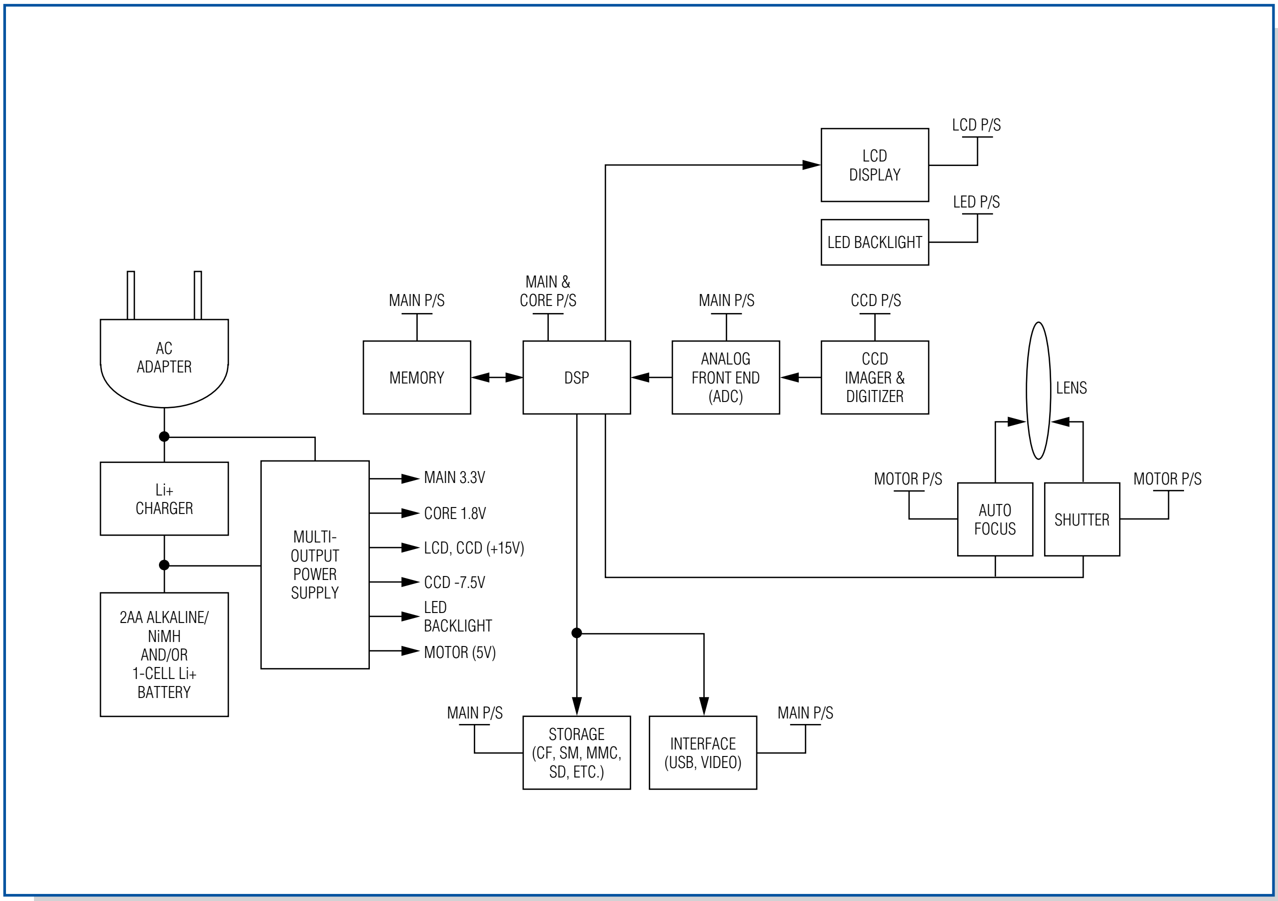
DALLAS SEMICONDUCTOR MAXIM

Engineering Journal

Volume Fifty-One



Compact digital-cameras benefit from integrated power supplies. (See article inside, page 3.)

MAXIM REPORTS REVENUES AND EARNINGS ABOVE GUIDANCE ESTIMATES FOR THE SECOND QUARTER OF FISCAL 2004 AND DECLARES QUARTERLY DIVIDEND

Maxim Integrated Products, Inc., (MXIM) reported net revenues of $338.1 million for its fiscal second quarter ending December 27, 2003, an 18.2% increase over the $286.1 million reported for the second quarter of fiscal 2003 and a 9.0% increase over the $310.2 million reported for the first quarter of fiscal 2004. Net income for the quarter was $98.5 million, a 27.8% increase over the $77.1 million reported last year and a 12.8% increase over the $87.4 million reported for the first quarter. Diluted earnings per share were $0.28 for the second quarter, a 21.7% increase over the $0.23 reported for the same period a year ago and a 12.0% increase over the $0.25 reported for the first quarter of fiscal 2004.

During the quarter, cash and short-term investments increased $34.9 million after the Company repurchased 2.0 million shares of its common stock for $100.6 million, paid dividends of $26.4 million, and acquired $70.0 million in facilities and capital equipment, $40.5 million of which was a wafer manufacturing facility on 168 acres in San Antonio, Texas. Accounts receivable increased $2.5 million in the second quarter to $133.4 million due to the increase in net revenues. Inventories decreased $7.2 million to $108.3 million.

Gross margin for the second quarter decreased from the first quarter of fiscal 2004, largely due to start-up costs at the Company's newly acquired wafer fabrication facility in San Antonio, Texas. Research and development expense was $71.2 million in the second quarter, compared to $70.1 million in the first quarter of fiscal 2004. The increase in research and development expense in the second quarter was the result of hiring additional engineers and increased expenses to support the Company's new product and process development efforts. Selling, general and administrative expenses increased from $21.4 million in the first quarter to $22.2 million in the second quarter but decreased as a percentage of net revenues from 6.9% to 6.6%.

Second quarter net bookings were approximately $417 million, a 19% increase over the previous quarter's level of $349 million. Turns orders received in the quarter were approximately $192 million, a 7% increase over the $180 million received in the prior quarter (turns orders are customer orders that are for delivery within the same quarter and may result in revenue within the same quarter if the Company has available inventory that matches those orders). Bookings increased by more than 10% in all geographic regions, and 11 of the Company's 14 business units saw a significant increase in bookings over the first quarter's levels.

Second quarter ending backlog shippable within the next 12 months was approximately $327 million, including approximately $293 million requested for shipment in the third quarter of fiscal 2004. The Company's first quarter ending backlog shippable within the next 12 months was approximately $252 million, including approximately $233 million that was requested for shipment in the second quarter of fiscal 2004.

Jack Gifford, Chairman, President, and Chief Executive Officer, commented on the quarter: "Second quarter bookings exceeded our expectations, with Maxim and Dallas Semiconductor bookings each up approximately 19% over the Q1 level. Bookings growth was particularly strong for our ICs that have industrial applications and for our traditional analog/mixed-signal products serving broad markets. It was also encouraging to see bookings from ATE customers pick up after so many quarters of sluggish performance. We believe that the ATE market will continue to improve during calendar 2004, as semiconductor companies increase their manufacturing capacity and add equipment."

Mr. Gifford continued: "In the next 6 months, there could be a shortage of foundry capacity for high-performance chip production. With our installed inhouse capacity plus our newly acquired capacity in San Antonio, Texas, Maxim has the capacity to meet our customers' revised and increased production requirements in most areas. Based on our current estimates for demand over the next two quarters, we have accelerated our schedule for production in San Antonio to the first quarter of fiscal 2005, approximately 9 months earlier than originally planned. Our timing of the acquisition could not have been more fortunate."

Mr. Gifford concluded: "The Company's Board of Directors has declared a quarterly cash dividend of $0.08 per share. Payment will be made on March 1, 2004 to stockholders of record on February 16, 2004."

High-level integration needed for compact digital-camera power

Digital cameras have replaced film cameras as the most popular means of taking pictures. Since the camera body has no need to hold 35mm or APS film, digital cameras are free to be nearly any shape and size that appeals to consumers. Camera functions also become free to incorporate into other products, such as cell phones and PDAs. These new ultra-compact shapes and sizes for cameras provide challenges for design of the battery and power management. These portions of the camera need to be increasingly efficient while using less and less space in each new generation of camera.

A digital camera may require six or more different voltages to operate. These include power to system logic, a low-voltage DSP core, shutter actuators and lens motors, CCD bias, LCD bias, and LCD backlighting. The block diagram of a typical compact digital camera is shown in **Figure 1**. The first generations of power ICs for digital cameras were, and in some cases still are, multi-channel PWM controller ICs that operate with external MOSFETs and transformers to generate multiple camera operating voltages. The limitations of those designs are poor efficiency, large numbers of external components, and large circuit size. Though the controller ICs themselves are inexpensive, the total circuit cost can be high, especially if high-performance MOSFETs and transformers are needed to maintain efficiency and not waste the limited battery capacity.

Advances in integration

IC process improvements in the last few years have allowed more integration of power switches with other functions. This integration, combined with IC-packaging advances, is supplying a new generation of integrated multifunction power ICs. These chips supply all the voltages needed for digital cameras, while offering significant battery-life improvement and major reductions in component count. Especially significant is the elimination of transformers for many designs. This not only reduces cost, but also speeds design time,

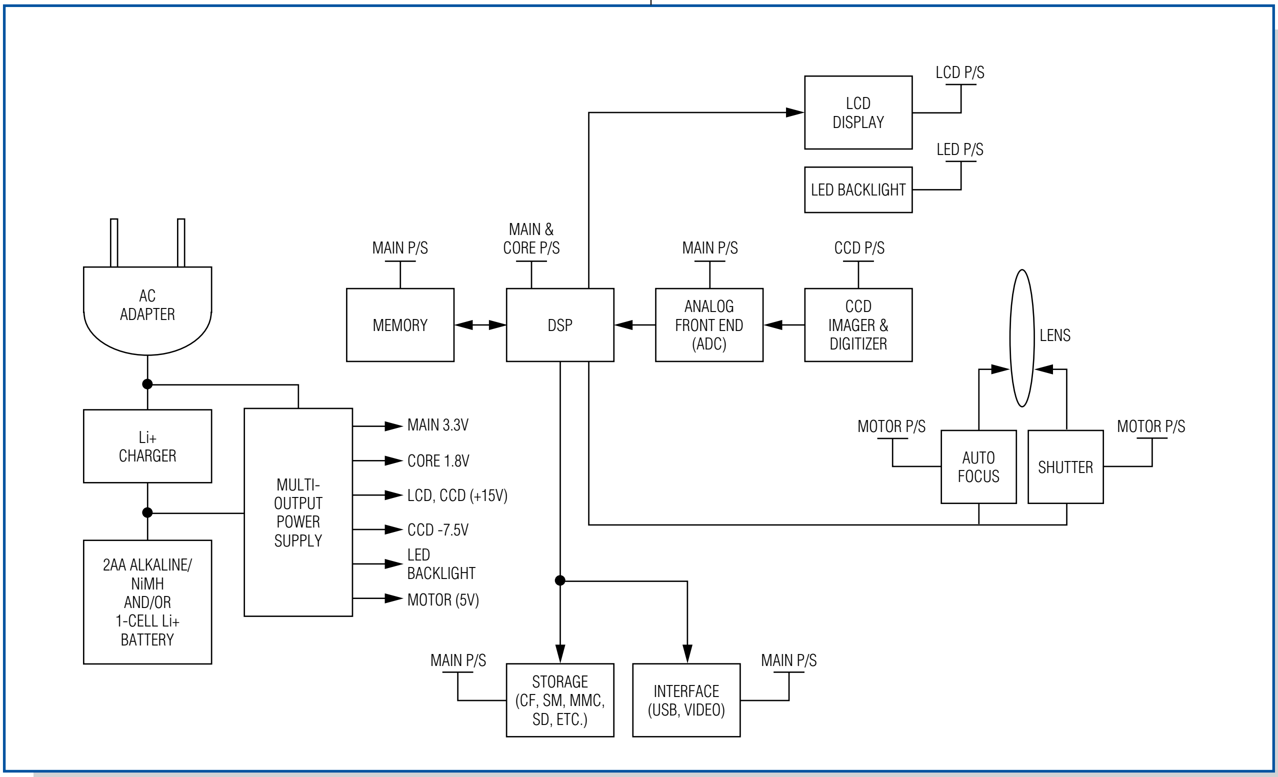


Figure 1. This compact digital-camera block diagram shows various operating voltages.

because transformers are not typically stocked by vendors. Transformers are custom components that require special ordering—something not required for standard, off-the-shelf inductors.

Besides eliminating transformers, newer power ICs increase operating frequency. This allows reductions in component size, because less energy needs to be stored on each switching cycle if more switching cycles can take place each second. As a result, inductance and filter-capacitor values are lowered and inductor and capacitor size reduced. Another benefit of smaller capacitor values is that, at 500kHz and above, filter values become small enough to allow ceramic capacitors. Ceramic capacitors have proven to be more reliable than polarized types and have very low ESR, which reduces ripple.

Optional power-IC design

A typical power supply for a compact or pocket-sized digital camera is shown in **Figure 2**. The multi-output IC combines six DC-DC power converters. One difficulty in developing large ICs for complex systems like digital cameras is that, unlike PCs, digital-camera power supplies are not all exactly alike. Differences in battery, CCD size, display, and functionality all create significant variation in required supply voltages and the power needed from each. Because of this variation from one camera to the next, the optimal power-IC design is a hybrid of internal and external MOSFET converters. On-chip MOSFETs are used for the voltages that consume the most power, while external MOSFET PWM channels retain flexibility for the remaining voltages.

The design shown in Figure 2 uses high-efficiency internal MOSFET channels for the camera’s main 3.3V logic supply, low-voltage DSP core, and 5V motor supply. These supplies operate for the greatest percentage of time, and/or use the largest amount of battery power. As a result, they benefit the most from the high efficiency afforded by internal MOSFET power switching and synchronous rectification. Power-conversion efficiency for these supplies approaches 95%. Additional voltages for the CCD image sensor, LCD display, and LED backlight vary more from design to design. Consequently, they are good candidates for external-FET channels, which allow optimization for different CCD pixel counts and LCD screen sizes.

For CCD bias, designs commonly use a transformer to generate positive (usually +15V) and negative (-7.5V) outputs. However, transformers are large and cause particular difficulty if height restrictions are imposed. In space-limited designs, like compact cameras, using inductor-based inverters and boost converters is preferred. This is especially true as pixel counts rise to 3MP and above, which increases the required current. Transformer efficiency and size limitations then become even more significant. The design example generates +15V for both LCD and CCD bias with external-FET boost channel (AUX1), and -7.5V for negative CCD bias with an external-FET inverter channel (AUX2).

Compared to higher end models, compact digital cameras tend to economize on features. Nonetheless, smaller pocket cameras are beginning to include larger camera features such as optical zoom, autofocus, and higher pixel resolutions. All these features, particularly mechanical functions that require a motor, like autofocus, typically use 5V power and draw high peak loads of several hundred milliamps or more. Even though the average load on this supply may be only one-tenth of its peak, the momentary peaks are not brief enough to allow use of a low-current power supply and a large capacitor. The capacitor size quickly becomes prohibitive, so the boost converter must be rated for peak motor-load current, which is often as much as 1A. High-power on-chip MOSFETs are needed to supply this load efficiently (up to 95%).

The buck/boost problem

Two battery configurations have emerged as the most popular for small digital cameras. These are 2-cell AA (alkaline or nickel-metal hydride) and 1-cell Li+ batteries. Occasionally, the camera may be designed to operate with both battery configurations. This can be especially challenging for the power-supply designer because, in some cases, the battery must be boosted to generate certain operating voltages (such as 3.3V). In other cases, it must be stepped down to generate that same voltage. This requires a step-up/down (or buck/boost) design. In older camera designs, this was done with flyback (transformer-based) designs that were large, awkward, and fairly inefficient—often no better than 70% efficiency.

Integrated designs with multiple outputs make it easy to create a buck/boost converter, because a step-up supply can be used to power a step-down. This method was not commonly used to solve the buck/boost problem, as it required excellent efficiency from separate buck and boost stages to provide adequate combined efficiency. But now that current-mode step-up and step-down converters can achieve 95%, the combined efficiency reaches 90%, far better than is possible with flyback and SEPIC designs.

When and how stages should be combined for buck-boost operation depends on the battery type. Batteries comprised of two AA cells operate from about 1.8V to 3.6V, while Li+ batteries operate from 2.7V to 4.2V. A Li+-powered design may need a buck/boost converter to generate 3.3V. A design that uses two AA cells may also require a buck/boost converter, as the DSP core (typically 1.5V or 1.8V) supply may not have enough headroom to run from the battery when the cells are severely loaded. In both these cases, efficient buck/boost converters can be made by cascading DC-DC converter stages. A 3.3V supply can be made by first boosting to 5V (V_{SU} 5V,

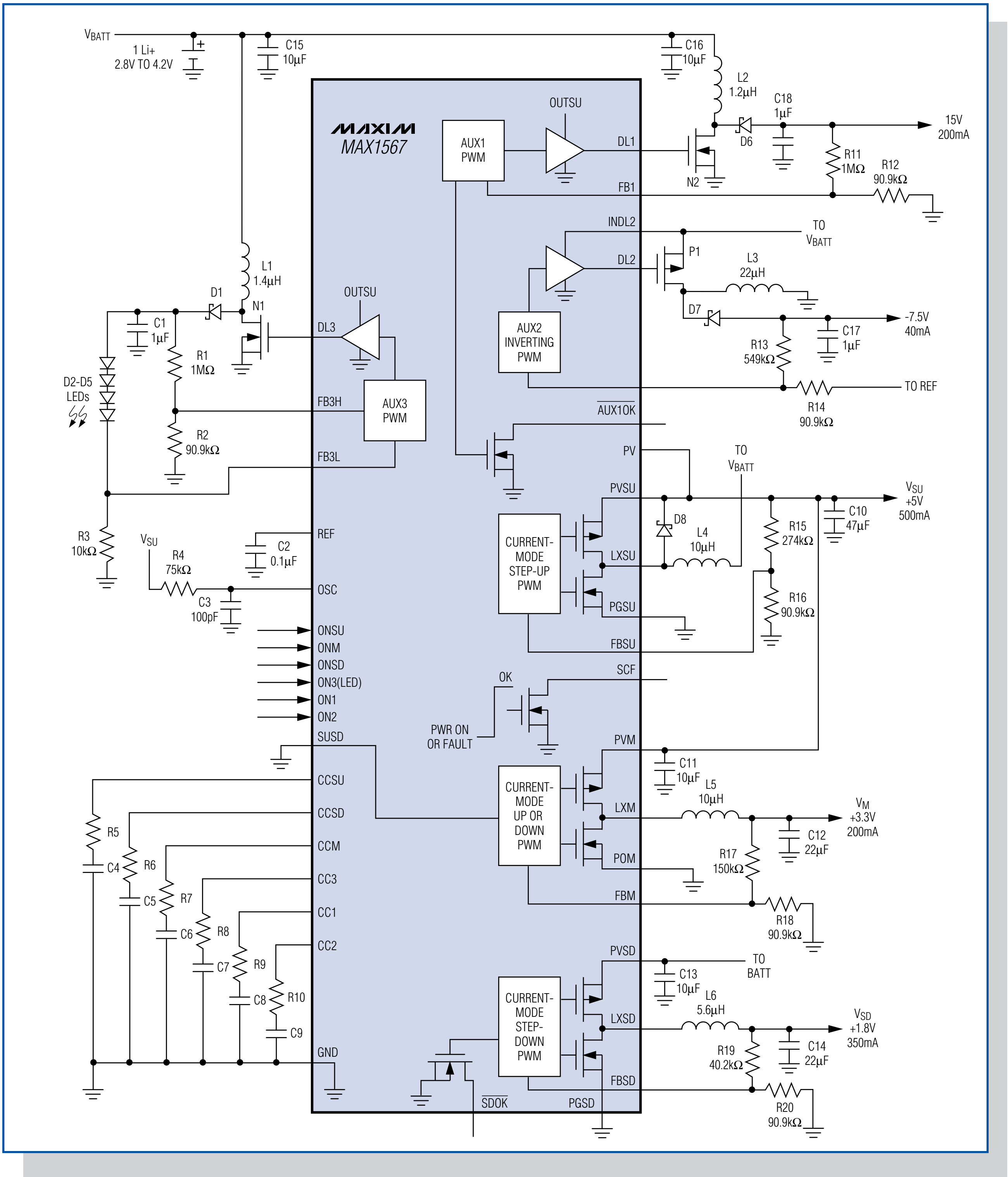


Figure 2. This highly integrated power supply for small digital cameras integrates six DC-DC power converters.

Figure 2), then stepping down to 3.3V (V_M 3.3V, Figure 2). A 1.8V supply can be made the same way by powering the step-down input (PVSD) from 5V. Of course, when using a Li+ cell, the core step-down supply can be powered directly from the battery (as in Figure 2).

Compact digital cameras are likely to have smaller batteries. Of course, high efficiency is needed when smaller batteries are used. Also, smaller batteries cannot supply the same load peaks as their larger counterparts. System power management must frequently turn off unused supplies to extend battery life. When supplies are turned back on, they must not draw large currents that pull the battery voltage down. The integrated supply in Figure 2 ramps up each input at a controlled rate so that each output minimizes input-current surges when activated. This also ensures that outputs rise in a predictable way for sequencing.

Reliability and safety enhancement

In addition to providing the necessary voltages with one IC, integrated power circuitry provides advantages for voltage and fault monitoring that would normally require numerous external components. This can be a benefit for both reliability and safety. In Figure 2, three outputs give the status of the three most critical voltages. $\overline{\text{SDOK}}$ provides the status of the supply that powers the DSP core. In some designs, the 3.3V supply to the DSP chip cannot be activated until the DSP core supply is in regulation. $\overline{\text{SDOK}}$ can signal the processor, or directly drive a P-channel MOSFET that gates 3.3V power. $\overline{\text{AUX1OK}}$ can perform the same function for one of the PWM controllers and provide an OK flag for CCD or LCD bias.

A portable device like a compact digital camera is likely to be subjected to harsh conditions. It may be dropped, get wet, or be exposed to extreme temperatures. A power-supply design cannot prevent damage from severe conditions, but it can minimize damage and enhance safety by shutting down when adverse conditions arise. On the other hand, the design must not be too sensitive, otherwise it may shut off during normal load transients. High-level integration supports a high safety level by monitoring all power channels. If any channel is overloaded or shorted for over 200ms, then all power supplies shut down. The 200ms delay is long enough to allow load transients to occur without false triggering. A fault flag (SCF) can tell the system that a fault has occurred. Additionally, the on-chip MOSFETs are protected by thermal shutdown.

Conclusion

Clearly, high-performance power management for small devices, like digital cameras, is best achieved with a high level of integration. Besides the obvious advantage of requiring only one IC, benefits include passive component reductions, significant efficiency improvements, simple implementation of buck/boost topologies, and improved reliability.

Power-on reset and related supervisory functions

A look at monitoring and controlling processor voltages

For many years now, the supervisory circuit has functioned to ensure that microprocessors and microcontrollers operate correctly. Although circuit designers have utilized the most popular supervisor function, the power-on reset, understanding how to select and apply the supervisory circuit is often imprecise. Moreover, improvements to this circuit continue to appear. This article describes the power-on reset and related supervisory functions (such as voltage sequencing, voltage tracking, manual reset, and power-fail and low-line signals), and explains some of the nuances of making them work properly.

One task of the power-on reset (POR) is ensuring that the processor starts at a known address when power is first applied. To accomplish that task, the POR logic output holds the processor in its reset state when the processor's power supply is first turned on. The POR's second task is to keep the processor from starting its operation from that known address until three events have occurred: the system power supplies have stabilized at the appropriate levels; the processor's clock(s) has (have) settled; and the internal registers have been properly loaded. The POR accomplishes this second task through an onboard timer, which continues to hold the processor in its reset state for a prescribed period of time. That timer triggers after the processor's power supply reaches a specific voltage threshold. After a set time elapses, the timer expires, causing the POR output to become inactive, which in turn makes the processor come out of reset and begin operation (**Figure 1**). The processor's data sheet specifies the required duration of the timer's delay. The timer, incidentally, is what differentiates a POR from a voltage detector, a device that also detects a voltage threshold, but does not time an event.

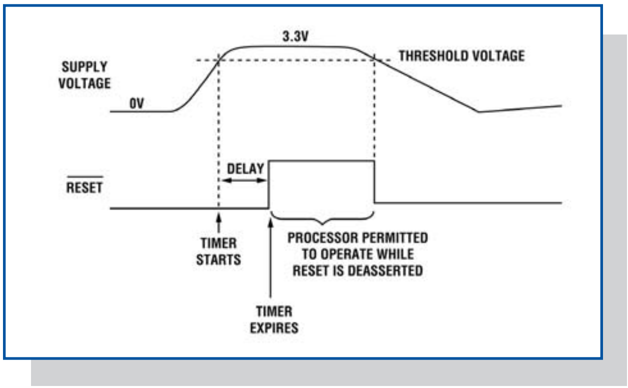


Figure 1. A POR holds a processor in its reset state until the supply voltage exceeds the POR threshold and a specific delay period has elapsed.

The superior noise immunity of a POR, which is necessary when monitoring a processor, also distinguishes it from a voltage detector. This is because a POR should not issue a reset when a small, fast glitch appears on the supply, as the processor itself does not react to such glitches. However, both a small glitch of long duration and a large glitch of short or long duration can cause problems for the processor. Therefore, the best approach is to use a POR that examines both the size and duration of disturbances to the power-supply voltage for determining when to assert a reset. The intent is to mirror the processor's own behavior and to assert a reset only when one is needed, as there is no point in resetting the processor if it is working properly. **Figure 2** is a graph from the MAX6381/MAX6382 data sheet that details an example of the magnitude/duration of the supply-voltage disturbance required to trigger a reset. This graph illustrates that the MAX6381/MAX6382 issues a reset when the monitored power supply is 100mV below the specified threshold for at least 10ms.

Should the supply voltage return above the threshold, the POR timer allows the reset signal to deassert only after the prescribed interval.

Some processors provide a bidirectional reset pin—a pin that can not only receive a reset signal, but can also transmit one. At first glance, a POR with an open-drain output would seem to be needed in this situation. However, other considerations apply, because the processor must determine whether it or an external device initiated the reset. A POR specially configured for such a situation is necessary (refer to the MAX6314 data sheet).

Determining the POR threshold voltage—single-supply processors

Determining the correct POR threshold level and the required accuracy for that level are both often misunderstood. To shed light on those tasks, assume a processor is used that guarantees accurate operation with a 3.3V ±0.3V supply voltage—specifically, from 3.00V to 3.60V. Board designers follow one of two strategies when choosing the threshold voltage.

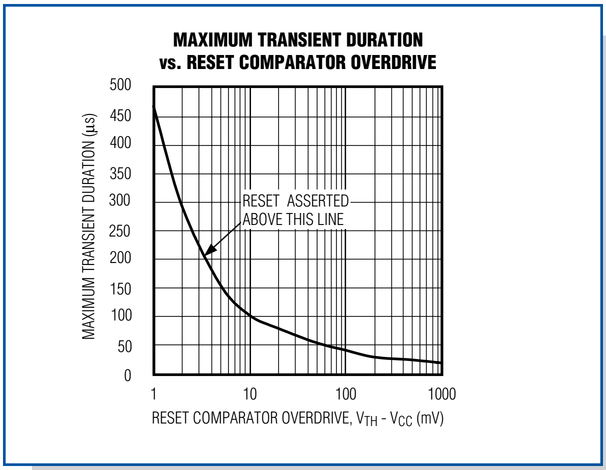


Figure 2. Whether a POR generates a reset is a function of both the amplitude and duration of the glitch.

One strategy is to ensure that the tolerance of the 3.3V supply is tight enough so they can use a POR with a threshold plus tolerance that remains entirely within the ±0.3V range. In that case, the POR threshold lies between the lower end of the supply's range (±3%) and the lower end of the processor's allowed voltage range (**Figure 3a**). Under this strategy, the POR does not issue a reset when the supply is within tolerance. However, the POR does issue a reset when the supply voltage has dropped below its tolerance level, and remains within the range where the processor is guaranteed to operate correctly. This ensures that reset occurs before the processor can operate erroneously at a voltage below its guaranteed operational level.

A suitable choice of POR for this strategy is the version of the MAX6381 with a threshold range of 3.00V to 3.15V over temperature (Figure 3a). With this POR included, the processor will reset after the power supply drops below its specified voltage range, but before the supply drops below the processor's specified voltage range. Also, given that the upper end of the threshold's range is 3.15V, a reset cannot occur when the power supply is within its allowed range. However, voltage drops through the edge connector and board trace that connect the supply voltage to the processor might cause the voltage at the processor to drop below 3.15V. In this case, a reset could occur even though the supply voltage is within specifications. A tighter tolerance supply or tighter tolerance POR threshold, or both, would be necessary.

This design approach is more susceptible to power-supply glitches and noise, because the supply voltage can be fairly close to the POR threshold (depending on where the POR threshold and supply voltage lie within their tolerances). Therefore, this approach is appropriate for systems where glitches and noise are minimized and power-supply tolerances are tight.

Some board designers adopt a second, different strategy when choosing a POR threshold level. They employ a POR with a threshold below the processor's guaranteed operating voltage (3.00V, in this example). This allows the processor to operate anywhere within the range of permitted voltages without encountering a reset. It also permits a looser tolerance power supply. These designers are comfortable assuming that, during power-up, the power

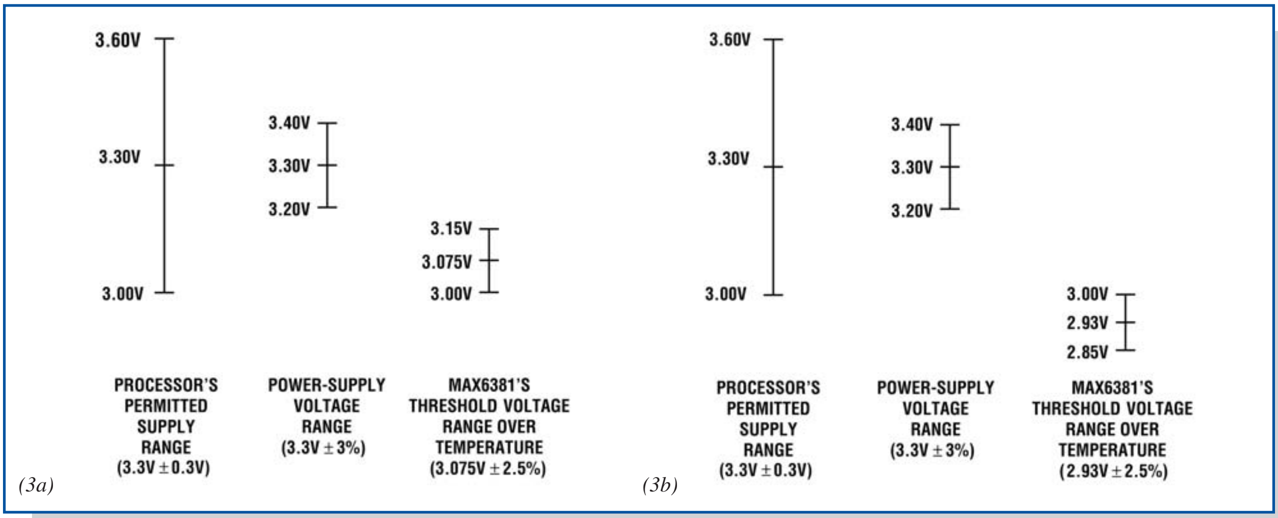


Figure 3. To ensure that the processor gets reset when the supply voltage is below the power supply's specified voltage range and above the bottom of the processor's range of permitted voltages, choose a POR threshold as shown in Figure 3a. However, choosing a POR threshold below the processor's range of permitted voltages (Figure 3b) guarantees that reset will not occur anywhere within that range and allows the use of a power supply with a looser tolerance.

supply will continue to rise above the POR threshold level and settle within its specified range of voltages (3.20V to 3.40V, in this case). This is expected to happen well before the POR timer times out and the processor begins to operate. Often, designers use the power-OK signal provided by some power supplies to ensure that the supply operates within its specified range.

These same designers are unconcerned about the effect of a brownout condition. If a brownout occurs, the processor could encounter a supply voltage that falls below its minimum guaranteed operating voltage, but remains briefly above the POR threshold level (beneath which the POR would generate a reset). While powered by supply voltages in that range, the processor could operate erroneously.

Contrary to choosing a threshold within the processor's permitted supply voltage range, the second approach is more appropriate for those systems where glitches and noise tend to be larger, because the POR threshold and the power-supply voltage are further apart. As mentioned above, this also permits wider tolerance power supplies.

The version of the MAX6381 that has a threshold range of 2.85V to 3.0V over temperature is a good choice here, because the threshold is below the low end of the processor's permitted range (**Figure 3b**). One could also use a power supply with a tolerance wider than that shown in Figure 3.

Occasionally board designers position their power supply's nominal voltage closer to the lower end of the processor's permitted range to reduce power consumption. Doing this can be quite effective, because power consumption is proportional to the square of the supply voltage. Given the 3.0V to 3.6V range of permitted processor voltages, a 3.15V ±2% supply would be suitable, provided there is no significant voltage drop through the edge connector and trace that connects the supply to the processor. The MAX6381 POR with the 2.85V to 3.0V threshold voltage range would be an appropriate choice, if noise levels are sufficiently low to prevent false resets.

Determining the POR threshold voltage—dual-supply processors

If a processor requires another supply (e.g., a 1.8V core supply) in addition to a 3.3V supply, then the design may call for a POR that monitors two voltages. This type of POR deasserts its reset only after both supplies are above the POR's two corresponding thresholds and the required timeout period has passed. PORs that monitor two, three, and four voltages are available.

The same choices apply when monitoring multiple supplies or a single supply. For the dual-supply case (e.g., 3.3V and 1.8V), one can elect to use a POR with two thresholds that are both above or below the processor's minimum guaranteed operating voltages. Also, one could use a threshold that is below the guaranteed operating voltage for the 3.3V I/O supply and another threshold that is above the guaranteed operating voltage for the 1.8V core supply. Some board designers opt for the latter strategy, because sometimes the core of the processor is more sensitive than its I/O to problems caused by a low supply voltage.

Core supply voltages have consistently dropped over time, and thus reduced POR threshold voltages have become necessary. Devices within the MAX6736 family provide thresholds as low as 788mV without external resistors, and as low as 488mV with external resistors. These thresholds are low enough to monitor most modern core voltages.

For low-cost systems, some circuit designers elect to monitor only the 3.3V supply if the 1.8V supply is derived from it. They assume that if the 3.3V supply reaches its correct voltage, the 1.8V supply will follow. For systems requiring higher reliability, designers usually decide to monitor both supplies.

Manual reset

It is often useful to manually trigger a reset while the power-supply voltage remains within tolerance. Not only is this feature used for debugging and final testing, it is also valuable when the processor locks up—it allows the processor to restart without turning off the power. This function is especially useful for those products with processors that are never powered down. It is common for an on/off switch to only wake up/suspend the processor without ever turning off the processor power.

Although a logic signal from an I/O line, a watchdog timer, or a power-fail output often initiates a manual reset, a pushbutton switch can also be used. When pressed, this type of switch usually bounces, opening and closing several times before settling in the appropriate state. Therefore, most manual-reset inputs include debounce circuitry that ignores the ringing caused by the pushbutton switch.

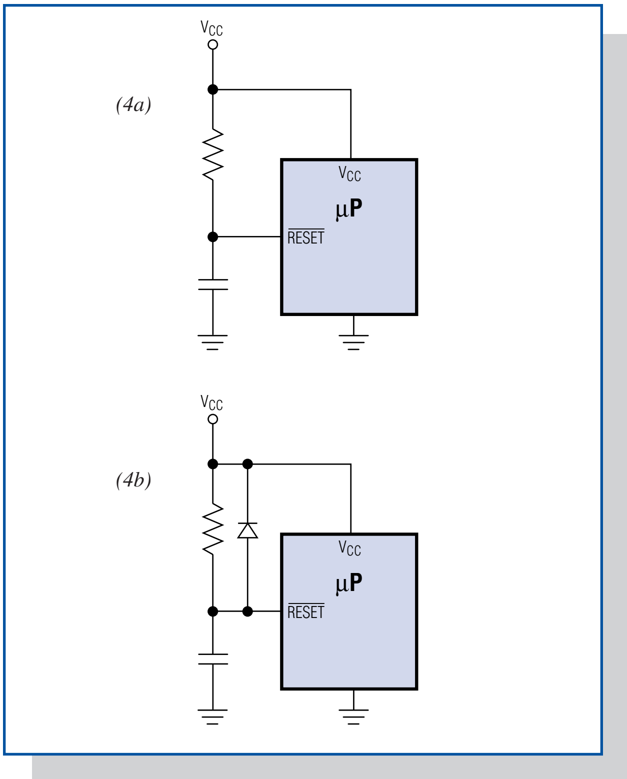


Figure 4. The discrete R/C POR (Figure 4a) is not reliable enough for most applications. In some cases, adding a diode to the circuit (Figure 4b) corrects quick-supply-cycling problems and improves the circuit's performance.

Discrete PORs and PORs internal to the processor

Using a discrete POR created with a resistor and capacitor (**Figure 4a**) is a risky proposition. The longer rise and fall times at the output of this type of POR can create problems for some processors—especially those with reset inputs not including a Schmitt trigger and for those with bidirectional reset pins. Adding a Schmitt trigger can help the former case, but can also contribute to cost, space, and startup issues.

Another problem arises when a discrete POR is used along with a supply that, when powering up, rises slowly in relation to the POR time constant. The processor can come out of reset well before it has stabilized. To prevent this problem, the time constant of the R/C circuit may need to be increased. Also, some manufacturers whose processors include an internal POR, recommend that an R/C (plus a diode described below) be added to the reset input if the power supply comes up slowly.

If the power supply has a glitch after power up, the R/C circuit might filter that glitch, thus preventing a reset from happening. Also, if the supply droops, the voltage at the processor's reset pin could remain higher than its V_{IH}, which is too high for a reset to occur. This can transpire even when the supply has dropped below the processor's minimum guaranteed operating voltage. This happens because a reset pin's V_{IH} is often lower than the processor's minimum guaranteed operating voltage. Another problem can arise if the power is turned off and then on again quickly—the capacitor might not have sufficient time to discharge prior to the power coming back on.

By adding a diode (**Figure 4b**), the R/C circuit can respond to glitches, because the diode quickly discharges the capacitor whenever a glitch appears. The glitch must be sufficiently large to drop the voltage at the reset pin to V_{IL} (min). Additionally, the other problems listed previously for the R/C circuit without the diode can potentially plague this circuit. However, sometimes the diode does fix the problem created when the supply is quickly cycled off and on.

Using an integrated POR makes the most sense for most equipment, as this device creates none of these problems.

Using a POR internal to a processor can also cause difficulties. These PORs often suffer from inaccuracy and can exhibit problems at lower voltages. Furthermore, some internal PORs are set up to provide a reset during power-up, but not when the supply voltage dips during a brownout condition. Some manufacturers suggest adding a discrete circuit to accommodate that condition.

Finally, a system powered by multiple supplies may pose another problem for an internal POR. For example, you could encounter a problem when an internal POR timeout period is appropriate for its processor, but not for external circuitry (e.g., memory) whose supply voltage comes up more slowly. In that case, a solution would be an external POR with a longer delay time that monitors both the processor and the external-circuit supplies.

Power-fail and low-line signals

Supervisor circuits that include power-fail or low-line signals warn the processor that a brownout or power failure is imminent. When either of those signals interrupts the processor, the processor can enter a power-down routine. This routine causes the processor to cease its current activities and back up important data prior to the POR placing the processor in reset.

To create a power-fail signal, the supervisor's power-fail comparator monitors the unregulated DC voltage (or some other upstream regulated voltage). This voltage feeds the regulator, which powers both the processor and supervisor circuit. The unregulated voltage drops before the

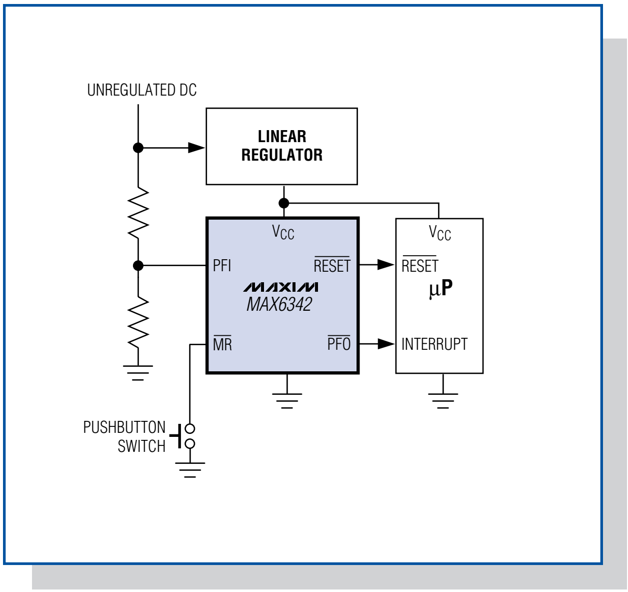


Figure 5. The power-fail comparator within the MAX6342 generates the power-fail signal ($\overline{\text{PFO}}$) by monitoring whether the unregulated DC supply has dropped.

regulator's voltage because the regulator's output capacitor retains its output voltage (**Figure 5**). Thus, a drop in the unregulated voltage indicates a possible drop in the regulator's voltage. Detecting that drop and interrupting the processor allow the processor to enter its power-down routine prior to being reset, if the power-supply voltage were to drop low enough.

When there is no access to the unregulated voltage (or an upstream regulated voltage), the processor can still receive warning of an imminent power failure. That warning could come from a supervisor that provides a low-line signal, which goes active whenever the monitored power supply drops to a level slightly above the reset threshold (e.g., 150mV above). Thus, the low-line signal warns the processor that the power-supply voltage may decrease enough to cause the POR to issue a reset. Here, as with a power-fail comparator's signal, the processor backs up important data in anticipation of the POR generating a reset due to a brownout or power failure.

Voltage sequencing and voltage tracking

Most data sheets of processors powered by two supplies specify the order in which the supplies should come up. Parts such as the MAX6819/MAX6820 can sequence the supplies in the proper order. If the processor's supplies are not sequenced properly, the processor can latch up, initiate incorrectly, or endure long-term reliability degradation. Sometimes, the various supply voltages are not locally generated (e.g., they come from a main system bus, an externally purchased silver box, or supplies that do not include enable and power-OK pins that facilitate sequencing). In such cases, power-on and power-off sequencing can be difficult to control or predict, thus making a voltage-sequencing IC necessary. This type of IC is also needed when different resistive and capacitive loads affect the turn-on and turn-off times of the various supplies. This makes it difficult to predict the order in which the supplies power up and down.

A unique method for sequencing two power supplies is found in the MAX6741/MAX6744. These devices work by first allowing one supply to power up. Then, after a delay period, they allow the second power supply to power up by issuing a power-OK signal, which takes the supply out of shutdown. After both supplies are up and another time delay elapses, the MAX6741/MAX6744 reset signal deasserts.

Some processors require that the two supplies track each other during power up. In that case, the MAX5039/MAX5040 can achieve tracking by clamping the two supplies together until the lower-voltage supply reaches its final voltage. At this point, the higher-voltage supply is free to continue up to its final voltage.

Reset sequencing

When a circuit incorporates two processors, often one processor must come out of reset prior to the second. Previously, board designers wired two PORs together to handle this requirement. The output of the first POR both reset the first processor and controlled the manual-reset input of the second. The second POR output reset the second processor (or, in some cases, the memory). Currently, dual PORs with time-staggered reset outputs are available for this task (**Figure 6**). These PORs assert both reset outputs whenever the master supply voltage (3.3V, in Figure 6) strays below the POR's internally set threshold. (The slave POR asserts slightly before the master.) Once the supply returns above this threshold, one of the two reset outputs deasserts after its timer has timed out ($\overline{\text{RESET1}}$, in Figure 6). For the second POR to initiate its timer and deassert its output, two conditions must be met: $\overline{\text{RESET}}$ must be deasserted; and the slave supply voltage, monitored by the second POR, must be above the threshold set by external resistors. If the same supply voltage powers both processors, RSTIN2 can be connected directly to the supply instead of using a voltage divider.

For the MAX6392 shown in Figure 6, the second POR output always comes out of reset after the first output. In fact, the time specified for it to come out of reset is measured from the time that the first output deasserts. Thus, the Figure 6 circuit forces the slave processor to

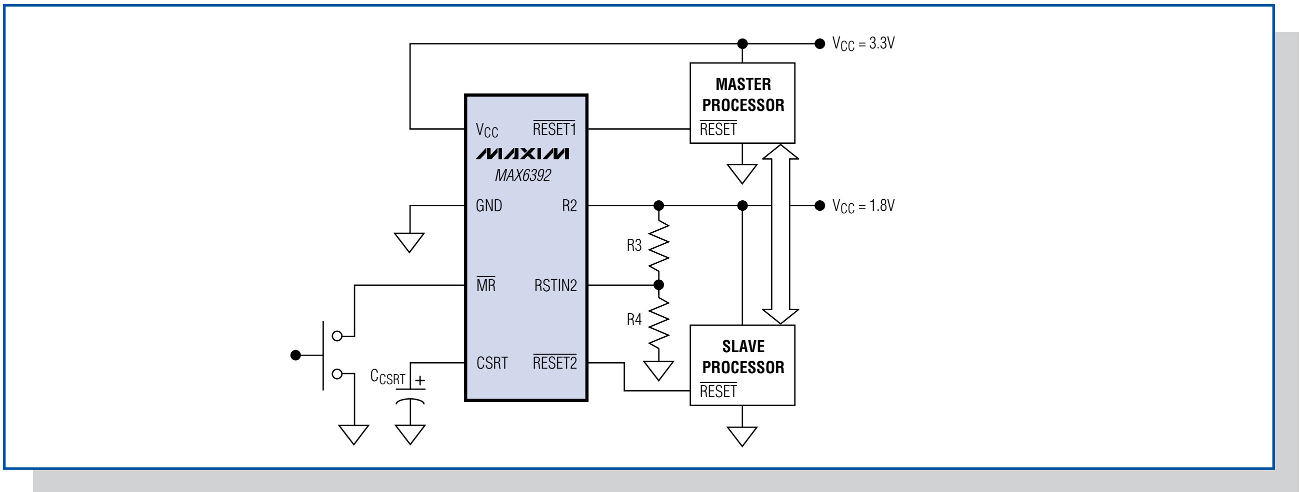


Figure 6. This circuit allows the master processor to come out of reset prior to the slave by monitoring the supplies that power the two processors.

come out of reset after the master processor has begun operating. The second POR delay time can be increased by adding a capacitor to the IC.

If three processors need to be sequenced, the DS1830 can be considered. The three PORs within this device operate with minimum reset periods of 10ms, 50ms, and 100ms from the time the power-supply voltage crosses the POR threshold. A single logic pin allows multiplication of those reset periods by a factor of two or five.

Conclusion

Although choosing the appropriate microprocessor supervisor and operating it correctly are often straightforward, some aspects of that exercise may require careful planning. Such is the case with power-on resets. Choosing the correct voltage and tolerance for both the power supply and the POR threshold requires some thought. Also, well worth considering are newer devices that accommodate processor requirements such as multiple-voltage reset, reset sequencing, power sequencing, and voltage tracking.

A similar article appeared in the April, 2004 issue of EDN.

Improve gain flatness without sacrificing dynamic performance in high-IF ADCs

The proper selection of board components is essential to meet the demanding high-dynamic-performance and gain-flatness requirements for using analog-to-digital converters (ADCs) at high-IF input frequencies. High-IF ADCs are used in digital-communications systems: primary receive chain and predistortion circuits used in communications receivers and transmitters; high-speed instrumentation found in communications test systems; general broadband communications systems, satellites, and radar arrays. These ADCs are popular because they allow a system designer to reduce the number of down-conversion stages in the receiver signal chain and thereby reduce system costs. These devices generally yield excellent noise and distortion performance in the 2nd through 5th Nyquist regions.

The circuits discussed here convert a single-ended signal, which typically originates from a buffered demodulator circuit, to a differential signal to be fed to the high-IF ADC. These circuits use a wide-band transformer, termination resistors, and filter capacitors to accomplish this task. Also discussed is the best termination scheme for the transformer to maintain a high-speed ADC's high dynamic range, while minimizing the effects of gain peaking and bandwidth reduction.

Single-ended-to-differential conversion with a 200MHz transformer

The MAX1449 was chosen for demonstration and analysis of two potential input configurations. **Figure 1** shows a typical, AC-coupled, single-ended-to-differential conversion design using a wide-band transformer, such as the T1-1T-KK81 (200MHz) from Mini-Circuits®, which has 50Ω primary-side termination and a 25Ω/22pF filter network. In this configuration, a single-ended signal from a 50Ω impedance source is converted to a differential signal through the transformer. Primary-side termination into 50Ω allows excellent matching between the signal source and the transformer. However, this also means that there is a mismatch between the primary and the secondary sides of the transformer. The primary side looks into a combined impedance of 25Ω, while the secondary side experiences a large impedance mismatch with the 20kΩ input resistance of the ADC shunted by 22pF. This impacts the frequency response of the input network, ultimately affecting the frequency response of the converter. The transformer's nominal leakage inductance can range from 25nH to 100nH. Combined with an input filter capacitor of 22pF, this creates a disturbing resonance frequency

$$f_0 = \frac{1}{2}\pi \sqrt{L_{XFORMER} \text{ x } C_{IN}}$$

occurring between 110MHz and 215MHz, which results in undesirable gain peaking in this frequency range.

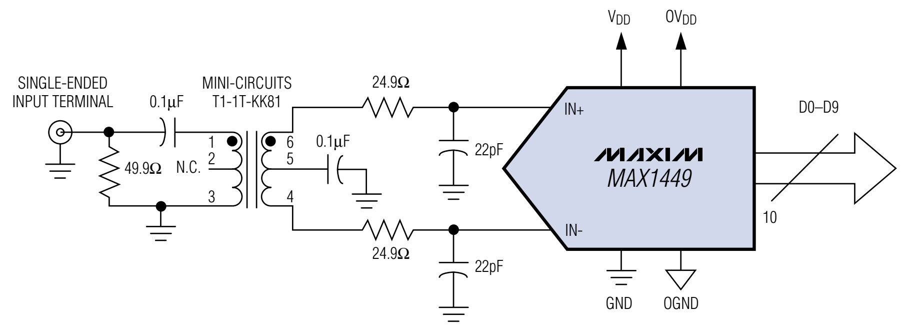


Figure 1. A single-ended signal from a 50Ω-impedance source is taken and converted to a differential signal through a 200MHz transformer.

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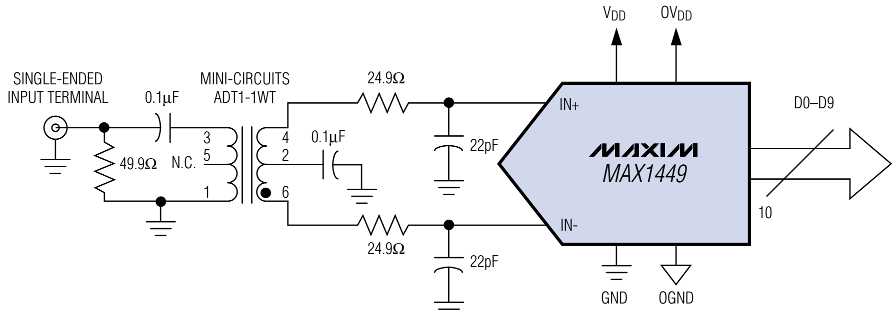


Figure 2. Similar to Figure 1, a single-ended signal is converted to a differential signal. However, this instance occurs through an 800MHz transformer, providing better performance.

Single-ended-to-differential conversion with an 800MHz transformer

Figure 2 depicts a similar AC-coupled configuration. However, this circuit was designed with a better performing wide-band transformer, such as Mini-Circuits' ADT1-1WT (800MHz), which includes a primary-side termination and a 25Ω/10pF filter network. Although, this transformer has an impedance of 75Ω, its lower leakage inductance yields a significantly better frequency response of -1dB up to 400MHz, compared to only 50MHz for the T1-1T-KK81.

Transformers—200MHz vs. 800MHz

Figure 3 shows the results for both termination schemes and selected filter network components and transformers. A significant improvement can be observed between the two graph plots. The input bandwidth plot for the T1-1T-KK81 transformer clearly shows a gain peaking of about 0.5dB between 90MHz and 110MHz, while the plot for the ADT1-1WT transformer remains flat within 0.1dB for frequencies up to 300MHz. The dynamic performance for this condition (ADT1-1WT transformer, 50Ω primary-side termination, and 10pF input filter capacitors at INP and INN) still yields an excellent SNR of 58.4dB for f_{IN} = 50MHz. Though Figure 3 only displays tested input frequencies of 80MHz and 260MHz (ADT1-1WT only), lab tests have proven that the gain remains flat within 0.1dB to input frequencies well beyond the 8th Nyquist region.

Matching the secondary-side impedance of the transformer can help to further enhance gain flatness. One way to do this is by using a secondary-side termination rather than a primary-side termination.

Particularly for high-IF applications, the location of the termination impedance is very important. Depending on the requirements for gain flatness and dynamic performance, an AC-coupled input signal can be terminated on either side of the transformer. Wide-band transformers are popular components that support a fast and easy way to convert a single-ended signal to a differential signal over a wide range of frequencies.

Primary-side termination

The MAX1124 (10-bit, 250Msps) was selected to demonstrate different termination schemes and their impact on gain bandwidth and dynamic performance of the ADC. Starting with a primary-side termination configuration (**Figure 4a**), a 50Ω impedance source signal is applied to

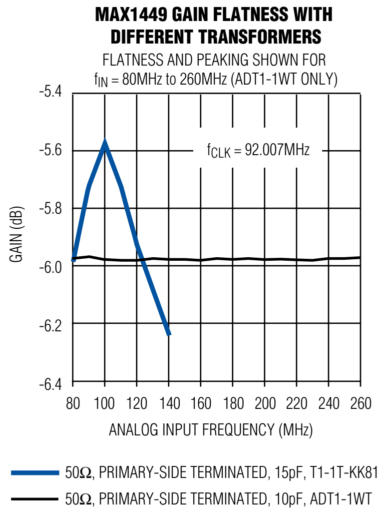
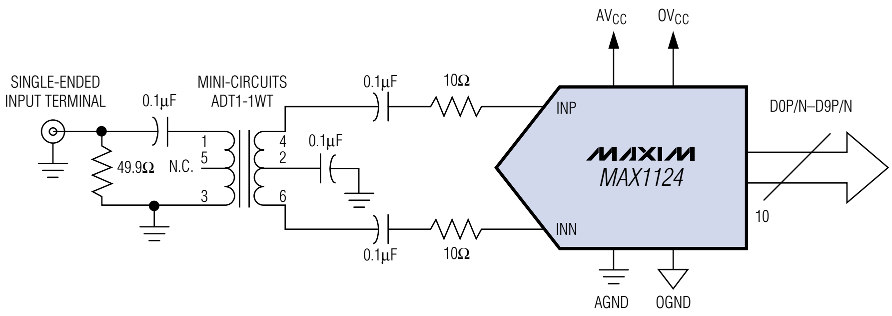
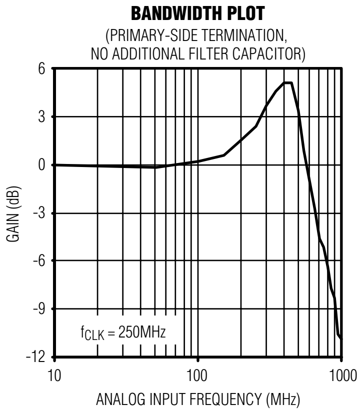


Figure 3. This graph illustrates the significant improvement in gain flatness obtained by using an 800MHz transformer vs. a 200MHz transformer.



(4a)

Figure 4. The well-balanced primary side of the transformer in this primary-side termination configuration (Figure 4a) is offset by an imbalance on the secondary side, producing maximum frequency peaking between 450MHz and 550MHz (Figure 4b).



(4b)

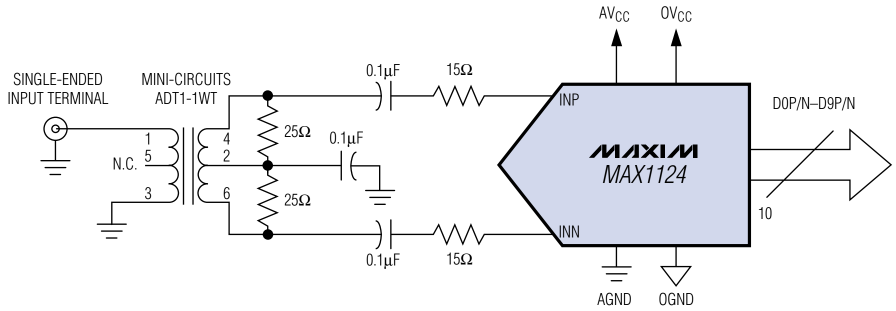
the ADT1-1WT transformer's primary side. Its secondary side connects directly to the input filter network (10Ω isolation resistor and input impedance of the ADC) of the MAX1124 through 0.1µF AC-coupling capacitors. No additional input filter capacitors are installed on INP and INN. In this configuration, the primary side of the transformer is well balanced, though the secondary side looks straight into the nominal 4kΩ/3pF input impedance of the ADC. The imbalance on the secondary side, combined with the leakage inductance of the transformer, generates a resonant circuit, which produces maximum frequency peaking between 450MHz and 550MHz (**Figure 4b**).

Secondary-side termination

To eliminate frequency peaking almost completely while driving the input differentially, the primary-side termination is removed and the 50Ω source impedance signal is instead applied to the ADT1-1WT with secondary-side termination. In this case, secondary-side termination means two 25Ω resistors are placed between the top/bottom and center taps of the transformer (**Figure 5a**). Followed by 0.1µF capacitors for AC-coupling purposes and an input filter network (15Ω series resistor and input impedance of the ADC), a well-balanced secondary-side signal is now applied to the converter. As with the configuration in Figure 4a, no additional input filter capacitors are installed on INP and INN. With this configuration, frequency peaking in the range of 450MHz to 550MHz can be completely eliminated. If required, more DC attenuation can be added by exchanging the 15Ω isolation resistors for 30Ω resistors. Although this approach makes the frequency response smoother, it causes a loss in frequency bandwidth (**Figure 5b**).

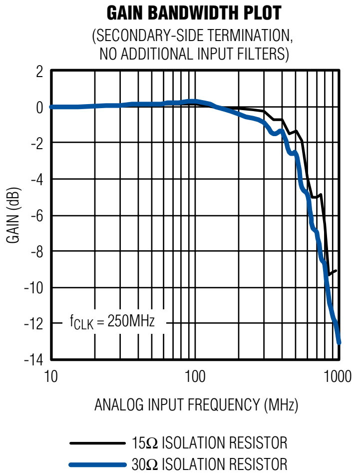
Conclusion

This article shows that not only the proper choice of passive components plays an important role in designing input networks for high-speed data converters, but the proper use of these components is significant as well. For instance, if gain flatness is an important factor in a system, care must be taken to avoid imbalances and resonances at the differential inputs of the converter to ensure that its true dynamic performance can be replicated. That both configurations do not use input filter capacitors might raise some concern about the impact of additional noise pickup at INP and INN. A brief analysis of this showed a degradation of the signal-to-noise ratio (SNR) between 0.2dB to 0.5dB. As long as wide bandwidth and stability over a wide range of frequencies (gain flatness) and a high dynamic performance are desired, most high-IF applications will accept this rather minor degradation in noise performance for a 10-bit data converter.



(5a)

Figure 5. A well-balanced secondary-side signal is applied to the converter (Figure 5a), completely eliminating frequency peaking in the 450MHz to 550MHz range. DC attenuation can be increased, making frequency response smoother, but this will cause loss in frequency bandwidth (Figure 5b).



(5b)

Selecting temperature sensors for system measurement and protection

A number of technologies are available for designers who need to measure temperature within a system. Thermistors, thermocouples, RTDs, and temperature-sensor ICs each have advantages and disadvantages in any given situation. This article compares the most popular temperature-sensing technologies and discusses the suitability of each for monitoring common targets such as PC boards, ambient air, and high-power circuits such as CPUs and FPGAs.

Temperature-sensing technologies

Sensors are often used within electronic systems to monitor temperature and provide protection from excessive temperature excursions. The most common technologies for use within systems are listed below.

Thermocouples are made by joining two wires of dissimilar metals. The point of contact between the wires generates a voltage that is approximately proportional to temperature. Characteristics include wide temperature range (up to 1250°C), low-cost, very low output voltage (on the order of 40µV per °C for type K), reasonable linearity, and moderately complex signal conditioning (cold-junction compensation and amplification). There are several thermocouple types, which are designated by letters. The most popular is type K. Maxim manufactures ICs (MAX6674 and MAX6675) that perform the signal conditioning functions for type-K thermocouples, simplifying the design task and significantly reducing the number of components required to amplify, cold-junction compensate, and digitize the thermocouple's output. Thermocouples are available in probes and with bare leads.

RTDs are essentially resistors (often made from platinum wire) whose resistance varies with temperature. Characteristics include wide temperature range (up to 750°C), excellent accuracy and repeatability, reasonable linearity, and the need for signal conditioning. Signal conditioning for an RTD usually consists of a precision current source and a high-resolution ADC. Cost can be high. RTDs are available in probes, in surface-mount packages, and with bare leads.

Thermistors are temperature-dependent resistors, usually molded from conductive materials. The most common thermistors have a negative temperature coefficient (NTC) of resistance. Characteristics include moderate temperature range (up to 150°C), low-to-moderate cost (depending on accuracy), poor but predictable linearity, and the need for some signal conditioning. Thermistors are available in probes, in surface-mount packages, with bare leads, and in a variety of specialized packages. Maxim manufactures ICs that convert thermistor resistance to digital form.

IC temperature sensors are complete, silicon-based sensing circuits with either analog or digital outputs. Characteristics include moderate temperature range (up to about 150°C), low cost, excellent linearity, and additional features like signal conditioning, comparators, and digital interfaces. Digital formats are numerous and include 3-wire and 4-wire (such as SPI™), 2-wire (I^2C™ and SMBus™), and single-wire (1-Wire®, PWM, frequency, and period). Note that signal conditioning, analog-to-digital conversion, and thermostatic functions all add costs to the other sensing technologies, but are normally included within sensor ICs. IC temperature sensors are available primarily in surface-mount packages.

Choosing the proper temperature sensor for system-measurement targets

Picking the right sensor technology begins with understanding the characteristics and requirements of the target whose temperature needs to be measured. Some common temperature-measurement targets are listed below and are summarized in **Table 1**.

PC board

Surface-mount sensors are best for PC board measurement. RTDs, thermistors, and IC sensors are available in surface-mount packages and temperature ranges that are compatible with sensing the temperature of a PC board. RTDs are quite accurate and produce highly repeatable measurements, but can be costly compared to thermistors and ICs. Thermistors are very nonlinear, but the nonlinearity is predictable. When used over a narrow tempera-

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Table 1. Optimum sensor types for system-temperature monitoring

Measurement Target	Best Sensor Types	Advantages	Disadvantages
PC Board	IC (analog)	Cost, linearity	—
	IC (digital)	Cost, digital output, linearity	—
	Thermistor	Cost	Nonlinearity
	RTD	Repeatability	Cost
Air	Thermistor	Cost, low thermal mass	Nonlinearity
	Thermocouple	Cost, low thermal mass	Signal conditioning (increases cost)
	RTD	Repeatability	Cost
	IC (analog or digital)	Cost, linearity	Difficult to isolate from PC board temperature
CPU, FPGA, Power Device, Module, etc. (measured under or near device)	IC (analog)	Cost, linearity	—
	IC (digital)	Cost, digital output, linearity	—
	Thermistor	Cost	Nonlinearity
	RTD	Repeatability	Cost
CPU, FPGA, Power Device, Module, etc. (contact)	Thermistor	Cost, low thermal mass	Nonlinearity
	Thermocouple	Cost, low thermal mass	Signal conditioning (increases cost)
	RTD	Repeatability	Cost
CPU, FPGA, Power Device, Module, etc. (with thermal diode)	IC (remote digital temperature sensor)	Linearity, digital output, response time, accuracy	—

ture range, they can often be linearized reasonably well with just an external resistor or two. If accuracy is not critical, thermistors can be inexpensive; but, precision thermistors can be moderately expensive. The system cost and complexity can increase significantly if linearization calculations or lookup tables must be used. ICs have excellent linearity and additional features, such as digital interface or thermostat functions. These features usually give them the edge over other sensor technologies in terms of system cost, design complexity, and performance when measuring PC board temperature.

One of the keys to measuring PC board temperature accurately is positioning the sensor in the right place. It is common to measure the temperature of a specific component or group of components, either to ensure that the temperature does not exceed the safe operating range, or to compensate for temperature-induced changes in a component's performance. When location of the sensor is critical, look for temperature sensors in small packages, such as SOT23s, that can be easily placed in the appropriate location without disturbing the layout. Digital outputs are useful when sensors need to be located in sites that may be electrically noisy or far from the other temperature-related circuitry.

Ambient air

Ambient-air temperature is difficult to measure because the sensor's temperature must be influenced by the air, but isolated from other components (PC board, power supply, CPU) that might be at a different temperature. Thermistors, thermocouples, and RTDs are available on long leads that isolate the sensing elements from the PC board temperature. If the leads are long enough, the sensing element will be at the ambient temperature, while the leads are connected to the PC board, which is probably at a different temperature. ICs are usually difficult to use for measuring ambient temperature because the best thermal path for an IC sensor is through its leads, which are at the same temperature as the PC board. If the PC board is not at ambient temperature (for example, if it contains components that dissipate enough power to raise its temperature), the IC will not measure ambient temperature. Note that even conventional IC packages, such as TO92s, that raise the IC sensor above the PC board conduct heat so well through their leads that the measured temperature is effectively equal to the PC board temperature. However, because they have additional system features, such as digital outputs or thermostat functions, IC temperature sensors are sometimes used for ambient-air temperature sensing. This is usually done by placing them on small "satellite" PC boards that are at ambient temperature. ICs are also available that help with signal conditioning of other types of sensors. These ICs include ADCs and amplifiers for RTDs, thermistor-to-digital converters such as the MAX6691, and thermocouple-to-digital converters such as the MAX6675 (**Figure 1**).

CPU, graphics processor, FPGA, power device, module, etc.

The temperature of a high-power component can often be measured with a surface-mount sensor (thermistor, IC, or RTD) near or under the device. If this is impractical, or if the device has a heat sink or some other surface that must be measured, sensors with long leads (thermocouples, RTDs, and thermistors) can be placed in contact with the surface to be measured. If the temperature to be measured is more than approximately 150°C, a thermocouple or RTD is the best choice. Near or above 750°C, thermocouples become the only choice.

CPU, graphics processor, FPGA, power device, module, etc. (with on-board thermal diode)

Some components, especially high-performance ICs such as CPUs, graphics processors (GPUs), and FPGAs, include a diode-connected bipolar transistor for sensing temperature. Because the thermal-sensing transistor is on the IC die, measurement accuracy is far better than with other sensing technique and thermal time constants are quite small.

Maxim manufactures several ICs that are specifically designed to accurately measure the temperature of a thermal diode and convert it directly to digital form. Some of these ICs measure a single thermal diode, while others measure as many as four. The signal levels are small (on the order of 200µV per °C), but still larger than those of thermocouples. Internal and external filtering, combined with reasonable care in layout, allow remote diode sensors to be widely used in electrically noisy equipment such a computers, servers, and workstations. Most of these ICs provide additional functions to protect the target IC, such as overtemperature alarm pins that can be used to shut the system down if temperature exceeds the safe operating limits of the target. An example of a remote diode sensor (MAX6642) is shown in **Figure 2**. This IC measures the thermal diode temperature and its own temperature up to 150°C, and also provides an overtemperature alarm output with a trip temperature that is programmable over the SMBus.

Conclusion

There are several different temperature-sensing technologies available for the system designer. The right technology depends on the target temperature to be measured, and also on other system requirements such as cost, circuit size, and design time. Maxim's comprehensive selection of temperature-sensing ICs can help the designer solve common temperature-measurement problems with excellent performance and low overall cost.

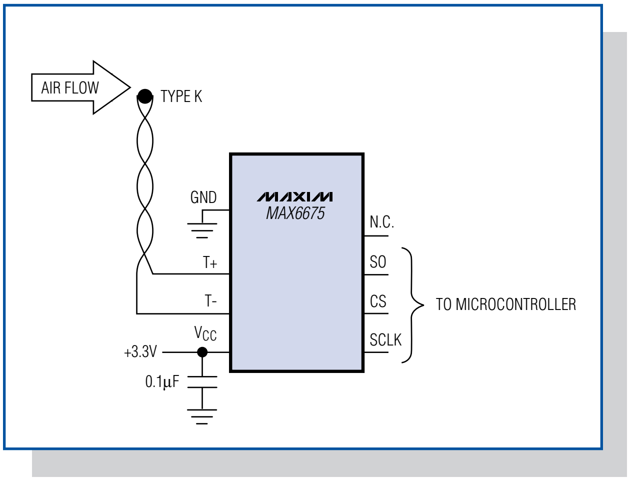

Figure 1. Using a thermocouple to sense ambient temperature, the MAX6675 provides cold-junction compensation and converts the output of the thermocouple directly to digital form.

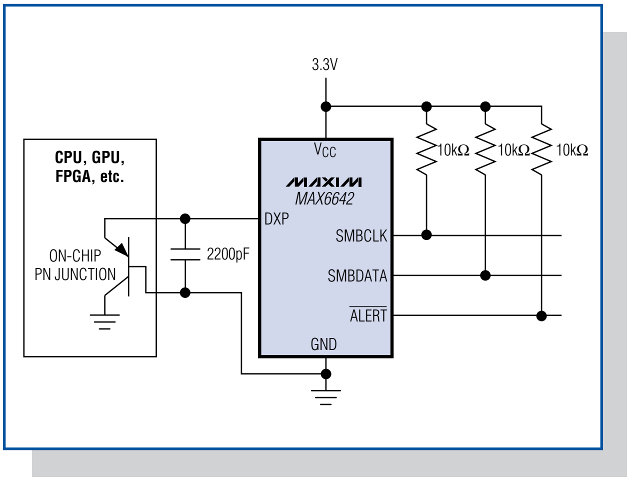

Figure 2. The MAX6642 is the world's smallest remote temperature sensor. It has an ALERT pin that may be used as an interrupt or as a system shutdown signal to protect the target IC from damage due to overheating.

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