LTM4652
Bidirectional Dual-Phase Single Output ±32A Inverting µModule Regulator

DESCRIPTION

Demonstration circuit 3230A features the LTM®4652, a high efficiency, bidirectional dual-phase µModule® regulator configured as a single 32A, –5V output. The input voltage range is from 4.5V to 13V. For this inverting output demo board, the maximum V_{IN} + $|V_{OUT}|$ should not exceed 18V. Derating is necessary for certain V_{IN}, V_{OUT}, frequency and thermal conditions.

This demo board can be configured to source or sink output load current. Hardware test setup diagrams for both conditions are described in later sections. This demo board is optimized using a default frequency of 780kHz under the $9V_{IN}$ and $–5V_{OUT}$ condition. The current mode architecture used in LTM4652 is peak current mode control.

The part operates in continuous current mode by default but can be placed in pulse-skipping mode to optimize efficiency at light loads.

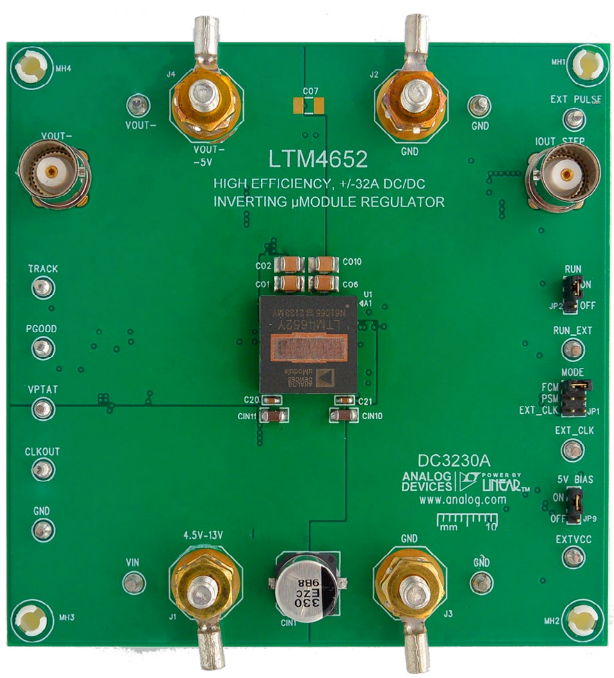
LTM4652 is available in a thermally enhanced 144-lead (16mm × 16mm × 4.92mm) BGA package. Temperature sensing options are included via onboard circuit. The module package features an exposed metal top, electrically unconnected for heatsinking capability.

Note that the inverting configuration of LTM4652 has a different maximum current limit compared to the non-inverting configuration. The LTM4652 data sheet gives a complete description of the operation and application information. It is recommended to read the data sheet and demo manual of LTM4652 prior to use or making any hardware changes to DC3230A.

Design files for this circuit board are available.

BOARD PHOTO

Part marking is either ink mark or laser mark



PERFORMANCE SUMMARY Specifications are at T_A = 25°C

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Dual-Phase Single Output						
V_{IN}	Input Voltage Range		4.5	9	13	V
V_{OUT}	Demo Board Default Output Voltage	V_{IN} = 4.5V to 13V; –32A ≤ I_{LOAD} ≤ 32A*		–5.1		V
V_{OUT}	Default Switching Frequency	f_{SET} Connected to $INTV_{CC}$		780		kHz
I_{OUT}	Continuous Output Current I_{OUT}	V_{IN} = 9V; V_{OUT} = –5V; f_{SW} = 780kHz			±32	A
η	Efficiency Sourcing Current Sinking Current	V_{IN} = 9V; V_{OUT} = –5V; f_{SW} = 780kHz CCM +32A Load –32A Load		 90.7 89.9		 % %

*Current limit inception in inverting mode configuration is a function of V_{IN}, V_{OUT}, and f_{SW}. Maximum achievable output current at 4.5V ≤ V_{IN} < 9V may be less than ±32A.

QUICK START PROCEDURE: SOURCING CURRENT CONDITION

Demonstration circuit 3230A is easy to set up to evaluate the performance of the LTM4652. Please refer to Figure 1 for proper measurement equipment setup for the sourcing current condition and follow the test procedures below.

1. With power off, connect the input power supply between VIN (J1) and GND (J3).
2. Connect the output load's positive lead to GND (J2) and the negative port to VOUT– (J4). Preset the load to 0A.
3. Connect a DMM between the input test points: VIN (E3) and GND (E5) to monitor the input voltage. Connect a DMM between GND (E2) and VOUT– (E8), to monitor DC output voltage.
4. Prior to powering up the DC3230A, check the default position of the jumpers. Make sure the RUN jumper is set in the "ON" position (refer to Table 1).

Table 1. Demo Board Default Jumpers and Switches Position

JUMPER	DESCRIPTION	DEFAULT POSITION
JP1	MODE	FCM
JP2	RUN	ON
JP9	5V BIAS	OFF

5. Turn on the power supply at the input, measure and increase V_{IN} between 4.5V and 13V. The typical output voltage should be –5.096V ±1% (or between –5.054V to –5.15V).
6. Once the input and output voltages are properly established, adjust the input voltage to 9V and the load current within the operating range of 0A to 32A max. Observe the output voltage regulation, output ripple voltage, switching node waveforms, and other parameters.

QUICK START PROCEDURE: SOURCING CURRENT CONDITION

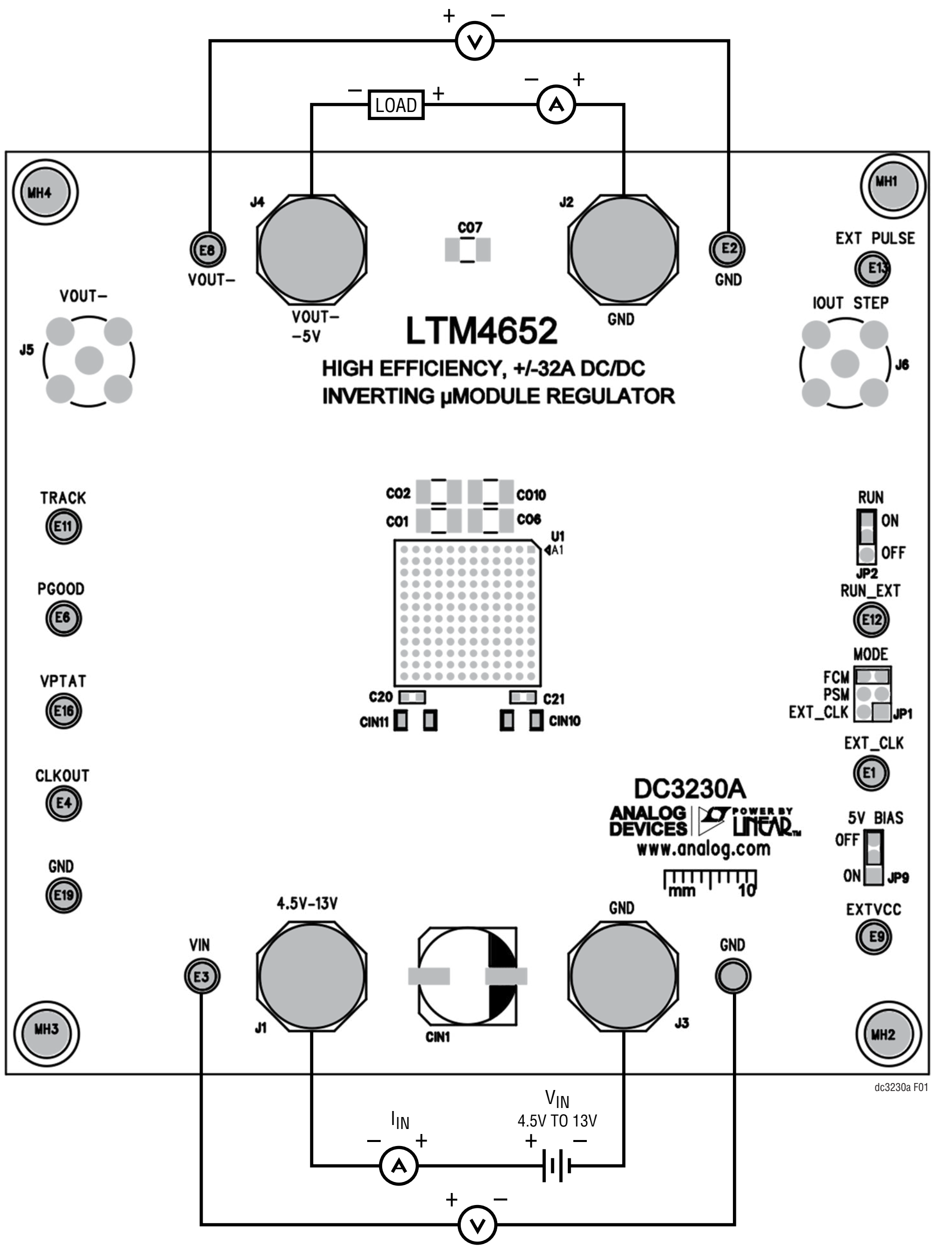


Figure 1. DC3230A Demo Board Test Setup for Sourcing Current

QUICK START PROCEDURE: SINKING CURRENT CONDITION

Please refer to Figure 2 for proper measurement equipment setup for the sinking current condition and follow the test procedures below. This procedure shows how to use electric load to test sinking current capability.

1. With power off, connect an ammeter to VIN (J1), then connect the input power supply and free-wheeling load in parallel between the ammeter and GND (J3).
2. On the output, starting from VOUT– (J4), connect the bias supply, the output load and the load reverse protection diode to GND (J2). The diode should have a current rating greater than the maximum desired output load value and a voltage rating greater than V_{F_DIODE} + $|V_{OUT}|$. Refer to 1N5831 as an example.
3. Connect a DMM between the input test points: VIN (E3) and GND (E5) to monitor the input voltage. Connect a DMM between GND (E2) and VOUT– (E8), to monitor DC output voltage.
4. Prior to powering up the DC3230A, check the default position of the jumpers (refer to Table 2).

Table 2. Demo Board Default Jumpers and Switches Position

JUMPER	DESCRIPTION	DEFAULT POSITION
JP1	MODE	FCM
JP2	RUN	ON
JP9	5V BIAS	OFF

5. Turn on the output bias power supply, measure and increase the voltage to 10V. Turn on the input power supply voltage and raise V_{IN} between 4.5V and 13V. The typical output voltage should be –5.096V ±1% (or between –5.054V to –5.15V).
6. Once the input and output voltages are properly established, adjust the input voltage to 9V.
7. When sinking current in this configuration, an electronic load is used as the free-wheeling load and it must be turned on first. Turn on the free-wheeling load and increase above $I_{OUT} \bullet |V_{OUT}|/V_{IN}$. Current will be flowing from V_{IN} power supply and into the free-wheeling load.
8. The output sinking current can now be applied within the operating range of 0A to a maximum –32A load. Observe the output voltage regulation, output ripple voltage, switching node waveforms, and other parameters.

   NOTE: When removing the loads and powering the circuit off, this procedure must be followed in reverse step order. Decrease the sinking current to 0A and turn off the output load, decrease the free-wheeling load to 0A and turn off the free-wheeling load, the run pin may be pulled low here. Then turn off the V_{IN} supply and lastly, turn off the output V_{BIAS} power supply.

QUICK START PROCEDURE: SINKING CURRENT CONDITION

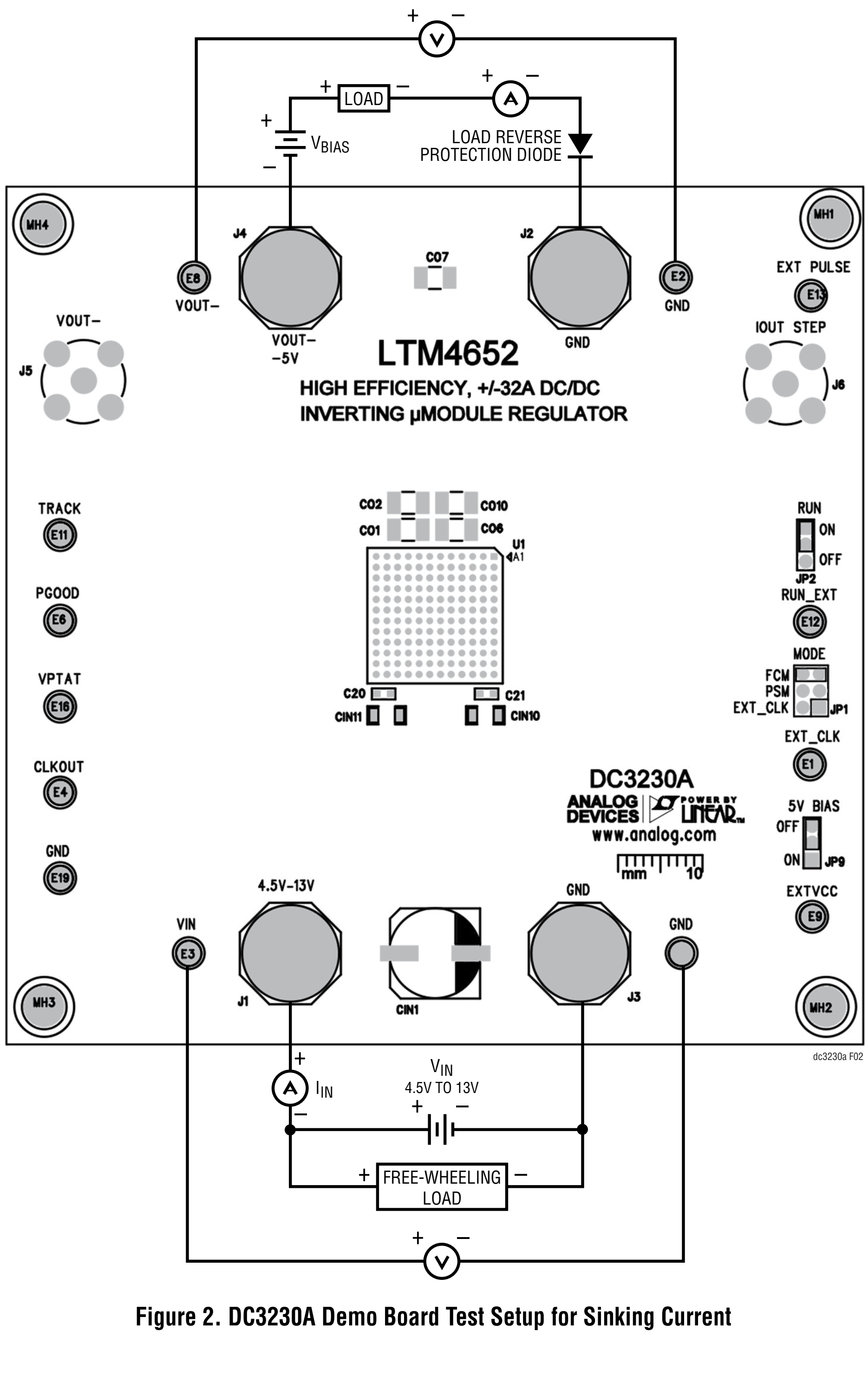


Figure 2. DC3230A Demo Board Test Setup for Sinking Current

QUICK START PROCEDURE: DEMO BOARD FEATURES

1. DC3230A provides a convenient onboard BNC terminal to accurately measure the output ripple voltage. Connect a short BNC cables from VOUT– (J5) to the input channel of an oscilloscope (scope probe ratio 1:1, AC-coupling) to observe the output ripple voltage.

   NOTE: To measure the input/output voltage ripples properly, do not use the long ground lead on the oscilloscope probe. See Figure 3 for the proper probing technique of input/output voltage ripples. Short, stiff leads need to be soldered to the (+) and (–) terminals of an input or output capacitor. The probe's ground ring needs to touch the (–) lead and the probe tip needs to touch the (+) lead.

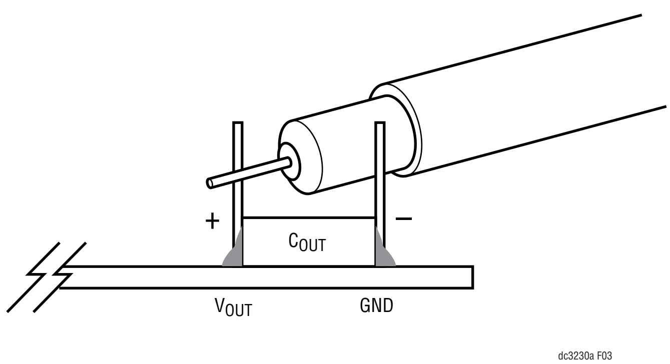


Figure 3. Scope Probe Placement for Measuring Input or Output Ripple Voltage

2. **Onboard Load Step Circuit:** DC3230A provides onboard load transient circuits to quickly check ΔV_{OUT} peak-to-peak deviation during rising or falling dynamic load transients for each channel.

   The simple load step circuit consists of a 40V N-channel power MOSFET in series with a two paralleled 10mΩ, 0.5W, 1% current sense resistors. The MOSFET is configured as a voltage control current source (VCCS) device; therefore, the output current step and its magnitude is created and controlled by adjusting the amplitude of the applied input voltage step at the gate of the MOSFET. Use a function generator to provide a voltage pulse between EXT PULSE (E13) and GND; this voltage pulse should be set at a pulse width less than 2ms and maximum duty cycle less than 1% to avoid excessive thermal stress on the MOSFET devices. The output current step is measured directly across the current sense resistors and monitored by connecting BNC cable from IOUT STEP (J6) to the input of the oscilloscope (scope probe ratio 1:0.005, DC-coupling). The equivalent voltage to current scale is 5mV/1A. The load step current slew rate di/dt can be varied by adjusting the rise time and fall time of the input voltage pulse.

3. **Level Shift Circuits (RUN, SYNC and PGOOD):** Level shift circuits are included on the demo board to allow users to reference GND instead of VOUT– when applying an external RUN voltage, an external CLKIN signal or when measuring PGOOD. To use an external RUN signal, stuff R31 with a 0Ω resistor. A voltage greater than 2.0V must be applied between RUN_EXT (E12) and GND to enable the part.

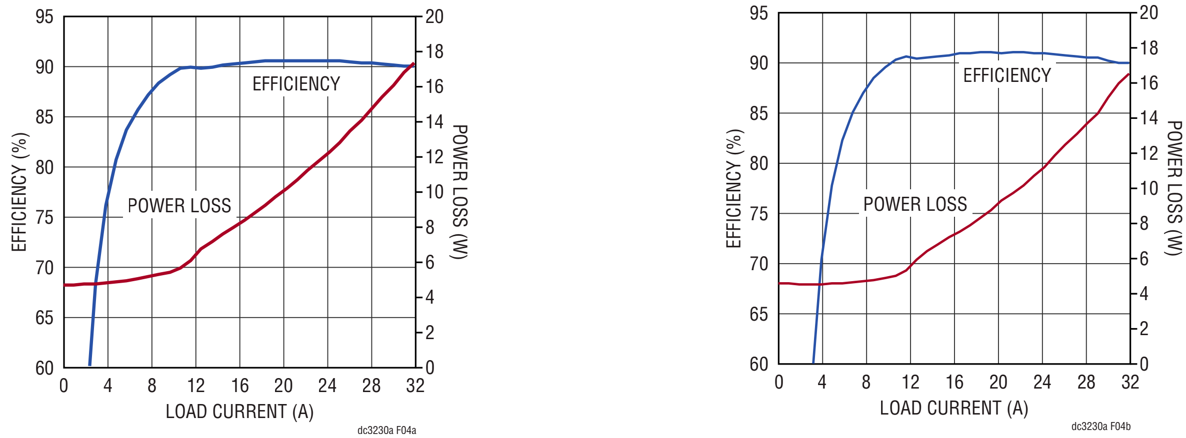
   An external clock can be applied between EXT_CLK (E1) and GND over a frequency range of 250kHz to 780kHz. The clock input high threshold is 2V and the clock input low threshold is 0.2V.

   To measure PGOOD with level shifter at the turret (E6), the 5V BIAS voltage should be enabled by moving jumper JP9 to the ON position, R112 is removed and a 0Ω resistor is placed at R111.

4. **Temperature Sensing:** LTM4652 IC temperature is measured with an onboard circuit utilizing LTC®2997. The 5V BIAS circuit must be enabled by placing jumper JP9 in the ON position. The LTC2997 converts the voltage from a diode-configured PNP transistor inside the LTM4652 through its $TEMP^+$ and $TEMP^-$ pins into VPTAT. This VPTAT voltage correlates to LTM4652 IC temperature using the following conversion:

   TEMP (K) = VPTAT/4mV

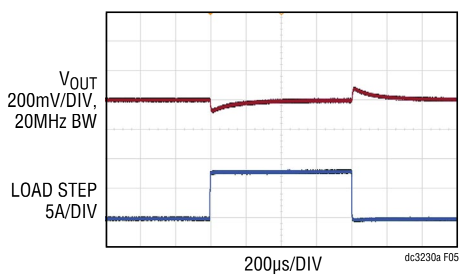
TYPICAL PERFORMANCE CHARACTERISTICS



(a) Sourcing Current

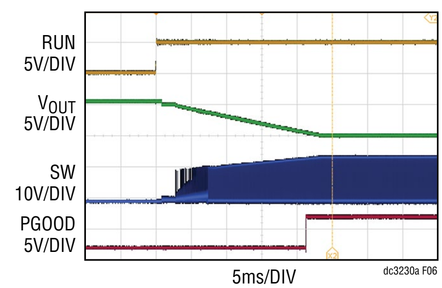
(b) Sinking Current

Figure 4. Measured Supply Efficiency and Power Loss (V_{IN} = 9V, V_{OUT} = –5V f_{SW} = 780kHz)



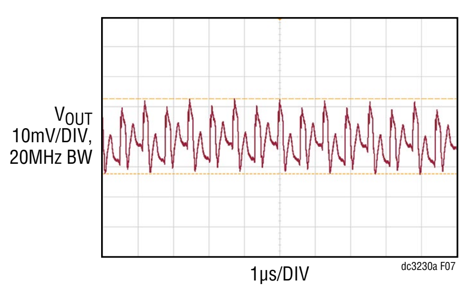
V_{IN} = 9V, V_{OUT} = –5V
f_{SW} = 780kHz
C_{OUT} = 220µF ×8 CERAMIC
C_{TH} = 47nF, R_{TH} = 2k, C_{THP} = 330pF
$I_{LOAD\ STEP}$ = 0A TO 8A TO 0A AT 10A/µs
$V_{OUT,P-P}$ = 174mV

Figure 5. Load Transient Response



V_{IN} = 9V, V_{OUT} = –5V
f_{SW} = 780kHz
C_{OUT} = 220µF ×8 CERAMIC
C_{SS} = 0.1µF

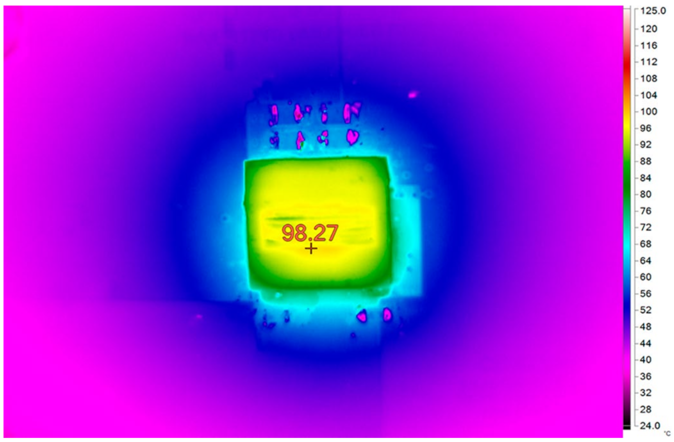
Figure 6. 9V_{IN} to –5V_{OUT} Start-Up into 32A Load



V_{IN} = 9V, V_{OUT} = –5V
f_{SW} = 780kHz
I_{LOAD} = 32A
$V_{OUT,P-P}$ = 25.1mV

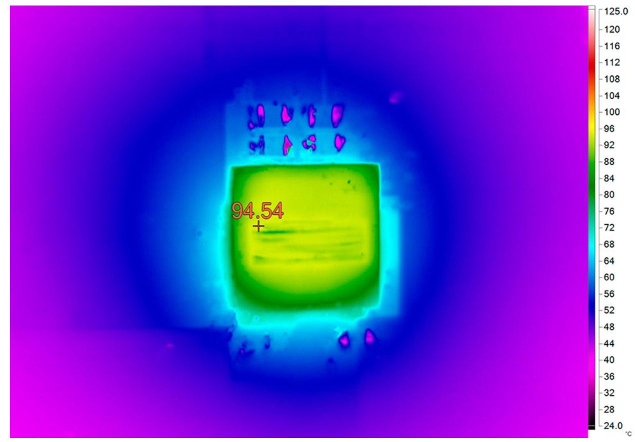
Figure 7. Output Voltage Ripple

TYPICAL PERFORMANCE CHARACTERISTICS



V_{IN} (V)	HEATSINK	AIRFLOW (LFM)	MAX CASE TEMP (°C)	V_{OUT} (V)	I_{OUT} (A)
9	None	400	98.27	–5	32

(a) Sourcing Current Condition



V_{IN} (V)	HEATSINK	AIRFLOW (LFM)	MAX CASE TEMP (°C)	V_{OUT} (V)	I_{OUT} (A)
9	None	400	94.54	–5	–32

(b) Sinking Current Condition

Figure 8. Measured Thermal Captures Without Forced Airflow

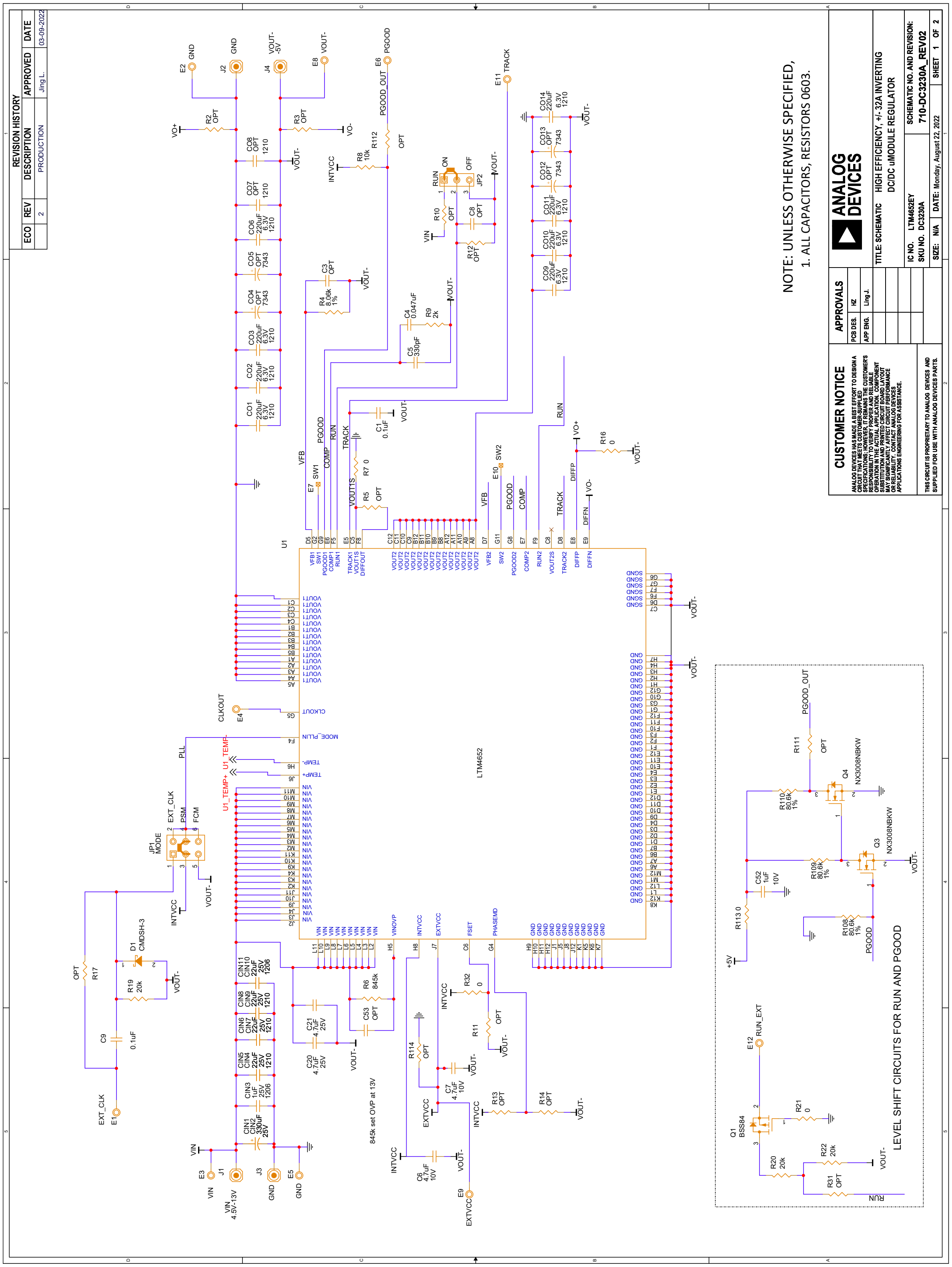
PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	4	C1, C9, C18, C22	CAP., 0.1µF, X7R, 25V, 10%, 0603	AVX, 06033C104KAT2A
2	2	C4, C49	CAP., 0.047µF, X7R, 50V, 10%, 0603	AVX, 06035C473KAT2A
3	1	C5	CAP., 330pF, C0G, 50V, 5%, 0603	AVX, 06035A331JAT2A
4	1	C6	CAP., 4.7µF, X5R, 10V, 10%, 0603	AVX, 0603ZD475KAT2A
5	1	C7	CAP., 4.7µF, X5R, 10V, 20%, 0603	WURTH ELEKTRONIK, 885012106012
6	2	C16, C52	CAP., 1µF, X7R, 10V, 10%, 0603	AVX, 0603ZC105KAT2A
7	1	C19	CAP., 470pF, X7R, 50V, 10%, 0603	AVX, 06035C471KAT2A
8	2	C20, C21	CAP., 4.7µF, X5R, 25V, 10%, 0603	MURATA, GRM188R61E475KE15D
9	2	C41, C48	CAP., 100µF, X5R, 10V, 20%, 1210	KEMET, C1210C107M8PACTU
10	1	C46	CAP., 10µF, X5R, 16V, 20%, 1210	AVX, 1210YD106MAT2A
11	1	C47	CAP., 220pF, X7R, 50V, 10%, 0603	AVX, 06035C221KAT2A
12	2	CIN1, CIN2	CAP., 330µF, ALUM POLYMER ELEC, 25V, 20%, SMD, 10mm × 10.2mm, AEC-Q200	PANASONIC, EEHZC1E331P
13	1	CIN3	CAP., 1µF, X7R, 25V, 10%, 1206	AVX, 12063C105KAT2A
14	6	CIN4-CIN9	CAP., 22µF, X5R, 25V, 10%, 1210, NO SUBS ALLOWED	MURATA, GRM32ER61E226KE15K
15	2	CIN10, CIN11	CAP., 22µF, X6S, 25V, 20%, 1206	MURATA, GRM31CC81E226ME11L
16	8	CO1-CO3, CO6, CO9, CO10, CO11, CO14	CAP., 220µF, X5R, 6.3V, 20%, 1210, NO SUBS ALLOWED	MURATA, GRM32ER60J227ME05K

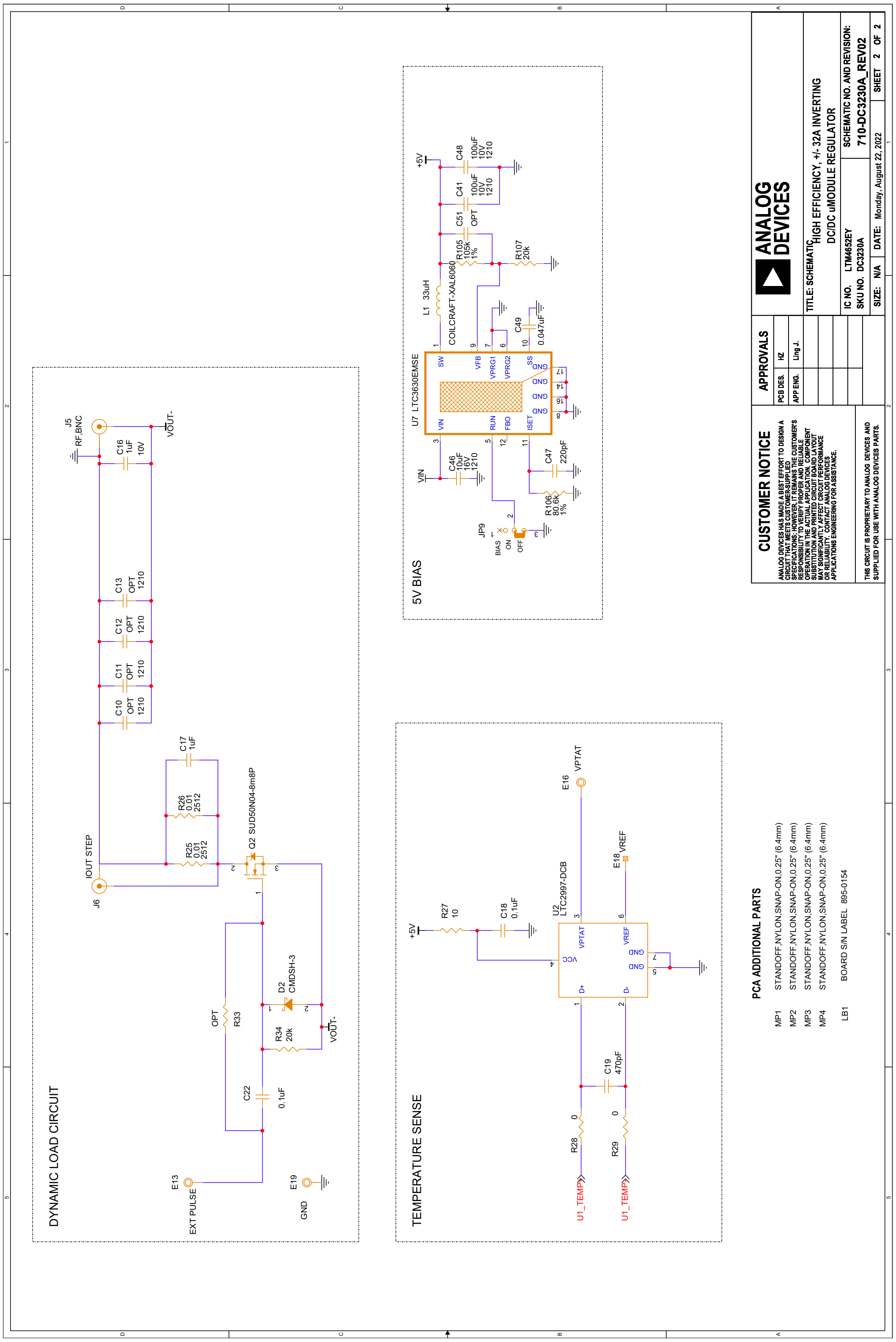
PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
17	2	D1, D2	DIODE, SCHOTTKY, 30V, 250mW, 100mA, SOD-323	CENTRAL SEMI., CMDSH-3 TR LEAD FREE
18	1	L1	IND., 33µH, PWR, SHIELDED, 20%, 3.6A, 105mΩ, 6.56mm × 6.36mm, AEC-Q200, XAL6060	COILCRAFT, XAL6060-333MEB
19	1	Q1	XSTR., MOSFET, P-CH, 50V, 0.13A, SOT23-3	FAIRCHILD SEMI, BSS84
20	1	Q2	XSTR., MOSFET, N-CH, 40V, 14A, DPAK (TO-252)	VISHAY, SUD50N04-8M8P-4GE3
21	2	Q3, Q4	XSTR., MOSFET N-CH, 30V, 350mA, SOT-323	NEXPERIA, NX3008NBKW, 115
22	1	R4	RES., 8.06k, 1%, 1/10W, 0603	YAGEO, RC0603FR-078K06L
23	1	R6	RES., 845k, 1%, 1/10W, 0603, AEC-Q200	VISHAY, CRCW0603845KFKEA
24	5	R7, R16, R112, R113, R115	RES., 0Ω, 1/10W, 0603, AEC-Q200	PANASONIC, ERJ3GEY0R00V
25	1	R8	RES., 10k, 5%, 1/10W, 0603, AEC-Q200	NIC, NRC06J103TRF
26	1	R9	RES., 2k, 1%, 1/10W, 0603	NIC, NRC06F2001TRF
27	2	R19, R34	RES., 20k, 1%, 1/10W, 0603	NIC, NRC06F2002TRF
28	3	R20, R22, R107	RES., 20k, 5%, 1/10W, 0603, AEC-Q200	NIC, NRC06J203TRF
29	4	R21, R28, R29, R32	RES., 0Ω, 1/10W, 0603, AEC-Q200	VISHAY, CRCW06030000Z0EA
30	2	R25, R26	RES., 0.01Ω, 1%, 1W, 2512, PWR, METAL, SENSE, AEC-Q200	VISHAY, WSL2512R0100FEA
31	1	R27	RES., 10Ω, 1%, 1/10W, 0603	VISHAY, CRCW060310R0FKEA
32	1	R105	RES., 105k, 1%, 1/10W, 0603, AEC-Q200	VISHAY, CRCW0603105KFKEA
33	4	R106, R108, R109, R110	RES., 80.6k, 1%, 1/10W, 0603	VISHAY, CRCW060380K6FKEA
34	1	U1	IC, BiDR µModule REG DUAL ±25A, or SINGLE ±50A DC/DC, PRELIM	ANALOG DEVICES, LTM4652EY#PBF
35	1	U2	IC, REMOTE INTERNAL TEMP SENSOR, 6-PIN DFN 2mm × 3mm	ANALOG DEVICES, LTC2997IDCB#TRMPBF
36	1	U7	IC, SYNCHR. STEP-DOWN CONVERTER, MSOP-16	ANALOG DEVICES, LTC3630EMSE#PBF
Additional Demo Board Circuit Components				
1	0	C3, C8, C17, C51, C53	CAP., OPTION, 0603	OPT
2	0	C10-C13, CO7, CO8	CAP., OPTION, 1210	OPT
3	0	CO4, CO5, CO12, CO13	CAP., OPTION, 7343	OPT
4	0	R2, R3, R5, R10-R14, R17, R31, R33, R111, R114	RES., OPTION, 0603	OPT
Hardware for Demo Board Only				
1	13	E1-E6, E8, E9, E11-E13, E16, E19	TEST POINT, TURRET, 0.064" MTG. HOLE, PCB 0.062" THK	MILL-MAX, 2308-2-00-80-00-00-07-0
2	4	J1-J4	EVAL BOARD STUD HARDWARE SET, #10-32	ANALOG DEVICES, 720-0010
3	2	J5, J6	CONN., RF, BNC, RCPT, JACK, 5-PIN, ST, THT, 50Ω	AMPHENOL RF, 112404
4	1	JP1	CONN., HDR, MALE, 2×3, 2mm, VERT, ST, THT	WURTH ELEKTRONIK, 62000621121
5	2	JP2, JP9	CONN., HDR, MALE, 1×3, 2mm, VERT, ST, THT, NO SUBS. ALLOWED	WURTH ELEKTRONIK, 62000311121
6	4	MP1-MP4	STANDOFF, NYLON, SNAP-ON, 0.25" (6.4mm)	KEYSTONE, 8831
7	3	XJP1, XJP2, XJP9	CONN., SHUNT, FEMALE, 2-POS, 2mm	WURTH ELEKTRONIK, 60800213421

SCHEMATIC DIAGRAM



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 NONINFRINGEMENT 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.