Applications of the LT1300 and LT1301 Micropower DC/DC Converters

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INTRODUCTION

The design of battery-powered equipment can often be quite challenging. Since few ICs can operate directly from the end-of-life voltage from a 2-cell battery (about 1.8V), most systems require a DC/DC converter. The system designer often has a limited area in which to place the DC/DC converter; associated inductors and capacitors must be small. Surface mount components are a must and heat sinks are out of the question! The LT1300 and LT1301 micropower DC/DC converter ICs provide new possibilities for more efficient, compact and cost effective designs. When designing equipment for battery-powered operation, a number of important design constraints should be considered. Some of these are detailed in the check list given here:

- Design for high efficiency. A high efficiency converter increases battery life, eliminates most heat sinks, reduces weight and decreases PC board area. The designer should strive for high efficiency at:
  - Full Load
  - Light Load
- Plan to utilize all the capacity of the battery. Can the circuit run down to the "dead cell" voltage? Is there a micropower shutdown mode?
- Can the DC/DC converter circuitry provide high output power for short time intervals? Often this is a requirement on battery-powered equipment.
- Cost. Is the complete circuit cost competitive?
- Does the design meet packaging constraints?
  - Height
  - PC Board Area
  - Weight

The LT1300 family of DC/DC converters allows a maximum of flexibility in the design of circuits which provide solutions for battery-operated and other equipment needing high efficiency, space efficient, micropower power solutions.

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NEW LT1300 AND LT1301 MICROPOWER DC/DC CONVERTERS

by Steve Pietkiewicz

Introduction

The new LT1300 and LT1301 micropower DC/DC converters provide improvements in both electrical and physical efficiency, two key areas of battery-based power supply design. Housed in 8-lead DIP or SOIC packages, the devices feature a 1A on-chip switch with a V_{CESAT} of just 170mV. The internal oscillator frequency is set at 155kHz, allowing the use of tiny, 5mm diameter surface mount inductors along with standard D-case size tantalum capacitors. A complete 2-cell to 12V, 5V, or 3.3V converter can fit in less than 0.4 square inches of PC board area.

The devices use Burst Mode™ operation to maintain high efficiency across the full load range. The fully operating quiescent current is only 120µA. It can be further reduced to 10µA by taking the SHUTDOWN pin high, which also disables the device. The output voltage of the LT1300 can be set at either 5V or 3.3V via the logic-controlled SELECT pin, and the LT1301 output can be set at either 5V or 12V using the same pin. The I_{LIM} pin allows the reduction of peak switch current and allows the use of even smaller components. The switch current is nominally set at 1A and can be reduced via the I_{LIM} pin to approximately 400mA, further improving efficiency in systems requiring lower peak powers.

Burst Mode™ is a trademark of Linear Technology Corporation

Theory of Operation

Figure 1 is a block diagram of the LT1300/LT1301. Refer also to Figure 2 for associated component hookup. When A1's negative input, related to the SENSE pin voltage by the appropriate resistor-divider ratio, is higher than the 1.25V reference voltage, A1's output is low. A2, A3 and the oscillator are turned off, drawing no current. Only the reference and A1 consume current, typically 120µA. When the voltage at A1's negative input decreases below 1.25V, overcoming A1's 6mV hysteresis, A1's output goes high, enabling the oscillator, current comparator A2, and driver A3. Quiescent current increases to 2mA as the device prepares for high current switching. Q1 then turns on in a controlled saturation for (nominally) 5.3µs or until current comparator A2 trips, whichever comes first. After a fixed off-time of (nominally) 1.2µs, Q1 turns on again. Refering to Figure 2, the LT1300's switching causes current to alternately build up in L1 and dump into output capacitor C1via D1, increasing the output voltage. When the output is high enough to cause A1's output to go low (Figure 1), switching action ceases. C1 is left to supply current to the

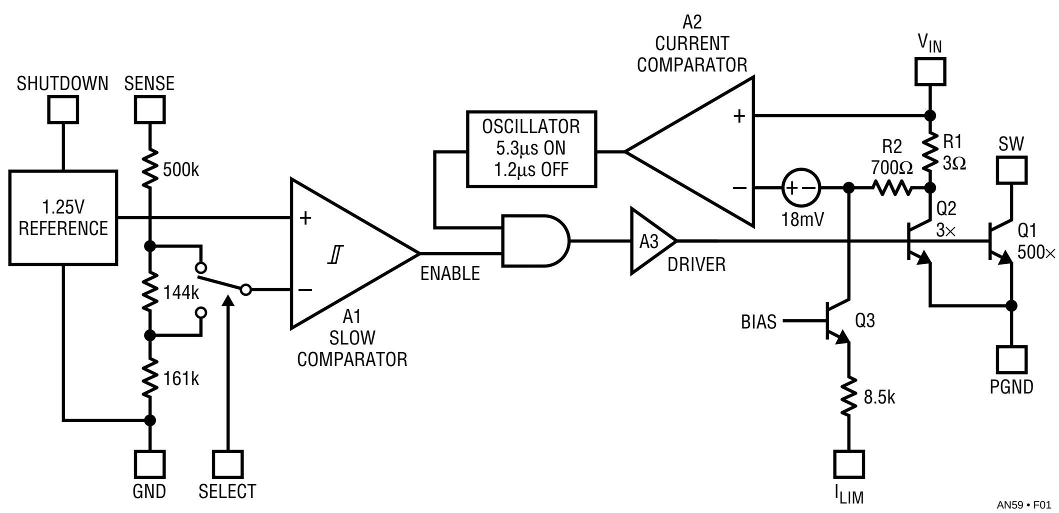

Figure 1. LT1300/LT1301 Block Diagram

load until V_{OUT} decreases enough to force A1's output high, and the entire cycle repeats. If switch current reaches 1A, causing A2 to trip, switch on-time is reduced and off-time increases slightly. This allows continuous mode operation during bursts. Current comparator A2 monitors the voltage across 3Ω resistor R1 which is directly related to inductor L1's current. Q2's collector current is set by the emitter-area ratio to 0.6% of Q1's collector current. When R1's voltage drop exceeds 18mV, corresponding to 1A inductor current, A2's output goes high, truncating the on-time portion of the oscillator cycle and increasing off-time to about 2μs as shown in Figure 3, trace A. This programmed peak current can be reduced by tying the I_{LIM} pin to ground, causing 15μA to flow through R2 into Q3's collector. Q3's current causes a 10.4mV drop in R2, so that only an additional 7.6mV is required across R1 to turn off the switch. This corresponds to a 400mA switch current, as shown in Figure 3, trace B. The reduced peak

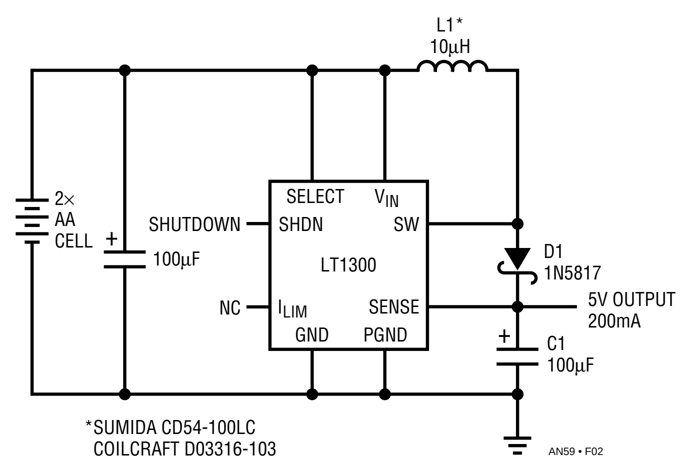

Figure 2. Two-Cell to 5V DC/DC Converter Delivers >200mA with a 2V Input

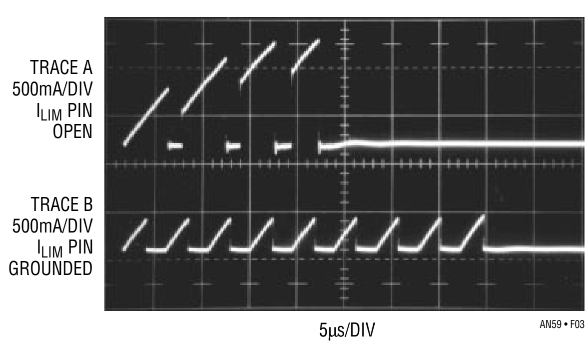

Figure 3. Switch Pin Current with I_{LIM} Floating or Grounded

Burst Mode™ Operation

Burst Mode™ operation, a technique used by many LTC switching regulator products, extends high efficiency over widely varying loads.

At light load, switching regulators employing traditional PWM regulation techniques suffer from low efficiency. This is primarily due to relatively high quiescent (or housekeeping) supply current and AC switching losses resulting from constant frequency operation.

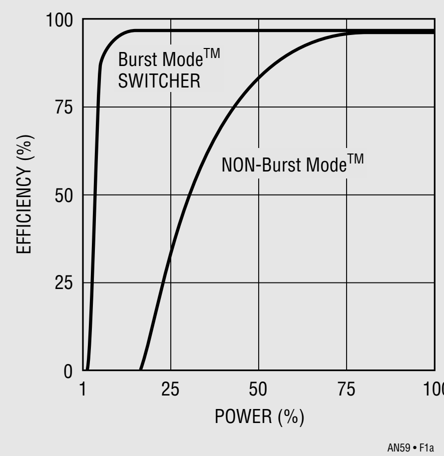

Figure 1a. Characteristics of Burst and Non-Burst Switchers

As seen in Figure 1a, the switching regulator not using Burst Mode™ operation does not reach peak efficiency until load power approaches 100%. Relatively high fixed power drain inside the regulator accounts for the efficiency fall-off as load is decreased. The regulator utilizing Burst Mode™ operation, on the other hand, maintains its high efficiency at light loads. It does this by delivering energy to the output in discrete peak efficiency packets. The energy packets result in a small amount of ripple voltage (typically 50mV) on the output. When not delivering these packets of energy to the output, the regulator puts itself in a "sleep" mode with only a voltage reference and a comparator powered up. These two functions can be accomplished with very low power drain. As the load is decreased to zero, even the small amount of power consumed in sleep mode becomes significant compared to the load, resulting ultimately in decreasing efficiency.

switch current reduces I^2R losses in Q1, L1, C1, and D1. You can increase efficiency by doing this provided that the accompaning reduction in full load output current is acceptable. Lower peak currents also extend alkaline battery life due to the alkaline cells' high internal impedance.

5V from 2 Cells

Figure 2's circuit provides 5V from a 2-cell input. Shutdown is effected by taking the SHUTDOWN pin high. V_{IN} current drops to 10µA in this condition. This simple boost topology does not provide output isolation and in shutdown the load is still connected to the battery via L1 and D1. Figure 4 shows the efficiency of the circuit with a range of input voltages, including a fresh battery (3V) and an "almost dead" battery (2V). At load currents below a few milliamperes, the 120µA quiescent current of the device becomes significant, causing the fall-off in efficiency detailed in Figure 4. At load currents in the 20mA to 200mA range, efficiency flattens out in the 80% to 88% range, depending on the input. Figure 5 details circuit operation. V_{OUT} is shown in trace A. The burst repetition pattern is clearly shown as V_{OUT} decays, then steps back up due to switching action. Trace B shows the voltage at the switch node. The damped, high frequency waveform at the end of each burst is due to the inductor "ringing off," forming an LC tank with the switch and diode capacitance. It is not harmful and contains far less energy than the high speed edge which occurs when the switch turns off. Switch current is shown in trace C. The current comparator inside the LT1300 controls peak switch current, turning off the switch when the current reaches approximately 1A.

Although efficiency curves present useful information, a more important measure of battery-powered DC/DC converter performance is operating life. Figures 6 and 7 detail battery life tests with Figure 2's circuit at load currents of 100mA and 200mA respectively. Operating life curves are shown using both Eveready E91 alkaline cells and new L91 "Hi-Energy" lithium cells. These lithium cells, new to the market, are specifically designed for high drain applications. The performance advantage of lithium is about 2:1 at 100mA load current (Figure 6), increasing to 2.5:1 at 200mA load (Figure 7). Alkaline cells perform poorly at high drain rates because their internal impedance ranges

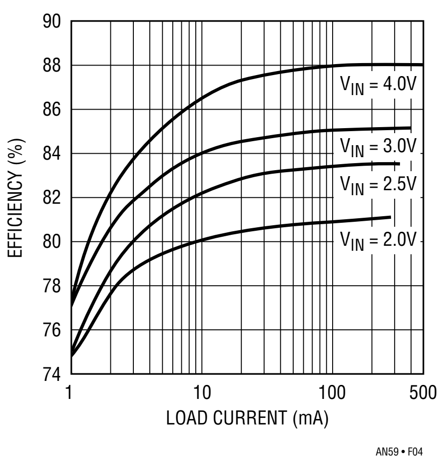

Figure 4. Efficiency of Figure 2's Circuit

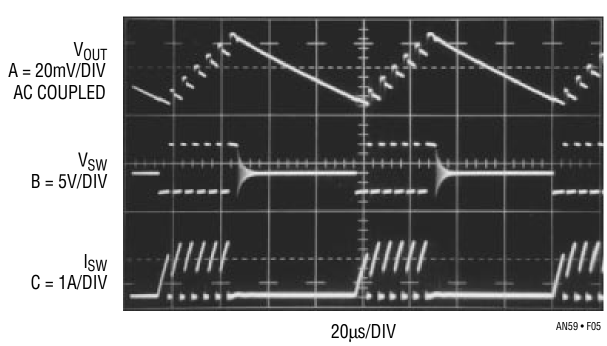

Figure 5. Burst Mode™ Operation in Action

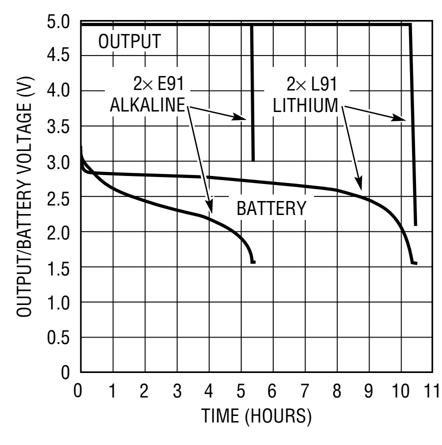

Figure 6. Two Eveready L91 Lithium AA Cells Provide Approximately Twice the Life of E91 AA Alkaline Cells at a 100mA Load Current

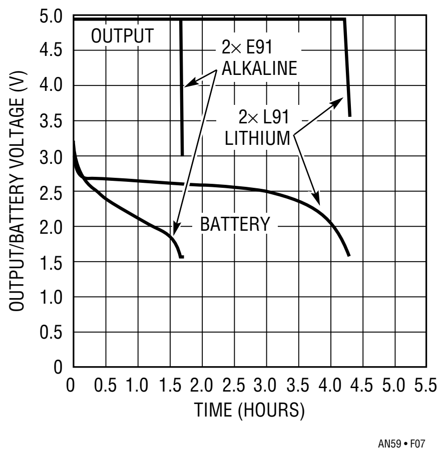

Figure 7. Doubling Load Current to 200mA Causes E91 Alkaline Battery Life to Drop by 2/3; L91 Lithium Battery Shows 2.5:1 Difference in Operating Life

from 0.20Ω to 0.50Ω, causing a large voltage drop within the cell. The alkaline cells feel quite warm at 200mA load current, the result of I^2R losses inside the cells.

The reduced power circuit shown in Figure 8 can generate 5V at currents up to 50mA. Here the I_{LIM} pin is grounded, reducing peak switch current to 400mA. Lower profile components can be used in this circuit. The capacitors are C-case size solid tantalum and inductor L1 is the tallest component at 3.2mm. The reduced peak current also extends battery life since the I^2R loss due to internal battery impedance is reduced. Figure 9

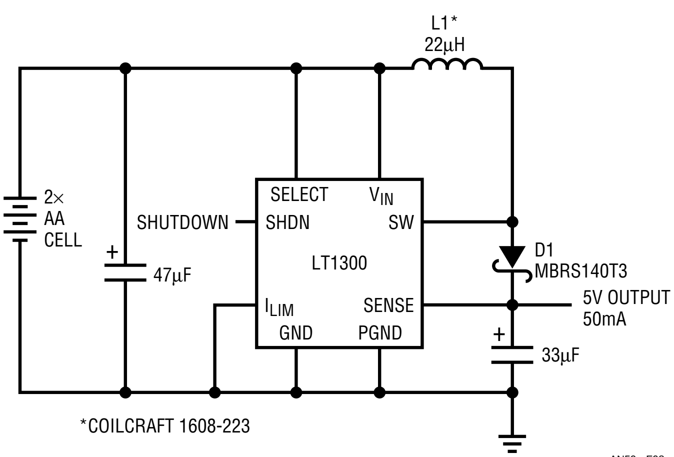

Figure 8. Lower Power Applications Can Use Smaller Components. L1 is Tallest Component at 3.1mm

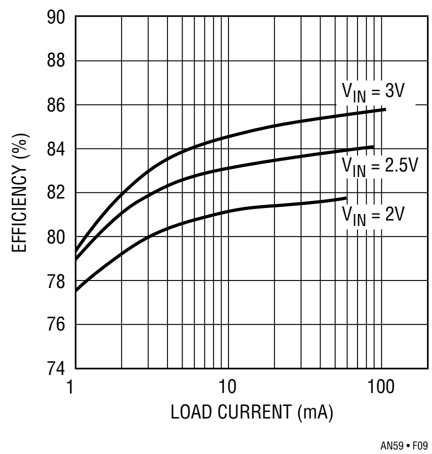

Figure 9. Efficiency of Figure 8's Circuit

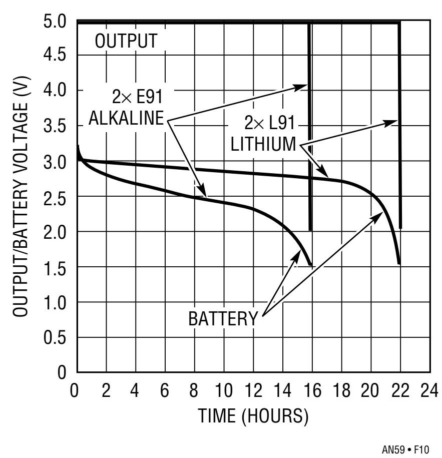

Figure 10. 50mA Load and Reduced Switch Current Are Kind to E91 AA Alkaline Battery; the Advantages of L91 Lithium Are Not as Evident

details efficiency versus load current for several input voltages and Figure 10 shows battery life at a 50mA load. Note that the L91 lithium battery lasts only about 40% longer than the alkaline. The higher cost of the lithium cells makes the alkaline cells more cost effective in this application. A pair of Eveready AAA alkaline cells (type E92) lasts 96.6 hours with 5mA load, very close to the rated capacity of the battery.

A 4-Cell Application

A 4-cell pack is a convenient, popular battery size. Alkaline cells are sold in 4-packs at retail stores and four cells usually provide sufficient energy to keep battery replacement frequency reasonable. Generating 5V from four cells, however, is a bit tricky. A fresh 4-cell pack has a terminal voltage of 6.4V but at the end of its life, the pack's terminal voltage is around 3.2V; hence, the DC/DC converter must step the voltage either up or down, depending on the state of the batteries.

A flyback topology with a costly, custom designed transformer could be employed, but Figure 11's circuit gets around these problems by using a flying capacitor scheme along with a second inductor. The circuit also isolates the input from the output, allowing the output to go to 0V during shutdown. The circuit can be divided conceptually into boost and buck sections. L1 and the LT1300 switch comprise the boost or step-up section, and L2, D1, and C3 comprise the buck or step-down section. C2 is charged to V_{IN} and acts as a level shift between the two sections. The switch node toggles between ground and $V_{IN} + V_{OUT}$, and the L2-C2 diode node toggles between $-V_{IN}$ and $V_{OUT} + V_D$. Figure 12 shows efficiency versus load current for the circuit. All four energy storage elements must handle power, which accounts for the lower efficiency of this circuit compared to the simpler boost circuit in Figure 2.

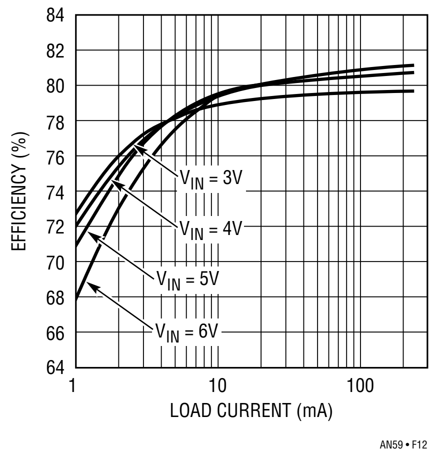

Figure 12. Efficiency of Up-Down Converter in Figure 11

Efficiency is directly related to the ESR and DCR of the capacitors and inductors used. Better capacitors cost more money. Better inductors do not necessarily cost more, but they do take up more space. Worst case RMS current through C2 occurs at minimum input voltage and measures 0.4A at full load with a 3V input. C2's specified maximum RMS current must be greater than this worst case current. The Sanyo capacitors noted specify a maximum ESR of 0.045Ω with a maximum ripple current rating of 2.1A. The Gowanda inductors specify a maximum DCR of 0.058Ω.

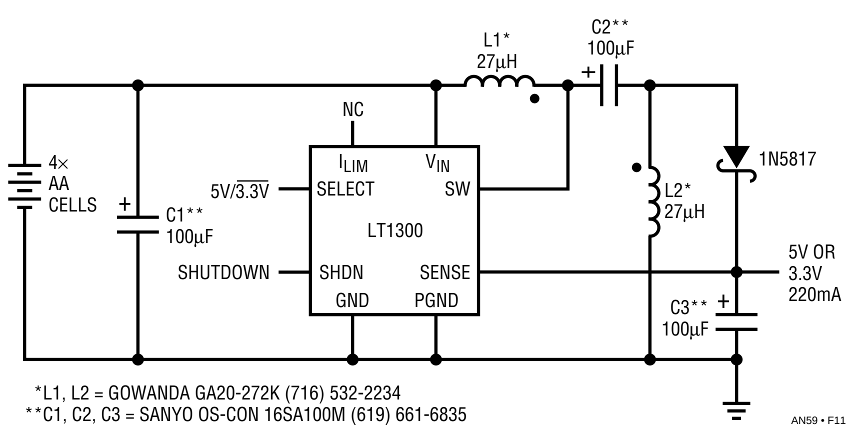

Figure 11. 4-Cell to 3.3V or 5V Converter Output Goes to Zero When in Shutdown. Inductors May Have, But Do Not Require Coupling; a Transformer or Two Separate Units Can Be Used

LT1301 Outputs 5V or 12V

The LT1301 is identical to the LT1300 in every way except output voltage. The LT1301 can be set to a 5V or 12V output via its SELECT pin. Figure 13 shows a simple 3.3V or 5V to 12V step-up converter. It can generate 120mA at 12V from either 3.3V or 5V inputs, enabling the circuit to provide VPP on a PCMCIA card socket. Figure 14 shows the circuit's efficiency. Switch voltage drop is a smaller percentage of input voltage at 5V than 3.3V, resulting in a high efficiency at 5V input.

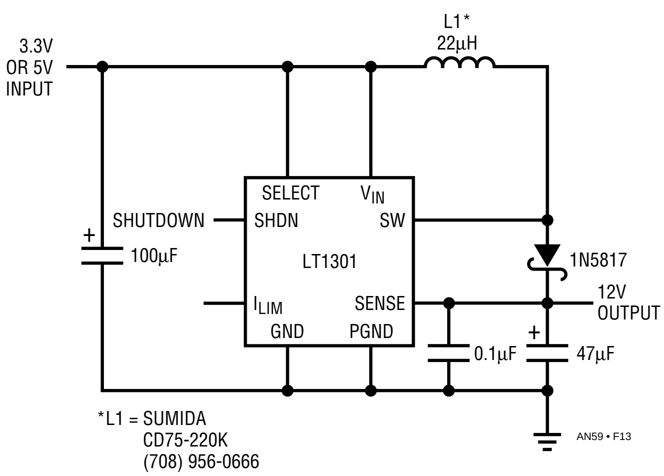

Figure 13. LT1301 Delivers 12V from 3.3V or 5V Input

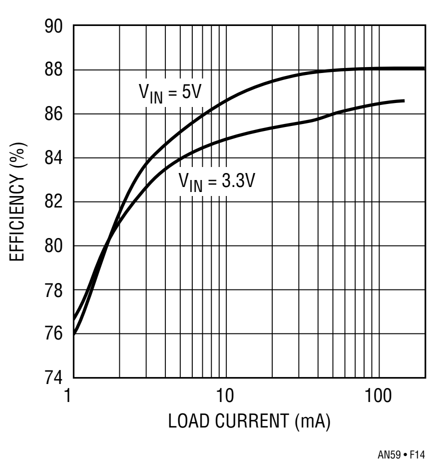

Figure 14. Efficiency of Figure 13's Circuit

THE LT1300: TWO CELLS TO REAL WORLD INTERFACE

By Dale Eagar

Introduction

The LT1300 micropower, high speed, step-up DC/DC converter opens up many new applications to the user, such as those requiring high efficiency in battery-operated equipment. The LT1300 can be used to produce high voltages for many specialized tasks with high efficiency. Here are three such applications. In the first application, a flame detector, the LT1300 is used to produce $325V_{DC}$ while drawing a mere 200µA from two C-size cells.

Flame Sensor

An interesting characteristic of flame is that it emits short wavelength ultraviolet light (<260nm). This short wavelength light falls into a window of the light spectrum that is relatively empty. Tungsten light, fluorescent light and sunlight below the atmosphere are almost totally devoid of spectral energy in this window. The circuit shown in Figure 15 uses a photoelectric sensor with a sufficiently high cathode work function to make it blind to anything with a wavelength longer than 260nm (such as normal UV, visible light or infrared). Cathode work function is a measure of how hard it is to free an electron from an atom; when related to light illuminating a cathode, it specifies the minimum energy of a photon that can liberate an electron. UV photons have higher energy than visible light.

Theory of Operation (see Figure 15)

The LT1300 and transformer T1 form a flyback converter to step up the voltage from 3V to 325V. The secondary winding of T1 connects through D1 (a MUR1100) to C1, a holding capacitor for the 325VDC, which in turn is applied to the anode of the photoelectric sensor tube V1. The LT1300 SENSE pin senses the voltage on C1, as scaled by the turns ratio, through T1. The voltage on the primary winding is programmed to be 10.6V, translating to 325V on C1. When C1 has charged to 325V the feedback loop comprised of D3, R2 and Q1 kicks in and charges C4 through D4. When the voltage at C4 exceeds 3.3V the LT1300 goes into its wait mode. In wait mode the LT1300

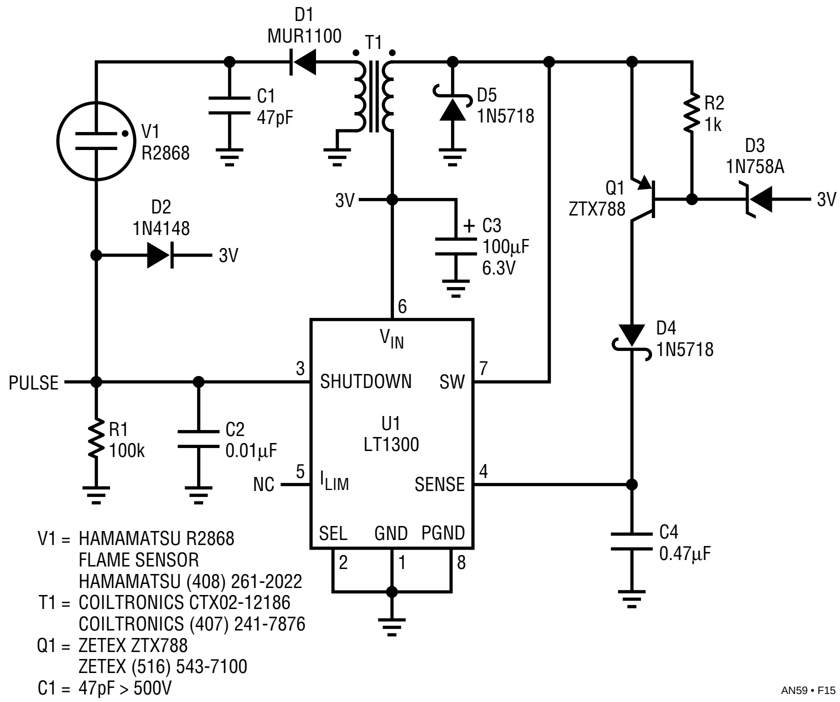

Figure 15. Flame Detector

consumes only 120µA of current. The LT1300 stays in wait mode until the voltage on C4 falls below 3.3V at which time the LT1300 turns on to burst recharge both C1 and C4. Burst Mode operation ensures 30Hz oscillation in this system. This rate is determined by the value of C4, the internal sense resistance to ground in the LT1300 (approximately 1MΩ), and the amount of overcharge C4 gets when charging. D5 is a Schottky catch diode to keep reverse current out of U1.

When illuminated with a photon of sufficient energy the photoelectric tube's cathode liberates an electron. The tube V1 has 325V across its terminals to get sufficient energy into a liberated photo-electron to ionize the gas that fills the tube. Once the gas in the tube ionizes there are more electrons available; they cause a chain reaction in the tube that causes the tube to avalanche. When the tube avalanches most of the charge on C1 is transferred to C2 and the voltage across C1 drops to a fraction of its original 325V. When C2 has charged to 3.6V all the excess charge residing in C1 gets bypassed through D2 back into the battery. The voltage across C2 is the output signal called PULSE. PULSE asserts the shutdown pin of the LT1300, allowing the plasma in the photoelectric tube to quench.

For you analog purists, page 8 of the October 1993 issue of *Linear Technology* magazine shows a discriminator circuit with low-battery detect for a complete 3V flame alarm. The discriminator is needed because the photo detector occasionally detects a cosmic ray or some rare room light photon.

Infinite Input Impedance Voltage Buffer

In the flame detector circuit (Figure 15), it is difficult to measure the voltage across C1 because almost any load invalidates the meter reading. This next application for the LT1300 is a voltage buffer that overcomes this measurement problem. This is a four-terminal, unity-gain buffer as shown functionally in Figure 16. The input impedance is

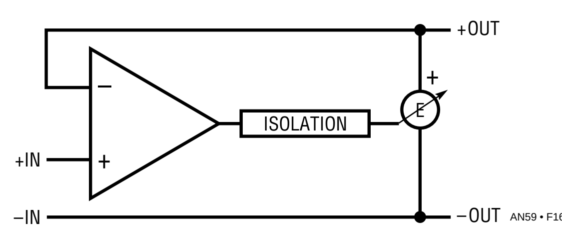

Figure 16. Voltage Buffer Block Diagram

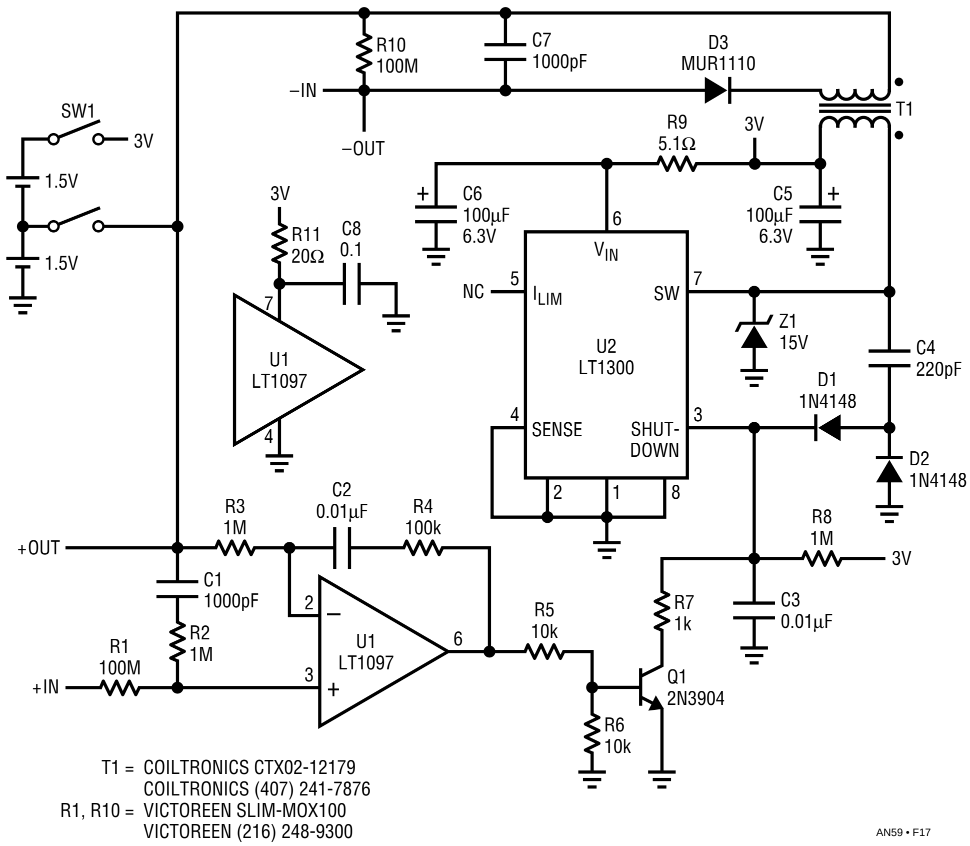

Figure 17. Voltage Buffer Schematic

essentially infinite, the input bias current is negligible and the input offset voltage is less than 0.05V. The output voltage tracks the input voltage from 0V to 520V. For safety (and to isolate the input capacitance) a 100M resistor is placed in series with the input, but with the ±570pA of input bias current (over temperature) for the LT1097, this translates into only ±57mV of additional offset. The input impedance of this buffer measures four trillion ohms when measured with a 100V to 400V input. The detailed circuit is shown in Figure 17.

Theory of Operation

U1 monitors the voltage difference between the circuit's noninverting input and output and attempts to make it zero. If the voltage on the noninverting input is less than the voltage on the noninverting output, U1's output goes positive, turning Q1 on slightly. Q1 acts as a current sink discharging C3. When the voltage on C3 falls below approximately 0.6V, U2 is enabled. When it is enabled U2 turns its switch on (U2's pin 7 pulls low, to near 0V). This causes approximately 3V to be imposed across the primary winding of T1. The magnetizing inductance of the primary winding of T1, across which a voltage is applied, requires a steadily increasing current. At the same time, C4 is charged through D2. When the current flowing through the switch of the LT1300 reaches 1A, the LT1300 switches off. The magnetizing inductance of the primary winding of T1, seeing that the LT1300 is attempting to discontinue current flow, takes over by swinging positive in voltage until it finds something that will take the 1A of magnetizing current. While the primary winding is finding somewhere to put the magnetizing current, the secondary winding takes it upon itself to do the same, but due to its turns ratio with the primary winding, it moves 100 times faster and 100 times as far as the primary winding. T1's secondary dumps a significant portion of the magnetizing energy into C7 via D3, thus forming a flyback inverter.

Z1 dissipates the energy stored in T1's leakage inductance. During the flyback time, C4 charges C3 through D1. This causes the voltage across C3 to exceed 0.6V, shutting down U2. U2 stays shut down until Q1 discharges C3 to restart the sequence.

When the +output voltage is more positive than the + input voltage the output of U1 goes low, Q1 stays off, R8 keeps C3 charged to more than 0.6V, and U2 stays shut down. The parallel combination of R10 and the load resistance (e.g., 10M in a handheld voltmeter) discharges C7 and the + output and the + input voltages are again equal. The current output of this circuit is limited to a safe value (1mA at 50V, 0.1mA at 500V) even when the + input is attached to 500V. We do not recommend increasing the value of C7 because at higher voltages it may become a shock hazard. Battery life is 40 hours for a pair of AA alkaline batteries driving 10MΩ at 500V.

Cold Cathode Florescent Lamp Driver

CCFLs seem to be the latest craze; they offer high brightness, long life, small size and produce white light. Figure 18 shows a CCFL driver circuit.

Theory of Operation

This is a forward/flyback inverter optimized for minimum parts count. When enabled, U1 charges the primary winding of T1 to 1A, and lets go. T1 then flies back exciting many hundreds of volts across its secondary winding, which in turn ionizes the CCFL. Because the initial current through the CCFL is only in one direction, C2 takes on a DC potential. As the circuit runs, the voltage across C2 stabilizes at about 100VDC. Additionally, C2 removes the DC current component from the tube, extending tube life. The nonlinear V/I characteristic of the CCFL, in conjunction with C2, forces the converter to run in both forward and flyback modes simultaneously. The light intensity can be pulse-width modulated by modulating the shutdown pin. When the shutdown pin is pulled high the LT1300 goes into its shutdown mode where it draws only 10µA of input current.

Electronic Light Stick

Camping in November with my kids has its own unique problems, even if we aren't camping in six feet of snow. Although we had the usual light sources something was missing, namely a light that simulates the natural sunset at bedtime to wind the kids down for the night. The circuit in Figures 18 and 19 (see explantation below) details a high efficiency fluorescent lantern with a built-in sunset feature.

The function of the circuit is as follows:

- To turn on: switch SW1 into the ON position.
- To turn off fast: switch SW1 into the OFF position.
- To simulate sunset:
  1. Turn light ON.
  2. Switch SW1 into the SUNSET position.

This application uses the circuitry of both Figure 18 and Figure 19. The pulse-width output of Figure 19 drives the pulse-width input of Figure 18.

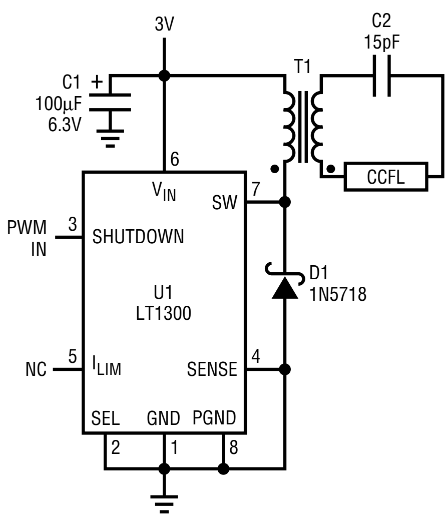

Figure 18. CCFL Driver

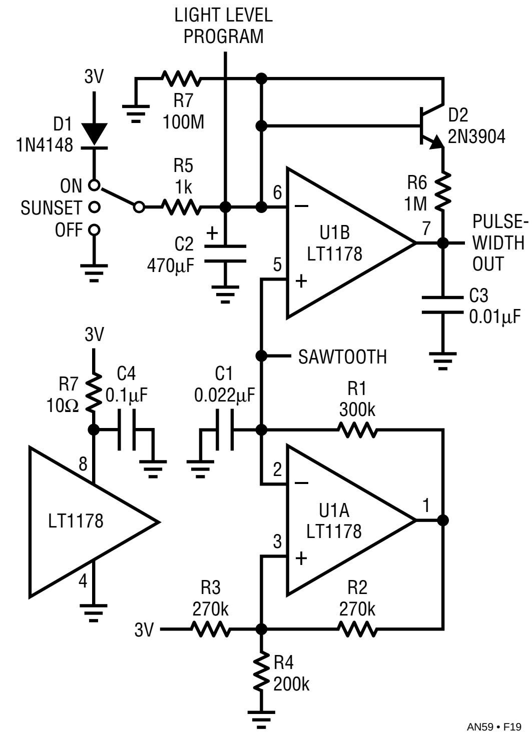

Figure 19. Electronic Light Stick Controller for the CCFL Driver Circuit Shown in Figure 18. This Controller, When Controlling the CCFL, Causes the Light Output Level to Fade from Full Brightness to Off, Thus Simulating a Natural Sunset.

U1A, R1 to R4 and C1 form a sawtooth oscillator for pulse-width modulating the light (implementing light levels less than 100%). U1B acts as a comparator, comparing the sawtooth output of the oscillator with the programmed light level (as seen on the +terminal of C2). C2 is the holding capacitor that programs the light level; when it is charged to 2.5V the light is on 100% of the time. As the voltage on C2 drops below 2.5V, the overall light level decreases because the light is being pulse-width modulated. When the voltage on C2 is at or below 1V the light is off. D1 and R5 charge and hold C2 when SW1 is in the ON position. R5 and SW1 discharge and hold C2 when SW1 is in the OFF position. The combination of D2, R6 and U1B discharge C2 when SW1 is in the SUNSET position. The discharging of C2 when in the SUNSET mode is doubly exponential causing the tail end of the simulated sunset to go very slowly (a good idea because kids have a logarithmic response to light). The first exponential aspect of the SUNSET decay is implemented by R6 and C2 which form an exponential RC time constant. The second exponential aspect of the SUNSET decay is implemented because R6 is driven by U1B pin 7, whose duty factor is changing, causing the off-time to decrease exponentially as the light level fades. The output of U1B is a pulse-width modulated level gating the light driver on and off. The lamp is illuminated when U1B's output is low. C3 is a trash compactor and R7 and C4 form a trash compactor to decouple U1 from the high frequency ripple generated by the switcher.

Constant Current Source

The LT1300 can be configured as a constant current source, a current source that not only possesses good power conversion efficiency, but can be shut down to a state of practically no current draw. These benefits coupled with the LT1300's ability to operate over a wide input voltage range, make the LT1300 an ideal candidate for many current operated devices. Popular uses include solenoid drivers, relay drivers, small motor drives and LED drivers.

Here is an example of a high efficiency LED driver. The LED light source (shown in Figure 20) is used in applications

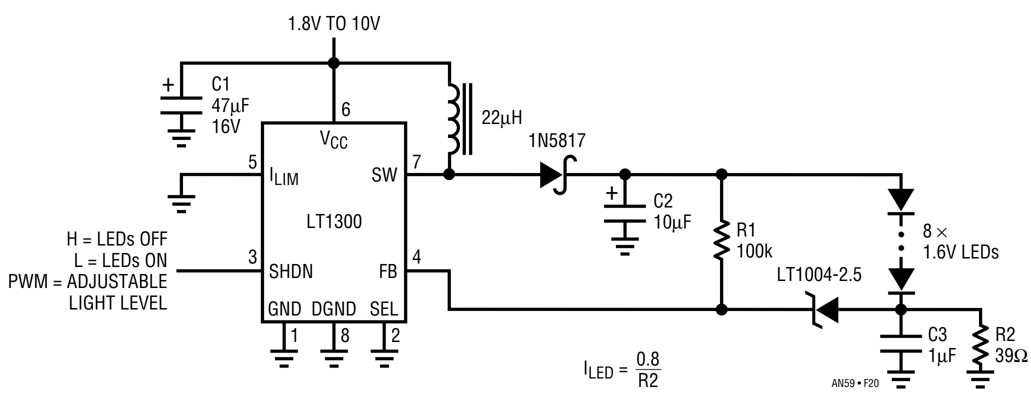

Figure 20. Backlight LED Driver

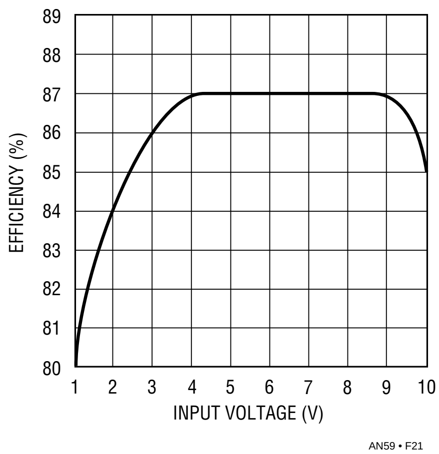

Figure 21. Efficiency of LED Driver

ranging from LCD backlights to special flashlights that preserve full night vision. This circuit sports an impressive list of features:

- Logic input to strobe LED's on/off
- Low current draw when off (10µA)
- Constant LED drive current when on (20mA)
- LED current unaffected by temperature
- LED current constant with input voltage range (1.8V to 10V)
- High overall efficiency (87%)
- Small size

Theory of Operation

When enabled the LT1300 runs in Burst Mode™, regulating the voltage on the FB pin to 3.3V. Subtracting 2.5V (corresponding to the knee voltage of the LT1004-2.5) from the 3.3V voltage at the FB pin yields 0.8V, which is seen across R2. This 0.8V and the value of R2 sets the output current level through the LEDs. For proper functionality the voltage across the LED stack should be:

1. Greater than the maximum input voltage less one Schottky drop.
2. Less than 14V.

The LT1300 is optimized for battery operation and lends itself to these and many more applications.

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