LINEAR TECHNOLOGY

Pentium® Processor Switching Regulator Power Module Demo Board

DESCRIPTION

Demonstration Circuit 064B is a power supply module which is compliant with the Intel module specification and will work with any motherboard configured to accept such modules. It will power any Pentium® processor including the VR and VRE CPUs. The design will meet these specifications under all conditions and will hold up to the scrutiny of a worst-case analysis. An onboard jumper selects the nominal output voltage: 3.30V, 3.383V (VR) or 3.525V (VRE), as required by a particular CPU. The static tolerances are extremely tight (0.65%) and transient response is excellent so as to minimize the required output capacitance. The input is specified at 5.0V ±5%. This module can be evaluated using DC065, which is designed to accept Pentium processor VR/VRE modules.

The circuit is based on the LTC®1266 switching regulator controller with an LT®1431 used as a precision reference and high gain error amplifier. The advantages of this design include: all N-channel MOSFETs, tight regulation and set-point accuracy as well as symmetric, high speed response to load transients. The circuit operates at approximately 200kHz to minimize the inductor size. The inductor used is wound on a low cost powdered iron core. Circuit efficiency is better than 90% through most of the normal load range.
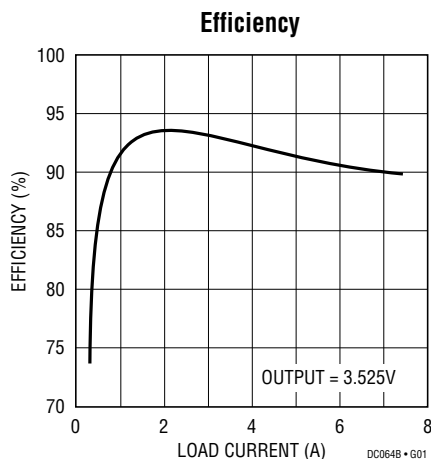
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PERFORMANCE SUMMARY

Input Voltage Range		5.0V ±5%
Output (25°C, No Load)	JMP1 Removed	3.525V ±0.65%
	JMP1 Position 1	3.383V ±0.9%
	JMP1 Position 2	3.30V ±1.4%
Line Regulation (Static)	V_{IN} from 4.75V to 5.25V	0.03%
Load Regulation (Static)	I_O from 0A to 7A	0.05%
Transient Response	I_{MIN} > 0.2A, ΔI = 3.8A* (Measured at the Load)	< 50mV Peak
Temperature Drift	25°C to 75°C	< 30ppm/°C
Efficiency (Typical)	Load Current = 5A	TBD%

*Assumes 6 each, 100µF, 10V, AVX type TPS tantalum capacitors or equivalent and 10 each, 1µF 1206 ceramics at the load.

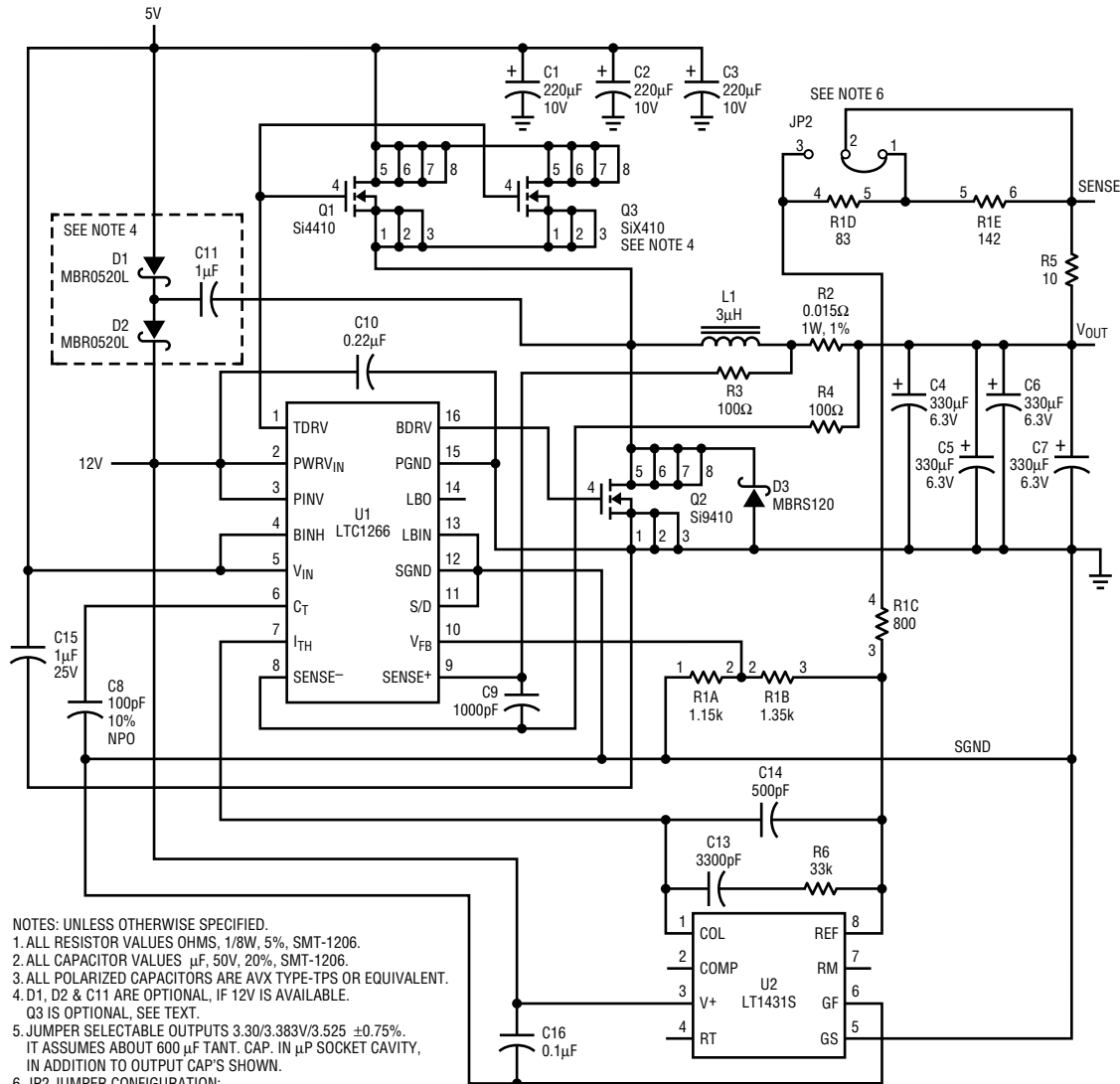# TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTOS

Efficiency

OUTPUT = 3.525V

DC064B • G01

Component Side

Solder Side

PACKAGE AND SCHEMATIC DIAGRAMS

NOTES: UNLESS OTHERWISE SPECIFIED.
1. ALL RESISTOR VALUES OHMS, 1/8W, 5%, SMT-1206.
2. ALL CAPACITOR VALUES μF, 50V, 20%, SMT-1206.
3. ALL POLARIZED CAPACITORS ARE AVX TYPE-TPS OR EQUIVALENT.
4. D1, D2 & C11 ARE OPTIONAL, IF 12V IS AVAILABLE.
   Q3 IS OPTIONAL, SEE TEXT.
5. JUMPER SELECTABLE OUTPUTS 3.30/3.383V/3.525 ±0.75%.
   IT ASSUMES ABOUT 600 μF TANT. CAP. IN μP SOCKET CAVITY,
   IN ADDITION TO OUTPUT CAP'S SHOWN.
6. JP2 JUMPER CONFIGURATION:
   FOR VRE, NO JUMPERS INSTALLED.
   FOR VR, INSTALL BETWEEN PINS 1 AND 2.
   FOR 3.3V, INSTALL BETWEEN PINS 2 AND 3.
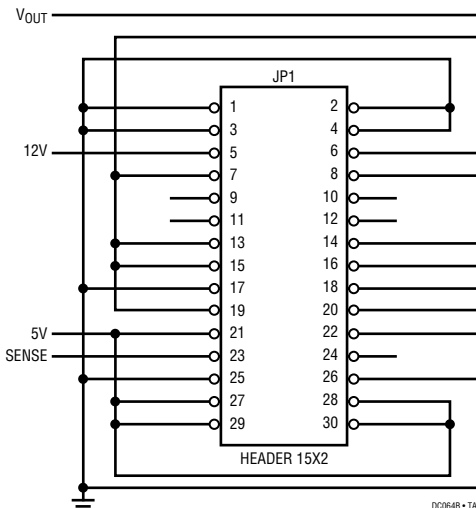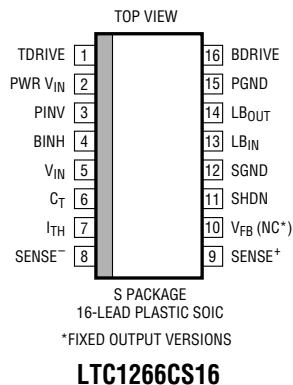7. R1A-E ARE PART OF A NETWORK IN AN SO-14 PACKAGE.

Figure 1. High Efficiency Switching Regulator for Pentium VRE Processor

PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C1-3	3	TPSE227M010R0100	Cap., Tantalum, 220µF, 10V, 20%	AVX	(207) 282-5111
C7	4	TPSE337M006R0100	Cap., Tantalum, 330µF, 6.3V, 20%	AVX	(207) 282-5111
C8	1	12065A101KAT2A	Cap., NPO, 100pF, 50V, 10%	AVX	(803) 946-0362
C9	1	12065C102ZAT2A	Cap., X7R, 1000pF, 50V, 20%	AVX	(803) 946-0362
C10	1	12063G224ZAT2A	Cap., Y5V, .22µF, 25V, 20%	AVX	(803) 946-0362
C11,15	2	12063G105ZAT2A	Cap., Y5V, 1µF, 25V	AVX	(803) 946-0362
C12	1	12065C104ZAT2A	Cap., X7R, .1µF, 50V, 20%	AVX	(803) 946-0362
C13	1	12065C332MAT2A	Cap., X7R, 3300pF, 50V, 20%	AVX	(803) 946-0362
C14	1	12065C501MAT2A	Cap., X7R, 500pF, 50V, 20%	AVX	(803) 946-0362
D1,D2	2	MBR0520LT1	Diode, Schottky, 20V, 0.5A	MOTOROLA	(602) 244-5768
D3	1	MBRS130LT3	Diode, Schottky, 30V, 1A	MOTOROLA	(602) 244-5768
JP1	1	532956-5	Con., Recept, 30-Pin, 2-Row	AMP	(717) 564-0100
JP2	1	TSW-103-07-G-S	Jumper, 3-Pin, .100cc	SAMTEC	(800) 726-8329
JP2	0	SNT-100-BK-T	Shunt, .100cc, Optional	SAMTEC	(800) 726-8329
L1 (Note 1)	1	CTX3-6-52	Inductor, Toroid, 3µH	COILTRONICS	(407) 241-7876
Q1	1	Si4410DY	Xistor, MOSFET, Si4410, SO-8	SILICONIX	(408) 970-3927
Q2	1	Si9410DY	Xistor, MOSFET, Si9410, SO-8	SILICONIX	(408) 970-3927
Q3	0		Optional, See Text		
R1	1	627V100	Res., Network	BI TECH	(714) 447-2759
R2	1	WSL-2512-0.015-1%	Res., SMT-2512, 0.015, 1W, 1%	DALE	(408) 985-5733
R3,R4	2	CR32-101J-T	Res., SMT-1206, 100Ω, 5%	AVX	(803) 946-0524
R5	1	CR32-100J-T	Res., SMT-1206, 10Ω, 5%	AVX	(803) 946-0524
R6	1	CR32-333J-T	Res., SMT-1206, 33kΩ, 5%	AVX	(803) 946-0524
U1	1	LTC1266CS16	I.C., SO16, LTC1266, Sw-Reg	LTC	(408) 432-1900
U2	1	LT1431CS8	I.C., SO8, LT1431, Prog Ref	LTC	(408) 432-1900

Note 1. Alternate source: Gowanda Electronics Part # 51-656. (716) 532-2234.

OPERATION

The circuit shown in Figure 1 is intended to plug into a 30-pin header which conforms to the Intel specification and provides power to a Pentium microprocessor designed to operate from 60MHz to 100MHz. It is intended to be fully compliant with all requirements of the Intel specification. The design specifications presented here are intended to be used as guidelines for volume production of compliant power modules.

The LTC1266 is a current mode, synchronous buck regulator controller designed to drive all N-channel MOSFETs. The use of a synchronous regulator is almost mandatory to obtain the step response required of the power supply to meet the Intel specification. The constant off time architecture eliminates the need for slope compensation and contributes to fast transient response. In addition to the all N-channel drive, the LTC1266 has a burst inhibit function which proves quite useful in this application. The undedicated comparator and its reference on the LTC1266 are not used in this design. If desired, an undervoltage lockout, overvoltage detector or power good indicator may be implemented. The LT1431 shunt regulator is used in this circuit as an extremely accurate (±0.4%) reference and a wide band error amplifier.

OPERATION

Circuit operation is straightforward. The output voltage is scaled by the precision resistor network and connected to Pin 8 of the LT1431. The REF pin is actually the input to a transconductance amplifier. Internally, the other input to this amplifier connects to a precision 2.5V reference. The voltage on Pin 8 is compared to the internal reference and the difference is multiplied by the amplifier transconductance. The resulting current flows into the base of the LT1431 output transistor, sinking some collector current to ground. The feedback divider also divides the output to 1.15V; this point is connected to the LTC1266 V_{FB} pin. This pin is the input to the LTC1266 internal error amplifier. The LTC1266 internal reference is 1.25V. Since its V_{FB} pin is held at 1.15V, the LTC1266 "sees" the output as being too low and therefore forces its internal error amplifier output to its 2.0V maximum. In this configuration, the internal error amplifier acts as a current source. This output is connected to the LT1431 open collector. This open collector current sink works against the LTC1266 error amp current source, and since the sink capability of the LT1431 is much greater than the LTC1266 source capability, the LT1431 can servo the LTC1266 I_{TH} pin as required. The LTC1266 regulates the inductor peak current to a fixed multiple of the voltage on the I_{TH} pin. The servo action of the LT1431 will adjust I_{TH} as required to set the output current such that the output voltage remains within specifications. Burst Mode™ operation must be inhibited with this circuit configuration or the output. Operation voltage will rise substantially at light load.

A major advantage of synchronous rectifiers is their ability to both source and sink load current. When the load current is less than 1/2 the peak-to-peak inductor ripple current, the inductor current will actually reverse during part of the cycle, removing energy from the output capacitors and returning this energy to the input supply. This is very helpful in holding the output within specification when a heavy load is suddenly removed from the output. Most non-synchronous regulators would overshoot substantially. There would also be a significant change in the small signal dynamics of the feedback loop as the inductor current became discontinuous. The difference in loop dynamics between light load and heavy load requires a compromise in loop compensation to prevent oscillations

Burst Mode is a trademark of Linear Technology Corporation.

at one of the load extremes. This limits the transient performance the regulator can be expected to deliver. Synchronous converters suffer no such ill effects. Since discontinuous conduction can not occur, the inductor ripple current may be increased substantially. This results in much faster response to load steps.

BACK TO BASICS

The large-signal performance of the regulator is limited by the inductor current ramp-rate. It does not matter how fast the control loop is if the power stage cannot respond. Remember the basic definition of inductance L = V dt /di? What this dictates for our application is: the rate of change of inductor current, di/dt, is equal to the voltage impressed across the inductor divided by the inductance. The voltage across the inductor is the input voltage minus the output voltage. With only 5V in and 3.525V out this is a relatively small number. Hence, if L is not quite small, the resultant di/dt is small and one must wait a long time until the inductor current can ramp up to a higher load current. The price you must pay for the long wait is more capacitors to store energy until the inductor lets the supply current equal the load current. The only negative to using a small inductor is the need to operate at a high switching frequency (200kHz), otherwise the ripple current will get exceedingly large. High speed operation tends to hurt efficiency since switching losses and core losses increase with frequency. Fortunately, desktop computer applications do not require ultra-high efficiency and 90% is still quite respectable.

GATE DRIVE REQUIREMENTS

In order to drive the gate of the high side FET Q1, a supply at least 4.5V above the 5V input supply is required. There are two ways to power the drive circuit. The simplest and best way is to use the 12V supply which exists on most desktop systems today. This provides 7V of enhancement for Q1. If a 12V supply does not exist, there is a charge pump circuit on the demo board that bootstraps the gate drive from the 5V input. The charge pump circuit provides approximately 4.8V of drive to the high side FET. No configuration changes are required to switch from one mode of operation to the other. If 12V is available, simply

OPERATION

hook it up. If only 12V operation is desired, the two bootstrap diodes and the charge pump capacitor may be eliminated.

IN-CIRCUIT TESTING

DC064B is intended to be used in conjunction with demonstration board DC065 and an Intel "Power Validator" module which simulates the loading conditions of a Pentium microprocessor. Contact your local Intel representative for information on obtaining a power validator. The power supply module plugs into the 30-pin header on the DC065 board. See the DC065 manual and the Intel Power Validator manual for setup information. The output voltage of DC064 may be changed by moving (or removing) JMP1.

The Intel system specification requires a minimum of 100 linear feet/minute of air flow over the power module. This module will function in still air but some airflow is desirable to keep junction temperatures down.

The power module is equipped with remote sense capability. The output voltage is regulated at the load, not at the module itself. Therefore, the output voltage should be measured at the load. If the output is measured at the power module, it will appear to increase with load as the regulator corrects for I•R drops between the supply and the load. Measure the output voltage at the two output test points on DC065.

The dynamic performance is viewed by connecting an oscilloscope to the BNC connector on DC065. The transients are best seen by triggering the oscilloscope on the falling edge of the output voltage waveform with the scope's "high frequency reject" function active. The scope should be AC coupled and set for 20mV to 50mV/div; the sweep rate should be set to 200μs to 500μs/div. To look at a detailed view of the transient leading edge, set the sweep rate to 2μs/div. Figures 2 and 3 show how a properly setup system will perform.

COMPONENTS SELECTION

Care must be exercised in choosing critical components for switching regulators. Many regulator problems that have been attributed to a controller IC have in fact been the
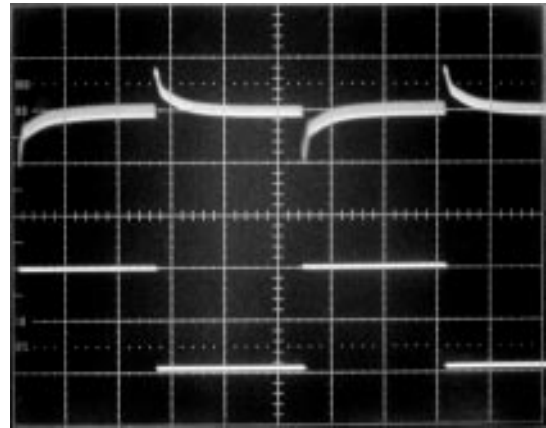

Figure 2. Transient Response: Top Output Voltage = 50mV/Div, Bottom = 2A/Div. ΔI = 200mA to 4.0A, Horizontal = 200μs/Div
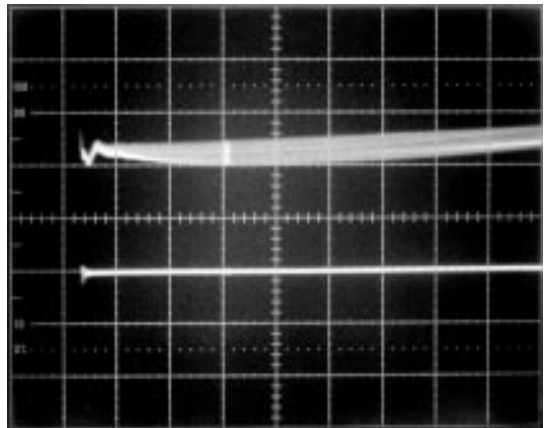

Figure 3. 'Load On' Transient Same as at 2μs/Div Figure 2

result of poor component selection. In many cases components selected for low cost are inappropriate for the application in switching regulators. In order to ensure satisfactory long-term operation, high quality components must be utilized.

Capacitors

Capacitors are easily misapplied in switcher designs. Generally, ESR and ripple current are specified at a frequency of 100kHz for capacitor types intended for service in a switching regulator application. Use only parts that carry adequate ripple current ratings for the conditions imposed by the regulator. The most stringent demands are placed on the input capacitors. By comparison, the

OPERATION

ripple current through the output capacitors is limited to a relatively low value by the buck inductor. The RMS ripple current imposed on the input capacitors is approximately 50% of the average *output* current. This varies with duty factor, peaking at 50% duty/factor and reducing by approximately 10% over a duty factor range of 30% to 70%. It is therefore simpler and not overly conservative to use the 50% number.

The use of solid tantalum or organic semiconductor type capacitors is recommended. These exhibit good ripple current ratings, low ESR and long life. If aluminum electrolytics are used, keep in mind that they exhibit long-term degradation due to electrolyte evaporation. Better long-term performance is obtained from aluminum electrolytics with sealed terminations than from non-sealed designs as the evaporation takes place more slowly. Over an extended period of time however, the ESR will increase. Therefore it will be necessary to overdesign to obtain the desired life expectancy. Solid electrolyte type capacitors do not experience this performance degradation. One note of caution if using solid tantalums is the need to derate substantially for voltage. AVX recommends a 50% voltage derate on any parts that can experience high dV/dt. This is, in fact, the case for input capacitors in systems where the supply voltage can be applied suddenly. If in doubt as to the suitability of a particular capacitor, consult the manufacturer.

Inductors

The choice of inductors is very important for proper operation of a switching regulator. It is unfortunate that most engineers today are so afraid of magnetics. They are the one component type that the designer may easily customize to suit the needs of a particular application. There are a wide variety of core configurations and materials available today; many options are open to the designer.

A decision was made for this design that cost was more important than efficiency. With that in mind an iron powder core was selected. In the interest of size, a small core was chosen. Because of these choices the inductance

"swings" downward as the load current is increased. At full load the inductance is down approximately 35% from its no load value. The result is higher ripple current at heavy load than at light load, a very desirable effect. This improves the regulator's ability to respond to large-signal load changes without circulating undesirably large AC currents at light load.

If efficiency is the primary concern, a larger core made of a low loss material such as MPP or Kool Mμ® should be considered. As usual the cost would be higher for the added performance. The design chosen here is very simple and can be produced by most magnetics suppliers. Coiltronics is prepared to supply this design in volume.

MOSFETS

The choice of power transistor is critical to the operation of any switching regulator. Major factors to consider are "on-resistance", gate drive requirements and switching speed. At high currents, on-resistance will usually dominate the losses in the switch. However, when operating at nearly 200kHz, the AC losses will be significant.

The part chosen for the high-side switch, Q1, is an Si4410. The on-resistance is specified at 0.0135Ω at 10V of gate drive and 0.02Ω at 4.5V of drive. These specs highlight the advantage of using the 12V supply for gate drive (if available). With 7V of enhancement the on-resistance is approximately 0.015Ω. At only 4.8V of enhancement the on resistance is about 0.018Ω. This difference translates to slightly over 0.1W of additional conduction loss in the switch with only a 0.01W decrease in drive power.

The RMS current in the switch is approximately equal to the load current times the square root of the duty factor. In this system this could be as high as 6.3A in the high-side switch. Since the low-side switch operates at a much lower duty factor, the RMS current is only 3.8A. Therefore, the smaller Si9410 was chosen. Be careful when choosing the MOSFET. Some parts are designed for load switch applications and have very slow transition times. If these parts are used in a high frequency switching regulator, the switching losses will be severe. The result will be gross overheating of the FET. When comparing two possible
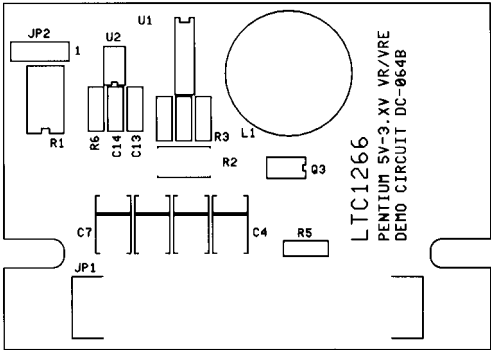
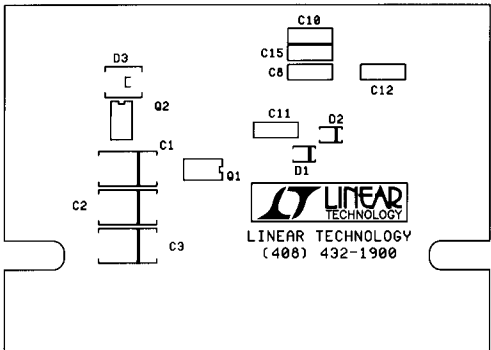Kool Mμ is a registered trademark of Magnetics, Inc.

OPERATION

choices, a good figure of merit is the $R_{DS(ON)} \cdot Q_g$ product. The smaller this number is, the more efficient the switch will be. Space is provided on the board for an optional

MOSFET, Q3. Q1 can be changed to an Si9410 and Q3 populated with an Si9410 for performance similar to that obtained with a single Si4410 high-side switch.
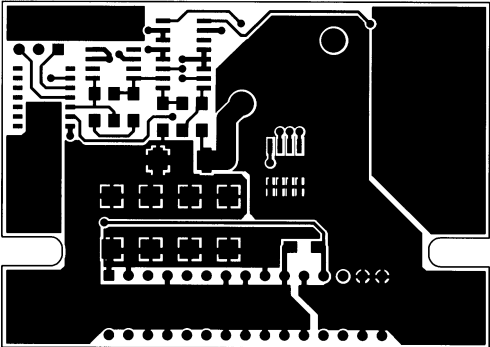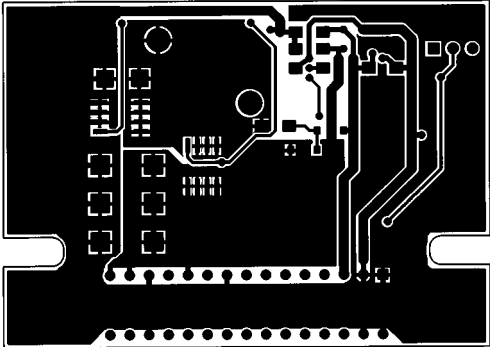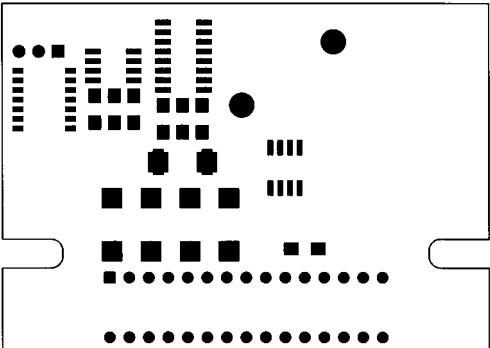
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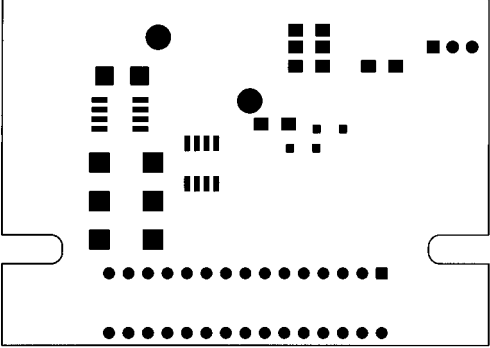

Component Side Silkscreen

Solder Side Silkscreen

Component Side Copper

Solder Side Copper

Component Side Solder Mask

Solder Side Solder Mask
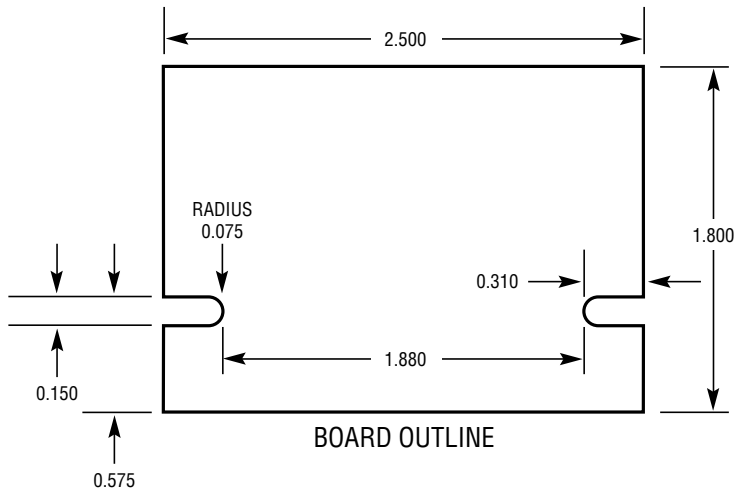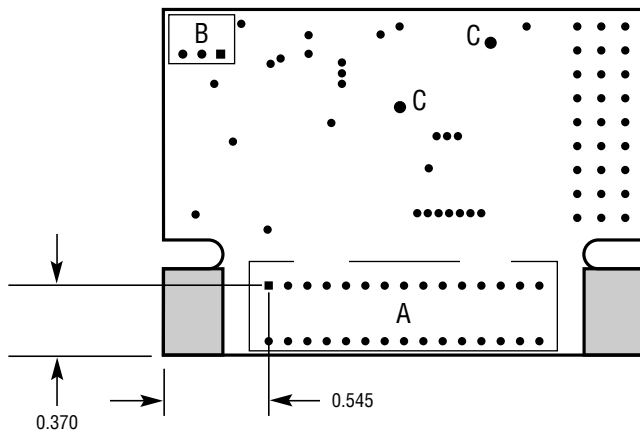
PC FAB DRAWING

BOARD OUTLINE

NOTES: UNLESS OTHERWISE SPECIFIED.
1. FINISHED MATERIAL IS FR4, 0.062" THICK, 2 OUNCE COPPER.
2. PCB WILL BE DOUBLE SIDED WITH PLATED THROUGH HOLES.
3. PTH SIZES AFTER PLATING, 0.001" MIN WALL THICKNESS.
4. SOLDER MASK BOTH SIDES.
5. SILKSCREEN BOTH SIDES.
6. ALL DIMENSIONS IN INCHES, ±0.005".
7. ALL HOLE SIZES AFTER PLATING, ±0.003" MAX.
8. FAB-LOGO MAY ONLY BE PLACED AS SHOWN.

BOARD DRILL VIEW

FAB-LOGO OK IN SHADED AREAS,
BOTH SIDES
4-PLACES

HOLE CHART			
SYMBOL	DIAMETER	NUMBER OF HOLES	PLT
A	0.035	30	YES
B	0.039	3	YES
C	0.055	2	YES
NONE	0.020	53	YES
	TOTAL HOLES	88	

DC064B • PCB01

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