# DEMO MANUAL DC164
## DESIGN READY SWITCHER
## LTC1624 Constant Frequency, 8-Pin N-Channel DC/DC Converter

## DESCRIPTION

Demonstration Circuit 164 is a constant-frequency step-down (buck) regulator implemented entirely in surface mount, using the LTC®1624 switching regulator controller. DC164 is usable in a wide range of portable, industrial, computer and communications applications. The output voltage is programmable to 2.5V, 3.3V or 5V via a jumper. The input voltage can range from 4.8V to 28V (limited by the external MOSFET). The circuit highlights the capabilities of the LTC1624, which uses a current mode, constant-frequency architecture to switch an N-channel power MOSFET while providing 95% maximum duty cycle. Operating efficiencies exceeding 90% are obtained.

This results in a power supply that has very high efficiency, low ripple and fast transient response. At low output currents the LTC1624 automatically switches to Burst Mode™ operation to reduce switching losses and maintain high operating efficiencies. Additionally, the supply current can be shut down to less than 20µA ($V_{IN}$ = 10V). This feature is an absolute necessity to maximize battery life in portable applications. **Gerber files for this circuit board are available. Call the LTC factory.**

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Burst Mode is a trademark of Linear Technology Corporation.

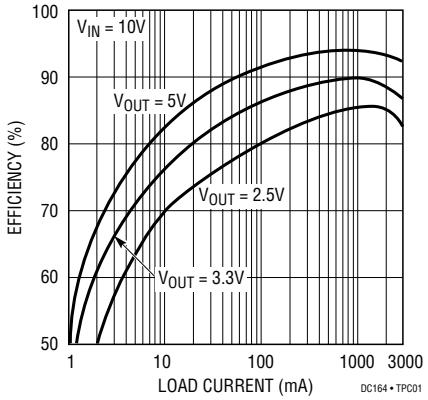
## PERFORMANCE SUMMARY

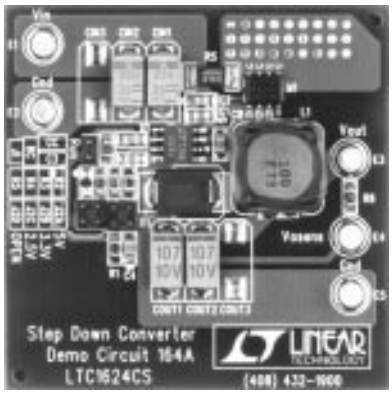
**Operating Temperature Range 0°C to 50°C.**

| | | |
|---|---|---|
| Input Voltage Range | (Maximum Input Voltage Limited by External MOSFET and Input Capacitor) | 4.8V to 28V |
| Output | Output Voltage (Jumper Selectable) | 2.5V, 3.3V, 5V |
| | Max Output Current (Continuous) | 3.0A |
| | Max Output Current (Peak) | 3.5A |
| | Typical Output Ripple at 10MHz Bandwidth (Burst Mode Operation) $I_O$ = 100mA | 50 $mV_{P-P}$ |
| | Typical Output Ripple at 10MHz Bandwidth (Continuous) $I_O$ = 1A | 35$mV_{P-P}$ |
| $V_{IN}$ | Line Regulation 4.5V to 20V | 0.002%/V |
| $I_{OUT}$ | Load Regulation No Load to Full Rated Output | –1% |
| $I_Q$ | Supply Current with No Load (Typical), $V_{IN}$ = 10V | 550µA |
| | Supply Current in Shutdown (Typical), $V_{IN}$ = 10V | 16µA |
| $V_{ITH/RUN}$ | Run Pin Threshold (Typical) | 0.8V |
| Frequency | Operating Frequency (Typical) | 200kHz |

## TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

**Efficiency**



## PACKAGE AND SCHEMATIC DIAGRAMS

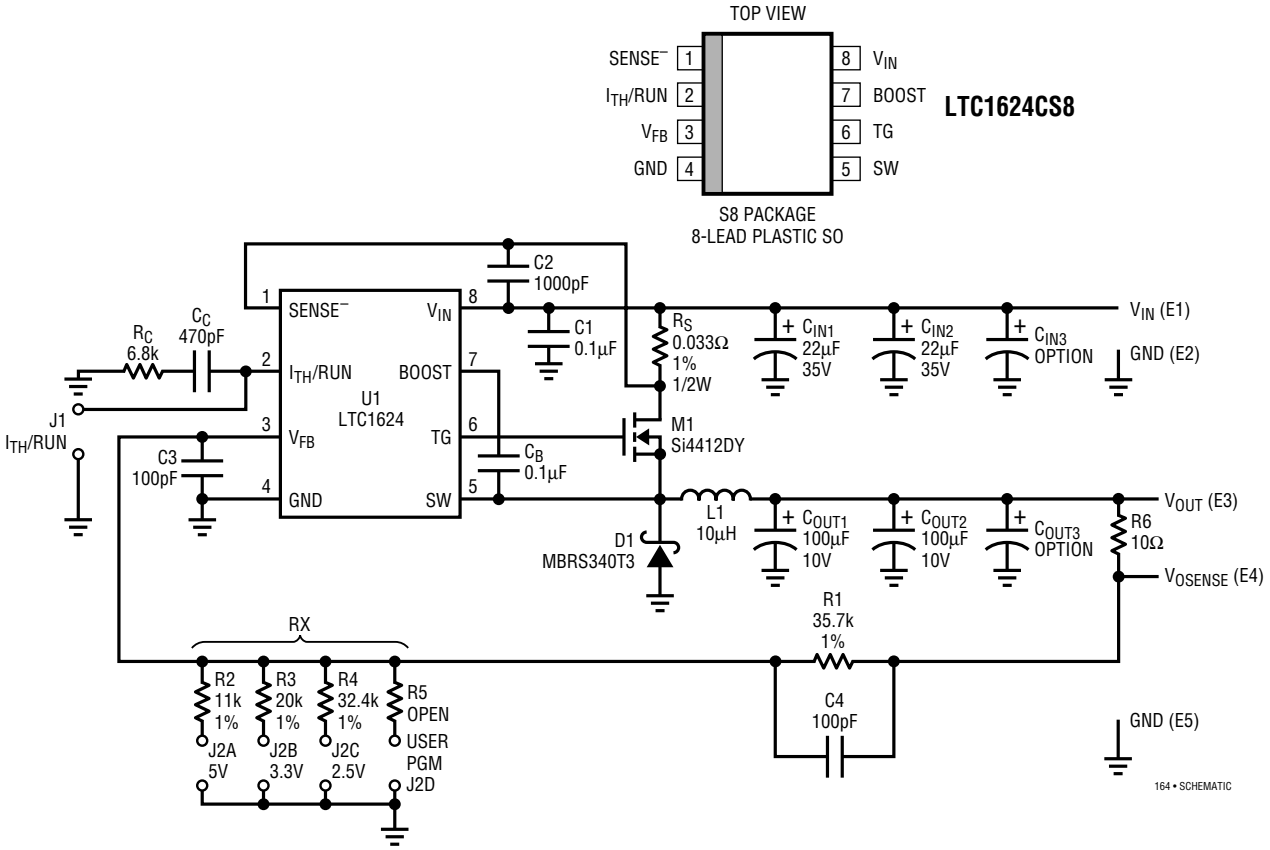



**Figure 1. Demo Board Schematic**

## PARTS LIST

| REFERENCE DESIGNATOR | QUANTITY | PART NUMBER | DESCRIPTION | VENDOR | TELEPHONE |
|---|---|---|---|---|---|
| $C_C$ | 1 | 08055A471MAT1A<br>08055A681MAT1A (5A) | 470pF 50V 10% Chip Capacitor NPO<br>680pF 50V 10% Chip Capacitor NPO | AVX<br>AVX | (803) 448-9411<br>(803) 448-9411 |
| $C_{IN1}$, $C_{IN2}$, ($C_{IN3}$) | 2 (3, 5A) | TPSE226M035R0300 | 22µF 35V 20% Tantalum Capacitor | AVX | (803) 448-9411 |
| $C_{OUT1}$, $C_{OUT2}$, ($C_{OUT3}$) | 2 (3, 5A) | TPSD107M010R0065 | 100µF 10V 20% Tantalum Capacitor | AVX | (803) 448-9411 |
| C3, C4 | 2 | 08055A101KAT1A | 100pF 50V 10% Chip Capacitor NPO | AVX | (803) 448-9411 |
| C8, C1 | 2 | 08055C104MAT2A | 0.1µF 50V 20% Chip Capacitor X7R | AVX | (803) 448-9411 |
| C2 | 1 | 08055A102MAT2A | 1000pF 50V 20% Chip Capacitor NPO | AVX | (803) 448-9411 |
| D1 | 1 | MBRS340T3<br>MBRD835L (5A) | BVR = 40V Schottky Diode<br>BVR = 35V Schottky Diode | Motorola<br>Motorola | (602) 244-3576<br>(602) 244-3576 |
| E1, E2, E3, E4, E5 | 5 | 2502-2 | Turret Terminal | Keystone | (718) 956-8900 |
| JP1, JP2A, JP2B, JP2C, JP2D | 5 | 2802S-03-G2 | 2mm Pin Header | COMM CON | (818) 301-4200 |
| J1, J2A, J2B, J2C, J2D | 2 | CCIJ2MM-138-G | Jumper | COMM CON | (818) 301-4200 |
| L1 | 1 | CDRH125-10<br>CDRH127-10 (5A) | 10µH Inductor<br>10µH Inductor (Alternate) | Sumida<br>Sumida | (847) 956-0666<br>(847) 956-0666 |

## PARTS LIST

| REFERENCE DESIGNATOR | QUANTITY | PART NUMBER | DESCRIPTION | VENDOR | TELEPHONE |
|---|---|---|---|---|---|
| M1 | 1 | Si4412DY<br>Si4410DY (5A) | N-Channel MOSFET<br>N-Channel MOSFET | Siliconix<br>Siliconix | (800) 554-5565<br>(800) 554-5565 |
| R1 | 1 | TAD CR10-3572F-T | 35.7k 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| R2 | 1 | TAD CR10-1102F-T | 11k 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| R3 | 1 | TAD CR10-2002F-T | 20k 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| R4 | 1 | TAD CR10-3242F-T | 32.4k 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| R5 | 1 | User Defined | User Defined 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| R6 | 1 | TAD CR10-100J-T | 10Ω 1/10W 1% Resistor Chip | TAD | (714) 255-9123 |
| $R_C$ | 1 | TAD CR10-682J-T<br>TAD CR10-332J-T (5A) | 6.8k 1/10W 5% Resistor Chip<br>3.3k 1/10W 5% Resistor Chip | TAD<br>TAD | (714) 255-9123<br>(714) 255-9123 |
| $R_S$ | 1 | WSL-2010<br>WSL-2010 (5A) | 0.033Ω 1/2W 1% Resistor<br>0.02Ω 1/2W 1% Resistor | Dale<br>Dale | (605) 665-9301<br>(605) 665-9301 |
| U1 | 1 | LTC1624CS | LTC1624CS8 IC | LTC | (408) 432-1900 |

## QUICK START GUIDE

This demonstration board is easily set up to evaluate the performance of the LTC1624. Please follow the procedure outlined below for proper operation.

- Refer to Figure 3 for board orientation and proper measurement equipment setup.
- Connect the input power supply to the $V_{IN}$ and GND terminals on the left side of the board. Do not increase $V_{IN}$ over 28V or the MOSFET, M1, **will be damaged**.
- Connect the load between the $V_{OUT}$ and GND terminals on the right side of the board.
- The $I_{TH}$/RUN pin can be left unconnected. To shut down the LTC1624, connect a jumper from this pin to ground at J1. (A spare jumper installed in position D in J2 is supplied for this purpose).
- **Do not** short or load the $V_{OSENSE}$ pin. The $V_{OSENSE}$ pin is used for remote output voltage sensing only.
- Set the desired output voltage with jumper J2 as shown in Figure 2/Table 1.

**Table 1. Output Voltage Selection**

| POSITION | OUTPUT VOLTAGE |
|---|---|
| A | 5V |
| B | 3.3V |
| C | 2.5V |
| D | User Defined |

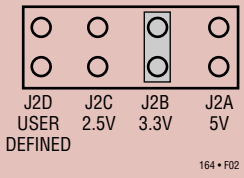



**Figure 2. Output Voltage Selection (J2) (3.3V Position Shown)**

## OPERATION

The circuit in Figure 1 highlights the capabilities of the LTC1624 configured as a step-down switching regulator. The application circuit is set up for a variety of output voltages. Output voltages from 2.5V to 5V are available by selecting the appropriate jumper position. An additional jumper position is also available for a user-selectable output voltage by adding the appropriate feedback divider resistor at R5.

The LTC1624 is a current mode switching regulator controller that drives an external N-channel power MOSFET using a fixed-frequency architecture. Burst Mode operation provides high efficiency at low load currents. Operating efficiencies typically exceed 90% over two decades of load current range. A maximum duty cycle limit of 95% provides low dropout operation that extends operating time in battery-operated systems.

Small spring-clip leads are very convenient for small-signal bench testing and voltage measurements but should not be used with the high currents associated with this circuit. Soldered wire connections are required to properly ascertain the performance of the PC board.

This demonstration unit is intended for the evaluation of the LTC1624 switching regulator IC and was not designed for any other purpose. Further detailed information and alternate topology applications are shown in the LTC1624 data sheet.

### LTC1624 CONTROLLER DESCRIPTION

#### Main Control Loop

The LTC1624 uses a constant-frequency, current mode architecture. During normal operation, the top MOSFET is turned on during each cycle when the oscillator sets a latch, and turned off when the main current comparator resets the latch. The peak inductor current that resets the latch is controlled by the voltage on the $I_{TH}$/RUN pin, which is the output of the error amplifier. $V_{FB}$ allows the error amplifier to receive an output feedback voltage from an external resistive divider. When the load current increases, it causes a slight decrease in $V_{FB}$ relative to the 1.19V reference, which in turn causes the $I_{TH}$/RUN voltage to increase until the average inductor current matches the new load current. While the top MOSFET is off, an internal bottom MOSFET is turned on for approximately 300ns to 400ns to recharge the bootstrap capacitor $C_B$.

The top MOSFET driver is biased from the floating bootstrap capacitor $C_B$, which is recharged during each off cycle. The dropout detector counts the number of oscillator cycles that the top MOSFET remains on and periodically forces a brief off period to allow $C_B$ to recharge.

The main control loop is shut down by pulling $I_{TH}$/RUN below its 1.19V clamp voltage. Releasing $I_{TH}$/RUN allows an internal 2.5μA current source to charge compensation capacitor $C_C$. When the $I_{TH}$/RUN pin voltage reaches 0.8V,

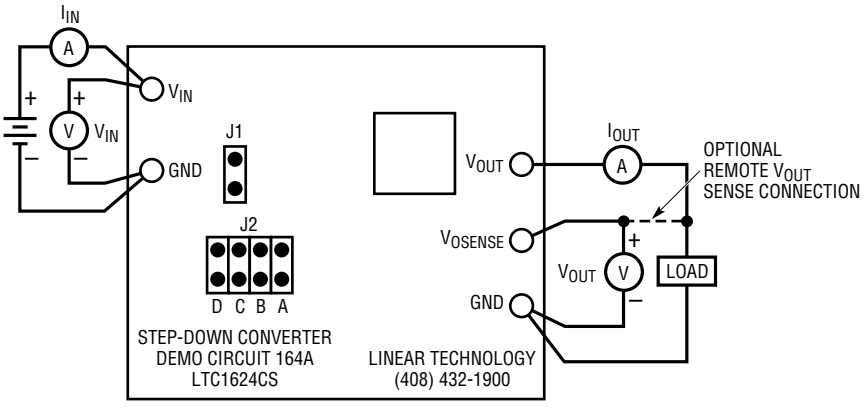



**Figure 3. Proper Measurement Setup**

## OPERATION

the main control loop is enabled with the $I_{TH}$/RUN voltage pulled up by the error amp.

A built-in comparator guards against transient output overshoots >7.5% by turning off the top MOSFET and keeping it off until the output decreases.

### Low Current Operation

The LTC1624 is capable of Burst Mode operation, in which the external MOSFET operates intermittently based on load demand. The transition to low current operation begins when a comparator detects that the $I_{TH}$/RUN voltage is below 1.5V. If the voltage across $R_{SENSE}$ does not exceed approximately 20mV for one full cycle, the top and internal bottom drives will be disabled on the following cycles. This continues until the $I_{TH}$ voltage exceeds 1.5V, which causes drive to be returned to TG on the next cycle.

### $INTV_{CC}$ Power/Boost Supply ($C_B$, $D_B$)

Power for the top and internal bottom MOSFET drivers is derived from $V_{IN}$. An internal regulator supplies the power. To power the top driver in step-down applications, an internal high voltage diode recharges the bootstrap capacitor $C_B$ during each off cycle from the internal supply. A small internal N-channel MOSFET pulls the switch node (SW) to ground each cycle after the top MOSFET has turned off, ensuring that the bootstrap capacitor is kept fully charged.

When the top side MOSFET is to be turned on, the driver places the $C_B$ voltage across the gate-source of the MOSFET. This enhances the MOSFET and turns on the top-side switch. The switch node voltage SW rises to $V_{IN}$ and the BOOST pin rises to $V_{IN}$ + 5V.

Significant efficiency gains can be realized by supplying top-side driver operating voltage from the output, since the $V_{IN}$ current resulting from the driver and control currents will be scaled by a factor of (Duty Cycle)/(Efficiency). For 5V regulators this simply means connecting the BOOST pin though a small Schottky diode (such as a CMDH-3) to $V_{OUT}$.

For low input voltage operation ($V_{IN} \leq 7V$), a Schottky diode can be connected from $V_{IN}$ to BOOST to increase the external MOSFET gate drive voltage. Be careful not to exceed the maximum voltage on the BOOST to SW pins of 7.8V.

### $I_{TH}$ / RUN Function

The $I_{TH}$/RUN pin is a dual purpose pin that provides the loop compensation and a means to shut down the LTC1624.

An internal 2.5µA current source charges the external capacitor $C_C$ (Figure 4). When the voltage on $I_{TH}$/RUN reaches 0.8V, the LTC1624 begins operating. At this point the error amplifier pulls up the $I_{TH}$/RUN pin to its maximum of 2.4V (assuming $V_{OUT}$ is starting low). Soft start can also be implemented with this pin, as shown in Figure 4c. Soft start reduces surge currents from $V_{IN}$ by gradually increasing the internal current limit. Power supply sequencing can also be accomplished using this pin.

During normal operation the voltage on the $I_{TH}$/RUN pin will vary from 1.19V to 2.4V, depending on the load current. Pulling the $I_{TH}$/RUN pin below 0.8V puts the LTC1624 into a low quiescent current shutdown ($I_Q$ < 30µA). This pin can be driven directly from logic, as shown in Figures 4a and 4b.

The operating frequency is set internally to 200kHz.

In addition to shutdown, the dual function pin $I_{TH}$/RUN allows external compensation for optimum load-step

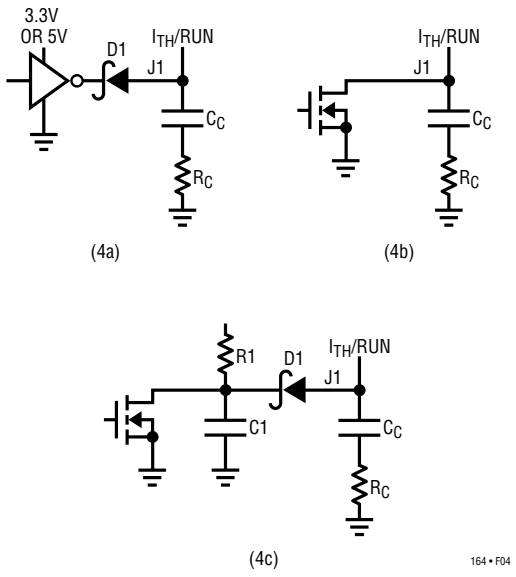



**Figure 4. $I_{TH}$/RUN Pin Interfacing**

## OPERATION

response. Compensation is provided by $R_C$ and $C_C$. The operating current level is user-programmable via an external current sense resistor ($R_S$) and is set to 3.0A. Short-circuit current limit is set to approximately 4A.

This demo board is optimized for 3.3V outputs. A wide input supply range allows operation from 4.8V to 28V for $V_{OUT}$ voltages of 3.3V and 2.5V. For 5V outputs the minimum input voltage is 5.4V at full load.

The lowest operating input voltage is limited by the external MOSFET M1. For operation below 4.8V, subthreshold-level MOSFETs should be substituted. The minimum input voltage of the LTC1624 is 3.5V.

### Remote Output Voltage Sensing

Remote output voltage sensing can be accomplished by externally connecting a sense lead from $V_{OSENSE}$ directly to the load. To prevent the output from overshooting in case of a sense-lead fault, a 10Ω resistor (R6) is connected on the printed circuit board across the $V_{OUT}$ and $V_{OSENSE}$ terminals. This prevents $V_{OSENSE}$ from floating. Connect the external load only to $V_{OUT}$, **not** to $V_{OSENSE}$. The surface mount 10Ω resistor mentioned above cannot handle the load current that would pass though it should the load be incorrectly connected to $V_{OSENSE}$.

### How to Measure Voltage Regulation

When trying to measure voltage regulation, remember that all measurements must be taken at the point of regulation. This point is where the LTC1624's control loop looks for the information to keep the output voltage constant. In this demonstration board this information point occurs between the signal ground and the output side of R1. These points correspond to the GND (E5) and $V_{OSENSE}$(E4) terminals of the board. Output voltage test leads should be attached directly to these terminals. The load should be placed across $V_{OUT}$ (E3) to GND (E5). Measurements **should not** be taken at the end of test leads at the load; refer to Figure 3 for the proper monitoring equipment configuration.

This applies to line regulation (input to output voltage regulation) as well as load regulation tests. In doing line regulation tests always look at the input voltage across the input terminals.

For the purposes of these tests the demonstration circuit should be fed from a regulated DC bench supply so additional variation on the DC input does not add an error to the regulation measurements.

### Output Voltage Programming

The jumper (J2) selects the output voltage according to Table 1. Output voltages of 5V, 3.3V, 2.5V and one user programmable output voltage are jumper selectable. Resistor R5 (see Figure 1) is left unstuffed so a user selectable output voltage can easily be programmed.

The output voltage is set by a resistive divider according to the following formula (refer to Figure 1):

$$V_{OUT} = 1.19V\left(1+\frac{R1}{RX}\right)$$

R1 is set to 35.7k; jumper J2 selects the value of RX. If no jumpers are in place for J2 or if only jumper J2D is selected without a resistor in place for R5, the output voltage will be 1.19V (since the equivalent value of RX will be infinite). Be careful not to exceed the output capacitor's maximum voltage rating of 10V when selecting R5.

At high input-to-output differential voltages, the on-time becomes very small. Due to internal gate delays and response times of the internal circuitry, the minimum recommended on-time is 450ns. Because this board allows for a wide output voltage range and the operating frequency remains constant at 200kHz, a potential duty cycle limitation exists when low output voltages are selected ($V_{OUT}$ < 2.5V). When the duty cycle is less than 9%, cycle skipping may occur; this increases the inductor ripple current but does not cause $V_{OUT}$ to lose regulation. Avoiding cycle skipping imposes a limit on the input voltage for a given output voltage only when $V_{OUT}$ < 2.2V.

$$V_{IN(MAX)} = 11.1V_{OUT} + 5V \qquad \text{For DC} > 9\%.$$

### Modification For 5A Output Current

The DC164 demo board has provisions for higher output currents. Additional pad locations are available for adding one extra input and output capacitor together with a larger footprint for a Schottky diode. The following list shows the

## OPERATION

component changes necessary for a 5A output current version:

| | | |
|---|---|---|
| | L1 | Sumida CDRH127-10 |
| | M1 | Siliconix Si4410DY |
| | D1 | Motorola MBRD835L |
| | $R_S$ | 0.02Ω |
| | $C_C$ | 680pF |
| | $R_C$ | 3.3k |
| add: | $C_{IN3}$ | AVX TPSE226M035R0300 |
| | $C_{OUT3}$ | AVX TPSD107M010R0065 |

At high input voltages the duty cycle decreases and the Schottky diode is on for a higher percentage of the cycle. This increases the diode's power dissipation. At higher input voltages together with high output currents, the Schottky diode will dissipate a couple of watts and heat sinking will be needed. Remember that the most stressful condition on the Schottky diode is a short circuit. For applications greater than 5A, synchronous operation may be preferred. Refer to the LTC1435 data sheet and demo board DC094.

### Component Manufacturers

Table 1 is a partial list of alternate component manufacturers that can be used in LTC1624 applications. Using components other than the ones supplied on the demonstration board will require careful analysis to verify that no component specifications are exceeded. Finally, recharacterizing the circuit for efficiency is necessary.

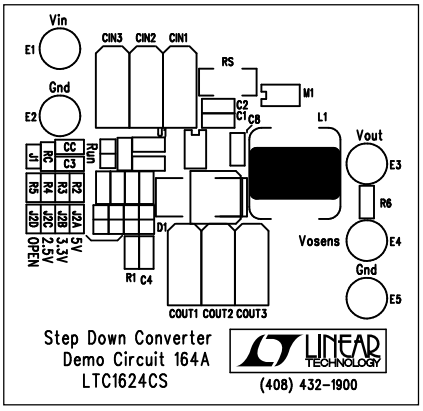
**Table 1. List of Alternative Component Manufacturers**

| MANUFACTURER | DEVICE | PHONE | FAX |
|---|---|---|---|
| AVX | Capacitors | (803) 448-9411 | (803) 448-1943 |
| Central Semiconductor | Diodes | (516) 435-1110 | (516) 435-1824 |
| Coilcraft | Inductors | (847) 639-6400 | (847) 639-1469 |
| Coiltronics | Inductors | (561) 241-7876 | (561) 241-9339 |
| COMM CON | Connectors | (818) 301-4200 | (818) 301-4212 |
| Dale | Inductors/Sense Resistors | (605) 665-9301 | (605) 665-0817 |
| International Rectifier | MOSFETs/Diodes | (310) 322-3331 | (310) 322-3332 |
| IRC | Sense Resistors | (512) 992-7900 | (512) 992-3377 |
| KRL | Sense Resistors | (603) 668-3210 | (603) 624-0634 |
| Motorola | MOSFETs/Diodes | (602) 244-3576 | (602) 244-4015 |
| Murata-Erie | Capacitors | (770) 436-1300 | (770) 436-3030 |
| Sanyo | Capacitors/MOSFETs | (619) 661-6835<br>[81] 0952-82-3959 | (619) 661-1055<br>[81] 0952-82-4655 |
| Siliconix | MOSFETs | (800) 554-5565 | (408) 970-3979 |
| Sprague | Capacitors | (603) 244-1961 | (603) 224-1430 |
| Sumida | Inductor | (847) 956-0666<br>[81] 03-3607-5111 | (847) 956-0702<br>[81] 03-3607-5144 |
| TDK | Inductors | (847) 803-6100 | [81] 03-3278-5358 |

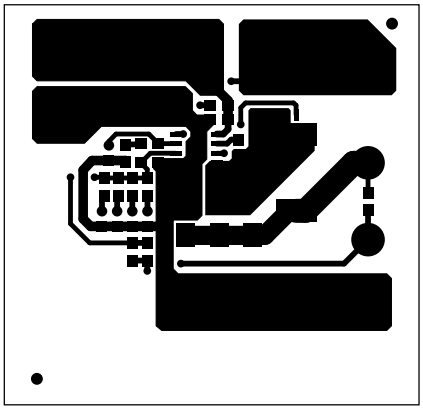
LINEAR TECHNOLOGY

Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

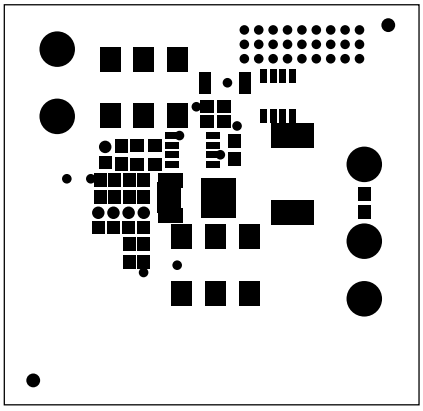
## PCB LAYOUT AND FILM



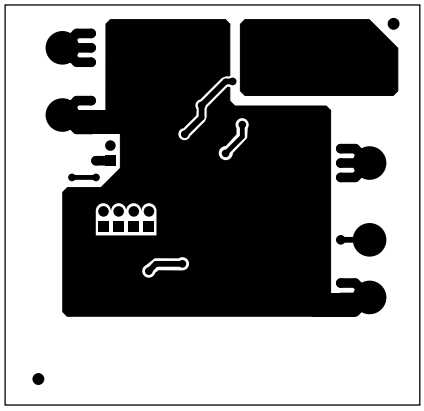

**Component Side Silkscreen**



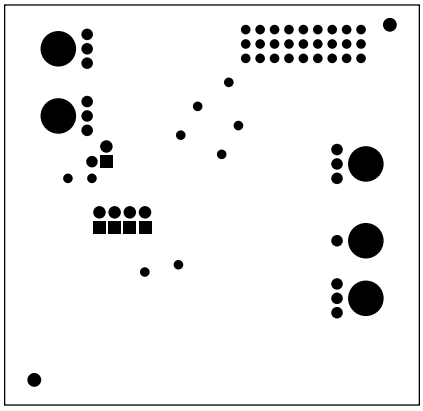
**Component Side**



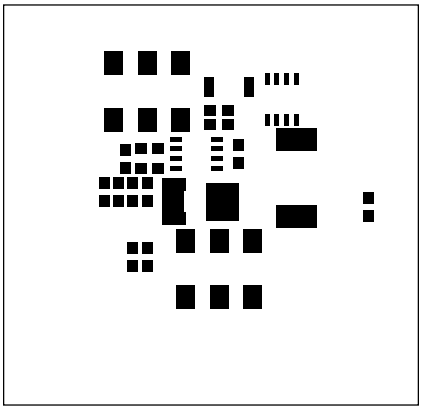
**Component Side Mask**



**Solder Side**

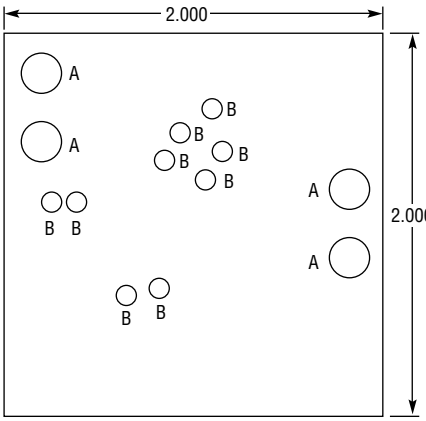


**Solder Side Mask**



**Pastemask Top**

## PC FAB DRAWING




NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: FR4 OR EQUIVALENT EPOXY, 2 OZ.
   COPPER CLAD THICKNESS 0.062 ±0.006 TOTAL OF TWO 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 |
|---|---|---|
| A | 0.020 | 9 |
| B | 0.095 | 4 |
| | TOTAL | 13 |

164 • FAB DWG



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