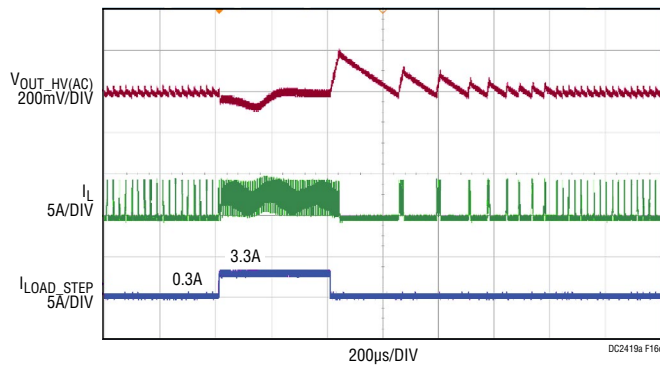
QUICK START PROCEDURE



(a) 3A to 6A Load Step Response, 2A Load Each on V_{OUT1-4} , FCM



(b) 0.3A to 3.3A Load Step Response, No Load on V_{OUT1-4} , Pulse-Skipping Mode



(c) 0.3A to 3.3A Load Step Response, No Load on V_{OUT1-4} , Burst Mode Operation

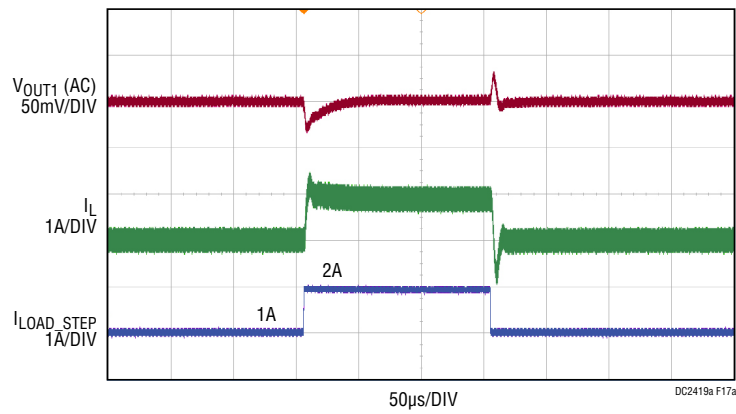
$C_{OUT(BULK)}$: 2x T520B157M006ATE025
(150µF, 6.3V, 25mΩ)

$C_{OUT(CER)}$: TMK325ABJ476MM-T
(47µF, 25V, X5R, 1210)

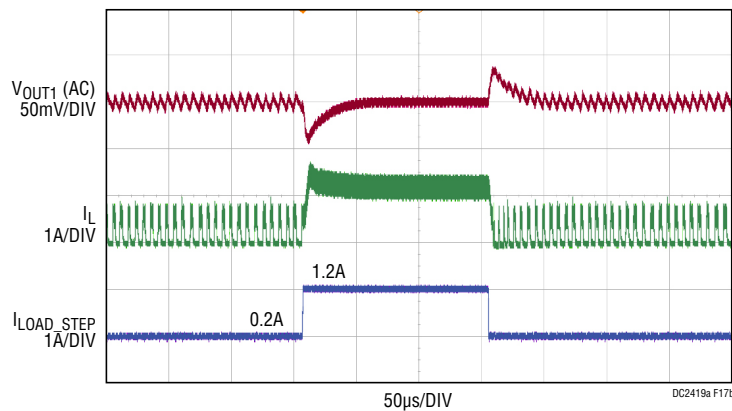
f_{SW} : 330kHz

Figure 16. Load Step Response of the HV Converter (V_{OUT_HV}), $V_{OUT_HV} = 5V$, $V_{IN} = 12V$

QUICK START PROCEDURE



(a) 1A to 2A Load Step Response, FCM



(b) 0.2A to 1.2A Load Step Response, Burst Mode Operation

C_{OUT} : 2× GRM21BR60J476ME15L
(47µF, 6.3V, X5R, 0805)

f_{SW} : 2MHz

Figure 17. Load Step Response of the LV 1.2V, 2A Regulator (V_{OUT1}), V_{IN_LV} = 5V

PARTS LIST

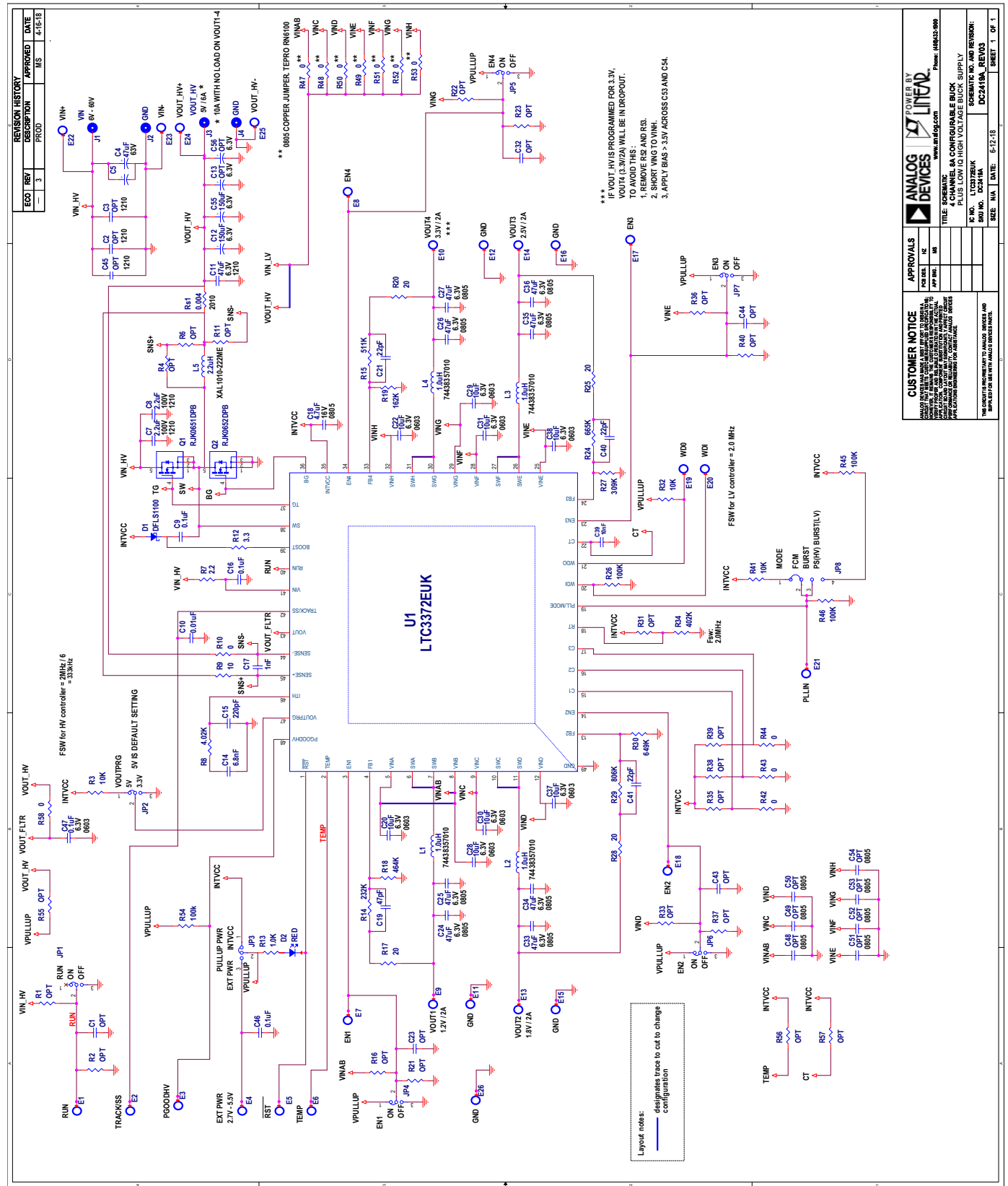
ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	1	C10	CAP, 0.01 μ F 10% 25V X7R 0402	MURATA, GRM155R71E103KA01J
2	1	C39	CAP, 0.01 μ F 10% 50V X7R 0402	MURATA, GRM155R71H103KA88D
3	3	C9, C16, C46	CAP, 0.1 μ F 10% 100V X7R 0603	MURATA, GRM188R72A104KA35D
4	1	C17	CAP, 1000pF 5% 50V NPO 0402	MURATA, GRM1555C1H102JA01D
5	9	C20, C22, C28 TO C31, C37, C38, C47	CAP, 10 μ F 20% 16V X5R 0603	MURATA, GRM188R61C106MA73D
6	2	C7, C8	CAP, 2.2 μ F 10% 100V X7R 1210	MURATA, GRM32ER72A225KA35L
7	1	C15	CAP, 220pF 5% 25V NPO 0402	YAGEO, CC0402JRNPO8BN221
8	3	C21, C40, C41	CAP, 22pF 5% 50V NPO 0402	MURATA, GRM1555C1H220JA01D
9	2	C12, C55	CAP, 3528 150 μ F 6.3V POLY TANT	KEMET, T520B157M006ATE025
10	1	C18	CAP, 4.7 μ F 10% 25V X5R 0805	MURATA, GRM21BR61E475KA12L
11	1	C19	CAP, 47pF 5% 50V NPO 0402	MURATA, GRM1555C1H470JA01D
12	1	C11	CAP, 47 μ F 20% 1210 25V X5R	TAIYO YUDEN, TMK325ABJ476MM-T
13	8	C24 TO C27, C33 TO C36	CAP, 47 μ F 20% 6.3V X5R 0805	MURATA, GRM21BR60J476ME15L
14	2	C4, C5	CAP, 47 μ F 63V, 30mW, 2.1A RMS	SUNCON ELEC, 63HVH47M
15	1	C14	CAP, 6800pF 10% 50V X7R 0402	YAGEO, AC0402KRX7R9BB682
16	1	D1	DIODE, SCHOTTKY 100V	DIODES INC, DFLS1100-7
17	1	U1	IC LTC3372EUK	ADI, LTC3372EUK#PBF
18	4	L1 TO L4	IND, 1 μ H 7.4A 13.5mW	WURTH ELEKTRONIK, 74438357010
19	1	L5	IND, 2.2 μ H 32.0A 2.55mW	COILCRAFT, XAL1010-222MEB
20	6	R47 TO R53	JUMPER, 0mW 0805	TEPRO, RN61
21	1	Q1	MOSFET, N-CH 60V 25A LFPK	RENESAS, RJK0651DPB-00#J5
22	1	Q2	MOSFET, N-CH 60V 35A LFPK	RENESAS, RJK0652DPB-00#J5
23	4	R10, R42, R43, R44	RES, 0W, 0402	VISHAY, CRCW04020000Z0ED
24	1	R58	RES, 0W, 0603	VISHAY, CRCW06030000Z0EA
25	4	R54, R26, R45, R46	RES, 100k 1% 0603	VISHAY, CRCW0603100KFKEA
26	3	R3, R32, R41	RES, 10k 5% 0603	VISHAY, CRCW060310K0JNEA
27	1	R9	RES, 10W, 5% 0402	VISHAY, CRCW040210R0JNED
28	1	R19	RES, 162k 1% 0402	VISHAY, CRCW0402162KFKEA
29	1	R7	RES, 2.2W 1% 0603	VISHAY, CRCW06032R20FKEA
30	1	RS1	RES, 2010 4mW 1% 1W	VISHAY, WSL20104L000FEA
31	4	R17, R28, R20, R25	RES, 20W 1% 0603	VISHAY, CRCW060320R0FKEA
32	1	R14	RES, 232k 1% 0402	VISHAY, CRCW0402232KFKEA
33	1	R12	RES, 3.3W 1% 0603	VISHAY, CRCW06033R30FKEA
34	1	R27	RES, 309k 1% 0402	VISHAY, CRCW0402309KFKEA
35	1	R8	RES, 4.02k, 1% 0402	VISHAY, CRCW04024K02FKED
36	1	R34	RES, 402k 1% 0402	VISHAY, CRCW0402402KFKEA
37	1	R18	RES, 464k 1% 0402	VISHAY, CRCW0402464KFKEA
38	1	R15	RES, 511k 1% 0402	VISHAY, CRCW0402511KFKEA
39	1	R30	RES, 649k 1% 0402	VISHAY, CRCW0402649KFKEA
40	1	R24	RES, 66k 1% 0402	VISHAY, CRCW0402665KFKEA
41	1	R29	RES, 806K 1% 0402	VISHAY, CRCW0402806KFKEA

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PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Additional Demo Board Circuit Components				
1	0	C1, C23, C32, C43, C44	CAP, 0402 OPT	
2	0	C48 TO C54	CAP, 0805 OPT	
3	0	C2, C3	CAP, 1210 OPT	
4	0	C13, C56	CAP, 3528 OPT	
5	1	D2	LED, RED	WURTH ELEKTRONIK, 150060RS75000
6	1	R13	RES, 1k 1% 0603	VISHAY, CRCW06031K00FKEA
7	0	R1, R2, R4, R6, R11, R16, R21, R22, R23, R31, R33, R35 TO R40, R55 TO R57	RES, OPTIONAL	
Hardware: For Demo Board Only				
1	7	JP1 TO JP7	HEADER, SINGLE ROW 3PIN	WURTH ELEKTRONIK 62000311121
2	1	JP8	HEADER, SINGLE ROW 4PIN	WURTH ELEKTRONIK 62000411121
3	4	J1, J2, J3, J4	JACK, BANANA	KEYSTONE, 575-4
4	8	XJP1 TO XJP8	SHUNT	WURTH ELEKTRONIK 60800213421
5	4		STANDOFF, NYLON, SNAP-ON, 0.375"	WURTH ELEKTRONIK 702933000
6	26	E1 TO E26	TURRET	MILL MAX 2501-2-00-80-00-00-07-0

SCHEMATIC DIAGRAM



**ESD Caution**

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

Legal Terms and Conditions

By using the evaluation board discussed herein (together with any tools, components documentation or support materials, the "Evaluation Board"), you are agreeing to be bound by the terms and conditions set forth below ("Agreement") unless you have purchased the Evaluation Board, in which case the Analog Devices Standard Terms and Conditions of Sale shall govern. Do not use the Evaluation Board until you have read and agreed to the Agreement. Your use of the Evaluation Board shall signify your acceptance of the Agreement. This Agreement is made by and between you ("Customer") and Analog Devices, Inc. ("ADI"), with its principal place of business at One Technology Way, Norwood, MA 02062, USA. Subject to the terms and conditions of the Agreement, ADI hereby grants to Customer a free, limited, personal, temporary, non-exclusive, non-sublicensable, non-transferable license to use the Evaluation Board FOR EVALUATION PURPOSES ONLY. Customer understands and agrees that the Evaluation Board is provided for the sole and exclusive purpose referenced above, and agrees not to use the Evaluation Board for any other purpose. Furthermore, the license granted is expressly made subject to the following additional limitations: Customer shall not (i) rent, lease, display, sell, transfer, assign, sublicense, or distribute the Evaluation Board; and (ii) permit any Third Party to access the Evaluation Board. As used herein, the term "Third Party" includes any entity other than ADI, Customer, their employees, affiliates and in-house consultants. The Evaluation Board is NOT sold to Customer; all rights not expressly granted herein, including ownership of the Evaluation Board, are reserved by ADI. **CONFIDENTIALITY.** This Agreement and the Evaluation Board shall all be considered the confidential and proprietary information of ADI. Customer may not disclose or transfer any portion of the Evaluation Board to any other party for any reason. Upon discontinuation of use of the Evaluation Board or termination of this Agreement, Customer agrees to promptly return the Evaluation Board to ADI. **ADDITIONAL RESTRICTIONS.** Customer may not disassemble, decompile or reverse engineer chips on the Evaluation Board. Customer shall inform ADI of any occurred damages or any modifications or alterations it makes to the Evaluation Board, including but not limited to soldering or any other activity that affects the material content of the Evaluation Board. Modifications to the Evaluation Board must comply with applicable law, including but not limited to the RoHS Directive. **TERMINATION.** ADI may terminate this Agreement at any time upon giving written notice to Customer. Customer agrees to return to ADI the Evaluation Board at that time. **LIMITATION OF LIABILITY.** THE EVALUATION BOARD PROVIDED HEREUNDER IS PROVIDED "AS IS" AND ADI MAKES NO WARRANTIES OR REPRESENTATIONS OF ANY KIND WITH RESPECT TO IT. ADI SPECIFICALLY DISCLAIMS ANY REPRESENTATIONS, ENDORSEMENTS, GUARANTEES, OR WARRANTIES, EXPRESS OR IMPLIED, RELATED TO THE EVALUATION BOARD INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTY OF MERCHANTABILITY, TITLE, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS. IN NO EVENT WILL ADI AND ITS LICENSORS BE LIABLE FOR ANY INCIDENTAL, SPECIAL, INDIRECT, OR CONSEQUENTIAL DAMAGES RESULTING FROM CUSTOMER'S POSSESSION OR USE OF THE EVALUATION BOARD, INCLUDING BUT NOT LIMITED TO LOST PROFITS, DELAY COSTS, LABOR COSTS OR LOSS OF GOODWILL. ADI'S TOTAL LIABILITY FROM ANY AND ALL CAUSES SHALL BE LIMITED TO THE AMOUNT OF ONE HUNDRED US DOLLARS (\$100.00). **EXPORT.** Customer agrees that it will not directly or indirectly export the Evaluation Board to another country, and that it will comply with all applicable United States federal laws and regulations relating to exports. **GOVERNING LAW.** This Agreement shall be governed by and construed in accordance with the substantive laws of the Commonwealth of Massachusetts (excluding conflict of law rules). Any legal action regarding this Agreement will be heard in the state or federal courts having jurisdiction in Suffolk County, Massachusetts, and Customer hereby submits to the personal jurisdiction and venue of such courts. The United Nations Convention on Contracts for the International Sale of Goods shall not apply to this Agreement and is expressly disclaimed.