LTC1628 Dual-Phase Multioutput High Current Converter

DESCRIPTION

Logic and computing devices draw more current as supply voltages continue to drop. Using a linear regulator to generate the required voltage is inefficient at high currents. The LTC®1628 dual, current mode, PolyPhase™ controller is capable of driving two synchronous buck converters 180 degrees out of phase to obtain two high current outputs. Because of input ripple current cancellation, the size and cost of the input capacitors is much smaller than in a single-phase configuration. This results in a dramatic reduction in the number of input capacitors required.

Demo board DC271 is designed to provide a maximum output current of 12A per main output. The input voltage range is 5V to 24V and the typical output voltages are 5V and 3.3V or lower. If an external, low power, 5V supply is available, the main input voltage of DC271 can be below 5V, for example, 3.3V. The maximum input voltage can also be increased to beyond 24V if 30V capacitors are used for input filtering. With an overwinding on the buck inductor, a third low power voltage output, typically 12V, can

TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

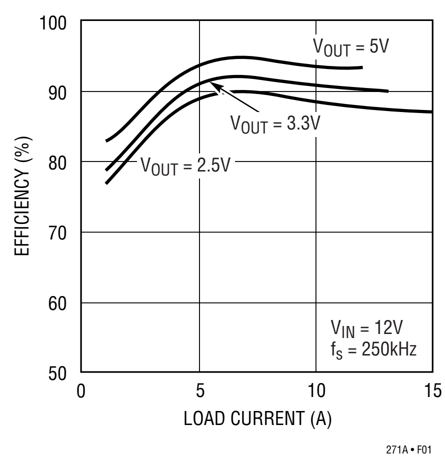
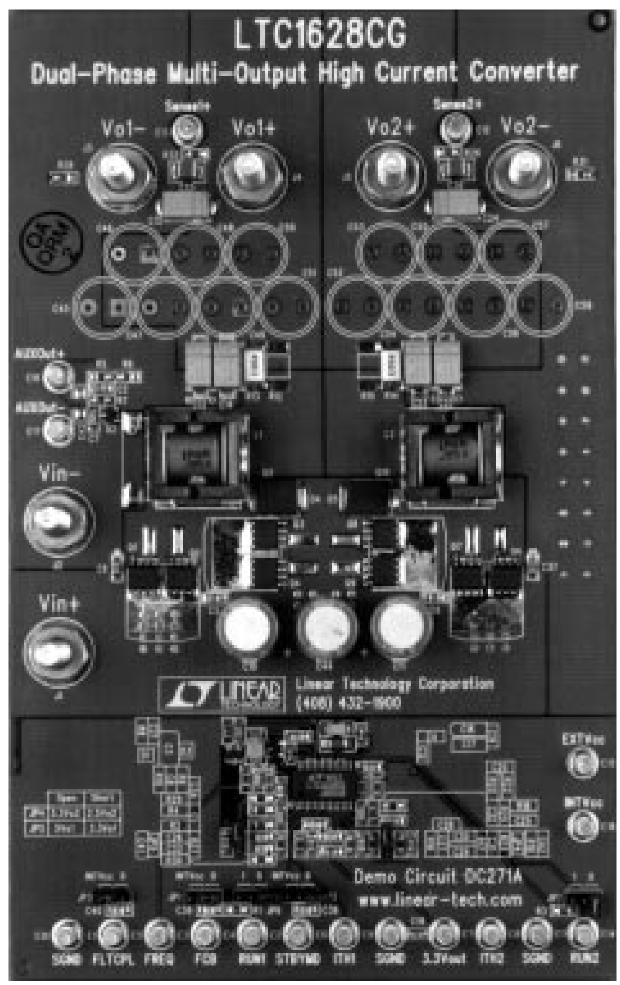


Figure 1. Measured Efficiency at Different Loads (FCB = 0, Forced Continuous Conduction Mode)

Component Side



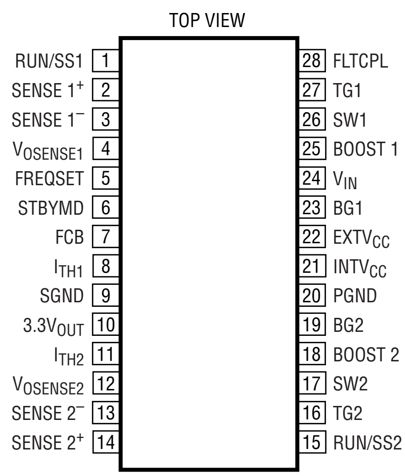
DESCRIPTION

also be obtained. This demo board always supplies 3.3V at 10mA. If the input voltage is higher than 6V, the power supply also provides a 5V low power output. To facilitate the evaluation of different MOSFETs and capacitors, the layout of DC271 allows the use of MOSFETs in SO-8, DPAK or D2PAK, and OS-CON, tantalum or multilayer ceramic input and output capacitors. The output is easily configured for different voltages. Test results are presented for outputs of 5V and 3.3V with a 12V input. **Gerber files for this circuit board are available. Contact the LTC factory.**

PERFORMANCE SUMMARY

PARAMETER		CONDITIONS	VALUE
Input Voltage			5V to 24V
Output Voltages			0.8V to 5V (Configured for 5V, 3.3V)
			0.8V to 5V (Configured for 3.3V, 2.5V)
		Standby	3.3V ± 0.15V
		V_{IN} > 6V, Standby	5V ± 0.2V
		Auxiliary	Optional Overwinding Output
Output Currents	V_{01}	Maximum, Room Temperature	12A Max for $5V_{OUT}$ and $3.3V_{OUT}$
	V_{02}		12A Max for $3.3V_{OUT}$, 15A Max for $2.5V_{OUT}$
	$INTV_{CC}$		10mA Max
	$3.3V_{OUT}$		10mA Max
	AUXOUT		Optional Overwinding Output
Load Regulation of V_{01} and V_{02}		Zero to Full Load	< 20mV
Output Ripple at V_{01} and V_{02}		Full Load, Peak-to-Peak, V_{IN} = 12V	< $60mV_{P-P}$ Typ
Transient Response at V_{01} and V_{02}		Load Switch Between 5A and 10A, 50µs Rise and Fall Time, V_{IN} = 12V	< 70mV Peak Typ
Efficiency		V_{IN} = 12V, Room Temperature	93% for $5V_{OUT}$ 12A
			90% for $3.3V_{OUT}$ 12A
			87% for $2.5V_{OUT}$ 15A

PACKAGE DIAGRAM



G PACKAGE
28-LEAD PLASTIC SSOP

LTC1628CG

SCHEMATIC DIAGRAM

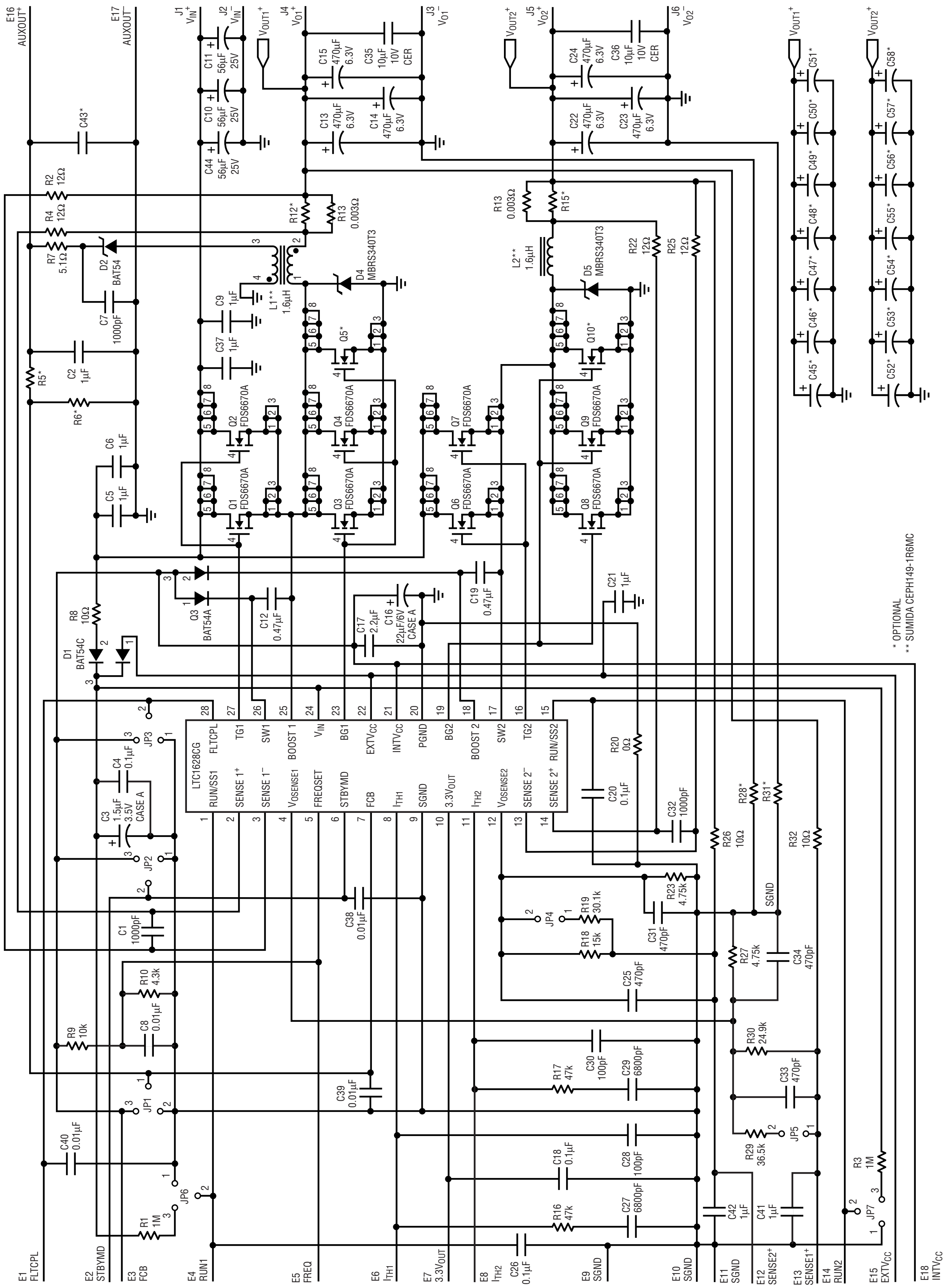


Figure 2. LTC1628 Dual-Phase Multioutput High Current Converter Schematic

PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C1, C7, C32	3	08055C102MAT1A	1000pF 50V X7R Capacitor	AVX	(843) 946-0362
C2, C5, C6, C9, C21, C37, C41, C42	8	0805ZC105KAT1A	1μF 10V X7R Capacitor	AVX	(843) 946-0362
C3	1	TAJB155M035 CASE-A	1.5μF 16V Tantalum Capacitor	AVX	(207) 282-5111
C4, C18, C20, C26	4	0805YC104MAT1A	0.1μF 16V X7R Capacitor	AVX	(843) 946-0362
C8, C38, C39, C40	4	08055C103KAT1A	0.1μF 50V X7R Capacitor	AVX	(843) 946-0362
C10, C11, C44	3	25SP56M CODE F	56μF 25V Electrolytic Capacitor	Sanyo	(619) 661-6835
C12, C19	2	EMK107F474ZA	0.47μF 16V Y5V Capacitor	Taiyo Yuden	(408) 573-4150
C13, C14, C15, C22, C23, C24	6	T510X477K006AS CASE-D	470μF 6.3V Tantalum Capacitor	Kemet	(408) 986-0424
C16	1	T494A226M010AS CASE-A	22μF 10V Tantalum Capacitor	Kemet	(408) 986-0424
C17	1	1206YG225ZAT 1026	2.2μF 16V Y5V Capacitor	AVX	(843) 946-0362
C25, C31, C33, C34	4	08055A471MAT1A	470pF 50V NPO Capacitor	AVX	(843) 946-0362
C27, C29	2	08055C682MAT1A	6800pF 50V X7R Capacitor	AVX	(843) 946-0362
C28, C30	2	08055A101MAT1A	100pF 50V NPO Capacitor	AVX	(843) 946-0362
C35, C36	2	LMK325BJ106MN 1210	10μF 10V Ceramic Capacitor	Taiyo Yuden	(408) 573-4150
C43, C45 to C58	0		Optional		
D1	1	BAT54CTA SOT-23	Diode Switchmode Rectifier	Zetex	(631) 543-7100
D2	1	BAT54TA SOT-23	Diode Switchmode Rectifier	Zetex	(631) 543-7100
D3	1	BAT54ATA SOT-23	Diode Switchmode Rectifier	Zetex	(631) 543-7100
D4, D5	2	MBRS340 SMC	40V, 3A Schottky Diode	Fairchild	(408) 822-2126
E1 to E18	18	2501-2 PAD.092	Turret Pad	MILL-MAX	(516) 922-6000
J1 to J6	6	KFH-032-10	Test Pin Stud	PEM	
J1 to J6	6	#10-32	Brass Nut	Any	
J1 to J6	0	#10	Lug Ring	Keystone	(718) 956-8900
J1 to J6	0	#10	Tin Plated Brass Washer	Any	
JP1, JP2, JP3, JP6, JP7	5	2802S-03-G1	3-Pin 1 Row 0.079"cc Header	Comm-Con	(626) 301-4200
JP1 to JP7	7	CCIJ2MM-138G	0.079"cc Shunt	Comm-Con	(626) 301-4200
JP4, JP5	2	2802S-02-G1	2-Pin 1Row 0.079"cc Header	Comm-Con	(626) 301-4200
L1, L2	2	CEPH149-1R6MC	1.6μH SMT Inductor	Sumida	(847) 956-0667
Q1 to Q4, Q6 to Q9	8	FDS6670A	N-Channel MOSFET	Fairchild	(408) 822-2126
R1, R3	2	CR10-105JM 0805	1M 1/10W 5% Chip Resistor	TAD	(714) 255-9123
R2, R4, R22, R25	4	CR10-120JM 0805	12Ω 1/10W 5% Chip Resistor	TAD	(714) 255-9123
R5, R6, R12, R15, R28, R31	0		Optional		
R7	1	CR10-5R1JM 0805	5.1Ω 1/10W 5% Chip Resistor	TAD	(714) 255-9123
R8, R26, R32	3	CR10-100JM 0805	10Ω 1/10W 5% Chip Resistor	TAD	(714) 255-9123
R9	1	CR10-103JM 0805	10k 1/10W 5% Chip Resistor	TAD	(800) 508-1521
R10	1	CR10-432JM 0805	4.3k 1/10W 5% Chip Resistor	TAD	(800) 508-1521
R13, R14	2	LRF2512-01-R003-J	0.003Ω 1W 5% Chip Resistor	IRC	(361) 992-7900
R16, R17	1	CR10-473JM 0805	47k 1/10W 5% Chip Resistor	TAD	(800) 508-1521
R18	1	CR10-1502FM 0805	15k 1/10W 1% Chip Resistor	TAD	(800) 508-1521
R19	1	CR10-3012FM 0805	30.1k 1/10W 1% Chip Resistor	TAD	(800) 508-1521
R20	1	CJ10-0R0JM 0805	0Ω 1/10W 5% Chip Resistor	TAD	(800) 508-1521
R23, R27	2	CR10-4751FM 0805	4.75k 1/10W 1% Chip Resistor	TAD	(800) 508-1521
R29	1	CR10-3652FM 0805	36.5k 1/10W 1% Chip Resistor	TAD	(800) 508-1521
R30	1	CR10-2492FM 0805	24.9k 1/10W 1% Chip Resistor	TAD	(800) 508-1521
U1	1	LTC1628CG	IC	LTC	(408) 432-1900

QUICK START GUIDE

The circuit is very simple as far as the basic input and output connections are concerned. However, due to the high current nature of this design, care must be exercised or unreliable results will be obtained. The first consideration is the wire gauge for input and output power connections. The load current of 12A will require at least 3 strands of AWG 18 wire or equivalent for the output power and ground connections. The input wire size is 1 to 3 strands of AWG 18 or equivalent, depending on the input voltage. There is one pair of connector terminals for the inputs of the DC271 and one pair for each output. It is important that all these connections be tightened and secured before applying power to the circuit.

The lab supply used for the input source of DC271 must be capable of supplying a current estimated at $1.2 \bullet (V_{O1} \bullet I_{O1} + V_{O2} \bullet I_{O2})/V_{IN}$. To prevent interaction between the lab supply and the demo board, additional low impedance electrolytic capacitors at the output of the lab supply are recommended. This is particularly important for transient load testing, especially at low input voltages.

Since foldback current limiting is built into the LTC1628, some caution must be exercised when testing the DC271. If a constant-current mode electronic load is used, the initial current must be set to a low value (1A recommended) to bring up the circuit. Otherwise, the circuit may not be able to start because the I-V characteristics of the electronic load will trigger the foldback current limit function within the LTC1628 and, shortly thereafter, the shutdown mechanism. Also, pay attention to the current rating of the electronic load. Some electronic loads cannot provide the rated current when the voltage is 3V or lower. For low voltage, high current applications, the resistance of the output cables of DC271 must be minimized to obtain the highest possible load current from the electronic load. Older style, Darlington-based electronic loads may not be useful for 3.3V or lower outputs.

When the input voltage is below 5V, another 5V lab supply capable of 500mA must be used to power the LTC1628. Otherwise, the MOSFETs will not have sufficient gate drive voltage. This lab supply should be connected to the $EXTV_{CC}$ and SGND terminals on the demo board with a pair of twisted wires. The maximum allowable voltage applied on $EXTV_{CC}$ is 7V. In this case, turn on the main power supply first before turning on the 5V supply during start-up.

The remote sense pins, $SENSE1^+$ and $SENSE2^+$, should be connected directly to the positive terminal of each output.

Attach the voltmeters directly to the input and output connectors to measure the input voltage and output voltage, respectively. Always use current shunts to measure the output current (and the input current if the input voltage is below 12V). Put one in each power path and do not remove either during the efficiency measurements (refer to Figure 3).

Before turning on the circuit, preset the input voltage to the desired voltage and the load to 1A. After the circuit is powered up, increase the load to the desired level.

The maximum current of each output is about 12A. Smaller current sense resistors will allow higher output currents.

The demo board is shipped with the following settings:

JP1(FCB)	0
JP2(STBYMD)	Open
JP3(FLTCPL)	$INTV_{CC}$
JP4(V_{O2})	Open, Configure for 3.3V Output
JP5(V_{O1})	Open, Configure for 5V Output
JP6(RUN1)	Open
JP7(RUN2)	Open

QUICK START GUIDE

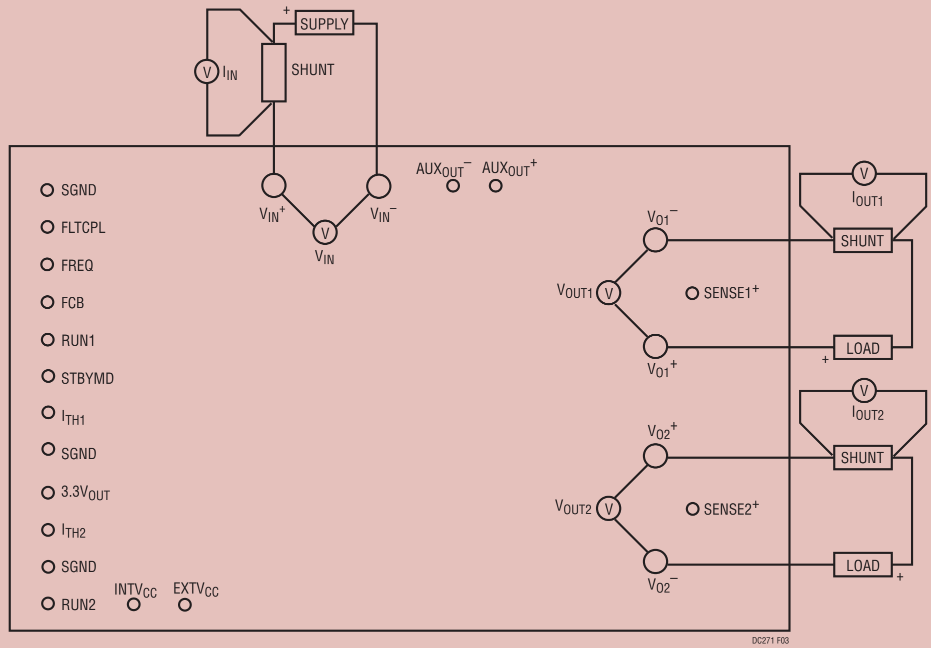


Figure 3. Test Diagram

OPERATION

DC271 receives the input power from V_{IN}^+ and V_{IN}^- and supplies load to V_{O1}^+ and V_{O1}^-, V_{O2}^+ and V_{O2}^-. An external bias supply of 5V may be connected to $EXTV_{CC}$ to boost the light load efficiency. If an overwinding is used on the buck inductor (L1) in the V_{OUT1} output circuit, a third output voltage, typically 12V, may be made available at the AUXOUT ± terminals. The $3.3V_{OUT}$ pin supplies 3.3V at 10mA DC and 50mA PEAK. If the input voltage is above 6V, the $INTV_{CC}$ pin will supply a 5V reference output.

Configuration of Different Operating Modes

The RUN1 and RUN2 pins can be used for soft-start and run control of V_{OUT1} and V_{OUT2}, respectively, depending on the state of the FLTCPL pin. Pulling the RUN pin below 1.3V will shut down the corresponding output. For normal operation, leave the RUN pins open or connect them to $INTV_{CC}$. Soft-start capacitors are included on DC271. For a longer soft-start time, additional capacitance may be connected to the RUN pins. The FCB pin controls the light-load operating modes of the synchronous buck circuits: forced continuous conduction, Burst Mode™ operation and Burst Mode operation disable. Refer to Table 1 and the LTC1628 data sheet. The STBYMD pin determines which circuitry remains active when the controllers are shut down and/or provides a common control point to shut down both controllers. Refer to the LTC1628 data sheet for details. The FLTCPL pin determines whether the two controllers operate individually or in combination. See Table 2 for details.

Table 1. Low Current Operating Modes

FCB	< 0.8V	0.8V to $INTV_{CC}$ – 0.5V	$INTV_{CC}$
Low Current Operating Mode	Continuous Conduction Mode	Burst Mode Operation	Burst Mode Operation Disable (Discontinuous Conduction Mode)

Frequency Setting

Applying a different voltage on the FREQ pin can alter the switching frequency. Refer to the LTC1628 data sheet for details. R10 on the schematic diagram (Figure 2) can be varied to obtain the desired switching frequency. The suggested values are from 0k to 5.6k, corresponding to a frequency range of 150kHz to 300kHz.

Burst Mode is a trademark of Linear Technology Corporation

OPERATION

Table 2. Fault Coupling Pin

FLTCPL	0	$INTV_{CC}$
Relationship Between Two Controllers	Two Controllers Operate Individually	Two Controllers Operate in Combination
FCB	Only Applies on Controller 1	Applies on Both Controllers
Overcurrent Latch Off	Only Latch Off the Controller Having the Overcurrent Condition	Latch Off Both Controllers When Either Has an Overcurrent Condition

Output Voltage Setting

JP4 and JP5 can be used to set different output voltages.

Table 3. Output Voltage Settings

Output Voltages	Jumpers	Open	Closed
V_{O1}	JP5	5V	3.3V
V_{O2}	JP4	3.3V	2.5V

R18 and R30 on the schematic can be changed to obtain the desired output voltage:

$$R30(18) = 4.75k(1.25V_{O1(2)}) – 1 \quad (1)$$

Sense Resistor

The current sense resistor is selected according to the channel current. The starting resistance value is estimated to be

$$R_{CS} = \frac{V_{SENSE(MAX)}}{\left(I_{LDC} + \Delta I_{L/2}\right)} \quad (2)$$

where I_{LDC} is the maximum DC inductor current, ΔI_L is the maximum peak-to-peak inductor ripple current and $V_{SENSE(MAX)}$ is the maximum current sense threshold at the operating duty cycle. Refer to the LTC1628 data sheet for the plot of “Maximum Current Sense Threshold vs Duty Factor.” The power rating can be estimated to be

$$P_{CS} = \left(I_{LDC}{}^2 + \frac{1}{12}\Delta I_L{}^2\right)R_{CS} \quad (3)$$

The final sense resistor value may be varied based on current limit requirement.

MOSFETs

The selection of MOSFETs is determined by the output current, input voltage and switching frequency. Low $R_{DS(ON)}$ MOSFETs are usually used for high current output applications because they reduce conduction loss; however they also tend to introduce high switching-related losses at high switching frequencies because of the large gate charge and parasitic capacitances. For a given current requirement and selected switching frequency, both $R_{DS(ON)}$ and gate charge (Q_G) should be evaluated to minimize the sum of the conduction losses, driving losses and switching loss. For a high input voltage, the high dV/dt applied on the Miller capacitance of the bottom MOSFET may cause false turn-on of the bottom MOSFET when the top MOSFET turns on. The resulting shoot-through current may damage the top MOSFET. Therefore, MOSFETs with a low ratio of Miller capacitance charge to the prethreshold gate charge should be used for the bottom switches.

For the specified applications, a number of MOSFETs can be good choices: Si4410, Si4420, Si4884 and Si4874 (Siliconix), FDS6680A and FDS6670A (Fairchild) and IRF7807, IRF7811, IRF7805 and IRF7809 (International Rectifier) may be used.

In the breadboard tests, two FDS6670s were used for the top switch and two FDS6670As were used for the bottom switch. One catch diode (MBRS340T3) was used for each buck circuit to bypass the body diode of the bottom MOSFET during the switching transitions. The purpose of this catch diode is to minimize the conduction loss and the reverse recovery losses related to the MOSFET body diode.

Inductors

The selection of inductors is driven by the load current amplitude and the switching frequency. The LTC1628 senses the inductor current with a low value current sense resistor. Therefore, the inductor ripple current must be large enough to produce a reasonable AC sense voltage. It is estimated that an inductor value of around 1.5µH will be suitable for a 3.3V or 5V output at a frequency range between 200kHz and 300kHz. A number of off-the-shelf

OPERATION

surface mount inductors are available for the specified applications: P1608, PE53691 (Pulse Engineering), ETQP6F1R3L (Panasonic) and CEPH149-1R6MC (Sumida). Any inductor of the desired value and current capability should work correctly.

Capacitors

The selection of the input capacitors is driven by the RMS value of the input ripple current. Large capacitor ripple currents introduce high power losses due to the ESR of the capacitor and tend to reduce the capacitor life. Low ESR capacitors must be used. The layout of the input capacitors on this demo board allows the use of OS-CON capacitors or a combination of multilayer ceramic capacitors and low ESR aluminum electrolytic capacitors. The data presented here was obtained with Sanyo OS-CON capacitors (25SP56M 56µF/25V), whose maximum allowable ripple current is rated at about $3.26A_{RMS}$. The maximum input RMS ripple current is estimated to be about $8.3A_{RMS}$ for a 7V to 24V input range, 3.3V (0A to 15A) and 5V (0A to 15A) outputs. Therefore, a minimum of 3 OS-CON capacitors are needed. Figure 4 plots the maximum input ripple currents with respect to the input voltage. It is apparent that the conventional single-phase configuration will increase the worst case input ripple current to $13.2A_{RMS}$, a 60% increase. A conventional single-phase controller requires a minimum of five OS-CON capacitors. Hence, the LTC1628 based dual-phase circuit saves two OS-CON capacitors.

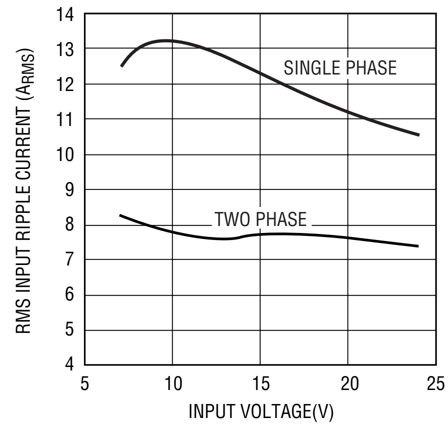


Figure 4. Maximum Input Ripple Current vs Input Voltage in a 2-Output Power Supply: 7V to $24V_{IN}$, $3.3V_{OUT1}$ at 0A to 15A, $5V_{OUT2}$ at 0A to 15A

To minimize output switching ripple voltage and meet load transient requirements, low ESR capacitors are usually required on the output. Good candidates for the output capacitor are low ESR tantalum capacitors (Kemet T510, etc.), POSCAPs (Sanyo), OS-CONs (Sanyo) and SPs (Panasonic). A combination of multilayer ceramic capacitors and low ESR aluminum electrolytic capacitors is also an option. The layout of DC271 allows the evaluation of all these types of capacitors. Test data was obtained with KEMET (T510X477M006AS 470(F/6.3V), ultralow ESR (30mΩ) surface mount tantalum capacitors. There are three tantalum capacitors on each output. More capacitors (optional) may be added to meet stricter noise and load transient requirements.

TEST RESULTS

Figure 5 shows measured waveforms of the switch-node voltages. The two buck stages are interleaved 180 degrees out of phase to reduce the input ripple current.

Efficiency was measured under different loading conditions for each output. The input voltage was measured at the input terminals and the output voltage was measured at the output terminals (refer to test diagram shown in Figure 3). The switching frequency was 250kHz, the input voltage was 12V and both channels were operated in forced continuous conduction mode (FCB = 0). Figure 1 shows the measured efficiency for three different output voltages. The efficiencies are 93% for 5V/12A and 90% for 3.3V/12A output. The light load efficiencies can be improved by enabling Burst Mode operation.

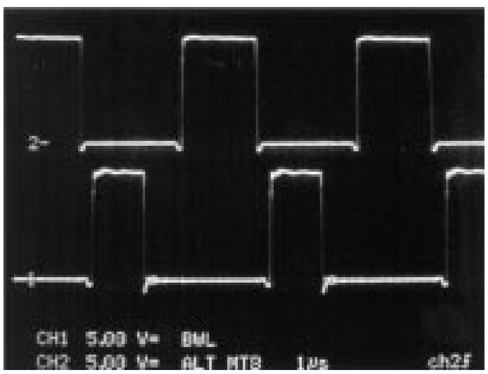
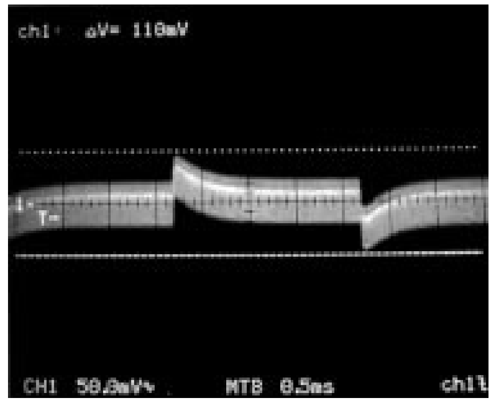
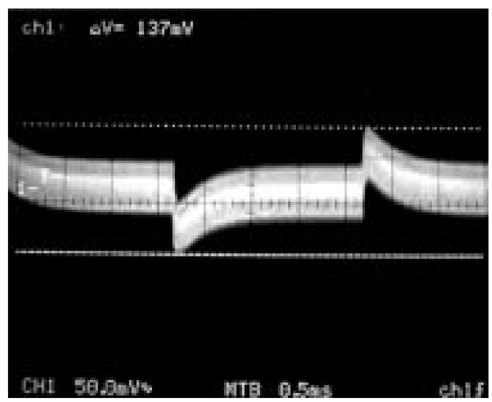


Figure 5. Typical Waveforms of Switch-Node Voltages (Drain-to-Source Voltage of Synchronous Switch)

Load transient testing was also performed with the load switching between 5A and 10A for each output. The rise and fall times were 50µs. Test results are shown in Figures 6a and 6b. Both the overshoot and undershoot are below 60mV for the 3.3V output and around 70mV for the 5V output. For load steps with very high di/dt, larger output capacitors with lower ESR would be required. The demo board allows the installation of additional output capacitors to meet more stringent load transient requirements.



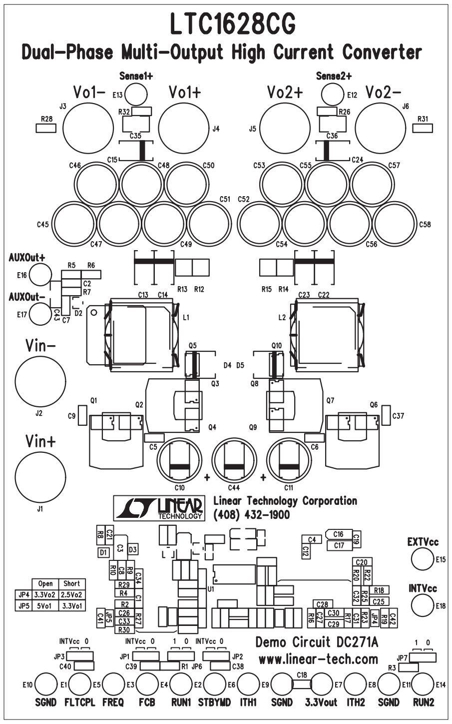
(a) 3.3V Output Voltage



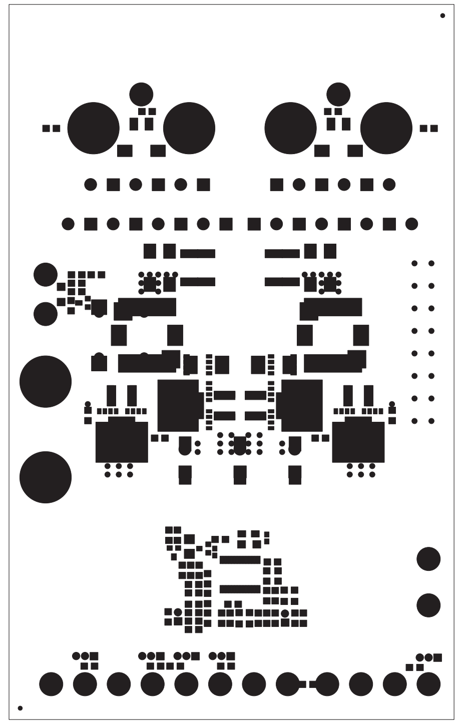
(b) 5V Output Voltage

Figure 6. Load Transient Response Waveforms with Load Switching between 5A and 10A. Voltage Scale: 50mV/DIV, Time Scale: 500µs/DIV

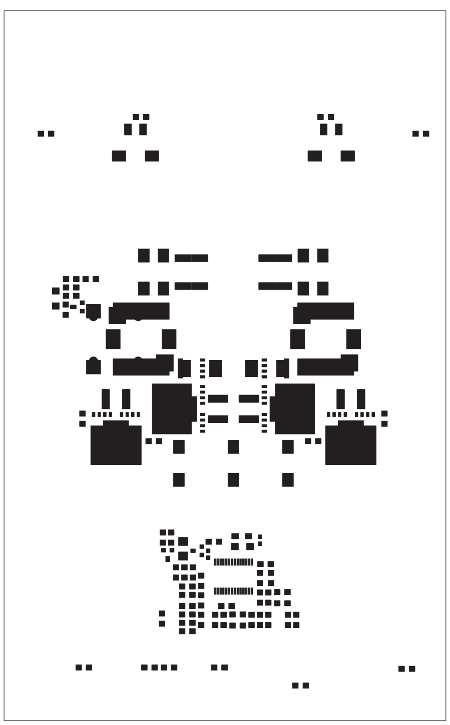
PCB LAYOUT AND FILM



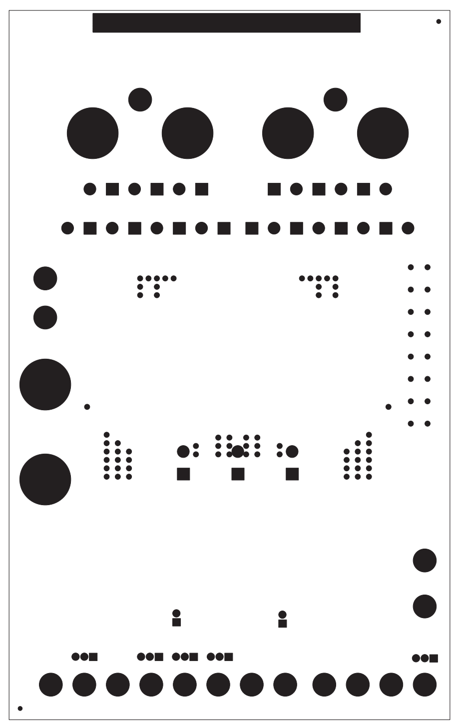
Silkscreen Top



Solder Mask Top

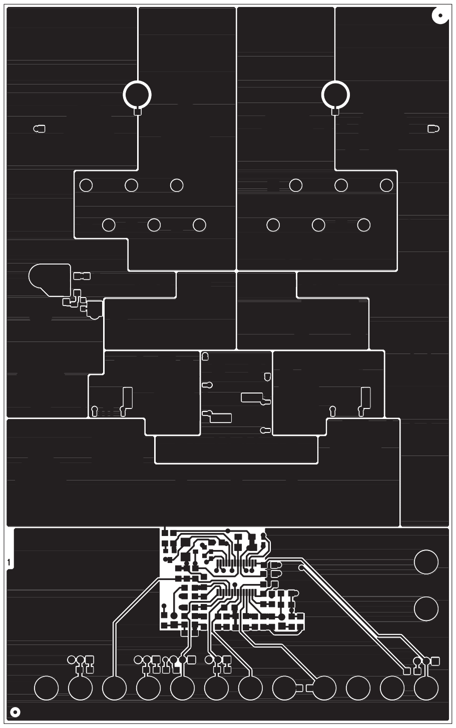


Paste Mask Top

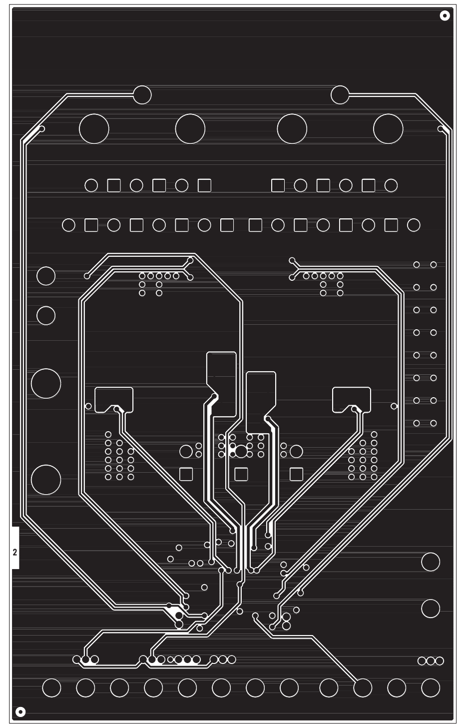


Solder Mask Bottom

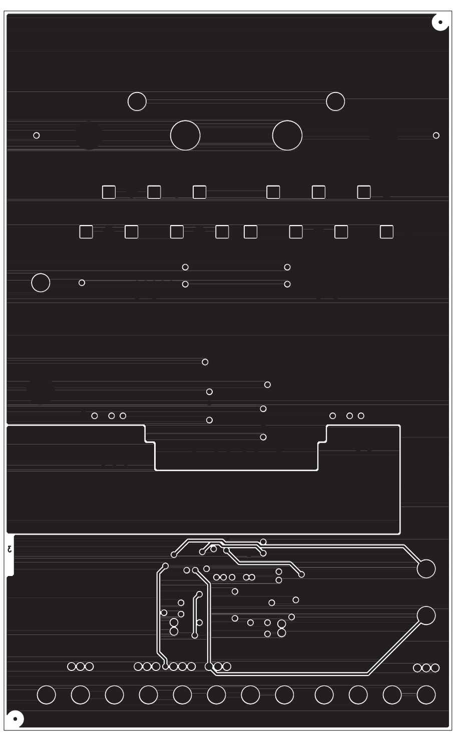
PCB LAYOUT AND FILM



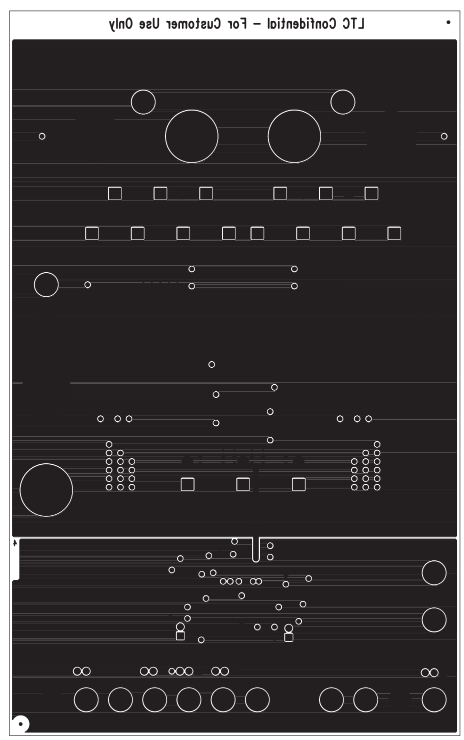
Copper Layer 1 (Top)



Copper Layer 2

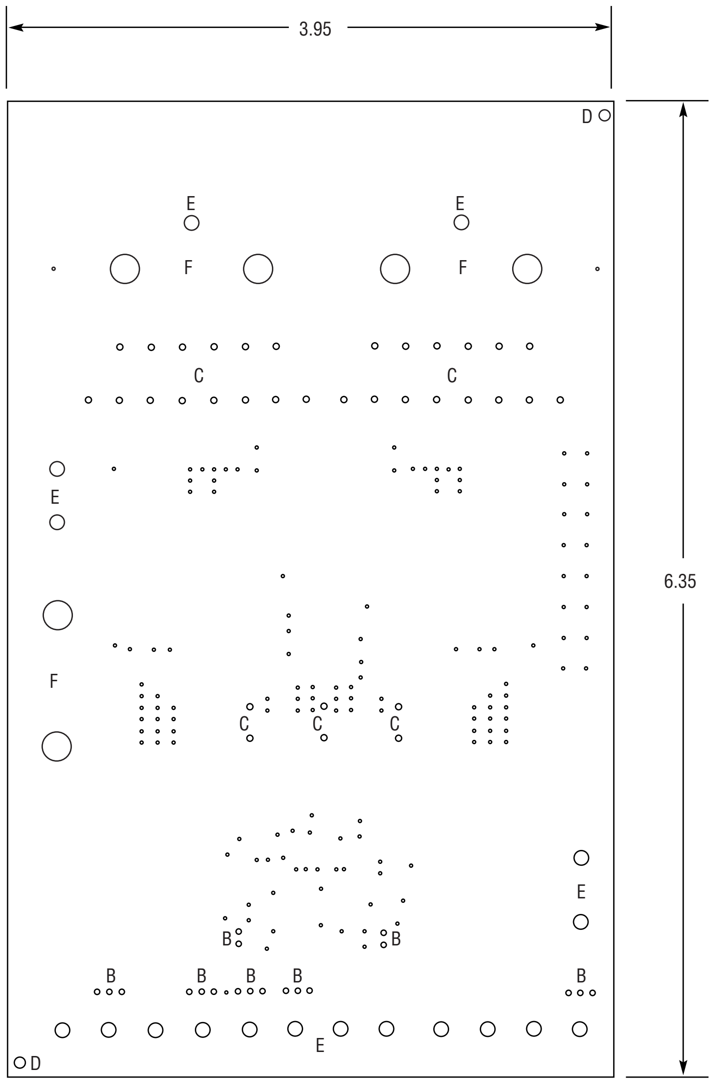


Copper Layer 3



Copper Layer 4 (Bottom)

PC FAB DRAWING



NOTES: UNLESS OTHERWISE SPECIFIED
1. MATERIAL: FR4 OR EQUIVALENT EPOXY,
   2 OZ COPPER CLAD THICKNESS 0.062 ± 0.006
   TOTAL OF 4 LAYERS
2. FINISH: ALL PLATED HOLES 0.001 MIN/0.0015 MAX COPPER PLATE
   ELECTRODEPOSITED TIN-LEAD COMPOSITION
   BEFORE REFLOW, SOLDER MASK OVER BARE COPPER (SMOBC)
3. SOLDER MASK: BOTH SIDES USING SR1020 OR EQUIVALENT
4. SILKSCREEN: USING WHITE NONCONDUCTIVE EPOXY INK
5. ALL DIMENSIONS ARE IN INCHES

SYMBOL	DIAMETER	NUMBER OF HOLES	PLATED
A	0.020	138	YES
B	0.035	19	YES
C	0.040	34	YES
D	0.072	2	NO
E	0.095	18	YES
F	0.189	6	YES
	TOTAL HOLES	217	

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