

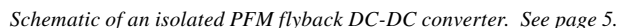
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Maxim Provides Resources for Energy-Efficient Design

Recently, I calculated the energy usage of devices in my home. To my surprise, I discovered that my media server is using \$473 worth of electricity a year—that means that I spend more to operate the server over one to two years than I paid for the server itself! I wonder if the server manufacturer is worried about this, and whether their customers are aware of this high total cost of ownership. If the manufacturer could reduce the energy usage of this device, it would give all their customers an effective discount. Not only would this energy efficiency reduce our impact on the environment, but it would be a competitive advantage.

This is precisely the challenge that we face as engineers. With the rising costs of energy and increased awareness of global warming, consumers are demanding more environmentally friendly products. This demand poses complex technical challenges for engineers, but it also represents a new business opportunity. That is, electronics manufacturers who offer higher-efficiency products will have a competitive advantage in today's marketplace.

When you think about it, this new emphasis simply rewards designers for good engineering. Even before "green" became a byword, low-power design was good design. Greater power efficiency means smaller power supplies, lower costs, greater board densities, improved battery life, reduced heat, and higher reliability.

In the past, efficiency was one of several parameters that engineers traded off to meet customer needs. However, with the energy challenges facing our world today, efficiency is a tradeoff that we can no longer afford to make.

Maxim has designed "green" products for over 25 years. You know us as leaders in high-efficiency DC-DC converters, battery-management ICs, and low-power products such as amplifiers. And, of course, we have been working for years to make our products lead-free and reduce the use of hazardous materials.

You can count on Maxim to deliver innovative, energy-efficient solutions. We are devoting more engineering resources to exciting, environmentally friendly technologies, in addition to the ones that we already pioneered. Specifically, we are applying our expertise to hybrid automotive, solar power conversion and control, high-brightness LEDs, display drivers, notebook power, and many other new areas.

We are also reorganizing our website to make it easier to find green design resources. Over the years, we have written over 2000 application notes, many of which can help you improve the efficiency of your products. We have assembled these and other design resources on one easy-to-use microsite: www.maxim-ic.com/green-design.

Our engineers will continue to provide new design tips, reference designs, and application notes to help you maximize efficiency. Stay tuned to Maxim's website for technical information and products that will help you meet your customers' demand for greener solutions.

This edition of the *Engineering Journal* features four articles written for engineers facing the energy challenges of today. I hope that they inspire you with new ways to conserve resources.

Together, we can meet today's most pressing technical and business challenges and make the world a better place. That's "Engineering Success."

A handwritten signature in blue ink, reading "Tunc Doluca".

Tunç Doluca
President and Chief Executive Officer

*Do you know how much your devices cost to operate?
Find out with Maxim's energy cost calculator:
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Reduce Standby Power Drains with Ultra-Low-Current, Isolated, Pulse-Frequency-Modulated (PFM) DC-DC Converters

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This article explains how to reduce the level of low-current consumption in isolated DC-DC power supplies and how to improve the performance of those supplies under no-load conditions. Sensitive to today's need for innovative "green" solutions, the discussion especially focuses on ways to extend the battery life of battery-powered electronic devices and communication-system devices with discontinuous transmission.

Today, many industrial systems employ battery-powered sensors and transponders to eliminate expensive cable installations and to reduce overall system power consumption. These industrial systems typically have an active mode and a standby mode. In active mode the sensor delivers data to the transponder (a radio modem) which transmits the data to a host system. In standby mode the transponder and sensor go to sleep for a fixed or variable time period. This start-and-stop operation, often referred to as a discontinuous operating mode, maximizes the battery life of the device.

For an application like a watering system that leverages GSM radio modules for the sensors, maintenance costs would be high if the batteries powering the GSM radios had to be replaced every few days, or even every few weeks. Since such a system spends most of its time in standby or sleep mode, minimizing the power drain from the battery when no activity is taking place would go a long way toward extending battery life. In this system no-load quiescent current becomes a key design

consideration, and for safety concerns, galvanic isolation is an important aspect of the design.

To address these concerns, designers must focus on the design of the DC-DC converter to ensure that it consumes as little current as possible during no-load conditions. All DC-DC converters, even during standby, can consume significant quiescent current. One commercial power-supply module (the Recom® R-78A3.3-1OR), for example, draws about 7mA under no-load conditions. However, with some attention to topology and careful design, an isolated DC-DC converter module with a no-load current drain of less than 1mA can be implemented.

The 30X difference in current drain can translate into reduced battery replacements. For example, even if the system's batteries are rechargeable, then additional recharge cycles might be needed if the higher current-drain supply is used. Moreover, batteries that are recharged often, wear out sooner and end up in landfills. Similarly, if the device employs one-time-use batteries, they will discharge sooner with a higher standby current and get discarded more frequently.

While there are several approaches to the challenge, this article looks at the use of pulse-frequency modulation (PFM) to achieve a 1700:1 ratio between the device's on and standby states.

System Characteristics

Typical power consumption versus time looks like the graph in **Figure 1**. Here the load current spikes during operation or active charging, and then drops when the device is idle. The idle current, I_Z , must be minimized to reduce the battery drain and extend the battery life and standby time. Thus, the isolated DC-DC converter needs ultra-low current consumption when no load is connected, and should also provide high isolation from input to output. Ideally, the converter should also offer high conversion efficiency and a small footprint.

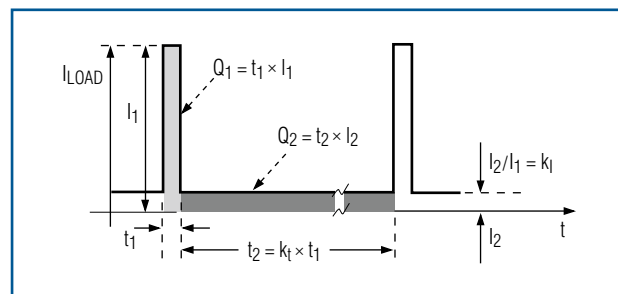


Figure 1. The relationship between the on and standby states of a communication device with discontinuous transmission.

Table 1. Characteristics of Commercial DC-DC Converters

Manufacturer	Model	V_I (V)	V_O (V)	I_O (A)	I_I ($I_O = 0$, mA)	η (%)	Isolation
Traco® Electronic AG	TEN 5-1210	12	3.3	1.2	20	77	✓
XP Power	JCA0412S03	12	3.3	1.2	38	83	✓
Recom Power International	RW-123.3S	12	3.3	0.7	21	65	✓
C&D Technologies®	HL02R12S05	12	5	0.4	40	60	✓
Bourns® Inc.	MX3A-12SA	12	3.3	3.0	11	93	
Recom Power International	R-78A3.3-1	12	3.3	1.0	7	81	

The typical commercial DC-DC converters listed in **Table 1** show input currents of 7mA to 40mA when no load is connected with an input of 12V. These converters traditionally employ pulse-width-modulation (PWM) controllers. However, PWM controllers always have an active oscillator, even when there is no load, and that oscillator continually draws current from the battery.

A PFM Controller Topology

An alternative approach is to use a DC-DC converter that employs a pulse-frequency-modulation (PFM) controller.¹ A PFM controller uses two one-shot circuits that only work when the load drains current from the DC-DC converter's output. The PFM is based on two switching times (the maximum on-time and the minimum off-time) and two control loops (a voltage-regulation loop and a maximum peak-current, off-time loop).

The PFM is also characterized by control pulses of variable frequency. The two one-shot circuits in the controller define the T_{ON} (maximum on-time) and the T_{OFF} (minimum off-time). The T_{ON} one-shot circuit activates the second one-shot, T_{OFF} . Whenever the comparator of the voltage loop detects that V_{OUT} is out of regulation, the T_{ON} one-shot circuit is activated. The time of the pulse is fixed up to a maximum value. This pulse time can be reduced if the maximum peak-current loop detects that the current limit is surpassed.

The quiescent current consumption of a PFM controller is limited only to the current needed to bias its reference and error comparator (10s of μ A). In contrast, the internal oscillator of a PWM controller must be turned on continuously, leading to a current consumption of several milliamps. The implementation presented in this article keeps the current consumption to less than 1mA at 12V by using a PFM controller topology.

Field systems such as the watering system must endure harsh environments, and thus the DC-DC converter in those systems should be galvanically isolated. A transformer provides the isolation, but the challenge is to feed back the voltage reference from the secondary side to the primary side without breaking the isolation.

The most common approach solves the problem by using either an auxiliary winding or an optocoupler.

The power-supply topology is a step-down approach; the battery pack used by the application has a nominal voltage of 12V, while the internal electronic circuits in the system operate at 3.6V, nominal. **Figure 2** shows the schematic diagram of the DC-DC switching regulator, and the Bill of Materials with component values is provided in **Table 2**. When the control loop is regulating the voltage, the optocoupler requires a constant current through the LED on the primary side of the transformer. The lower limit of the current is fixed by the optocoupler's CTR at low bias currents (63% at 10mA, and 22% at 1mA) and by a reduction of the response time (2 μ s at 20mA and 6.6 μ s at 5mA).

The current consumption of the output voltage-divider (formed by resistors R5 and R11) is fixed to 7 μ A. Because of this, the 0.5 μ A required by the reference input plus its thermal deviation does not significantly affect the output voltage. Additionally, the voltage measured at the divider output does not suffer a relevant delay, thanks to the low-input capacitance. This latter fact precludes the need for a capacitive divider to reduce the input capacitance of the precision reference. In the optocoupler, the phototransistor draws 60 μ A ($|I_{FB}| < 60$ nA), which translates into a current flow through the LED of less than 230 μ A (CTR ~26%).

Controlling It All

To implement a PFM controller, the MAX1771 BiCMOS step-up, switch-mode power-supply controller (U1) can be used to provide the necessary timing. The MAX1771 offers improvements over prior pulse-skipping control solutions: reduced size of the inductors required, due to a 300kHz switching frequency; the current-limited PFM control scheme achieves 90% efficiencies over a wide range of load currents; and a maximum supply current of just 110 μ A. Besides these advantages, the main characteristics of the MAX1771 in a nonisolated application are: 90% efficiency with load currents ranging from 30mA to 2A; up to 24W of output power; and an input-voltage range of 2V to 16.5V.

The resistances of the voltage-control loop have been chosen to have the highest possible values. This decision represents a trade-off between current consumption and loop stability. As a result, the current through the voltage-divider is less than 7 μ A. Since the filtering capacitors are nonideal, capacitor leakage current must be added to this current. In this design, filter capacitor-leakage current in C5 and C8 is less than 20 μ A. If lower leakage is required, these caps could be upgraded to ceramic capacitors with

the following characteristics: 100 μ F, 6.3V, X5R, and 1206 size (Kemet® C1206C107M9PAC). Using ceramic capacitors reduces the capacitor leakage to just a few microamps. Note, however, that the ceramic capacitors cost about 3x that of the tantalum capacitors, and that difference would increase the system cost.

Figure 3 shows the prototype PFM DC-DC converter that draws a quiescent current of just 0.24mA. The

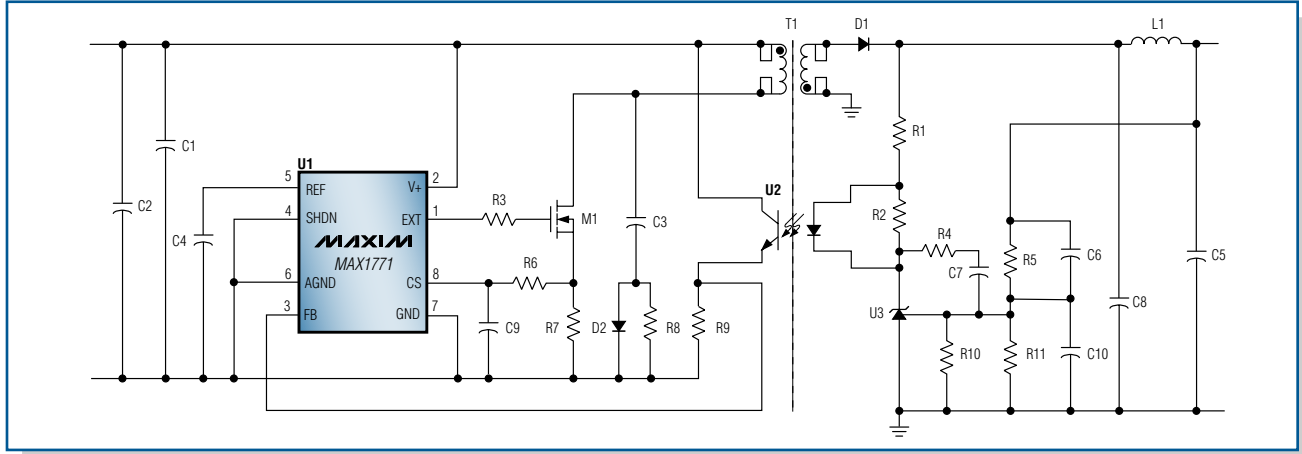


Figure 2. Schematic of an isolated PFM flyback DC-DC converter.

Table 2. Component Bill of Materials for PFM Flyback DC-DC Converter

Reference	Values	Description	Manufacturer
C2	470 μ F 25V	CEL 470 μ F, 25V, +105°C, 10mm x 10mm SMD	UUD1E471MNL1GS (Nichicon®)
C10	180pF	CS 180p C COG, 50V 0603/1	GRM39 COG 181 J 50 PT (Murata®)
C1, C4, C7	100nF 16V	#CSMD 100nF K X7R 16V 0603/1	GRM39X7R104K16PT (Murata)
C5, C8	100 μ F 16V 0.1 Ω	CEL TAN 100 μ F $\pm$ 20% E 16V 0.1 Ω	T495D107K016ATE100 (Kemet®)
C6	100pF	CS 100p C COG 50V 0603/1	GRM39 COG 101 J 50 PT (Murata)
C3	1nF 50V	#CS 1n M X7R 50V 0603/1	GRM39 COG 271 J 50 PT (Murata)
C9	150pF	CS 150p C COG 50V 0603/1	GRM39 COG 151 J 50 PT (Murata)
D1	MBRS230LT3G	D Schottky 2A, 30V SMB	MBRS230LT3G (ON Semiconductor(s))
D2	MBRA160T3G	D Schottky 1A, 60V SMA	MBRA160T3G (ON Semiconductor)
L1	22 μ H 1.2A 0.19 Ω	L SMD 22 μ H, 1.2A, 0.19 Ω	SRR0604-220ML (Bourns®)
M1	IRFR120	Q IRFR120 DPAK 8.4A, 100V, 0.270 Ω , NMOS	IRFR120 (Int.Rectifier.)
R1, R6	680 Ω	RS 680R J 1/16W 0603/1	RK73B 1J T TD 680 J (KOA Speer®)
R9, R2	100k Ω	#RS 100K F 1/16W 0603/1	RK73H 1J T TD 1003 F (KOA Speer)
R3	10 Ω	#RS 10R J 1/16W 0603/1	RK73B 1J T TD 100 J (KOA Speer)
R4	4.7k Ω	#RS 4K7 J 1/16W 0603/1	RK73H 1J T TD 4701 J (KOA Speer)
R5	390k Ω	#RS 390K F 1/16W 0603/1	RK73H 1J T TD 3903 F (KOA Speer)
R7	0.047 Ω	RS R047 J 1206 /1	SR73 2B T TD R047 J (KOA Speer)
R10	270k Ω	RS 270K F 0603 /1	RK73H 1J T TD 2703 F (KOA Speer)
R11	820k Ω	RS 820K F 0603 /1	RK73H 1J T TD 8203 F (KOA Speer)
R8	100 Ω	#R SMD 100R -J 1206/1	RK73B 2B T TD 101 J (KOA Speer)
T1	EP10 3F3	T SMD EP10 3F3 NUCTOR	CSHS-EP10-1S-8P-T (Ferroxcube®-Nuctor)
U1	MAX1771	DC-DC controller	Maxim Integrated Products
U2	TLV431A	U TLV431A V.REF 1.25V SOT23-5	TLV431ACDBVR (Texas Instruments™)
U3	SFH6106-2	#U SFH6106-2 OPTO 63-125%, 5.3kV SMD-4	SFH6106-2 (Vishay®)

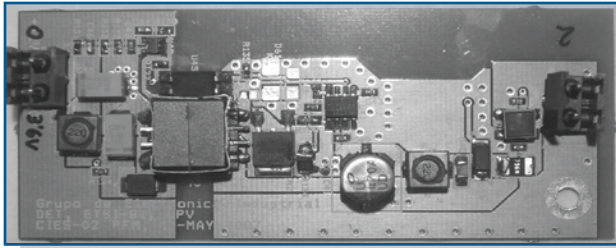


Figure 3. Top view of the DC-DC PFM converter prototype for wireless applications.

Table 3. Current Consumption Under a No-Load State for Different Input Voltages

V_{IN} (V)	I_{IN} (mA)	V_{OUT} (V)	I_{OUT} (A)
10.0	0.244	3.615	0
12.0	0.239	3.615	0
15.0	0.227	3.615	0

board measures less than 50mm by 30mm, can deliver 3.6W with an input-voltage range of 10V to 15V (12V nominal), and operates at a switching frequency of 300kHz. The converter can supply a maximum constant output current of 1A while delivering a regulated output of 3.6V. Employing a flyback topology (step down) with both current and voltage feedback control, the converter output is galvanically isolated from the input.

The prototype can be used in various wireless applications that operate in a discontinuous transmission mode. The current consumption of the modules can peak at 3A, and the maximum mean current is 1A. To reduce the current peaks and avoid the problems that they generate in the performance of the radio, the techniques described in references 2 and 3 are used. Additionally, some basic guidelines suggest that designers should use high-value capacitors that have low series resistances.

Qualifying Design Performance

To verify the performance of the power supply, the following parameters are measured: the input voltage, V_i ; the input current, I_i ; the nominal output voltage, V_o ; the load current consumption, I_o ; and the efficiency of the power supply. **Tables 3 and 4** show the measurement results, including the losses on the common-mode input filter and the losses of the protection circuitry. It is also important to remember that power supplies handling low power levels are not as efficient as power supplies handling higher loads. The higher-load power supplies are usually synchronous, which helps to reduce the losses in the active devices.

The current consumption of the power supply with a PFM control scheme has been reduced to 0.24mA. Due to component values selected, however, the control

Table 4. Efficiency at Nominal Voltage for Different Loads

V_{IN} (V)	I_{IN} (mA)	V_{OUT} (V)	I_{OUT} (A)	Efficiency (%)
12.0	0.24	3.615	0	0
12.0	61	3.615	0.14	69.14
12.0	83	3.615	0.2	72.59
12.0	121	3.615	0.3	74.69
12.0	160	3.615	0.4	75.31
12.0	200	3.615	0.5	75.31
12.0	240	3.615	0.6	75.31
12.0	281	3.615	0.7	75.04
12.0	323	3.615	0.8	74.61
12.0	367	3.615	0.9	73.88
12.0	411	3.615	1.0	73.30

loop may oscillate during certain load conditions. To prevent self-oscillation, designers must account for the various tolerances of the components in a production environment. Thus, the values of the resistors and capacitors used in the loop must be selected with care.

Table 4 provides the values for the input and output parameters of the power supply at various load conditions. The optimum efficiency is reached at normal conditions and within the nominal load range.

The efficiency of the DC-DC converter with no load is represented as zero (**Figure 4**), because the current consumed by the wireless device in standby mode and referred to the 3.6V output side is below 140 μ A. This current is negligible, when compared to the 0.24mA of the power supply's input-current consumption under no-load conditions.

The waveforms in **Figures 5a, b, c, and d** show the output voltage and control voltage for various loads; the control pulses at the gate of the switching device become more frequent as the load increases. The converter prototype shows the signals at no load, 100mA, 500mA, and 1A current loads. The scope traces graphically illustrate the operation of the PFM control scheme. The lower scope trace is scaled by 5x to make it more visible. The X axis represents the time and the Y axis the voltage.

Summary

Initial industry surveys indicate that the best commercial isolated DC-DC converters for power supplies with low current consumption under no-load conditions typically have about 20mA minimum current consumption. With minimal effort, however, designers can use a PFM scheme to implement a low- I_Q , isolated power supply that has the lowest current consumption on the market. The no-load current consumption of the power supply presented here is only 0.24mA.

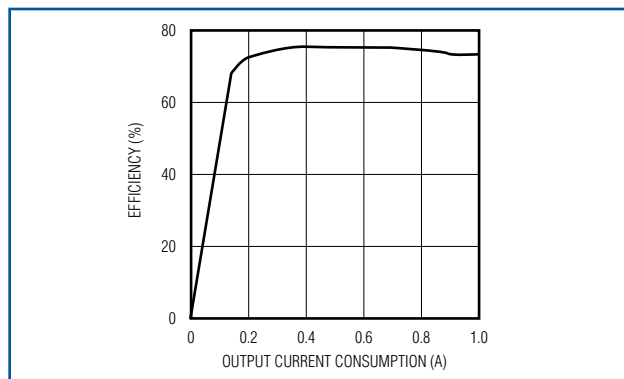


Figure 4. Efficiency of the power supply for different load conditions at the input nominal voltage (12V).

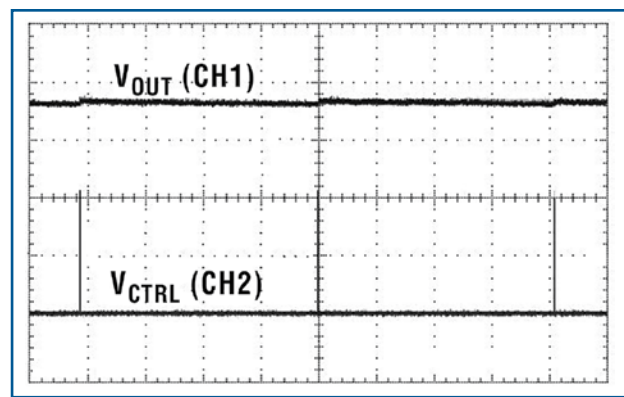


Figure 5a. Output voltage and control voltage without load (10ms/div, CH1 1V/div, and CH2 5V/div).

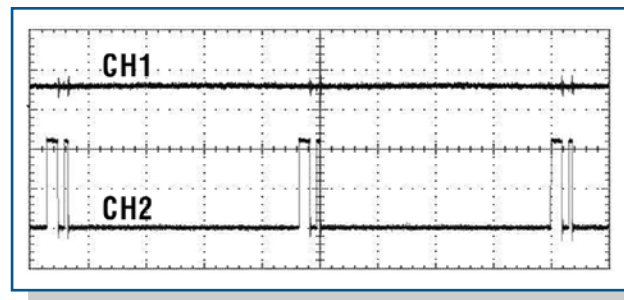


Figure 5b. Output voltage and control voltage for 0.1A load (20ms/div, CH1 1V/div, and CH2 5V/div).

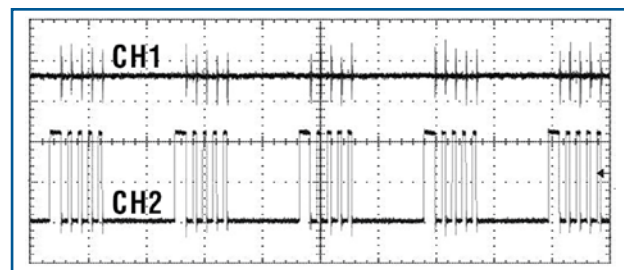


Figure 5c. Output voltage and control voltage for 0.5A load (20ms/div, CH1 1V/div, and CH2 5V/div).

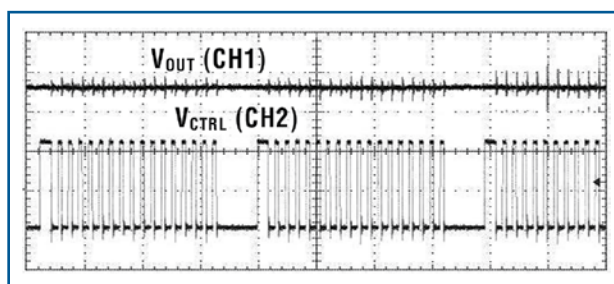


Figure 5d. Output voltage and control voltage for 1A load (20ms/div, CH1 1V/div, and CH2 5V/div).

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Keep Power Consumption in Check with Low-Power Comparators that Autosense Plugged-In Accessories

Arpit Mehta, Strategic Applications Engineer

Portable electronic devices usually include a single 3- or 4-conductor jack which can be a stereo headphone jack, a mono headphone jack with microphone input and hook switch, or a stereo headphone jack with microphone/hook-switch combination. Tiny, ultra-low-power comparators like the MAX9060 series can be configured in various ways not only to consume negligible power, but also to provide small, simple, and cost-effective detection of external accessories.

A common feature in most of the electronic devices used today (cell phones, PDAs, notebooks, handheld media players, game systems, etc.) is the provision for connecting external accessories. The devices, therefore, include dedicated logic circuitry not merely to detect the presence of an accessory, but to identify its type so the internal control circuitry can adjust accordingly.

Adding circuits to implement the autodetection/selection function can increase a system's power budget, and that is a problem. As designers, we need to minimize the power budget to ensure that the systems deliver the "greenest" possible solution with the smallest footprint. To that end, tiny, ultra-low-power comparators such as the MAX9060 series offer the best solution in the semiconductor market. These comparators are key to helping designers stay within their power-consumption budget.

Hardwiring Detects the Presence of a Jack

We begin with a quick review of the basics of automatic jack detection.

Consider a typical headphone-socket circuit (**Figure 1**). Connecting a pullup resistor to the detect pin, as shown here,

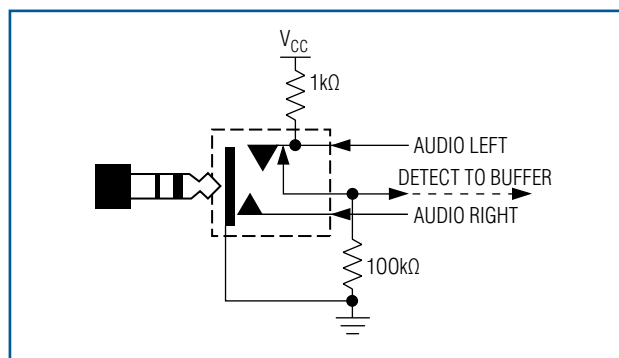


Figure 1. An automatic jack-detection circuit.

generates a signal to indicate the presence of a headphone or other external device. In a typical connection, the detect pin is disconnected if an external device is inserted.

The output signal is pulled high when no jack is present and pulled low when the jack is inserted. This detect signal is routed to a microcontroller port, which can then autoswitch the audio signal between a loudspeaker (headphone absent) and the headphone speakers (headphone present).

A simple transistor can buffer the detect signal before it reaches the microcontroller input. The transistor also provides any level translation necessary for interfacing with the controller. In space-constrained applications like cell phones and PDAs, a small transistor packaged no larger than a couple of millimeters is preferred. Buffering and level translation can also be implemented with low-cost, low-power comparators in ultra-small packages. Members of the MAX9060 family, for example, come in 1mm × 1mm chip-scale packages and consume just 1μA of current.

Headset Detection

The audio socket in Figure 1 is designed to handle the popular three-conductor audio plug. This plug connects either to a stereo headphone or a mono headset with microphone. You can easily differentiate between the stereo and mono-plus-microphone headset by using the circuits discussed below. These circuits leverage the fact that headphone resistance is low (usually 8Ω, 16Ω, or 32Ω) and that microphone resistance is high (600Ω to 10kΩ).

A brief introduction to the common audio jack and the electret microphone is helpful in understanding these circuits. In a three-conductor audio jack (**Figure 2**), the "tip" carries the left-channel audio for a stereo headphone or the microphone connection for a mono headset with microphone. For stereo headphones, "ring" connects to

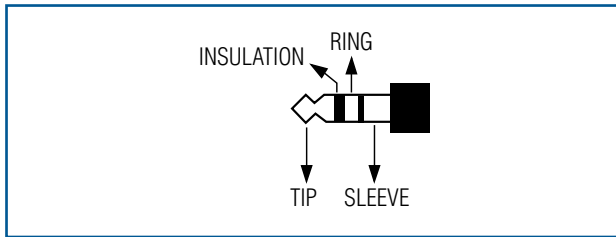


Figure 2. A three-conductor audio jack.

the right channel and “sleeve” to ground. For a mono headset with microphone, ring connects to the input audio channel for the mono microphone and sleeve connects to ground.

Electret Microphones

A typical electret microphone (**Figure 3**) has a condenser element whose capacitance varies in response to mechanical vibrations, thereby providing voltage variations proportional to the sound waves. Electret microphones have a permanent, built-in static charge and, therefore, require no external power source. They do, however, require a few volts to power an internal preamplifier FET.

The electret microphone appears as a constant-current sink that provides very high output impedance. Its high impedance is then converted by the FET preamplifier to the low impedance necessary for interfacing with the subsequent amplifier. Thus, the electret microphone’s low cost, small size, and good sensitivity make it a good choice for applications like hands-free cell-phone headsets and computer sound cards.

The microphone is biased through a resistor (usually $1\text{k}\Omega$ to $10\text{k}\Omega$) and a supply voltage that provides the necessary constant-bias current. This bias current ranges from $100\mu\text{A}$ to about $800\mu\text{A}$, depending on the particular microphone and its manufacturer. The bias resistor is selected according to the applied supply voltage, the desired bias current, and the required sensitivity. Based on these factors, the necessary bias voltage varies from part to part and with operating conditions. A $2.2\text{k}\Omega$ load resistor with 3V supply drawing $100\mu\text{A}$, for example, develops a bias voltage of 2.78V . A similar resistor drawing $800\mu\text{A}$ under similar conditions develops a bias voltage of 1.24V .

To detect the type of headset connected, refer to **Figure 4**. Here a $2.2\text{k}\Omega$ $R_{\text{MIC-BIAS}}$ resistor connects to a low-noise reference voltage from the audio controller ($V_{\text{MIC-REF}}$). When an audio jack is inserted, this $V_{\text{MIC-REF}}$ voltage is applied through $R_{\text{MIC-BIAS}}$ to the tip-to-ground resistance (not shown), thus

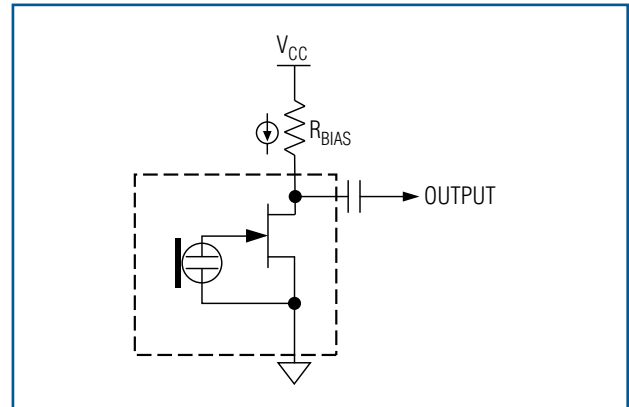


Figure 3. An electrical model of an electret microphone.

producing the voltage V_{DETECT} at the noninverting input of the MAX9063. This resistance can be small for stereo headphones (8Ω , 16Ω , or 32Ω), or high due to the microphone’s constant-current sink which ranges from $100\mu\text{A}$ to about $800\mu\text{A}$ according to the type of microphone. Because V_{DETECT} varies with the model of headset plugged in, the headset type is detected by monitoring V_{DETECT} with a comparator.

Assuming that the microcontroller’s reference voltage ($V_{\text{MIC-REF}}$) is 3V as shown, a 32Ω headphone load produces 43mV at V_{DETECT} . A constant $500\mu\text{A}$ microphone load, however, produces 1.9V . Note that a direct interface for V_{DETECT} can be challenging in most practical cases. Assuming that the CMOS inputs of a typical microcontroller port demand logic levels above $0.7 \times V_{\text{CC}}$ and below $0.3 \times V_{\text{CC}}$, then the input logic for a controller operating with a 3.3V supply should be above 2.3V and below 1V .

A 1.9V level generated by a $500\mu\text{A}$ microphone load does not qualify as a valid logic 1. Microphone bias currents from $100\mu\text{A}$ to $800\mu\text{A}$ generate V_{DETECT} levels from 2.78V to 1.24V , and any voltage below 2.3V violates the controller’s V_{IH} specification (input high level, assuming $2.2\text{k}\Omega$ for R_{BIAS}). To get 2.3V or above, the microphone bias current must be $318\mu\text{A}$ or less. Otherwise you must change the $2.2\text{k}\Omega$ bias-resistor value which, in turn, changes the sensitivity point of the microphone. Generating a logic low of 1V and below is easy, because headphones with typical 32Ω loads can easily pull the level close to ground.

To detect the type of headset connected, you therefore feed V_{DETECT} to one input of a comparator and a reference voltage to the other input. The comparator’s output state then represents the type of headset.

The comparator for this portable headset-detect application should be tiny and consume little power. The

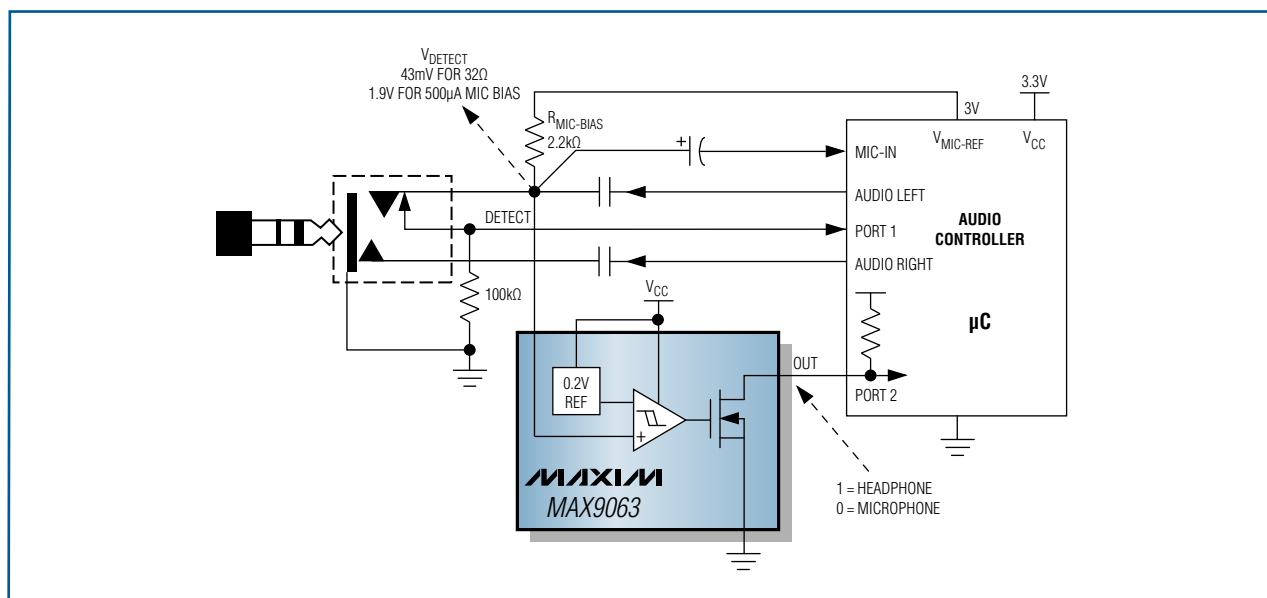


Figure 4. A comparator circuit used for headset detection.

comparator in Figure 4 is just 1mm × 1mm and draws a maximum supply current of only 1μA. Its strong immunity to cell-phone frequencies provides highly reliable operation. The comparator also has internal hysteresis and low-input bias currents. These features make it an excellent choice for headset detection in battery-operated, space- and power-sensitive applications like cell phones, portable media players, and notebook computers.

Hook-Switch Detection

Most hands-free headsets include a switch, usually known as a hook switch, that accepts and ends calls; provides the MUTE/HOLD function; and holds an ongoing call while receiving a second call. The microcontroller controlling the headset needs to detect the status of the hook switch and the presence of the headset. The jack (hence the headset) can be detected automatically (Figure 1). A signal for the hook-switch status can also be generated.

Status-detection circuitry for the hook switch comprises a 4-conductor stereo headset with microphone and a parallel hook switch (Figure 5). (A mono headset is similar, but has a 3-pin connector.) In both headset types the tip is connected to the microphone in parallel with the hook switch. As shown, the hook switch presents a low resistance when pressed, and a high microphone resistance when open. As with the headset detection explained above, an interface between the headphone-detection voltage and the CMOS inputs of the microcontroller can complicate the circuit design for microphone/hook-switch detection.

The voltage V_{DETECT} (Figure 5) is pulled close to ground when the hook switch is pressed, and interpreted as logic 0 by the microcontroller. When the hook switch is open, however, V_{DETECT} may violate the V_{IH} spec for the CMOS inputs. Those V_{DETECT} inputs can vary between 1.24V and 2.78V, depending on the value of $R_{\text{MIC-BIAS}}$ (2.2kΩ in this case) and the type of microphone in the headset.

Thus, a direct interface between the hook switch and the controller is not possible for all microphone types. Instead, a low-power comparator can be used as in Figure 5. Here the reference level is set to detect a given type of microphone, while also indicating the status of the hook switch. The comparator output is pulled high when the hook switch is pressed, and pulled low when the switch is open. Again, the MAX9060 series of comparators provides a low-power solution for these hook-switch-detect applications.

The scope shot of Figure 6 is triggered by pressing the hook switch of a mono headset. The setup is identical to that of Figure 5, but a 2.5mm universal headset for cell phones is used for the test. The headset tip has an electret microphone with hook switch and 32Ω speaker connected to its ring. That microphone draws a constant bias current of 212μA when powered with a 3V supply through the 2.2kΩ bias resistor.

The DC voltage observed at V_{DETECT} is 2.52V (Figure 6), which causes the MAX9063's output to assert low. Pressing the hook switch grounds V_{DETECT} , allowing the output to be pulled high by an external

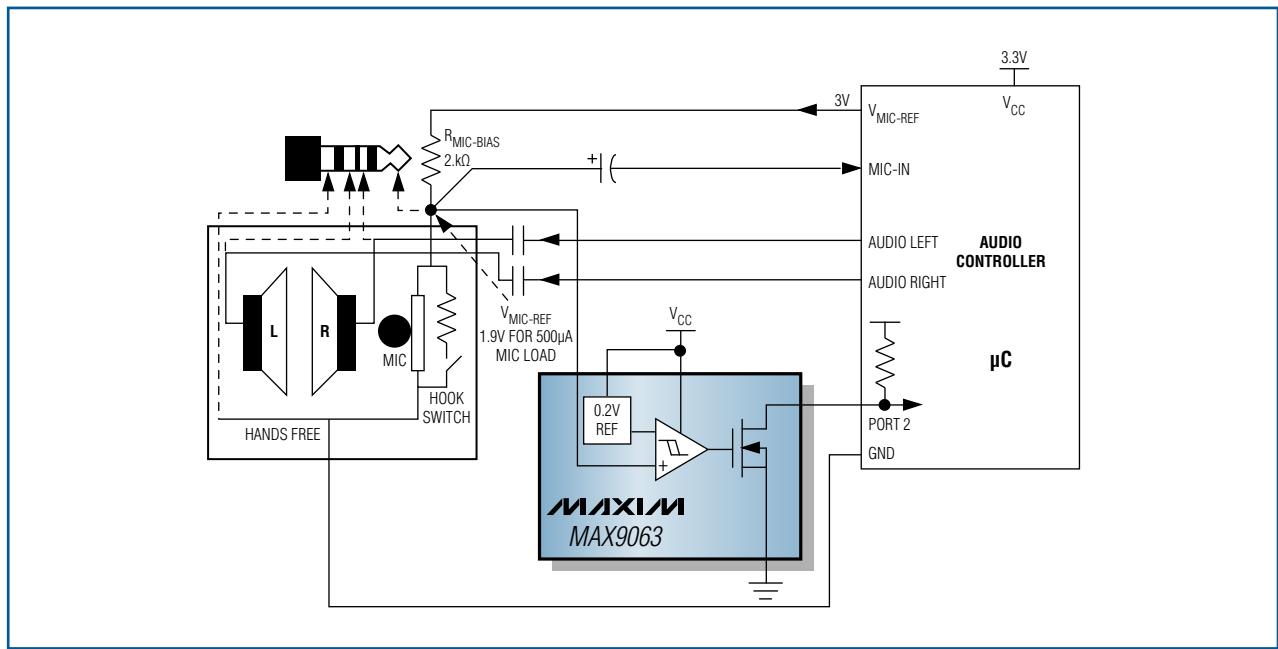


Figure 5. Hook-switch detection circuitry using the MAX9063 comparator.

10kΩ pullup resistor. Thus, the MAX9063 comparator in its tiny 1mm × 1mm CSP package is well suited for detecting hook switches and accessories. The MAX9028 comparator family is also suitable for these applications.

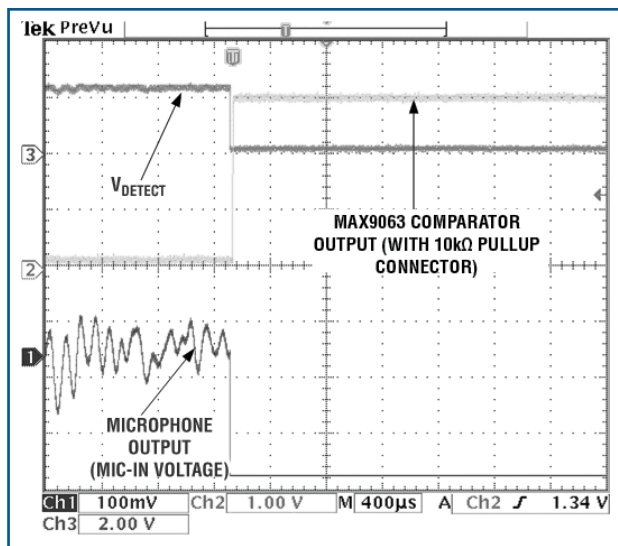


Figure 6. These waveforms are taken from an electret microphone with hook switch, controlled by a mono headset and its internal control circuitry. When the hook switch of a mono headphone is pressed, the comparator detects the shorted microphone, thereby allowing its output to be pulled to a logic high.

Summary

There is a common need for detecting jacks, headsets, and hook switches in portable applications. Dedicated comparators such as the MAX9063 and MAX9028 series devices are ideal for those applications, especially as they occupy very little real estate and consume negligible power. These comparators offer an economical solution for detection circuitry in portable applications.

Low-Loss LED Driver Improves a System's Green Footprint by Boosting Efficiency and Extending Battery Life

Keith Welsh, Senior Member of the Technical Staff

Providing power to drive high-brightness LEDs (HB LEDs) can be achieved by a number of different schemes. Because many systems are battery powered, energy efficiency is key to maximizing each battery charge and the system's operating time. By improving battery efficiency you also improve the system's "green" footprint. Over the life of the battery for the same number of charge cycles, longer times between charges translate into potentially hundreds of hours of additional use from the batteries. Thus fewer batteries may end up in landfills or hazardous waste-disposal sites.

The usual approach for low-power lighting is a simple linear regulator configured to operate in a constant-current mode (**Figure 1a**). This linear regulator offers the benefit of simple design. Its main disadvantage, however, is its high power loss, since the surplus headroom voltage is dissipated as heat in the current-measuring resistor and the regulator itself. This heat could also have a negative effect on the system's "green" footprint. More heat might require more cooling (a fan or large metal heatsink) which could consume still more energy, space, and weight while adding to materials cost and manufacturing time.

An alternative method employs a switch-mode-regulation scheme such as a buck regulator (**Figure 1b**). This type of regulator often requires a feedback voltage between 0.8V and 1.3V to regulate the current to the LED. The current-measurement scheme to set that voltage typically employs a low-value resistor in series with the LED. The voltage developed across this resistor provides the feedback voltage that maintains the constant-current power supply to the LED. The losses in the regulator can thus be reduced, but there are still losses in the system due to the power dissipated by the current-measuring resistor.

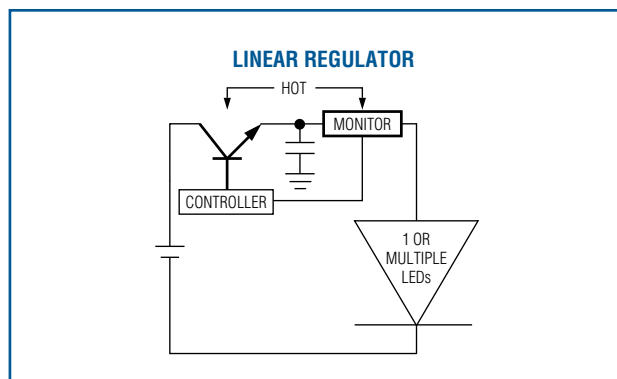


Figure 1a. A simple linear regulation scheme experiences power losses due to both the regulator and the current-setting resistor. The advantages of this circuit are its simplicity and the fact that it generates no EMI. The circuit can, however, only lower voltage and it does generate some heat.

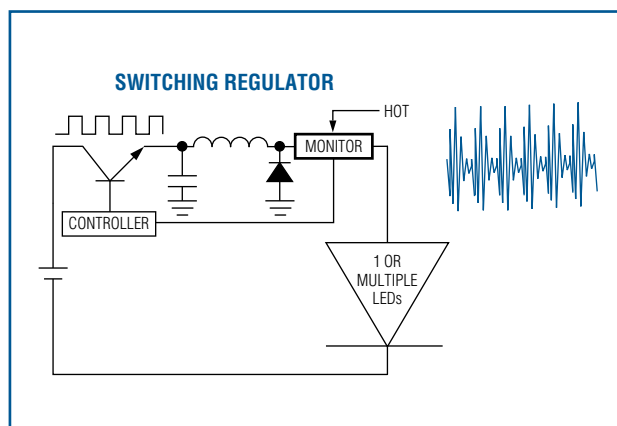


Figure 1b. In a basic switch-mode-regulation approach the main source of power loss comes from the energy dissipated by the current-sensing resistor. This design is highly efficient and can be reconfigured to boost voltages. It is, however, a more complex circuit and can generate EMI.

To reduce the power loss due to the current in the resistor, a low-loss current-measuring scheme such as a resistor/amplifier combination can be incorporated to provide the required feedback voltage to the switching converter. One such approach employs a dedicated, precision current-sense amplifier such as the MAX9938H, which generates 100V/V sensed across the series current-measuring resistor. This approach reduces the losses in the feedback portion of the circuit to only a few milliwatts. The low-value sense resistor required can even be derived from a short length of copper trace on the board at zero cost, making this an attractive solution.

In the circuit shown in **Figure 2**, the boost converter configuration features the MAX9938H current-sense

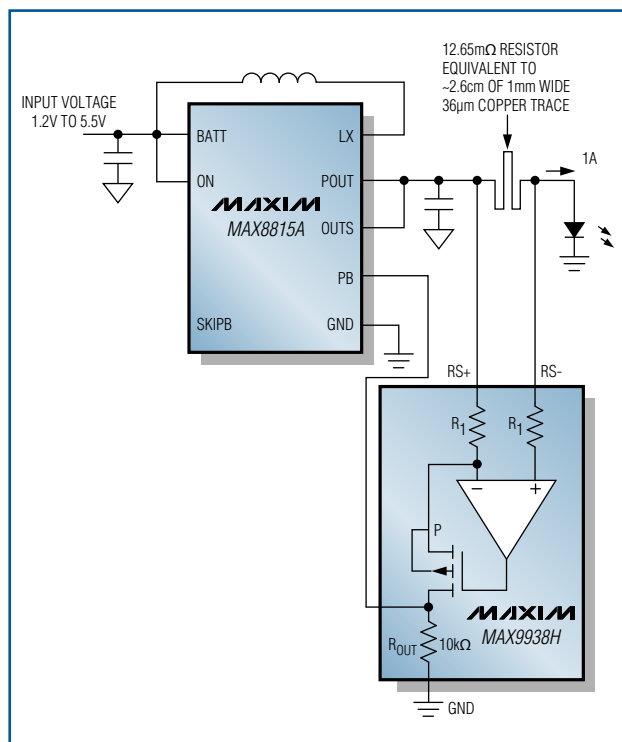


Figure 2. Working from Figure 1b, a current-sense amplifier such as the MAX9938H reduces power losses in the current-sensing resistor to just a few milliwatts vs. hundreds of milliwatts, or more, for the previous schemes in Figure 1.

amplifier and uses a MAX8815A step-up converter to get its power from two NiMH series-connected cells. The MAX8815A operates at switching frequencies up to 2MHz with efficiencies up to 97%. That high-switching frequency minimizes the size of external components; internal compensation further reduces the external component count for cost- and space-sensitive applications. The converter can generate any output voltage from 3.3V to 5V from a two-cell NiMH or NiCd source or a single-cell Li+/Li polymer battery.

The MAX8815A has two operating modes: a low-power mode and a fixed-frequency, forced-PWM mode for heavy loads. Low-power mode consumes only 30μA of quiescent current and allows the converter to switch only when needed at no load and light loads. Low-power mode delivers the best efficiency for light loads and helps minimize wasted power and drain on the battery.

The second mode handles heavier loads (typically above 90mA) and uses a fixed-frequency forced-PWM scheme in which the converter switches at a fixed frequency irrespective of the load. This mode allows easy noise filtering and lower output ripple, but consumes more power.

For this application, the MAX8815A would be used in the higher power fixed-PWM mode and the shutdown pin would either enable or shut down the drive. In shutdown mode, the MAX8815A consumes only 100nA of current from the battery, thus prolonging the battery's operational life and the time required between recharges.

Along with the MAX8815A converter, the MAX9938H current-sense amplifier controls the current, thereby keeping a constant 1A flowing into the LED. This amplifier integrates the gain-setting resistors on its inputs for a gain of 100V/V. Additionally, it offers precision accuracy specifications with a V_{OS} of less than 500μV (max) and a gain error of less than ±0.5% (max). The MAX9938H consumes just 1μA in its quiescent state. Other values of current can be achieved with a different value shunt resistor (possibly derived from a copper trace), perhaps modified or trimmed with a chip resistor in parallel.

This design approach presents a five-component solution, and the battery's operational life is maximized since the power losses are minimized in both the regulator and the control loop. Samples and evaluation kits for the MAX8815A and MAX9938H are available now.

Little Things Mean a Lot

Bill Laumeister, Principal Member of Technical Staff

Consumers demand long battery life in their portable devices. Meanwhile for nonportable devices, increasing energy costs and the latest Energy Star® guidelines are focusing public awareness on wasted standby power. Thus, meeting green energy regulations and reducing standby power has become designers' new mantra, especially when systems are active 24 hours a day. To meet the lower power-consumption levels, circuit designers know that the devil is in the details, with every single circuit required to justify its current budget. This article shows how Maxim chips can help system designers reduce the power budget of typical systems. The examples highlight just a few of the products in Maxim's broad portfolio of ultra-low-current devices.

Consumers demand long battery life in their portable devices, and rightfully so. Convenience is paramount, and that very concept permeates our society. We do not want to wait in lines, in traffic jams, etc., and further, we will often pay for that privilege. Hence, we have automatic teller machines dispensing cash 24/7; digital video recorders (DVRs) that allow us to time-shift our entertainment; mobile devices that let us communicate and entertain ourselves 24/7; and much more. "Little, light, fast, and easy" is today's consumer mantra. As equipment designers, we understand that our success requires meeting those expectations.

Making the equipment "greener" is a combination of integration, architecture, component selection, and function management to save every microamp in portable systems, and milliamps and more in line-powered systems. In portable systems, designers routinely count current in microamps. However, even that can be compromised when a single fingerprint on the circuit board might leak more current than a chip's standby current.

A popular song of the last five decades, "Little things mean a lot," teaches us how to design circuits for today's portable market. To paraphrase the song, with apologies to the song writers, "cause honestly, honey, they just cost" battery. We first think of the big items—a sleeping microprocessor, current-sipping displays, and flash memories—and then the rest of the circuitry. The devil is in the details, with every supporting circuit required to justify its current budget. Regulations vary by area, but typical goals for standby power are less than 0.5W to 3W,

while typical goals for operating efficiencies of more than 80% are becoming commonplace.

As a consumer, reading our home utility power bill can be frightening. As an engineer, we can design circuits to help consumers reduce their power bills. For example, just look at the HDTV DVR receiver. A typical unit draws 120W and often has no standby mode. Running 24/7, it would cost \$34.52 (US dollars) a month to operate (based on the penalty power rate of \$0.399 per kWh in northern California). This is just one appliance in our home, which emphasizes how the costs *or* potential savings can add up quickly. In a typical middle-class home there might be over 35 devices drawing power. Most, thankfully, probably have some form of standby power mode that reduces the power drain when the system is idle.

Increasing energy costs are focusing consumer attention on the total cost of ownership. Power consumption is critical, and remember that, for every watt going into a room, it will cost about two watts for air conditioning to remove it. So for us engineers, exceeding green energy regulations is smart for our business and our planet.

An Elementary Working Machine

Today, we have motors and microprocessors working for us in our homes and workplaces. When a natural disaster occurs, we quickly remember how dependant our lifestyles are on electrical power.

As we look at the block diagrams of machines, appliances, and entertainment devices, we see much in common. **Figure 1** illustrates the simplest definition of a useful machine. We, or a machine, sense something and then initiate an action. This is really a definition of most work. For example, we sense the room temperature and turn on a heater or air-conditioning unit. We sense the light level and turn on the lights. Our lawn sprinkler controller senses time and turns on the water solenoid for a programmed period.

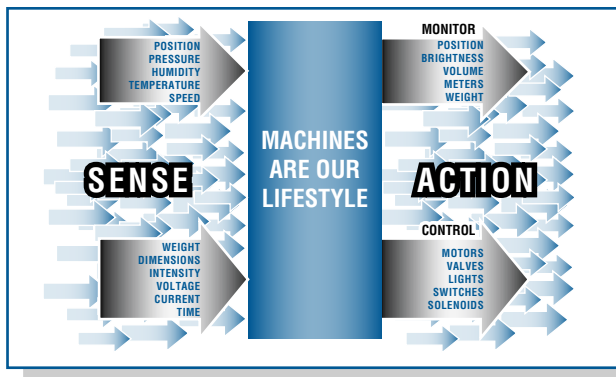


Figure 1. The shared characteristics of common machines dictate our lifestyles.

We start with the simplest of useful machines and then add features. **Figure 2** is such a machine; it senses some parameter, uses a processor to evaluate the stimulus against a predetermined criterion, and starts an output action. (Yes, we could show a heater, air conditioner, or refrigerator with a bimetal mechanical switch, but we are building on this machine to make more sophisticated devices.) In fact, we are describing a programmable logic controller (PLC). In **Figure 3** we start customizing the system to meet the customer's requirement.

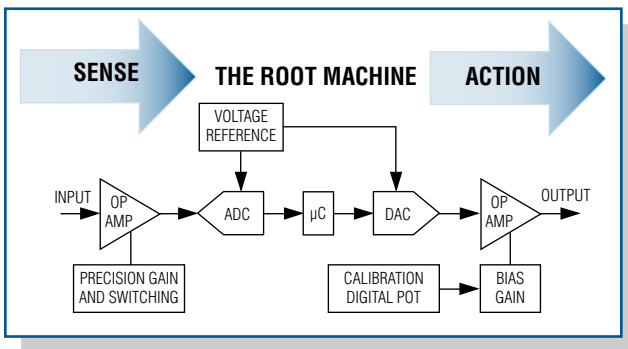


Figure 2. The concept of a simple useful machine is the basis for a PLC whose function is defined through a combination of software and silicon.

To arrive at the system in Figure 3, we took the sensor inputs and action outputs and partitioned functions by the speed needed. Relatively slow-changing inputs and outputs can be multiplexed around one PLC engine. Multiple parallel PLCs may be required for sensors and actions, such as safety items, which require constant attention. **Table 1** lists possible components for this root PLC engine. We can multiplex the sensors and condition the signals by switching gain and offset in the initial op amp. In any large-volume consumer device this amplifier must be inexpensive. A low-power CMOS op amp such as the MAX9915 can deliver the necessary precision for the control loop. The system dictates which of several amplifier configurations will be used.

There are several possible amplifier configurations:

The input amplifier stage may consist of a MAX9915 op amp and the MAX5490/MAX5492 precision-matched resistor-dividers, which are matched to within 0.025%. This combination leverages a relatively modest op amp, yet delivers precise gain and an excellent temperature coefficient.

We could add three op amps and a MAX5426 digitally-programmable resistor network to make a differential-input instrumentation amplifier.

If a programmable-gain amplifier with digitally-programmable precision gains of 1, 2, 4, and 8 is needed, then we combine the MAX5430 precision voltage-divider with an op amp.

Alternatively, the gain, bias, and offset could be set with digital potentiometers such as the MAX5128. The MAX5128 even integrates a nonvolatile memory so you can set and retain any gain setting. Upon power-up, the pot assumes the previous value—a potent tool for calibrating levels and offsets.

The ADC on the control loop is a MAX1108 or MAX1109. These devices are 8-bit, dual-channel, 50ksps converters with an internal reference. Table 1 also shows a low-power-consumption MAX6029 external voltage reference that can be added if the converters require the higher precision.

The DS80C320/DS80C323 are fast 8051-compatible microcontrollers. These high-integration controllers include four 8-bit I/O ports, two full-duplex hardware serial ports, timer/counters, a watchdog timer, and scratch-pad RAM. By allowing more sleep cycles, their high-speed architecture uses less power for equivalent work.

The output of the microprocessor is converted to an analog signal by the MAX5380/MAX5381/MAX5382, 8-bit DACs uses a two-wire serial interface to squeeze the circuit into a space-saving 5-pin SOT23 package. The DACs also integrate an output buffer amplifier to further reduce component count and board space.

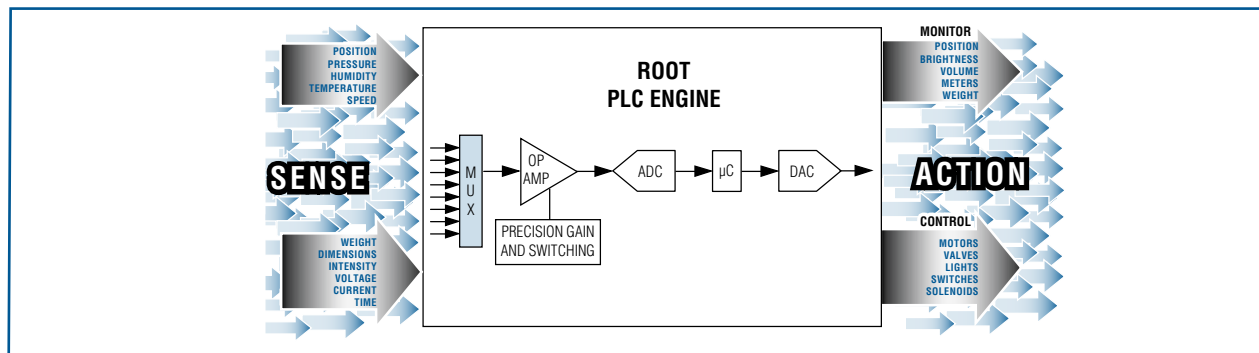


Figure 3. Highly integrated building-block ICs like those from Maxim can implement an elementary PLC.

Table 1. Typical Low-Current Maxim ICs Used for the Root PLC

Part	Description	Current Consumption
MAX1108/MAX1109	8-bit ADC, dual-channel, 50ksps	Operates on < 130 μ A; standby < 0.5 μ A
MAX6029	Series voltage reference, 0.15% initial accuracy	Operates on 5.25 μ A (max)
MAX5380/MAX5381/ MAX5382	8-bit DAC, 2-wire serial interface, 5-pin SOT23 package	Operates on 230 μ A; standby 1 μ A
MAX9915	Op amp, 1MHz unity-gain BW, rail to rail	Operates on 20 μ A; standby 0.001 μ A
MAX5490/MAX5491/ MAX5492	Precision-matched resistor-divider, 0.025% tolerance	Operates on ZERO A; standby ZERO A
MAX5426	Digitally-programmable resistor network for instrumentation amps	Operates on 90 μ A
MAX5430	Digitally-programmable precision voltage- divider for programmable-gain amps	Operates on 6 μ A
MAX308, MAX4581	8-to-1 multiplexer	Operates on < 17 μ A
MAX5128	Digital potentiometer, nonvolatile	Standby 0.5 μ A
DS80C320/DS80C323	Microcontrollers, 80C31/80C32 compatible, fast for power saving	Stop mode: 50 μ A with bandgap on, 1 μ A with bandgap off

Growing the Root PLC for More Complex Devices

By detailing the most elementary PLC engine, it is clear how features can be added to match the application. Everyone wants more convenience, which usually means more features/specialized functions. This is the “feature creep” that circuit designers hate. Sales wants many features included, but the retail price cannot increase. Designers thus must be clever enough to keep costs in check. Many of Maxim’s highly integrated solutions help designers meet their application goals by reducing current consumption, size, and cost.

We are all obligated to conserve energy, and Maxim takes that obligation seriously. The Company uses its R&D expertise to design and support a broad line of power-conserving and energy-efficient products. Only a few Maxim devices were highlighted in this article. These devices are just part of Maxim’s broad portfolio of ultra-low-current products. More energy saving devices including battery management, charging, and high-efficiency power supplies are listed at www.maxim-ic.com.

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