

## Power Conditioning for Notebook and Palmtop Systems

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### INTRODUCTION

Notebook and palmtop systems need a multiplicity of regulated voltages developed from a single battery. Small size, light weight, and high efficiency are mandatory for competitive solutions in this area. Small increases in efficiency extend battery life, making the final product much more usable with no increase in weight. Additionally, high efficiency minimizes the heat sinks needed on the power regulating components, further reducing system weight and size.

Battery systems include NiCad, nickel-hydrate, lead acid, and rechargeable lithium, as well as throw-away alkaline batteries. The ability to power condition a wide range of batteries makes the ultimate product much more attractive because power sources can be interchanged, increasing overall system versatility.

A main rechargeable battery may be any of the four secondary type cells, with a back-up or emergency ability to operate off alkaline batteries. The higher energy density available in non-rechargeable alkaline batteries allows the systems to operate for extended time without battery replacement.

The systems shown here provide power conditioning with high efficiency and low parts count. Trade-offs between complexity and efficiency have been made to maximize manufacturability and minimize cost. All the supplies operate over a wide range of input voltage allowing great flexibility in the choice of battery configuration.

### LT1432 Driver for High Efficiency 5V and 3.3V Buck Regulator

The LT1432 is a control chip designed to operate with the LT1170 or LT1270 family of switching regulators to make

a very high efficiency (Figure 1) 5V or 3.3V step-down (buck) switching regulator. These regulators feature a low-loss saturating NPN switch that is normally configured with the negative terminal (emitter) at ground. The LT1432 allows the switch to be floated as required in a step-down converter, yet still provides full switch saturation for highest efficiency.

Burst Mode™ is a trademark of Linear Technology Corporation.

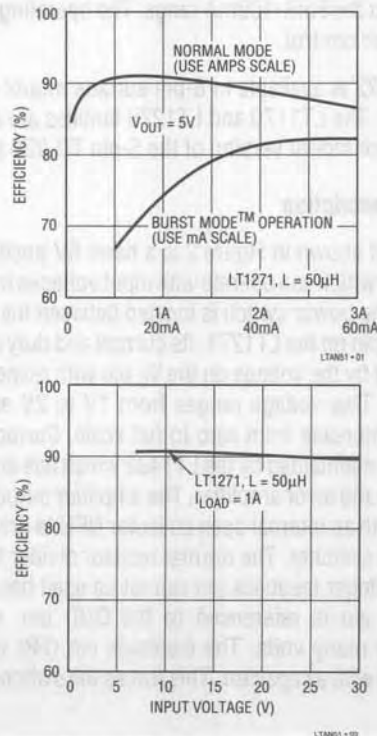


Figure 1. LT1432 5V Efficiency

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Many other features have been incorporated into the LT1432 to enhance operation in battery powered applications. An accurate current limit uses only 60mV sense voltage, allows for foldback, and uses "free" PC board trace material for the sense resistor. Logic controlled shutdown mode draws only 15 $\mu$ A battery current to allow for extremely long shutdown periods. The switching IC is powered from the regulator output to enhance efficiency and to allow input voltages as low as 6.5V.

The LT1432 has optional Burst Mode™ operation to achieve high efficiency at very light load currents (0mA to 100mA). In normal switching mode, the standby power loss is about 60mW, limiting efficiency at light loads. In burst mode, standby loss is reduced to approximately 15mW. Output ripple is 150mV<sub>p-p</sub> in this mode, but this is normally well within the requirements for digital logic supplies. Burst Mode™ operation would typically be used for "sleep" conditions where IC memory chips remain powered for data retention, but the remainder of the system is powered down. Load current in this mode is typically in the 5mA-100mA range. The operating mode is under logic control.

The LT1432 is available in 8-pin surface mount and DIP packages. The LT1170 and LT1270 families are available in a surface mount version of the 5-pin TO-220 package.

### Circuit Description

The circuit shown in Figure 2 is a basic 5V positive buck converter which can operate with input voltages from 6.5V to 25V. The power switch is located between the V<sub>SW</sub> pin and GND pin on the LT1271. Its current and duty cycle are controlled by the voltage on the V<sub>C</sub> pin with respect to the GND pin. This voltage ranges from 1V to 2V as switch currents increase from zero to full scale. Correct output voltage is maintained by the LT1432 which has an internal reference and error amplifier. The amplifier output is level shifted with an internal open collector NPN to drive the V<sub>C</sub> pin of the switcher. The normal resistor divider feedback to the switcher feedback pin cannot be used because the feedback pin is referenced to the GND pin, which is switching many volts. The feedback pin (FB) is simply bypassed with a capacitor. This forces the switcher V<sub>C</sub> pin

to swing high with about 200 $\mu$ A sourcing capability. The LT1432 V<sub>C</sub> pin then sinks this current to control the loop. C4 forms the dominant loop pole with a loop zero added by R1. C5 forms a higher frequency loop pole to control switching ripple at the V<sub>C</sub> pin.

A floating 5V power supply for the switcher is generated by D2 and C3 which peak detect the output voltage during switch "off" time. This is a very efficient way of powering the switcher because power drain does not increase with regulator input voltage. However, the circuit is not self-starting, so some means must be used to start the regulator. This is performed by an internal current path in the LT1432 which allows current to flow from the input supply to the V<sup>+</sup> pin during start-up.

In both the 5V and 3.3V regulators, D1, L1, and C2 act as the conventional catch diode and output filter of the buck converter. These components should be selected carefully to maintain high efficiency and acceptable output ripple.

Current limiting is performed by R2. Sense voltage is only 60mV to maintain high efficiency. This also reduces the value of the sense resistor enough to utilize a printed circuit board trace as the sense resistor. The sense voltage has a positive temperature coefficient to match the temperature coefficient of copper.

The basic regulator has three different operating modes, defined by the mode pin drive. Normal operation occurs when the mode pin is grounded. A low quiescent current Burst Mode™ operation can be initiated by floating the mode pin. Input supply current is typically 1.3mA in this mode, and output ripple voltage is 100mV<sub>p-p</sub>. Pulling the mode pin above 2.5V forces the entire regulator into micropower shutdown where it typically draws less than 20 $\mu$ A.

What are the benefits of using an active (synchronous) switch to replace the catch diode? This is the trendy thing to do, but calculations and actual breadboards show that the improvement in efficiency is only a few percent at best. This can be shown with the following simplified formulas:

$$\text{Diode loss} = V_f (V_{IN} - V_{OUT})(I_{OUT})/V_{IN}$$

$$\text{FET switch loss} = (V_{IN} - V_{OUT})(R_{SW})(I_{OUT})^2/V_{IN}$$

The change in efficiency is:

$$(\text{Diode loss} - \text{FET loss})(\text{Efficiency})^2 / (V_{\text{OUT}})(I_{\text{OUT}})$$

This is equal to:

$$(V_{\text{IN}} - V_{\text{OUT}})(V_f - R_{\text{FET}} \times I_{\text{OUT}})(E)^2 / (V_{\text{IN}})(V_{\text{OUT}})$$

If  $V_f$  (diode forward voltage) = 0.45V,  $V_{\text{IN}} = 10\text{V}$ ,  $V_{\text{OUT}} = 5\text{V}$ ,  $R_{\text{FET}} = 0.1\Omega$ ,  $I_{\text{OUT}} = 1\text{A}$ , and efficiency = 90%, the improvement in efficiency is only:

$$(10\text{V} - 5\text{V})(0.45\text{V} - 0.1\Omega \times 1\text{A})(0.9)^2 / (10\text{V})(5\text{V}) = 2.8\%$$

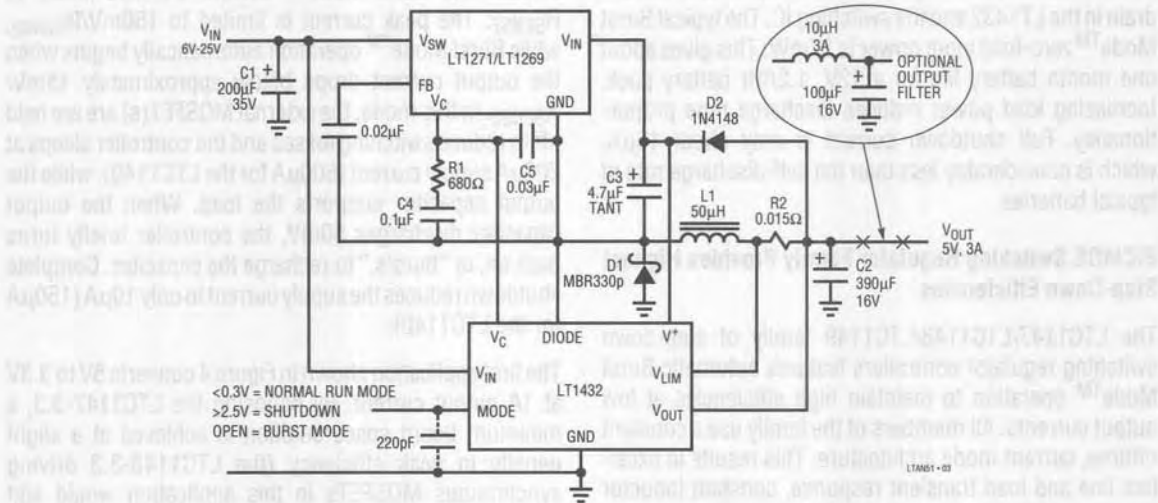


Figure 2. High Efficiency 5V Regulator with Manual Burst Mode™ Operation

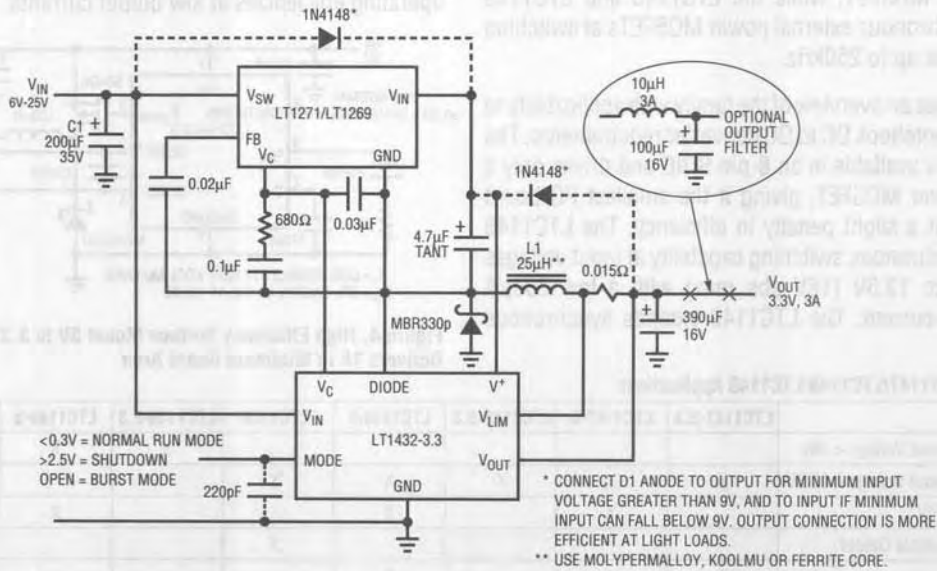


Figure 3. High Efficiency 3.3V Regulator with Manual Burst Mode™ Operation

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This does not take FET gate drive losses into account, which can easily reduce this figure to less than 2%. The added cost, size, and complexity of a synchronous switch configuration would be warranted only in the most extreme circumstances.

Burst Mode™ efficiency is limited by quiescent current drain in the LT1432 and the switching IC. The typical Burst Mode™ zero-load input power is 17mW. This gives about one month battery life for a 12V, 1.2Ahr battery pack. Increasing load power reduces discharge time proportionately. Full shutdown current is only about 15µA, which is considerably less than the self-discharge rate of typical batteries.

### BiCMOS Switching Regulator Family Provides Highest Step-Down Efficiencies

The LTC1147/LTC1148/LTC1149 family of step-down switching regulator controllers features automatic Burst Mode™ operation to maintain high efficiencies at low output currents. All members of the family use a constant offtime, current mode architecture. This results in excellent line and load transient response, constant inductor ripple current, and well controlled start-up and short circuit currents. The LTC1147 drives a single external P-channel MOSFET, while the LTC1148 and LTC1149 drive synchronous external power MOSFETs at switching frequencies up to 250kHz.

Table 1 gives an overview of the family with applicability to common notebook DC to DC converter requirements. The LTC1147 is available in an 8-pin SOIC and drives only a single power MOSFET, giving it the smallest PC board footprint at a slight penalty in efficiency. The LTC1148 offers synchronous switching capability at input voltages from 4V to 13.5V (16V abs max) with a low 200µA quiescent current. The LTC1149 extends synchronous

switching operation up to input voltages of 48V (60V abs max) with a slight penalty in quiescent current.

The rated current level for all three device types is set by the external sense resistor according to the formula  $I_{OUT} = 100mV/R_{SENSE}$ . The maximum peak inductor current and Burst Mode™ current are also linked to  $R_{SENSE}$ . The peak current is limited to  $150mV/R_{SENSE}$ , while Burst Mode™ operation automatically begins when the output current drops below approximately  $15mV/R_{SENSE}$ . In this mode, the external MOSFET(s) are held off to reduce switching losses and the controller sleeps at 200µA supply current (600µA for the LTC1149), while the output capacitor supports the load. When the output capacitor discharges 50mV, the controller briefly turns back on, or “bursts,” to recharge the capacitor. Complete shutdown reduces the supply current to only 10µA (150µA for the LTC1149).

The first application shown in Figure 4 converts 5V to 3.3V at 1A output current. By choosing the LTC1147-3.3, a minimum board space solution is achieved at a slight penalty in peak efficiency (the LTC1148-3.3 driving synchronous MOSFETs in this application would add approximately 2.5% to the high current efficiency). Figure 5 shows how Burst Mode™ operation maintains high operating efficiencies at low output currents.

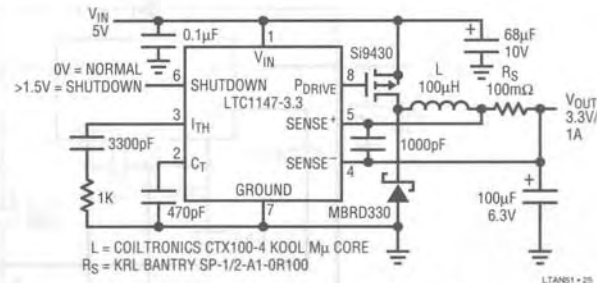


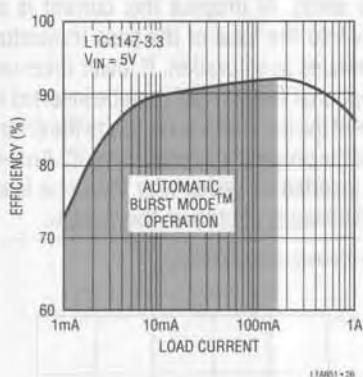
Figure 4. High Efficiency Surface Mount 5V to 3.3V Converter Delivers 1A in Minimum Board Area

Table 1. LTC1147/LTC1148/LTC1149 Applications

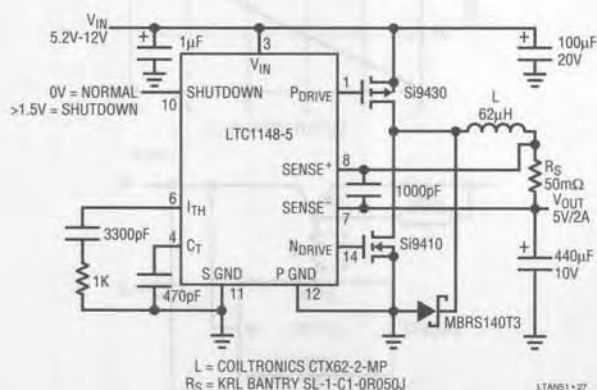
	LTC1147-3.3	LTC1147-5	LTC1148-3.3	LTC1148-5	LTC1148	LTC1149-3.3	LTC1149-5	LTC1149
Continuous Input Voltage < 48V						X	X	X
Continuous Input Voltage < 13.5V	X	X	X	X	X			
Low Dropout 5V		X		X			X	
Adjustable/Multiple Output					X			X
5V to 3.3V	X			X				
Minimum Board Area	X	X						



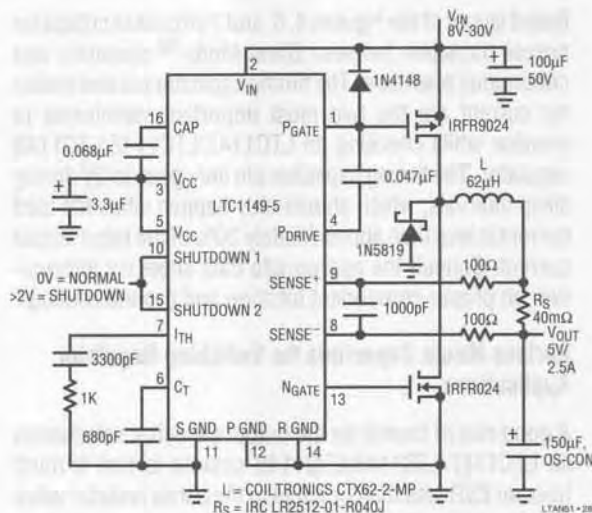
In the second application (Figure 6), an LTC1148-5 is used as the controller for a 10W high efficiency regulator. This circuit can be used with as few as 5 NiCad or NiMH cells thanks to its excellent low dropout performance. Like other members of the family, the LTC1148 goes to 100% duty cycle (P-channel MOSFET turned on DC) in dropout. The input to output voltage differential required to maintain regulation then simply becomes the product of the load current and total resistance of the MOSFET, inductor, and current sense resistor. In the Figure 6 circuit, this total resistance is less than 200mΩ. For operation at low input voltages, logic-level MOSFETs must be used.



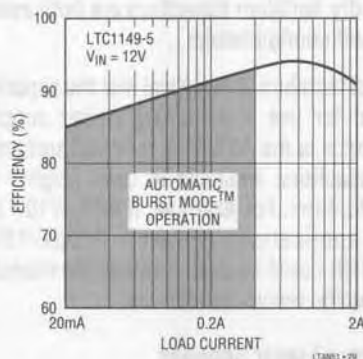
**Figure 5. High Operating Efficiency for Figure 4 Circuit Spans Three Decades of Output Current**



**Figure 6. High Efficiency Low Dropout 5V Switching Regulator Needs Only 200mV Headroom at 1A Output**



**Figure 7. High Efficiency 5V/2.5A Regulator Operates from AC Wall Adapters as High as 30V**



**Figure 8. Operating Efficiency for LTC1149-5 High Efficiency Converter**

While the 13.5V input voltage rating of the LTC1147 and LTC1148 can generally accommodate most battery packs, the AC wall adapters used in conjunction with notebook systems often dictate significantly higher input voltages. This is the primary home for the LTC1149, shown in the Figure 7 application. This 2.5A regulator can operate at input voltages from 8V (limited by the standard MOSFET threshold voltages) to 30V, while still providing excellent efficiency as shown in Figure 8. The synchronous switch plays an increasing role at high input voltages due to the low duty cycle of the main switch.

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Board layout of the Figures 4, 6, and 7 circuits is critical for proper transition between Burst Mode™ operation and continuous operation. The timing capacitor pin and inductor current are the two most important waveforms to monitor while checking an LTC1147/LTC1148/LTC1149 regulator. The timing capacitor pin only goes to 0V during sleep intervals, which should only happen when the load current is less than approximately 20% of the rated output current. Consult the appropriate data sheet for information on proper component location and ground routing.

### Surface Mount Capacitors for Switching Regulator Applications

A good rule of thumb for the output capacitor selection in all LTC1147/LTC1148/LTC1149 circuits is that it must have an ESR less than or equal to the sense resistor value (for example, 50mΩ for the Figure 6 circuit). In surface mount applications multiple capacitors may have to be paralleled to meet the capacitance, ESR, or RMS current handling requirements of the application. Aluminum electrolytic and dry tantalum capacitors are both available in surface mount configurations.

In the case of tantalum, it is critical that the capacitors are surge tested for use in switching power supplies. An excellent choice is the AVX TPS series of surface mount tantalum capacitors, available in case heights ranging from 2mm to 4mm. For example, if 440μF/10V is called for in an application, (2) AVX 220μF/10V (P/N TPSE227K010) could be used. Consult the manufacturer for other specific recommendations.

### High Efficiency Linear Supplies

The switching supplies operate over a wide input range while maintaining high efficiency. Alternative notebook systems have been developed for narrow supply operation using for example, four NiCad batteries and a linear regulator to provide the 5V output. At full charge, four NiCad batteries can be as high as 6V and are allowed to discharge down to 4.5V while directly powering the system. A high efficiency low dropout linear regulator suited for this technique is shown in Figure 9.

This is a complete IC in a very low cost TO-92 3-pin package driving a low saturation PNP transistor. The dropout voltage of this regulator depends on the PNP

transistor saturation and, for the one shown, is 0.25V at 3A output current — lower at lower current. The simplicity of this system is attractive for notebook applications and efficiency is good since little power is lost across the linear regulator at low input voltages.

For input voltages of 5.2V\* and above, the output is regulated at 5V. As the battery voltage decreases below 5.2V\*, the transistor saturates and the output voltage follows the input voltage down with the saturation voltage of the transistor subtracted from the input voltage.

The LT1123 low dropout driver can supply up to 125mA of base current to the MJE1123 pass transistor (any power PNP can be used). At dropout this current is supplied continuously into the base of the pass transistor as the transistor remains in saturation. If lower drive current is desired an optional resistor (R2) can be inserted in series with the base of the transistor to minimize the drive current and decrease the power dissipation in the IC. An N-channel FET can be inserted in series with the drive lead of the LT1123 to electrically shutdown the system.

\* Actual voltage depends on load current.

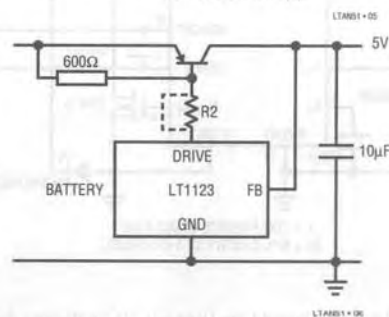
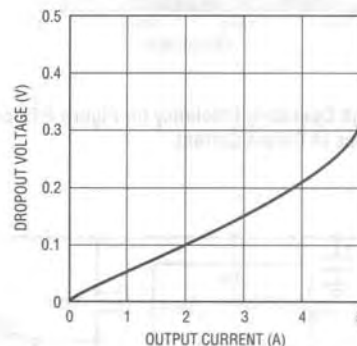


Figure 9. LT1123 Dropout Voltage

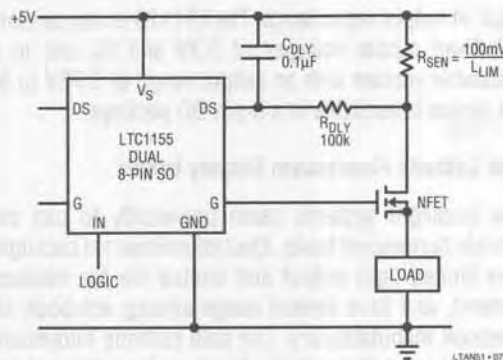


Figure 10. LTC1155 Dual Micropower N-Channel MOSFET Driver

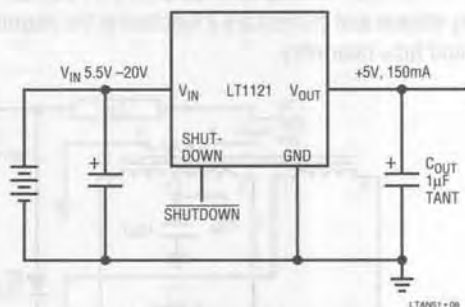


Figure 12. LT1121 Micropower Low Dropout Regulator

### Power Switching with Dual High Side Micropower N-Channel MOSFET Drivers

The LT1155 dual high side N-channel FET gate driver allows using low cost N-channel FETs for high side switching applications. No external components are needed since an internal charge pump boosts the gate above the positive rail, fully enhancing an N-channel MOSFET. Micropower operation, with 8µA standby current and 85µA operating current, allows use in virtually all battery powered systems even for main power switching.

Included on the chip is over-current sensing to provide automatic shutdown in case of short circuits. A time delay can be added in series with the current sense to prevent false triggering on high in-rush loads such as capacitors or lamps.

The LTC1155 operates off a 4.5V to 18V supply input and safely drives the gates of virtually all FETs. It is particularly

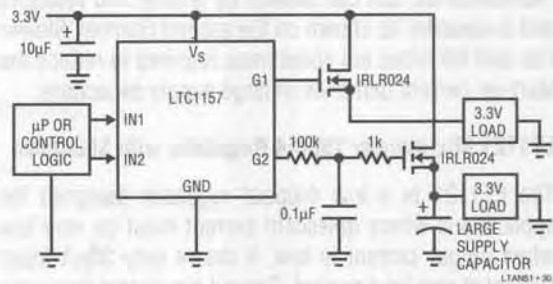


Figure 11. LTC1157 Dual 3.3V MOSFET Driver

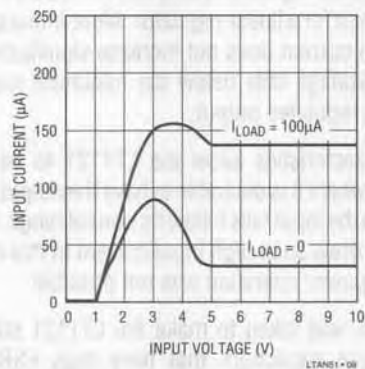


Figure 13. LT1121 Input Current

well-suited for portable applications where micropower operation is critical. The device is available in 8-pin SO and DIP packages.

The LTC1157 is a dual driver for 3.3V supplies. (N-channel switches are required at 3.3V because P-channel MOSFETs do not have guaranteed  $R_{DS(ON)}$  with  $V_{GS} = 3.3V$ .) The LTC1157 internal charge pump boosts the gate drive voltage 5.4V above the positive rail (8.7V above ground), fully enhancing a logic-level N-channel MOSFET for 3.3V high side switching applications. The charge pump is completely on-chip and therefore requires no external components to generate the higher gate voltage. The charge pump has been designed to be very efficient, requiring only 3µA in the standby mode and 80µA while delivering 8.7V to the power MOSFET gate.

Figure 11 demonstrates how two surface mount MOSFETs and the LTC1157 can be used to switch two 3.3V loads. The gate rise and fall time is typically in the tens of

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microseconds, but can be slowed by adding two resistors and a capacitor as shown on the second channel. Slower rise and fall times are sometimes required to reduce the start-up current demands of large supply capacitors.

## LT1121 Micropower 150mA Regulator with Shutdown

The LT1121 is a low dropout regulator designed for applications where quiescent current must be very low when output current is low. It draws only 30 $\mu$ A input current at zero load current. Ground pin current increases with load current, but the ratio is about 1:25, so the efficiency of the regulator is only about 4% below theoretical maximum for a linear regulator. More importantly, the ground pin current does not increase significantly when the input voltage falls below the minimum required to maintain a regulated output.

These characteristics allow the LT1121 to be used in situations where it is desirable to have the output track the input when the input falls below its normal range. Previous regulators drew such high input current in this condition that micropower operation was not possible.

Extra effort was taken to make the LT1121 stable with small output capacitors that have high ESR. A 1 $\mu$ F tantalum output capacitor is suggested, as compared to 10 $\mu$ F for previous designs. Larger output capacitors can be used without fear of instabilities.

The LT1121 is ideal for the backup and/or suspend mode power supply in notebook computers. A shutdown pin allows the regulator to be fully turned off, with input current dropping to only 16 $\mu$ A. Careful design of the IC circuitry connected to the input and output pins allows the output to be held high while the input is pulled to ground or reversed, without current flowing from the output back to the input. The input pin can be reversed up to 20V.

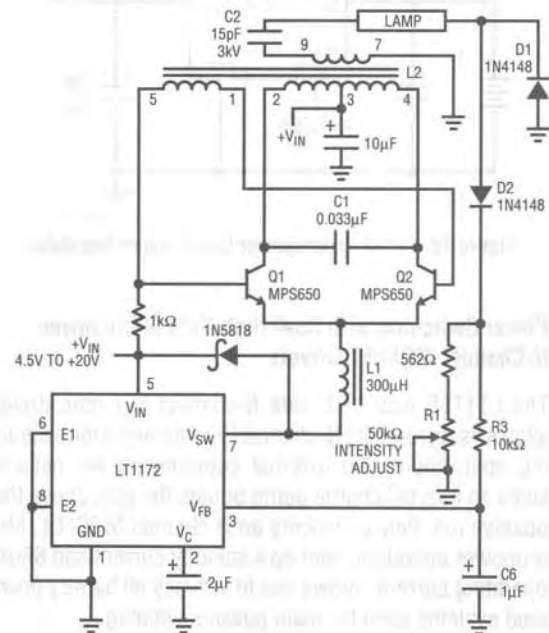
The LT1121 is available with a fixed output voltage of 3.3V or 5V and as an adjustable device with an output voltage range of 3.75V to 30V. Fixed voltage devices are available in 3-pin SOT-223, and 8-pin SO packages. Adjustable devices are available in an 8-pin SO package.

The LT1129, a 700mA version of the LT1121 is also available. The LT1129 includes all of the protection features of the LT1121. No load quiescent current is slightly higher at 50 $\mu$ A and the LT1129 requires a minimum of

3.3 $\mu$ F of output capacitance. The LT1129 is also available with fixed output voltages of 3.3V and 5V and in an adjustable version with an output range of 3.75V to 5V. The device is available in a 5-pin DD package.

## Cold Cathode Fluorescent Display Driver

New backlight systems seem universally to use cold cathode fluorescent tubes. Electroluminescent backlights have limited light output and limited life for notebook systems, and have limited usage among notebook and notebook manufacturers. The cold cathode fluorescent, on the other hand, has high efficiency, long life, and high light output. Typically the cold cathode fluorescent wants to be driven with 1mA to 5mA at 30kHz to 50kHz. The driving voltage and current are a function of the manufacturer and tube geometry.



- C1 = MUST BE A LOW LOSS CAPACITOR. METALIZED POLYCARB. WIMA FKP2 (GERMAN) RECOMMENDED.
  - L1 = SUMIDA-6345-020 OR COILTRONICS-CTX110092-1. PIN NUMBERS SHOWN FOR COILTRONICS UNIT
  - L2 = COILTRONICS-CTX300-4
  - Q1, Q2 = AS SHOWN OR BCP 56 (PHILIPS SO PACKAGE) DO NOT SUBSTITUTE COMPONENTS
- SUMIDA (708) 956-0666  
COILTRONICS (305) 781-8900

Figure 14. CCFL Inverter



Optimally the current through the tube should be regulated to control its brightness.

To understand the operation of the cold cathode fluorescent display driver in Figure 14, the circuit should be looked at as two sections; 1. The regulating loop, 2. The high voltage oscillator/driver.

The regulating loop consists of an LT1172 switching regulator in a buck mode configuration driving constant current into a self-oscillating converter coupled to a high voltage transformer. The architecture of the driver allows a wide input range of battery voltage while maintaining fluorescent tube current constant. In negative buck mode, the LT1172 periodically connects inductor L1 to ground via the switch pin. This creates a flow of current in L1 which is steered by self-oscillating transistors Q1 and Q2 to the primary of transformer L2. The output of L2 is a high voltage AC waveform that is partially ballasted by the 15pF capacitor. To achieve the desired regulation of actual bulb current, D1 and D2 rectify bulb current and pass one phase through R1. This rectified current is converted to a voltage by R1 and filtered by R3 and C6. The filtered signal becomes a feedback signal to the LT1172, which maintains it at 1.25V.

Enclosing the cold cathode fluorescent bulb in a feedback loop allows precise control of its operating current and allows microprocessor control of its brightness. Voltage fed through a resistor to the top of C6, either from a D/A converter or from logic, will control the current through the fluorescent tube, allowing brightness to be varied from a keyboard input.

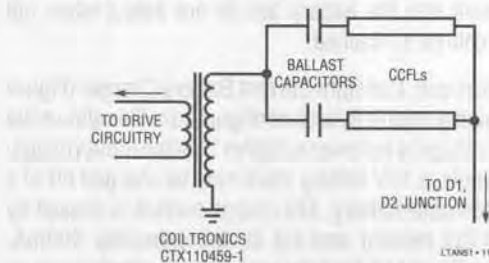


Figure 15. Two Bulb Adaption for Color

This architecture of a buck converter driving a self-oscillating inverter was chosen because it allows a wide range of input voltages. It is also tolerant of winding ratios on the cold cathode fluorescent transformer. One caution with this circuit is the voltage applied to the bulb terminals is not limited if the feedback loop is broken, so care must be taken to minimize the possibility of power being applied to this circuit with the fluorescent tube removed.

## BATTERY CHARGING

### Lead Acid Battery Charger

Though not as popular as NiCad, Lead acid rechargeable gel cells are attractive because of their high energy density per unit volume. These cells have a long life expectancy when treated properly, but often suffer premature failure because of improper charging. The circuit shown in Figure 16 provides a near ideal charging system for lead-acid cells. It has precise nonlinear temperature compensation, constant voltage charging with constant current override, and high efficiency over a wide range of input and battery voltages.

The basic charger is a flyback design to allow operation with input voltages above or below battery voltage. The LT1171 IC switcher operates at 100kHz and can deliver up to 15W into the battery. A dual op amp is used to control constant voltage and constant current modes. A1 activates as a current limiter when charging current through R7 exceeds a preset limit determined by R3, R6, and R7. This current limit is included to prevent excess charge current for heavily discharged batteries. Losses in R7 are kept low because the voltage drop across R7 is kept to several hundred millivolts.

Lead acid batteries have a nonlinear negative temperature coefficient which must be accurately compensated to ensure long battery life and full charge capacity. R5 is a positive temperature coefficient thermistor (tempistor) whose  $+0.7\%/^{\circ}\text{C}$  linear TC is converted to the required nonlinear characteristic by the parallel connection with R2. The combination of R2, R3, and R4 multiply the 1.244V feedback level of the LT1171 to the proper 2.35V

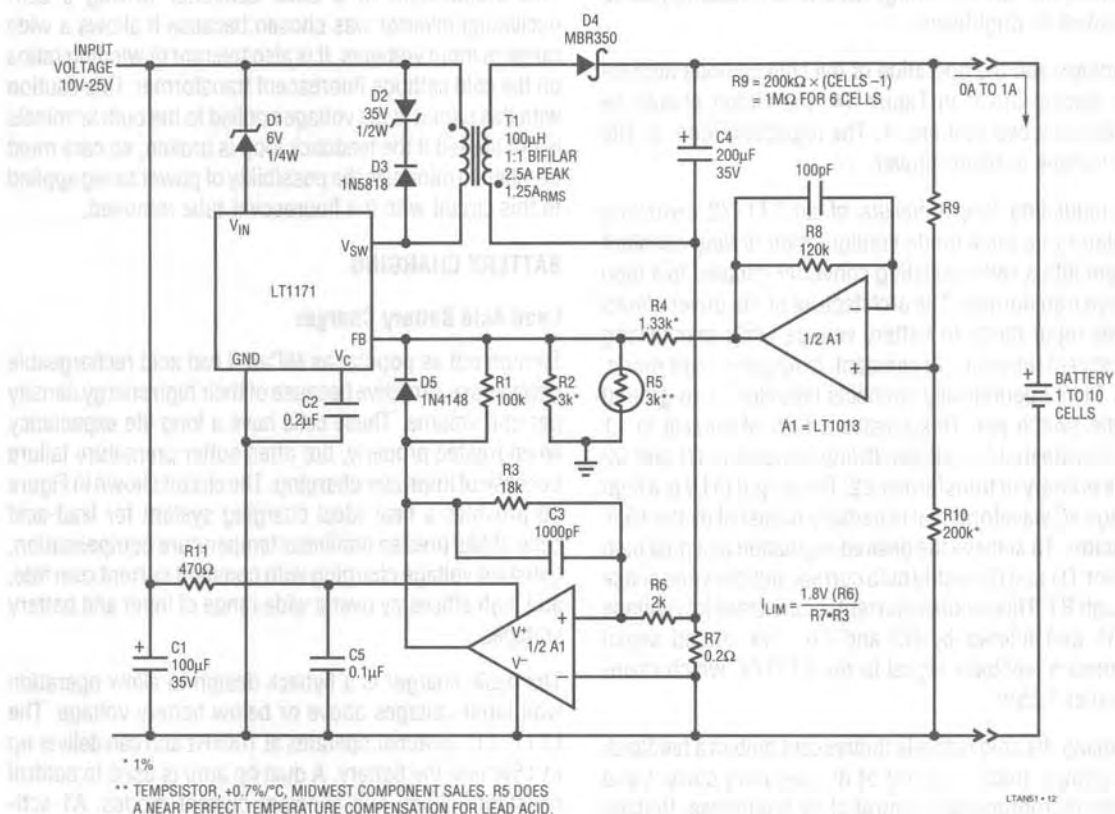


Figure 16. Lead Acid Battery Charger

level required by one cell at 25°C. A2 is used as a buffer to drive the resistor network. This allows large resistors to be used for the cell multiplier string, R9 and R10. R9 is set at 200k for each series cell over one. R9 current is only 12µA, so it can be left permanently connected to the battery. R1 is added to give the charger a finite output resistance ( $\approx 0.025\Omega/\text{cell}$ ) in constant voltage mode to prevent low frequency hunting.

## NiCAD Charging

Battery charging is a very important section of any notebook system. The battery charging circuits shown here for nickel cadmium or nickel metal hydride batteries control

the current into the battery but do not detect when full battery charge is reached.

The first circuit, Constant Current Battery Charger (Figure 17), is built around a flyback configuration. This allows the battery voltage to be lower or higher than the input voltage. For example, a 16V battery stack may be charged off of a 12V automobile battery. The charge current is sensed by R4, a 1.2Ω resistor and set at approximately 600mA. Resistors R5 and R6 limit the peak output voltage when no battery is connected. Diode D3 prevents the battery discharging through the divider network when the charger is off, while transistor Q1 allows electronic shutdown of the charger.

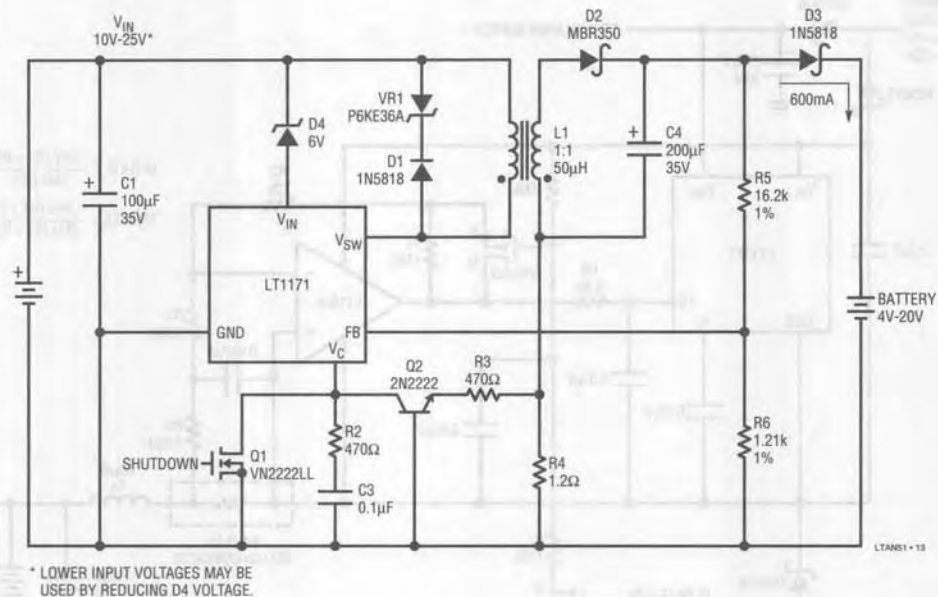


Figure 17. Constant Current Battery Charger

The next two chargers are a high efficiency buck charger configuration. The input voltage must be higher than the battery voltage for charging to occur. These chargers are 90% efficient when charging at maximum output current. No heat sinks are needed on either the switching regulator or diodes because the efficiency is so high.

The dual rate battery charger in Figure 18 uses a logic signal to toggle between a high charge rate, up to 2A, or a trickle rate for keep alive. An LT1006 amplifier senses the current into the battery and drives the feedback pin of an LT1171 switching regulator. The entire control circuit is bootstrapped to the LT1171 and floats at the switching frequency, so stray capacitance must be minimized.

A gain setting transistor changes the gain on the LT1006 by shorting or opening resistor R1. This changes the charge rate, for the value shown, between 0.1A and 1A.

The charger in Figure 19 is programmable with a voltage from D-A converters. The charging current is directly proportional to the program voltage. A small sense resistor in the bottom side of the battery senses the battery charging current. This is compared with the program voltage and a feedback signal is developed to drive the LT1171  $V_C$  pin. This controls the charging current from the LT1171 and with appropriate control circuits any battery current may be programmed. Efficiency during high charge currents is 90%.

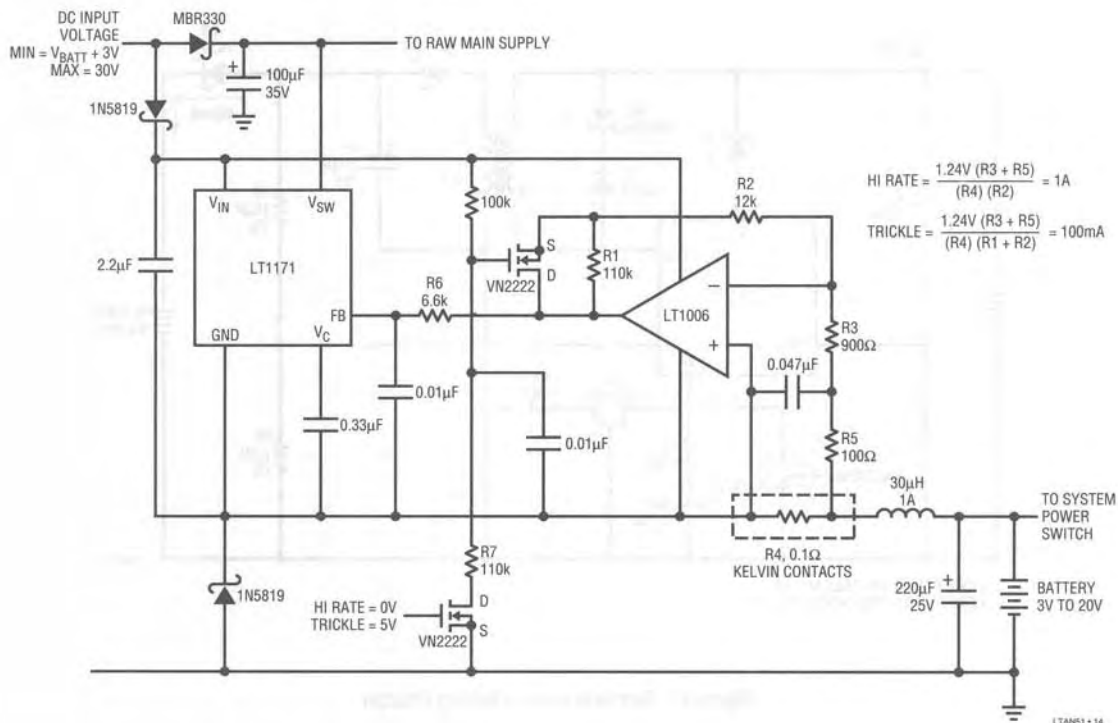


Figure 18. High Efficiency Dual Rate Battery Charger (Up to 2A)

### LCD Display Contrast Power Supply

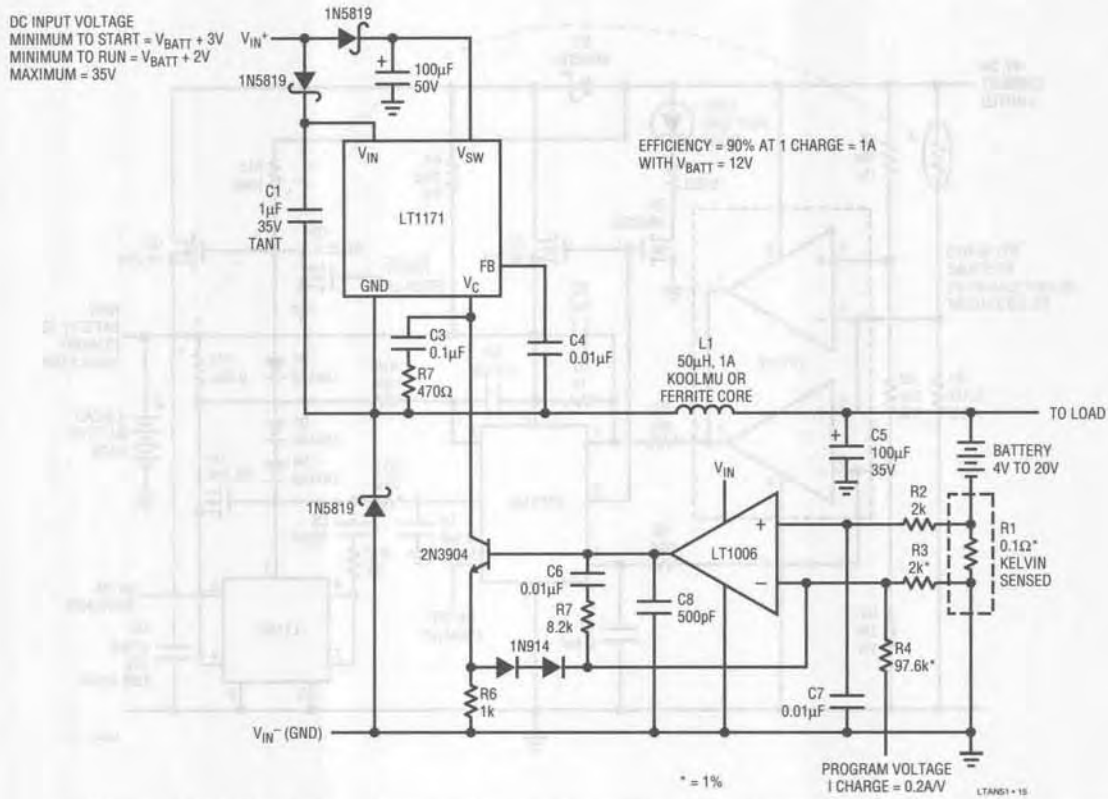
LCD display typically requires between  $-18V$  and  $-24V$  to set the contrast of the display. Usually, a switching regulator is needed in the system to generate this voltage although it runs at low power. The LT1172 generates the voltage with a minimum parts count.

The circuit in Figure 20 works by generating  $+18V$  to  $+24V$  in a boost configuration and then inverting the voltage by charge pumping. This allows the use of a small inductor for the converter rather than a transformer.

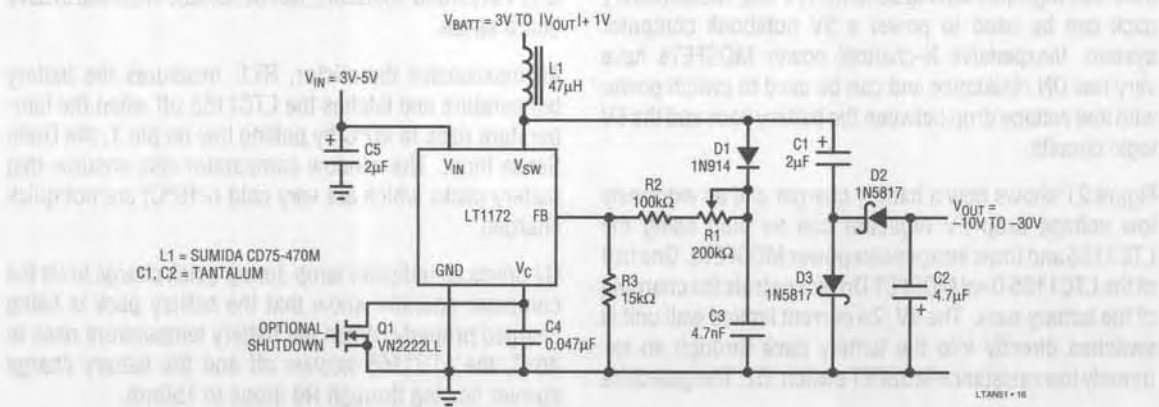
### A 4-Cell NiCad Regulator/Charger

The new LTC1155 Dual Power MOSFET Driver delivers 12V of gate drive to two N-channel power MOSFETs when powered from a 5V supply with no external components required. This ability, coupled with its micropower current demands and protection features, makes it an excellent choice for high side switching applications which previously required more expensive P-channel MOSFETs.

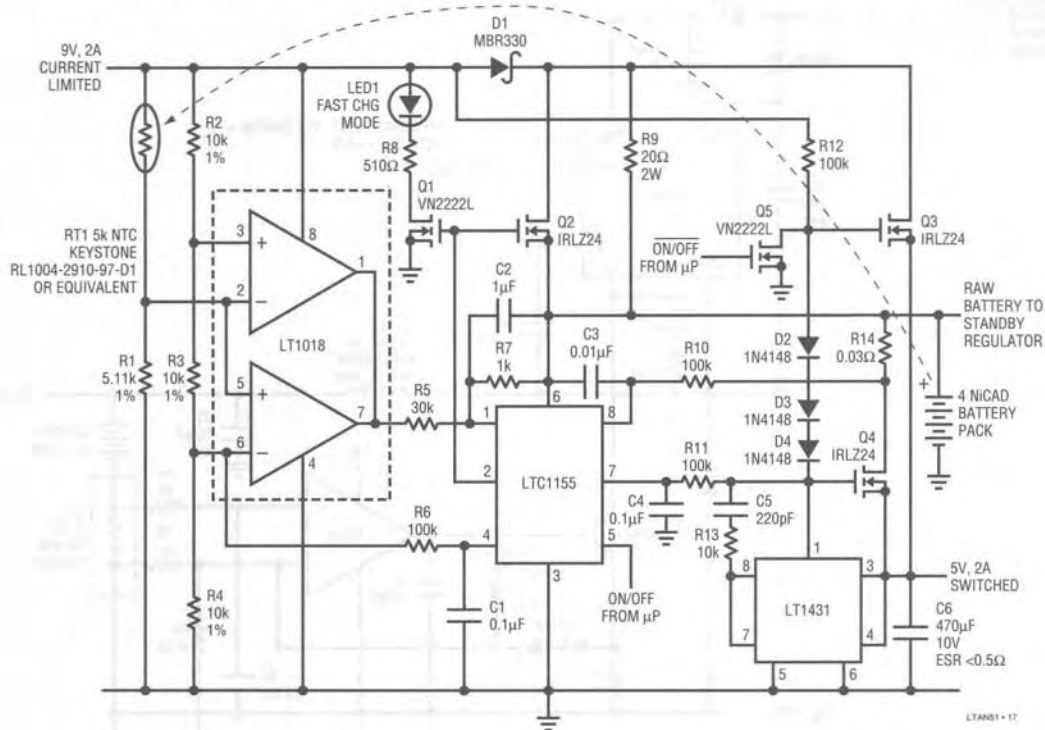




**Figure 19. High Efficiency Programmable Buck-Mode Battery Charger (Input Voltage Must be Higher than Battery Voltage)**



**Figure 20. LCD Bias Circuit Generates -24V**



**Figure 21. The LTC1155 Dual MOSFET Driver Provides Gate Drive and Protection for a 4-Cell NiCad Charger and Regulator**

A notebook computer power supply system in Figure 21 is a good example of an application which benefits directly from this high side driving scheme. A 4-cell, NiCad battery pack can be used to power a 5V notebook computer system. Inexpensive N-channel power MOSFETs have very low ON resistance and can be used to switch power with low voltage drop between the battery pack and the 5V logic circuits.

Figure 21 shows how a battery charger and an extremely low voltage drop 5V regulator can be built using the LTC1155 and three inexpensive power MOSFETs. One half of the LTC1155 Dual MOSFET Driver controls the charging of the battery pack. The 9V, 2A current limited wall unit is switched directly into the battery pack through an extremely low resistance MOSFET switch, Q2. The gate drive

output, pin 2, generates about 13V of gate drive to fully enhance Q1 and Q2. The voltage drop across Q2 is only 0.17V at 2A and, therefore, can be surface mounted to save board space.

An inexpensive thermistor, RT1, measures the battery temperature and latches the LTC1155 off when the temperature rises to 40°C by pulling low on pin 1, the Drain Sense Input. The window comparator also ensures that battery packs which are very cold (<10°C) are not quick charged.

Q1 drives an indicator lamp during quick charge to let the computer operator know that the battery pack is being charged properly. When the battery temperature rises to 40°C, the LTC1155 latches off and the battery charge current flowing through R9 drops to 150mA.

A 4-cell NiCad battery pack produces about 6V when fully charged. This voltage will drop to about 4.5V when the batteries are nearly discharged. The second half of the LTC1155 provides gate voltage drive, pin 7, for an extremely low voltage drop MOSFET regulator. The LT1431 controls the gate of Q4 and provides a regulated 5V output when the battery is above 5V. When the battery voltage drops below 5V, Q4 acts as a low resistance switch between the battery and the regulator output.

A second power MOSFET, Q3, connected between the 9V supply and the regulator output "bypasses" the main regulator when the 9V supply is connected. This means that the computer power is taken directly from the AC line while the charger wall unit is connected. The LT1431 provides regulation for both Q3 and Q4, and maintains a constant 5V at the regulator output. The diode string made up of diodes D2-D4 ensure that Q3 conducts all the regulator current when the wall unit is plugged in by separating the two gate voltages by about 2V.

R14 acts as a current sense for the regulator. The regulator latches off at 3A when the voltage drop between the second Drain Sense Input, pin-8, and the supply, pin-6, rises above 100mV. R10 and C3 provide a short delay. The  $\mu$ P can restart the regulator by turning the second input, pin-5, off and then back on.

The regulator is switched off by the  $\mu$ P when the battery voltage drops below 4.6V. The standby current for the 5V, 2A regulator is less than 10 $\mu$ A. The regulator is switched on again when the battery voltage rises during charging.

Power dissipation in the notebook computer itself is generally quite low. The current limited wall unit dissipates the bulk of the power created by quick charging the battery pack. Q2 dissipates less than 0.5W. R9 dissipates about 0.7W. Q4 dissipates about 2W for a very short period of time when the batteries are fully charged and dissipates less than 0.5W as soon as the battery voltage drops to 5V. The three integrated circuits shown are micropower and dissipate virtually no power. Q3, however, can dissipate as much as 7W if the full 2A output current is required while powered from the wall unit.

The circuit shown in Figure 21 consumes very little board space. The LTC1155 is available in an 8-pin SO package and the three power MOSFETs can also be housed in SO packaging. Q3 and Q4 must be heat sunked properly however. (Consult the MOSFET manufacturer data sheet for surface mount heat sink recommendations).

The LTC1155 allows the use of inexpensive N-channel MOSFET switches to directly connect power from a 4-cell NiCad battery pack to the charger and the load. This technique is very cost effective and is also very efficient. Nearly all the battery power is delivered directly to the load to ensure maximum operating time from the batteries.

### POWER SUPPLIES FOR PALMTOP COMPUTERS

Palmtop computer power supply designs present an entirely separate set of problems from notebook computers. Notebook machines typically use a 9V to 15V NiCad stack for the power source. Palmtop machines, due to their extremely small size, have room for only two or four AA cells. The palmtop machines require much longer operating time in sleep mode, since they presently do not have disk drives. A typical palmtop system may have several hours of operating life with the processor at full activity, tens of hours of quiescent operation with the processor shutdown but the display active, and up to two months life in sleep mode where all memory is retained but no computation takes place. Palmtop machines also use a lithium battery for backup power when the AA cells are dead or being replaced.

The power source for palmtops are usually disposable AA alkaline cells. The use of these disposable batteries generates a separate set of problems from notebook computers. Unlike power supply systems powered by rechargeable NiCad or NiMH batteries, high efficiency power converter circuits are not necessarily optimum for use with disposable batteries. Since rechargeable batteries have very low output impedance, the most efficient converter circuits result in maximum operating time.

Disposable cells, on the other hand, have relatively high internal impedance, so maximum battery life results when the battery load is low and relatively constant. Power supply converters that minimize both the loss in the

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converter circuit and minimize the effect of battery internal resistance will give longest system operating life. Some of the 4-cell designs presented here are optimized for low peak battery current to lengthen the disposable battery life. Other configurations, while they may have higher efficiency, require higher peak energy demands on the battery and consequently shorten the battery life. The converter circuits shown here have been tested using alkaline AA cells and provide long battery life.

### 2-Cell Input Palmtop Power Supply Circuits

A regulated 5V supply can be generated from two AA cells using the circuit shown in Figure 22. U1, an LT1108-5 micropower DC to DC converter, is arranged as a step-up, or "boost" converter. The 5V output, monitored by U1's SENSE pin, is internally divided down and compared to a 1.25V reference voltage inside the device. U1's oscillator turns on when the output drops below 5V, cycling the switching transistor at a 19kHz rate. This action alternately causes current to build up in L1, then dump into C1 through D1, increasing the output voltage. When the output reaches 5V, the oscillator turns off.

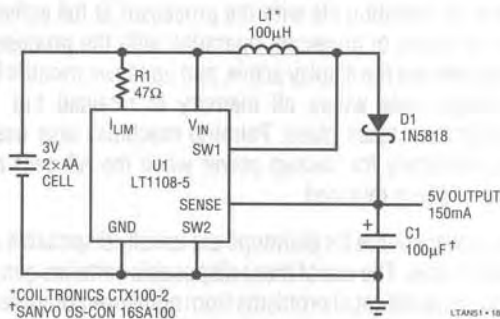


Figure 22. 2 AA Cells to 5V Deliver 150mA

The gated oscillator provides the mechanism to keep the output at a constant 5V. R1 invokes the current limit feature of the LT1108, limiting peak switch current to approximately 1A. U1 limits switch current by turning off the switch when the current reaches the programmed limit set by R1. Switch "on" time, therefore, decreases as  $V_{IN}$  is increased. Switch "off" time is not affected. This scheme keeps peak switch current constant over the entire input

voltage range, allowing minimum energy transfer to occur at low battery voltage without exceeding L1's maximum current rating at high battery voltage. Maximum current demands should be carefully considered, with R1 tailored to the individual application to obtain longest possible battery life. For example, if only 75mA maximum is required, R1 can be increased to 100Ω. This will limit switch current to approximately 650mA which has the effect of increasing converter efficiency and lowering peak current demands, considerably extending battery life.

The circuit delivers 5V at up to 150mA from an input range of 3.5V to 2.0V. Efficiency measures 80% at 3.0V, decreasing to 70% at 2.0V for load currents in the 15mA to 150mA range. Output ripple measures 75mV<sub>P-P</sub> and no-load quiescent current is just 135μA.

### LCD Bias from 2 AA Cells

A -24V LCD bias generator is shown in Figure 23. In this circuit U1 is an LT1173 micropower DC to DC converter. The 3V input is converted to +24V by U1's switch, L1, D1, and C1. The switch pin (SW1) then drives a charge pump consisting of C2, C3, D2, and D3 to level shift the +24V output to -24V. Line regulation is less than 0.2% from 3.3V to 2.0V inputs. Load regulation measures 2% from a 1mA to 7mA load. The circuit delivers up to 7mA from a 2.0V input at 73% efficiency.

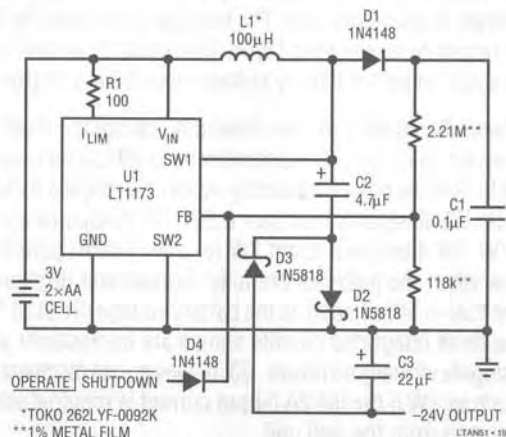


Figure 23. 2-Cell LCD Supply Generates -24 at 7mA



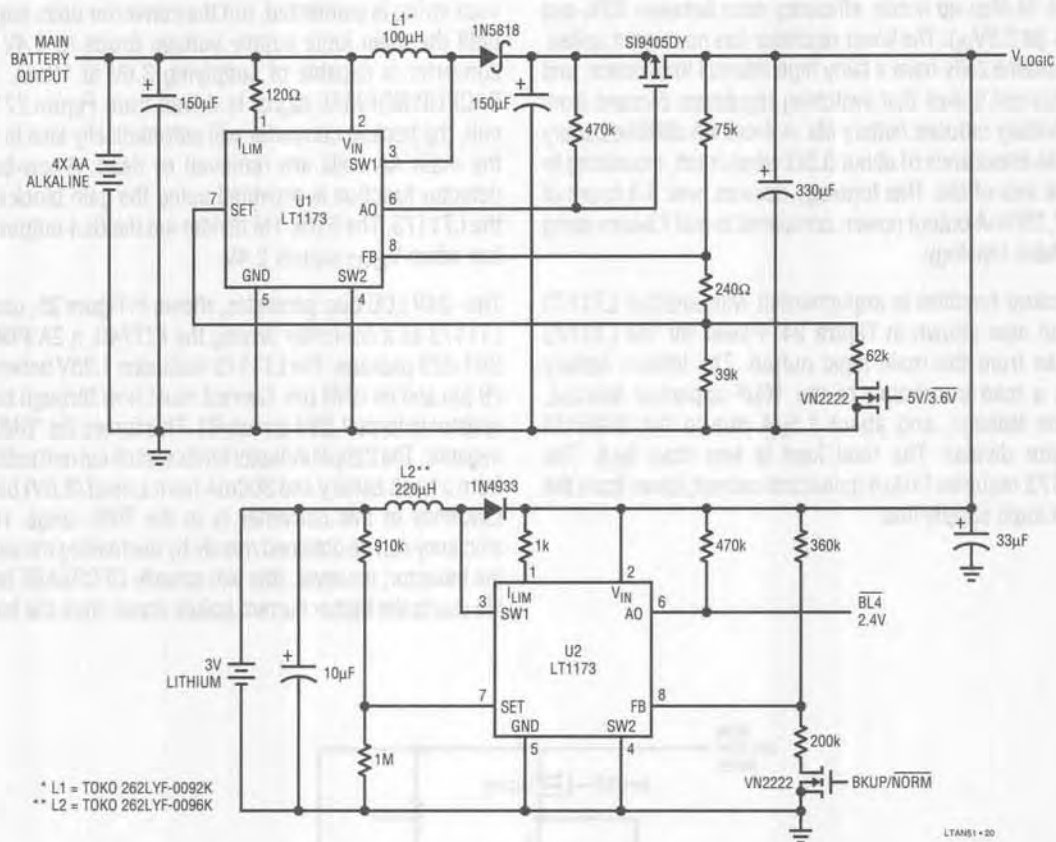


Figure 24. Main Logic Converter Generates 3.6V/5V at 200mA; Backup Converter Generates 3.4V when Main Battery is Dead or Removed

#### 4-Cell Input Palmtop Power Supply Circuits

Newer, more powerful palmtop machines using 386SX processors require more power than two AA cells can deliver for reasonable operating life. The circuits shown here provide a switchable 3.6V/5V output for main logic, a -23V output for LCD display bias, a +12V output for Flash memory  $V_{PP}$  generation, and an automatic backup supply using a 3V lithium cell. Under no-load conditions, the quiescent current required by the entire system is 380µA.

The main converter circuit shown in Figure 24 is a combination step-up/step-down converter. When the 4 AA cells are fresh, the circuit behaves as a linear regulator. While this may seem to be inefficient, note that the battery voltage normally quickly drops from 6V to 5V. At 5V input, the efficiency is 3.6V/5V or 72%. As battery voltage drops further, efficiency increases, reaching over 90% at 4.2V input. When the battery drops below 4V, the circuit switches over to step-up mode, squeezing every bit of available energy out of the battery.

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The converter delivers 200mA at 3.6V with as little as 2.5V input. In step-up mode, efficiency runs between 83% and 73% (at 2.5V<sub>IN</sub>). The linear regulator has no current spikes. AA alkaline cells have a fairly high internal impedance, and the current spikes that switching regulators demand from the battery reduces battery life. A 4-cell AA alkaline battery has an impedance of about 0.5Ω when fresh, increasing to 2Ω at end-of-life. This topology delivers over 9.3 hours of 3.6V, 200mA output power, compared to just 7 hours using a flyback topology.

A backup function is implemented with another LT1173 circuit also shown in Figure 24. Power for the LT1173 comes from the main logic output. The lithium battery sees a load consisting of the 10μF capacitor leakage, switch leakage, and about 1.5μA due to the 910k/1M resistor divider. The total load is less than 5μA. The LT1173 requires 110μA quiescent current, taken from the main logic supply line.

When the BACKUP/NORMAL input goes high, the feedback string is connected, but the converter does not cycle until the main logic supply voltage drops to 3.4V. This converter is capable of supplying 3.6V at 10mA. If the BACKUP/NORMAL signal is driven from Figure 27's circuit, the backup converter will automatically kick in when the main AA cells are removed or dead. A low-battery detector function is provided using the gain block inside the LT1173. The 910k/1M divider sets the BL4 output to go low when V<sub>BATT</sub> equals 2.4V.

The -24V LCD bias generator, shown in Figure 25, uses the LT1173 as a controller driving the FZT749, a 2A PNP in a SOT-223 package. The LT1173 maintains 1.25V between its FB pin and its GND pin. Current must flow through the 3M resistor to force 1.25V across R1. This forces the "GND" pin negative. The 220μH inductor limits switch current to 500mA from a fresh battery and 300mA from a dead (3.6V) battery. Efficiency of this converter is in the 70% range. Higher efficiency can be obtained merely by decreasing the value of the inductor; however, this will actually DECREASE battery life due to the higher current spikes drawn from the battery.

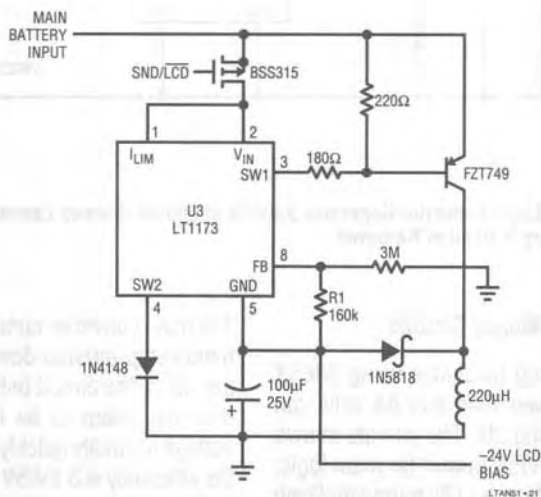


Figure 25. LCD Bias Generator Delivers -24V at 10mA

A Flash memory VPP generator is shown in Figure 26. Up to 40mA at 12V is available from the output. The converter is switched on and off via the small N-channel MOSFET connected to the 124k feedback resistor. When the MOSFET is turned on, the resistor is connected to ground and the converter generates 12V. When the MOSFET is off, the 124k resistor is disconnected and the feedback pin floats high, turning off the converter. When off, output voltage sits at battery voltage minus a diode drop. This condition is approved for Flash memory. Inadvertent programming cannot occur as the Flash chip contains a level detector. When the VPP pin voltage is less than 11.4V, the Flash chip itself will not allow programming to take place. Another low-battery

detect function is provided using the LT1173's gain block. The main alkaline battery is being sensed here, and the AO pin goes low when the battery voltage falls below 4.0V.

Finally, a micropower two-terminal reference and dual comparator form a pair of battery detectors. The upper comparator in Figure 27 senses the main battery directly. When the battery voltage falls below 2.5V (a very dead battery!) or the battery is removed, BL3 will go high. If connected to the BACKUP/NORMAL signal of the lithium backup converter, the backup will take over the main logic supply line automatically. The other comparator goes low when the battery voltage falls below 3.6V.

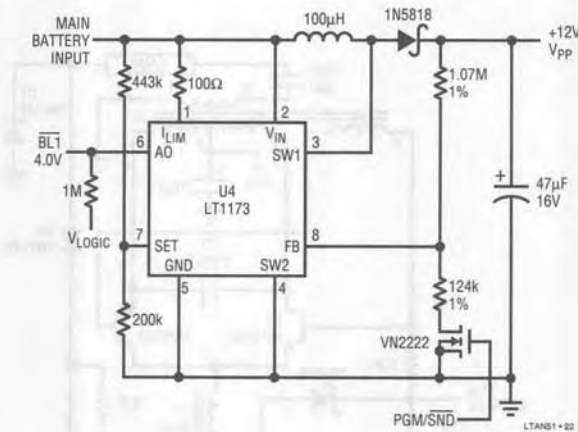


Figure 26. Flash Memory VPP Generator Delivers 12V, 40mA from 4 AA Input

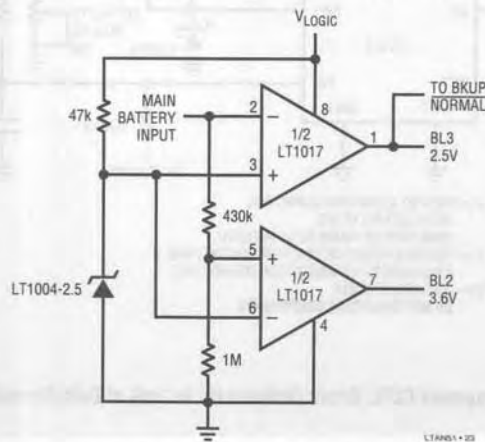


Figure 27. Battery Detectors Sense Removal of Main Battery, Indicate  $V_{BATT} < 3.6V$

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## A CCFL Backlight Driver for Palmtop Machines

Backlit displays have greatly enhanced user acceptance of portable computers. Palmtop machines have not used backlit displays because of the high power required by the inverter circuit used to drive the bulb. Figure 28's circuit, a micropower CCFL supply, overcomes this problem. A typical notebook CCFL supply drives the bulb at 5mA. This circuit, using an LT1173 micropower DC to DC converter, operates over an input range of 2.0V to 6V. Maximum bulb current is limited to 1mA. Control over bulb current is maintained down to 1 $\mu$ A, a very dim light! It is intended for palmtop applications where the longest possible battery life is desired.

L1, Q1, and Q2 comprise a current driven Royer class converter which oscillates at a frequency primarily set by L1's characteristics (including its load) and the 0.01 $\mu$ F capacitor. This entire converter is gated on and off by the burst mode operation of the LT1173. The 1M/0.01 $\mu$ F RC at the LT1173 feedback pin filters the half-sine appearing at the 3.3k-1M potentiometer chain. This signal represents 1/2 the lamp current. The LT1173 servos the energy in the lamp to maintain 1.25V at its feedback pin, closing a loop. For low bulb currents, the LT1173 idles most of the time, drawing only 110 $\mu$ A quiescent current. At the 1mA maximum bulb current, the circuit draws less than 100mA. A substantial amount of light is emitted by the bulb at an input current drain of less than 5mA.

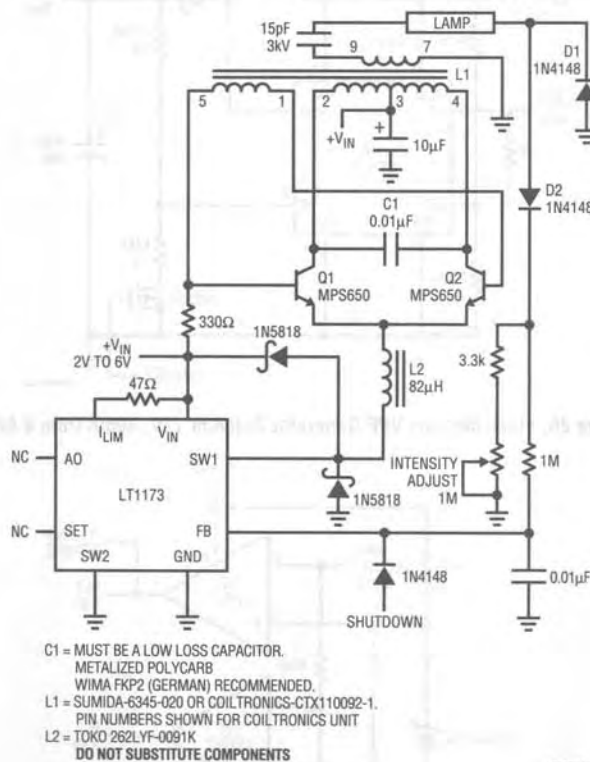


Figure 28. Micropower CCFL Driver Delivers Up to 1mA of Bulb Current from 2 AA Cells