# LTC1702
# Dual 550kHz Synchronous 2-Phase 15A DC/DC Converter

## DESCRIPTION

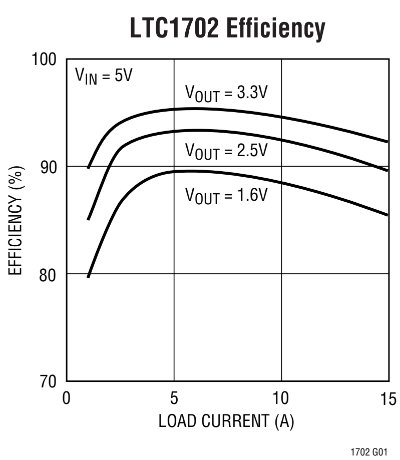
Demonstration circuit DC275 is a dual, high efficiency regulator using the LTC®1702 switching regulator controller. The LTC1702 is optimized for high efficiency with low input voltages. Typical applications are power for a digital signal processor (DSP), microprocessor and/or an application specific integrated circuit (ASIC). The input voltage of the LTC1702 can range from 3V to 7V. One of the output voltages ($V_{OUT2}$) is fixed at 3.3V and the other ($V_{OUT1}$) is programmable from 1.6V to 2.5V by means of a jumper. The LTC1702 includes two complete, on-chip, independent switching regulator controllers, each designed to drive a pair of external N-channel MOSFET devices in a voltage mode control, synchronous buck configuration. The LTC1702 also provides open-drain logic outputs (PGOOD1 and PGOOD2) that indicate whether either output has risen to within 5% of the final output voltage. An optional latching fault mode protects the load if the output rises 15% above the intended voltage. The LTC1702 uses a constant 550kHz switching frequency, minimizing external component size and maximizing load transient performance. Operating efficiencies exceeding 90% are obtained for load current currents from 1A to 14A. Additionally, the supply current in shutdown is less than 100µA. **Gerber files for this circuit board are available. Call the LTC factory.**

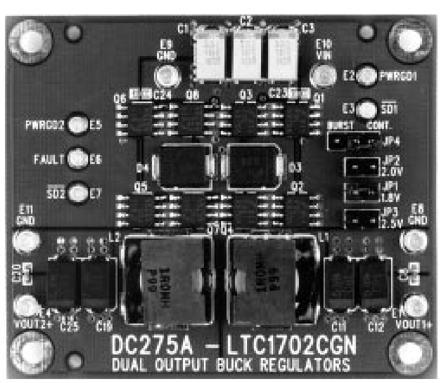


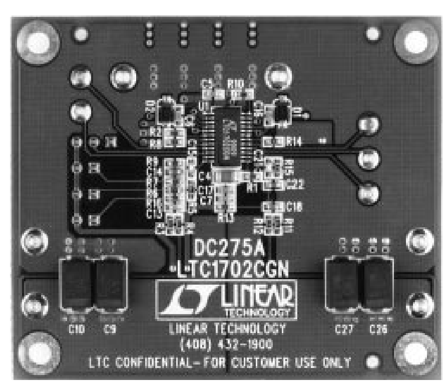
## PERFORMANCE SUMMARY

| PARAMETER | CONDITIONS | VALUE |
|---|---|---|
| $V_{IN}$ | Input Voltage Range | 4.75V to 7V |
| $V_{OUT2}$ | Fixed Output Voltage | 3.3V |
| $I_{OUT2}$ | Maximum Output Load Current | 15A |
| Typical Output Ripple | $I_{OUT}$ = 15A | 18mV |
| $V_{OUT1}$ | Jumper Selectable Output Voltage | 1.6V, 1.8V, 2V or 2.5V |
| $I_{OUT1}$ | Maximum Output Load Current | 15A |
| Typical Output Ripple | $I_{OUT}$ = 15A | 17mV |
| $I_Q$ | Supply Current in Shutdown | 100µA |

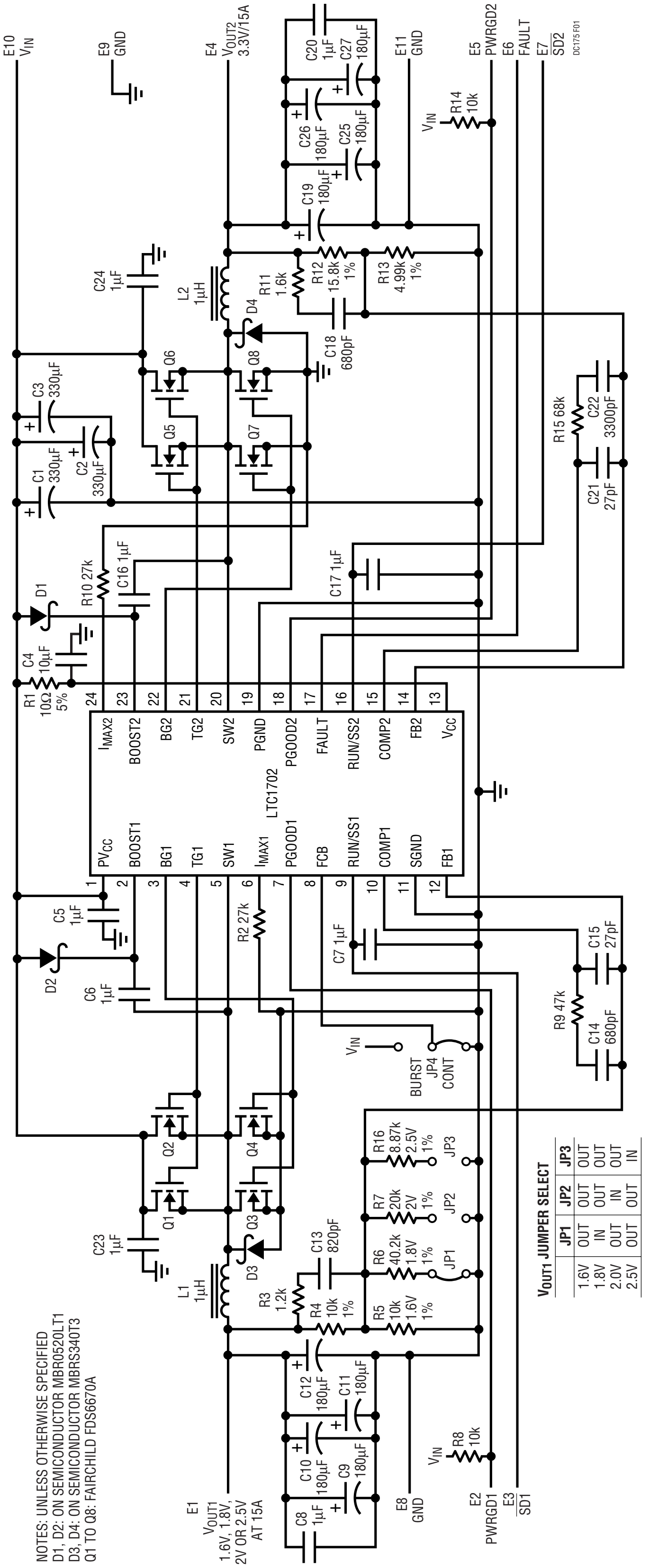
## TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO



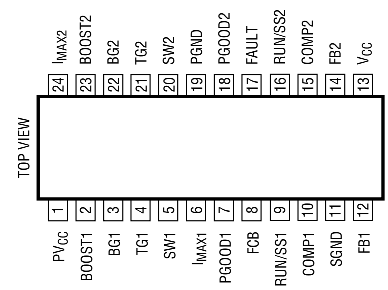
# PACKAGE AND SCHEMATIC DIAGRAMS




$V_{OUT1}$ JUMPER SELECT

| | JP1 | JP2 | JP3 |
|---|---|---|---|
| 1.6V | OUT | OUT | OUT |
| 1.8V | IN | OUT | OUT |
| 2.0V | OUT | IN | OUT |
| 2.5V | OUT | OUT | IN |

**Figure 1. Dual 550kHz Synchronous 2-Phase 15A DC/DC Converter**



GN PACKAGE
24-LEAD NARROW PLASTIC SSOP

**LTC1702CGN**

## PARTS LIST

| REFERENCE DESIGNATOR | QUANTITY | PART NUMBER | DESCRIPTION | VENDOR | TELEPHONE |
|---|---|---|---|---|---|
| C1 to C3 | 3 | T510X337K010AS | 330µF 10V 10% Tantalum Capacitor | Kemet | (408) 986-0424 |
| C4 | 1 | 1206ZG106ZAT1A | 10µF 10V Y5V Capacitor | AVX | (843) 946-0362 |
| C5 to C8, C16, C17, C20, C23 C24 | 9 | 06036D105MAT1A | 1µF 6V X5R Capacitor | AVX | (843) 946-0362 |
| C9 to C12, C19, C25 to C27 | 8 | EEFUEOG181R | 180µF 4V SP Capacitor | Panasonic | (714) 373-7334 |
| C13 | 1 | 06035C821MAT1A | 820pF 50V X7R Capacitor | AVX | (843) 946-0362 |
| C14, C18 | 2 | 06035C681MAT1A | 680pF 50V X7R Capacitor | AVX | (843) 946-0362 |
| C15, C21 | 2 | 06035A270MAT1A | 27pF 50V NPO Capacitor | AVX | (843) 946-0362 |
| C22 | 1 | 06035C332MAT1A | 3300pF 50V X7R Capacitor | AVX | (843) 946-0362 |
| D1, D2 | 2 | MBR0520LT1 | Schottky Diode | ON Semiconductor | (602) 244-6600 |
| D3, D4 | 2 | MBRS340T3 | Schottky Diode | ON Semiconductor | (602) 244-6600 |
| E1, E4, E8 to E11 | 6 | 2501-2 | 1-Pin Terminal | Mill-Max | (516) 922-6000 |
| E2, E3, E5 to E7 | 5 | 2308-2 | 1-Pin Terminal | Mill-Max | (516) 922-6000 |
| JP1 to JP3 | 3 | 3801S-02G2 | 0.100"CC 2-Pin Jumper | Comm Con | (626) 301-4200 |
| JP4 | 1 | 3801S-03G2 | 0.100"CC 3-Pin Jumper | Comm Con | (626) 301-4200 |
| JP1, JP4 | 2 | CCIJ230-G | 0.100"CC Shunt | Comm Con | (626) 301-4200 |
| L1, L2 | 2 | CEP125-1R0MC-H or ETQP6F1R0SSP | 1µH 20A SMT Inductor | Sumida Panasonic | (847) 956-0667 (714) 373-7334 |
| Q1 to Q8 | 8 | FDS6670A | SO-8 N-Channel MOSFET | Fairchild | (408) 822-2126 |
| R1 | 1 | CR16-100JM | 10Ω 1/16W 5% Chip Resistor | Tad | (714) 255-9123 |
| R2, R10 | 2 | CR16-273JM | 27k 1/16W 5% Chip Resistor | Tad | (714) 255-9123 |
| R3 | 1 | CR16-122JM | 1.2k 1/16W 5% Chip Resistor | Tad | (714) 255-9123 |
| R4, R5 | 2 | CR16-1002FM | 10k 1/16W 1% Chip Resistor | Tad | (714) 255-9123 |
| R6 | 1 | CR16-4022FM | 40.2k 1/16W 1% Chip Resistor | Tad | (714) 255-9123 |
| R7 | 1 | CR16-2002FM | 20k 1/16W 1% Chip Resistor | Tad | (714) 255-9123 |
| R8, R14 | 2 | CR16-103JM | 10k 1/16W 5% Chip Resistor | Tad | (714) 255-9123 |
| R9 | 1 | CR16-473JM | 47k 1/16W 5% Chip Resistor | Tad | (800) 508-1521 |
| R11 | 1 | CR16-162JM | 1.6k 1/16W 5% Chip Resistor | Tad | (800) 508-1521 |
| R12 | 1 | CR16-1582FM | 15.8k 1/16W 1% Chip Resistor | Tad | (800) 508-1521 |
| R13 | 1 | CR16-4991FM | 4.99k 1/16W 1% Chip Resistor | Tad | (800) 508-1521 |
| R15 | 1 | CR16-683JM | 68k 1/16W 5% Chip Resistor | Tad | (800) 508-1521 |
| R16 | 1 | CR16-8871FM | 8.87k 1/16W 1% Chip Resistor | Tad | (800) 508-1521 |
| U1 | 1 | LTC1702CGN | 24-Lead SSOP IC | LTC | (408) 432-1900 |

## QUICK START GUIDE

Refer to Figure 2 for proper measurement equipment setup and follow the procedure outlined below:

1. Connect the input power to the $V_{IN}$ and GND terminals on the board using 12-gauge or heavier wire soldered to the terminals. The input voltage is limited to between 4.75V and 7V.
2. Connect an ammeter in series with the input supply to measure input current.
3. Since this demo board operates from a low input voltage and supplies high output current, it is essential that the input supply voltage be well regulated. If the input power supply is equipped with remote sense lines, connect $SENSE^+$ to the $V_{IN}$ terminal and $SENSE^-$ to GND terminal on the board.
4. Connect either power resistors or an electronic load to the $V_{OUT1}$, $V_{OUT2}$ and GND terminals using 12-gauge or heavier wire, soldered to the terminals.
5. Connect an ammeter in series with each of the output loads to measure output currents.
6. The $\overline{SD1}$ and $\overline{SD2}$ pins should be left floating for normal operation and tied to GND for shutdown.
7. Connect a voltmeter across the $V_{IN}$ and GND terminals to measure input voltage.
8. Connect a voltmeter across the $V_{OUT1}$ and GND terminals and another across the $V_{OUT2}$ and GND terminals to measure the output voltages.
9. For applications where the minimum load current is greater than 1A, set jumper JP4 to the "Continuous" position.
10. Set the desired output voltage ($V_{OUT1}$) with jumpers JP1 to JP3, as shown in Table 1.
11. After all connections are made, turn on the power and verify that $V_{OUT1}$ and $V_{OUT2}$ are correct.

**Table 1**

| POSITION | OUTPUT VOLTAGE |
|---|---|
| No Jumper | 1.6V |
| JP1 | 1.8V |
| JP2 | 2.0V |
| JP3 | 2.5V |

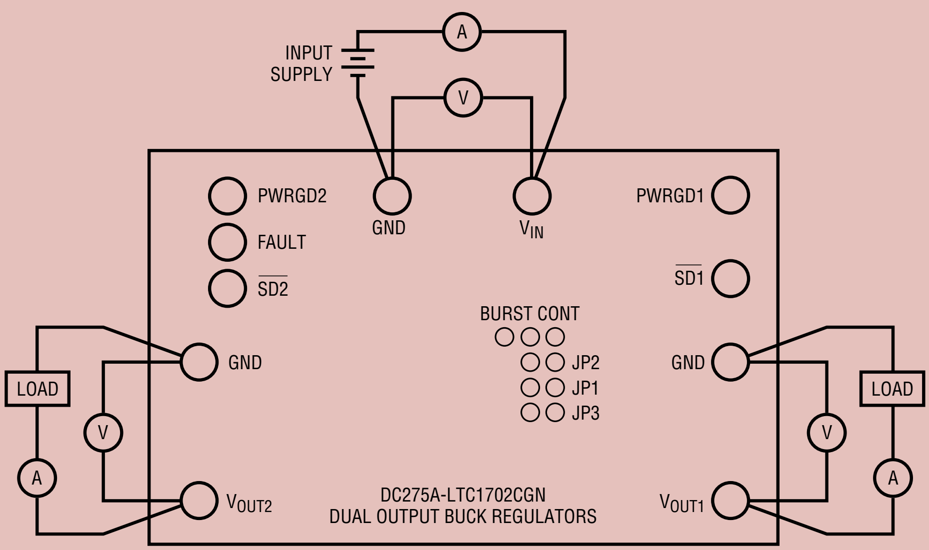



**Figure 2. Proper Measurement Setup**

# OPERATION

The circuit in Figure 1 highlights the capabilities of the LTC1702. This design provides one fixed 3.3V output ($V_{OUT2}$) and one output ($V_{OUT1}$) that is jumper selectable from 1.6V to 2.5V. The LTC1702 is a voltage mode controller, designed to drive a pair of external N-channel MOSFETs using a fixed 550kHz switching frequency. The synchronous buck architecture automatically shifts to discontinuous operation and then to Burst Mode™ operation as the output load decreases, ensuring maximum efficiency over a wide range of load currents. This mode is recommended for load currents less than 1A and can be implemented on the demo board by moving jumper JP4 to the "Burst" position.

### Theory of Operation

The LTC1702 has two independent switching regulators. For the sake of simplicity and to minimize repetition, only side "1" will be discussed. The divided output ($V_{OUT1}$) is compared to the 0.8V reference. The difference voltage is multiplied by the error amplifier's (FB) gain. The resulting error signal is then compared to an internally generated, fixed frequency sawtooth waveform by the PWM comparator, which generates a pulse width modulated signal. This PWM signal drives the external MOSFETs through TG1 and BG1. The output of this chopper circuit is then filtered by L1 and C9 to C12 to produce the desired DC output voltage.

### 2-Phase Operation

The LTC1702 dual switching regulator controller also features the considerable benefits of 2-phase operation. The LTC1702 includes a single master clock that drives the two sides such that side 1 is 180° out of phase with side 2. This technique, known as 2-phase switching, has the effect of doubling the frequency of the switching pulses seen by the input capacitor and significantly reduces their RMS value. With 2-phase switching, the input capacitor is sized as required to support the larger of the two sides at maximum load current. As the load current increases on the lower current side, it tends to cancel, rather than add to, the RMS current seen by the input capacitor; thus no additional capacitance is needed.

### Capacitor Considerations

The input capacitors are Kemet T510X337K010AS, 330µF, 10V tantalums. The input capacitors must be rated for the RMS input ripple. A good rule of thumb is that the input ripple current will be 50% of the output current. Since the LTC1702 uses 2-phase switching, the input bulk capacitors should be able to fully handle the RMS ripple current of just one load. As the load current increases on the other side, it tends to cancel, rather than to add to, the ripple current requirements for the input capacitors. For a continuous output current of 15A, the ripple current rating of the input capacitors should be 7.5A. The capacitors chosen are rated at 2.5A each, so three are adequate. Without the 2-phase operation, six capacitors would be required to handle two 15A loads.

Output capacitors need to have a ripple current rating greater than the RMS value of the inductor ripple current. This is a function of the operating frequency and inductor value, as well as input and output voltages. Because the ripple current is relatively small, the controlling parameter is generally the capacitor's ESR (equivalent series resistance). The maximum allowable ESR is equal to the maximum allowable peak-to-peak output ripple voltage divided by the peak-to-peak inductor ripple current. In general, if the ESR is low enough for the ripple voltage and transient requirements, the capacitors will have more than adequate ripple current capability.

### Inductor Selection

Inductor selection is not extremely critical. The inductor used here was chosen for fairly low cost and ready availability. The main concerns in choosing an appropriate inductor are the inductance value required, the saturation current rating and the temperature rise. Most manufacturers specify a DC current rating that produces a temperature rise of 40°C. If a design will not see high ambient temperatures, a larger temperature rise can usually be tolerated. Another maximum current specification is related to core saturation. A manufacturer may specify that maximum rated current is the point at which inductance is down by 10% (some specify 25%). Since most core materials and structures will result in a gentle,

## OPERATION

controlled roll off of inductance with DC bias, there is no magical point where the inductor is no longer useful. Look at what the inductance will be at the maximum load current expected and determine if the output ripple will remain within specified limits. If it will, the inductor will most likely work correctly. Ripple current is generally designed for between 10% and 40% of output current.

### MOSFET Selection

The main concern with FET selection in very low voltage applications is thermal management. At high current levels, power devices will get hot. The trick is to keep the temperature rise within acceptable limits. Most of the FETs' power dissipation will be due to conduction losses. Therefore, by choosing a FET with a sufficiently low $R_{DS(ON)}$, the power dissipation, and therefore, the temperature rise, can be made arbitrarily low. The price paid for very low temperature rise is more expensive FETs. Switching losses are a concern only for the high side FET. The low side FET turns on and off into a forward-biased diode, so its transition losses are very small. The high side FET, in contrast, must provide all of the reverse recovery charge that the low side FETs body diode will demand. This can result in a significant amount of switching loss in this device.

Although it may seem that a lower on-resistance FET is always desirable from an efficiency perspective, this is not necessarily true. A smaller device will have a lower gate-charge power requirement and will also exhibit faster switching transition times. The resulting reduction in AC losses may more than offset the increase in conduction losses. A smaller, higher on-resistance FET may prove the more efficient, as well as the lower cost solution. As the load current increases, gate-drive losses become less of a concern. At output currents on the order of 15A, lower resistance FETs will probably be better in terms of overall efficiency, but not necessarily the most cost effective choice. Each application will place a different value on a few points of efficiency.

### Shutdown/Soft-Start

Each half or the LTC1702 has a RUN/SS pin. This pin performs two functions: when pulled to ground, each shuts down its half of the LTC1702, and each acts as a conventional soft-start pin, enforcing a duty cycle limit proportional to the voltage at RUN/SS. An internal 4μA current source pull-up is connected to each RUN/SS pin, allowing a soft-start ramp to be generated with a single external capacitor (C7 for side 1 and C17 for side 2) to ground.

### Current Limit

The $I_{MAX}$ resistor, R2, sets the current limit by setting the maximum allowable voltage drop across the bottom MOSFET before the current limit circuit engages. The voltage across the bottom MOSFET is determined by its on-resistance and by the current flowing in the inductor, which is the same as the output current. To set the current limit, connect an $R_{IMAX}$ resistor from $I_{MAX}$ to GND. The value of $R_{IMAX}$ is calculated as follows:

$$R_{IMAX} = [(I_{LIM} \bullet R_{DS(ON)}) + 100mV]/10\mu A$$

$I_{LIM}$ should be chosen to be 150% of the maximum operating load current to account for MOSFET $R_{DS(ON)}$ variations with temperature.

### How to Measure Voltage Regulation and Efficiency

When trying to measure load regulation or efficiency, voltage measurements should be made directly across the $V_{OUT}$ and GND terminals and should not be taken at the end of test leads at the load. Similarly, input voltage should be measured directly on the $V_{IN}$ and GND terminals of the LTC1702 demo board. Input and output current should be measured by placing an ammeter in series with the input supply and load. Refer to Figure 2 for the proper test equipment setup. Refer to page one for typical efficiency curves for $V_{IN}$ = 5V, $V_{OUT}$ = 3.3V, 2.5V and 1.8V, for $I_L$ = 1A to 15A.

### How to Measure Output Voltage Ripple

In order to measure output voltage ripple, care must be taken to avoid a long ground lead on the oscilloscope probe. Therefore, a sturdy wire should be soldered on the output side of the GND terminal. The other end of the wire is looped around the ground side of the probe and should be kept as short as possible. The tip of the probe is touched directly to $V_{OUT}$ (see Figure 3). Bandwidth is generally

## OPERATION

limited to 20MHz for ripple measurements. Also, if multiple pieces of line-powered test equipment are used, be sure to use isolation transformers on their power lines to prevent ground loops, which can cause erroneous results. Figures 4 and 5 show the output voltage ripple for the 3.3V and the 2.5V supplies for a 15A load.

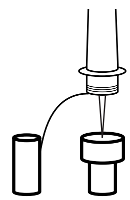



**Figure 3. Measuring Output Voltage Ripple**

### Transient Response

The LTC1702 uses true 25MHz gain bandwidth op amps as the feedback amplifiers. This allows the use of an OPTI-LOOP™ compensation scheme that can precisely tailor the loop response. The high gain-bandwidth product allows the loop to be crossed over beyond 50kHz while maintaining good stability, and significantly enhances load transient response. Figures 6 and 7 show the transient response of the 3.3V and the 2.5V output supplies for a 0A to 10A load step. For more information about loop compensation and stability analysis, consult the LTC1702 data sheet.

OPTI-LOOP is a trademark of Linear Technology Corporation.

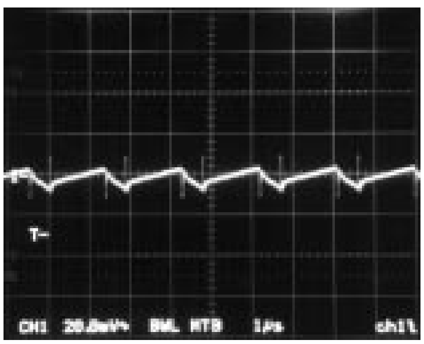


**Figure 4. 3.3V Output Voltage Ripple, $I_L$ = 15A**

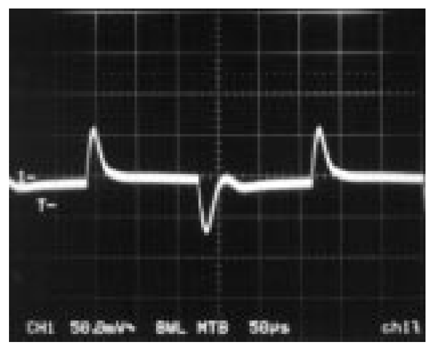


**Figure 6. 3.3V Transient Response, $I_L$ = 0A to 10A**

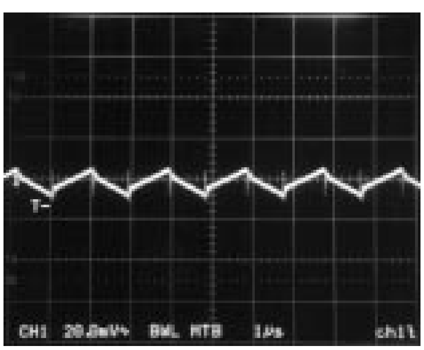


**Figure 5. 2.5V Output Voltage Ripple, $I_L$ = 15A**

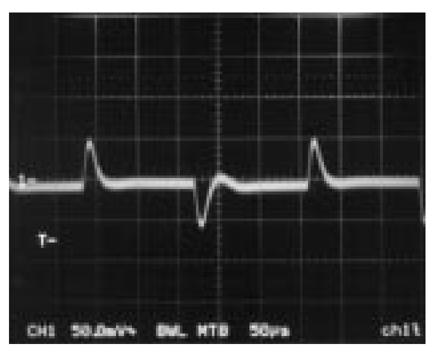


**Figure 7. 2.5V Transient Response, $I_L$ = 0A to 10A**

# OPERATION

### Heat Dissipation Issues

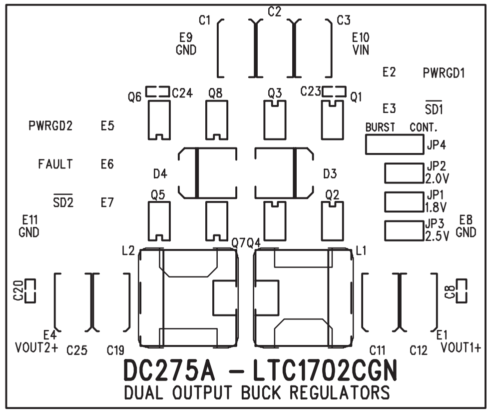
Since each side of the LTC1702 demo board can supply 15A of continuous load current, care must be taken not to exceed the maximum junction temperature for the power MOSFETs. A few possibilities for dissipating the power are to use heat sinks and/or forced air cooling. Another possibility is to use the PC board as a heat sink. On the LTC1702 demo board, power MOSFETS Q1 to Q8 are surrounded by ground and power planes on both sides of the PC board. Also, there is metal on the inner layers directly underneath the power MOSFETs. This helps in spreading the heat and improves the power dissipation capability of the PCB.

### Layout Guidelines

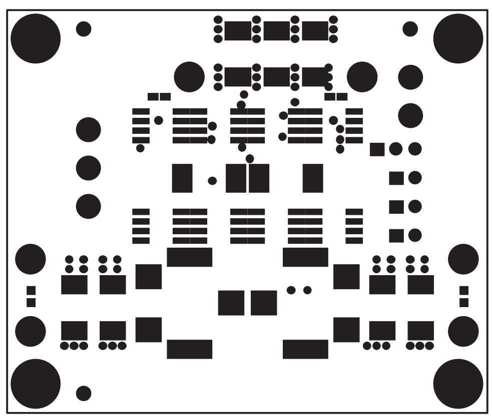
Since the LTC1702 is a switching regulator, a good layout is essential for good load regulation and minimizing radiated/conducted noise. If you want a layout that is guaranteed to work, copy the LTC1702 Gerber files provided with this demo board; otherwise, be sure to follow the layout guidelines below:

1. The inductor L1, MOSFETs Q1 to Q4 and the Schottky diode (D3) should be placed as close as possible to each other; similarly, L2, Q5 to Q8 and D4 should be placed as close together as possible. This junction forms the switch node and should be kept as small as possible to minimize radiated emissions. It must also be large enough to carry the full rated output current.
2. The SW1 and the SW2 pins should be connected directly to the respective switch nodes with a short trace.
3. C4 (10μF) should be as close as possible to Pin 13 on the LTC1702.
4. C5 (1μF) should be as close as possible to Pin 1 on the LTC1702.
5. R2 should be connected directly to the sources of Q3 and Q4.
6. R10 should be connected directly to the sources of Q7 and Q8.
7. Keep the trace from the FB1 pin to the junction of R4 and R5 short and use a long trace from the top of resistor R4 to the output terminal, rather than vice versa.
8. Keep the trace from the FB2 pin to the junction of R12 and R13 short and use a long trace from the top of resistor R12 to the output terminal, rather than vice versa.
9. The sources of the bottom MOSFETs Q3, Q4, Q7 and Q8 should be tied back to the ground of input capacitors C1 to C3 by means of a wide trace, not by the ground plane.
10. The grounds of the output capacitors C19–C20, C25–C27 and C8–C12 should be tied directly to the input capacitor's ground by means of a wide trace or by the ground plane.
11. The grounds of the feedback resistors, soft-start capacitors and C4 should be referenced to the chip SGND pin, which is then tied to the input bulk capacitors' grounds.
12. PGND, Pin 19, should connect directly to the ground plane.

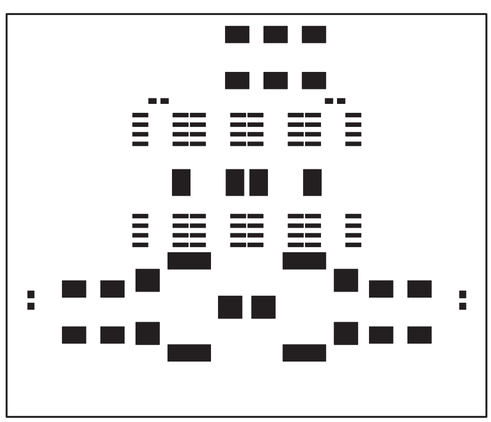
## PCB LAYOUT AND FILM




**Top Silkscreen**

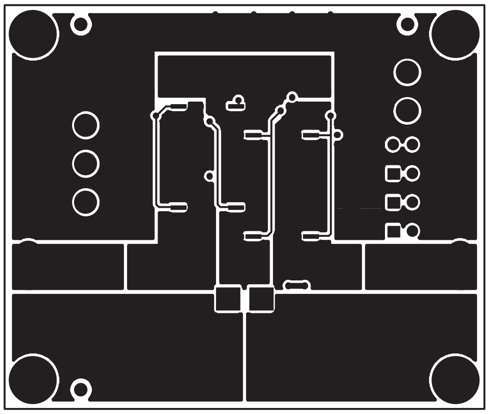


**Top Solder Mask**

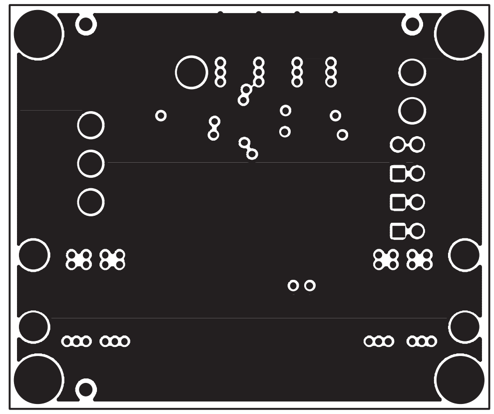


**Top Pastemask**

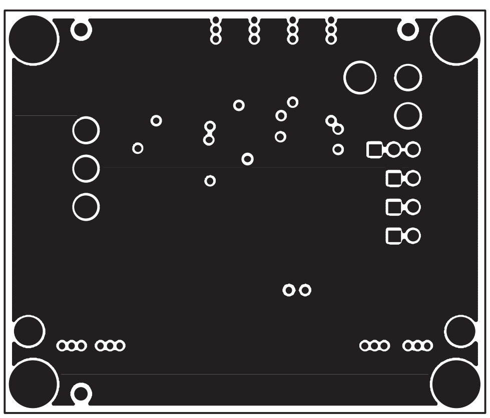
## PCB LAYOUT AND FILM



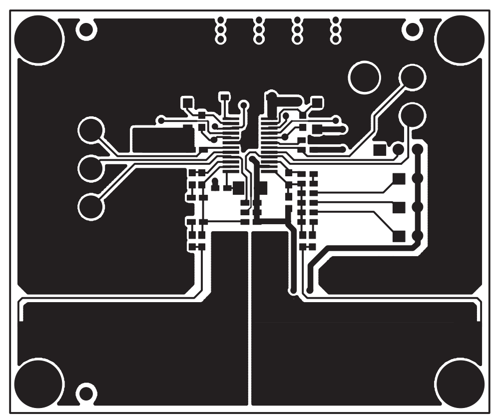
Layer 1, Top Layer



Layer 2, $V_{IN}$ Plane

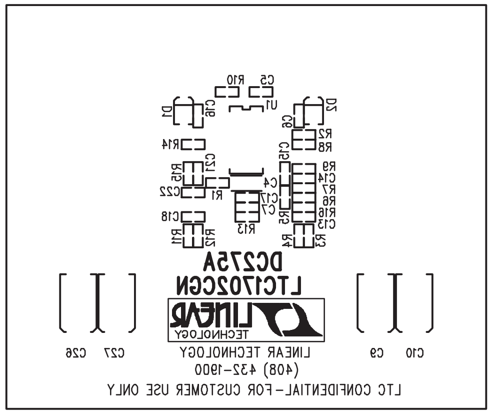


Layer 3, GND Plane

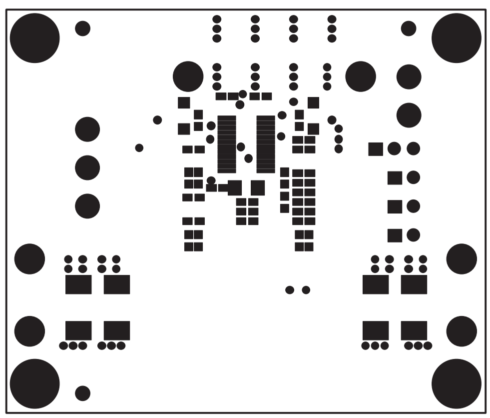


Layer 4, Bottom Layer

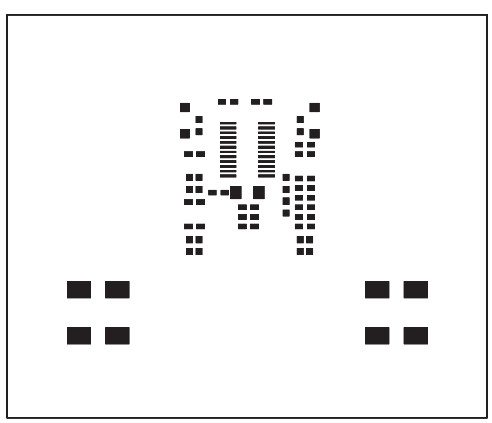
## PCB LAYOUT AND FILM



**Bottom Silkscreen**

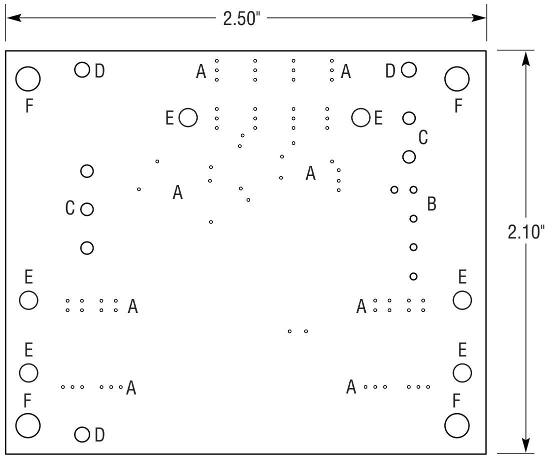


**Bottom Solder Mask**



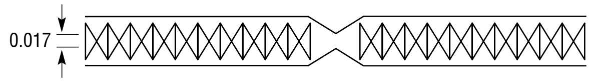
**Bottom Pastemask**

## 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 LPI OR EQUIVALENT
4. SILKSCREEN: USING WHITE NONCONDUCTIVE EPOXY INK
5. UNUSED SMD COMPONENTS SHOULD BE FREE OF SOLDER
6. FILL UP ALL VIAS WITH SOLDER
7. SCORING




| SYMBOL | DIAMETER | NUMBER OF HOLES |
|---|---|---|
| A | 0.015 | 70 |
| B | 0.035 | 5 |
| C | 0.064 | 5 |
| D | 0.070 | 3 |
| E | 0.094 | 6 |
| F | 0.125 | 4 |
| | TOTAL HOLES | 93 |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