DALLAS SEMICONDUCTOR MAXIM
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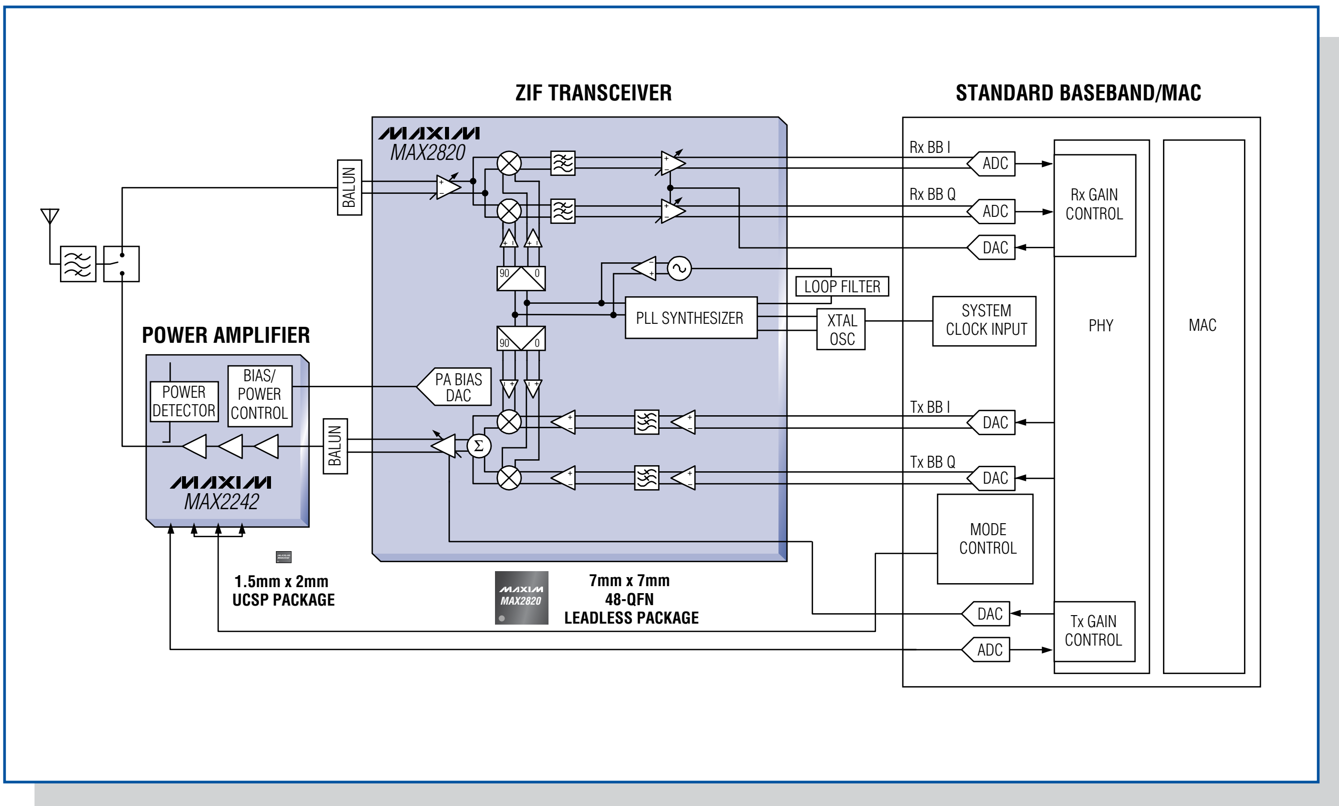

Maxim's complete IEEE 802.11b solution includes the MAX2820 single-chip ZIF transceiver and the MAX2242 linear power amplifier. (See article inside, page 12.)

News Brief

MAXIM REPORTS REVENUES AND EARNINGS FOR THE FIRST QUARTER OF FISCAL 2004 AND DECLARES QUARTERLY DIVIDEND

Maxim Integrated Products, Inc., (MXIM) reported net revenues of $310.2 million for its fiscal first quarter ending September 27, 2003, a 5.1% increase over the $295.0 million reported for the Company's last reported quarter, the fourth quarter of fiscal 2003. Net income for the quarter was $87.4 million, a 19.4% increase over the $73.2 million reported last year and a 6.9% increase over the $81.7 million reported for the fourth quarter. Diluted earnings per share were $0.25 for the first quarter, a 13.6% increase over the $0.22 reported for the same period a year ago and a 4.2% increase over the $0.24 reported for the fourth quarter of fiscal 2003.

During the quarter, cash and short-term investments increased $130.6 million after the Company repurchased 379,000 shares of its common stock for $15.5 million, paid dividends of $26.1 million, and acquired $23.0 million in capital equipment. Accounts receivable increased $4.2 million in the first quarter to $131.0 million due to the increase in net revenues, and inventories decreased $5.7 million to $115.4 million.

Gross margin for the first quarter remained consistent with the prior quarter, after inventory reserves were increased by $2.2 million. Research and development expense was $70.1 million or 22.6% of net revenues in the first quarter, compared to $67.2 million or 22.8% of net revenues in the fourth quarter of fiscal 2003. The increase in research and development expense in the first quarter was due to hiring additional engineers and increased expenses to support the Company's new product development efforts. Selling, general and administrative expenses increased slightly from $21.0 million in the fourth quarter to $21.4 million in the first quarter but decreased as a percentage of net revenues from 7.1% to 6.9%.

First quarter bookings were approximately $349 million, a 12% increase over the fourth quarter's level of $313 million. Turns orders received in the quarter were approximately $180 million, a 12% increase over the $161 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 in all geographic locations, with the greatest bookings improvement in the Pacific Rim region.

First quarter ending backlog shippable within the next 12 months was approximately $252 million, including approximately $233 million requested for shipment in the second quarter of fiscal 2004. The Company's fourth quarter ending backlog shippable within the next 12 months was approximately $227 million, including approximately $199 million that was requested for shipment in the first quarter of fiscal 2004.

Jack Gifford, Chairman, President, and Chief Executive Officer, commented: "We were pleased to see such a broad-based improvement in bookings this quarter, with 11 of our 14 business units seeing improved orders over last quarter. This is the third consecutive quarter of improved bookings, and bookings are at their highest level since the second quarter of fiscal 2001."

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 November 28, 2003 to stockholders of record on November 10, 2003."

Digital-to-analog converters (DACs) for high-performance communications

The generation of multiple carriers in UMTS, CDMA, and GSM systems mandates the use of DACs that provide the highest levels of dynamic performance. DACs for these applications must allow high operating frequencies and must supply superior SFDR, IMD, SNR, and ACPR performance. Also, the power amplifiers used in some of these applications benefit from DACs that correct power-amplifier nonlinearity through digital predistortion techniques. Finally, high-speed, high-dynamic-performance DACs are useful in communication systems that employ higher orders of quadrature amplitude modulation (QAM) as well as in applications that use direct digital synthesis (DDS).

Superior information bandwidths—required to support the exchange of digital information in modern communications systems—are achieved through a variety of modulation and encoding schemes. Such schemes demand greater dynamic performance in the transmitter's signal-processing chain. Applications such as UMTS, cdma2000™, and GSM/EDGE also call for greater dynamic performance as they approach the requirement of multicarrier generation from a single, signal-generating source.

UMTS requires up to four carriers per transmitter. For GSM/EDGE and cdma2000 applications, four to eight carriers may be desired for a single transmitter. The generation of multiple carriers requires substantially more dynamic range in the signal path. As the generator of this complex modulation waveform, the DAC has become the performance-limiting element in the signal path.

UMTS base stations are now introducing multicarrier signal generation. These base stations, therefore, require DACs that meet the UMTS standard with adequate margins. Also helpful in this application are DACs that correct power-amplifier nonlinearity by introducing digital predistortion to the signal. That characteristic alone can increase the DAC's required signal bandwidth by a factor of three to five. Thus, the signal bandwidth necessary for four UMTS carriers (as high as 100MHz) demands higher sample rates and higher analog-output frequencies. The 500Msps update rate of the MAX5888 is designed for such applications. This device delivers the performance defined above and surpasses the UMTS specifications for up to four UMTS carriers.

The accuracy and signal bandwidths of such DACs also support communications systems that employ higher orders of QAM. Modulations up to QAM256 require wider dynamic ranges to accurately generate these modulated waveforms.

Transmit waveforms in GSM/EDGE systems demand even more dynamic performance from the DAC. The generation of multicarrier signals pushes SFDR, IMD, and SNR values to extremes. For those demanding applications, the MAX5195 offers the highest SFDR, SNR, and IMD specifications in the industry. Generating instrumentation signals in DDS applications also requires DACs with exceptional dynamic performance; both the MAX588X family (MAX5886/MAX5887/MAX5888) and MAX5195 are well suited for that application.

Advantages of the MAX588X family and the MAX5195

DACs of the MAX588X family offer excellent dynamic performance at low levels of power dissipation with a maximum industry-leading sample rate of 500Msps. For a 50MHz output frequency and 400Msps sample rate, MAX5888 SFDR exceeds 67dBc. Also excellent is the SNR (-155dB/Hz) and 2-tone IMD (-72dBc) at output frequencies of 80MHz. That performance is achieved at a 500Msps sampling rate, from a single 3.3V power supply, and with low power dissipation (235mW).

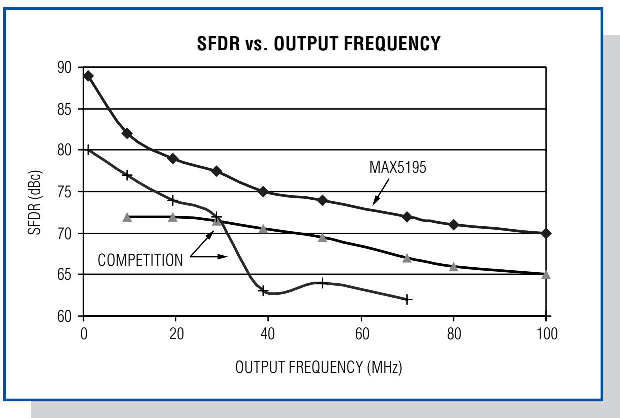

Figure 1. This SFDR graph compares the MAX5195 to the best available competitive devices for a range of output frequencies.

cdma2000 is a registered certification mark of Telecommunications Industy Association.

Digital data is applied through an LVDS interface, which has two beneficial attributes: an LVDS-based logic family supports 500Msps data rates very effectively, and the digital signals' differential-input swings help to reduce system-level noise at the digital interface. Such considerations are important when designing wide-dynamic-range systems.

The dynamic performance of the MAX588X family is exceeded only by that of the new MAX5195, seen in **Figure 1**, which surpasses that of any other device on the market. Besides exemplary SFDR performance, its SNR leads the industry at -160dB/Hz and its two-tone IMD (87dBc at 32MHz output frequency) is unbeaten. The digital interface of this 14-bit DAC incorporates LVPECL, which, like LVDS, reduces the system-level noise associated with high-speed digital data transmission.

All these DACs come in small QFN packages: a 68-pin version for the MAX588X family and a 48-pin version for the MAX5195. The leadless QFN package combines small physical size (down to 7mm x 7mm) with excellent thermal and electrical characteristics. The exposed paddle provides unusually low ground impedance that reduces the spurious output signals even further.

Additional applications

How else might these DACs be used? Consider again a multicarrier UMTS application that includes digital predistortion techniques. Such an application combines demanding dynamic performance with 100MHz signal bandwidths. The UMTS mask for spurious emissions requires that spurious products within a 1MHz measurement bandwidth be no greater than -58dBc. **Figure 2** illustrates the spectral output for a single tone at 60MHz and a sample rate of 300Msps. A part such as the MAX5888, with its margin over a desired 100MHz bandwidth (more than 8dB greater than mask requirements), allows relaxed margins elsewhere in the transmitter signal chain. A spread-spectrum signal further reduces the spurious outputs, providing even more margin to the specification.

Another important specification for this application is the adjacent-channel power ratio (ACPR). **Figure 3** shows a single-carrier UMTS spectral response with the carrier centered at 60MHz. One can see that the ACPR mask levels for first and second adjacent channels (-45dBc and -50dBc) are met with a comfortable margin in excess of 25dB.

Figure 4 illustrates ACPR performance for the MAX5888 in a four-carrier UMTS application—probably the most demanding requirement for any ACPR measurement. The MAX5888 (which offers the highest performance available for this application) meets both the -45dBc and -50dBc mask requirements with a margin in excess of 20dB.

CDMA carrier generation requires similar performance measurements. The dominant specification for this architecture is the spurious emissions mask, which includes the ACPR mask requirements. Mask levels for this standard vary, depending on the frequency band and the transmitter's output-power level. **Figure 5** depicts an eight-

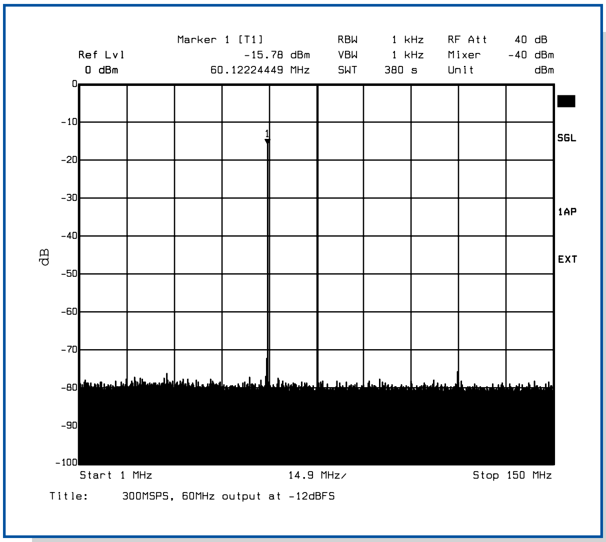

Figure 2. Typical MAX5888 SFDR for a 60MHz output frequency is shown over a 100MHz bandwidth.

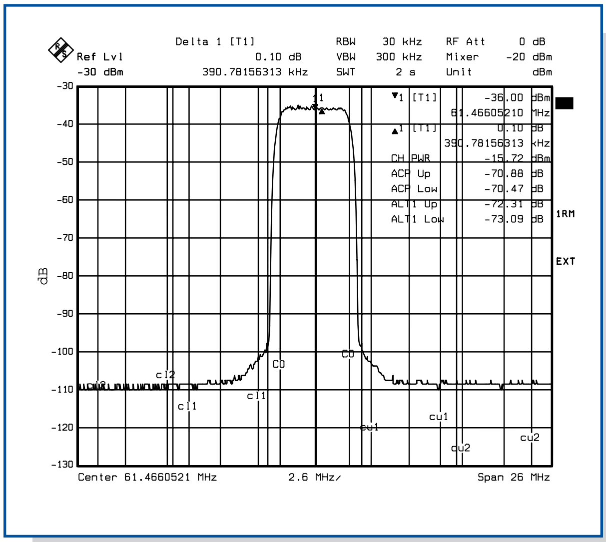

Figure 3. The UMTS ACPR spectral response of the MAX5888 is shown for a single, fully loaded carrier at a 61MHz output frequency.

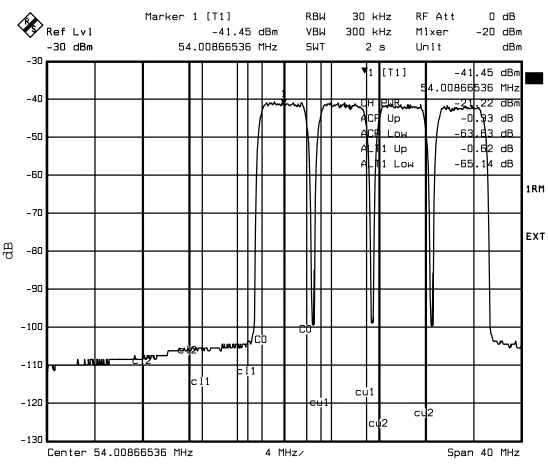

Figure 4. The UMTS ACPR spectral response of the MAX5888 is shown for a test case, with four fully loaded carriers centered at 61MHz.

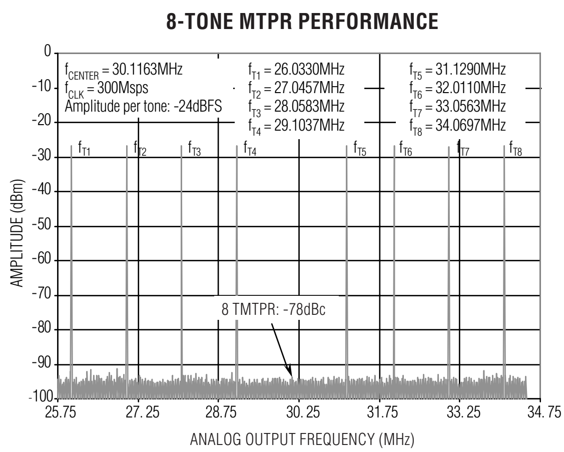

Figure 5. This eight-carrier test-vector spectral plot illustrates the MAX5888's superior multitone IMD performance for CDMA applications. The selected output frequency is centered at 30MHz.

tone system in which the tones are separated by 1MHz at an IF frequency centered at 30MHz. For the various bands' most demanding mask combination, the spurious-emission mask level is -59dBc at an assumed transmitter output-power level of 40W. For this worst-case sinusoidal test-simulation case, the MAX5888 meets CDMA mask requirements with a margin of 19dB.

Among the currently popular wireless-communications protocols, GSM/EDGE-based architectures impose the greatest dynamic-range requirements. Limitations in DAC performance have made multicarrier transmitters impractical in the past, but the MAX5195 lifts that restriction, as shown by its IMD performance for four sinusoid tones with 1MHz spacing between the tones (**Figure 6**). The individual tones have carrier levels of -18dBFS to avoid signal clipping in the DAC's output waveform. This spectral plot covers a 25MHz window, with the tones centered at 48MHz.

The IMD mask limit of -70dBc is easily met with an 8dB margin by the MAX5888. A smaller back-off in output level (only -15dB from full scale) improves performance by 6dB. The MAX5888's -160dB/Hz SNR also leads the industry, making it the highest performance DAC available for demanding, multicarrier GSM-/EDGE-based applications.

Conclusion

Thus, two types of DACs from Maxim offer new options for communication-system designers in the arena of multicarrier signal generation. The MAX5886/MAX5887/MAX5888 family combines excellent dynamic performance with low power dissipation and low-noise system-level operation. The MAX5195 enables multicarrier GSM generation by offering the highest available dynamic range at sample rates up to 260Msps.

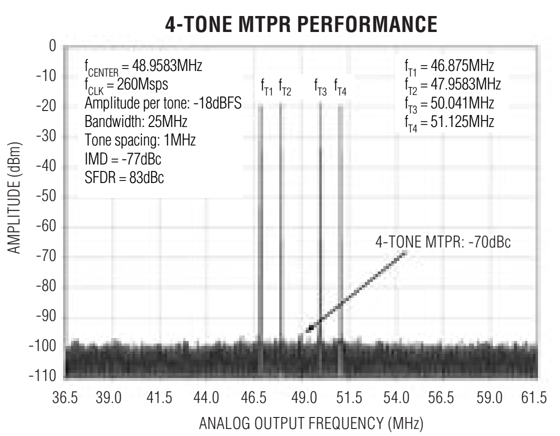

Figure 6. This four-carrier test-vector spectral plot illustrates the MAX5195's superior multitone IMD performance for GSM applications. The output frequency is centered at 48MHz.

Powering high-performance ASICs and microprocessors

Today's highest performing ASICs and microprocessors can consume more than 150W. With supply voltages of 1V to 1.5V, the required current for these devices can easily exceed 100A. Using multiphase DC-DC converters makes the task of providing power to these devices more manageable.

Currently, scalable power-supply controllers are available that allow the designer to choose the number of phases for specific DC-DC converters. On-board PLL-based clock generators allow the controllers to be synchronized; scalability allows several controllers to be paralleled and synchronized.

Multiphase topologies

While no hard-and-fast power limit exists for a single-phase buck regulator, the advantages of designing with multiphase converters become apparent as load currents rise above 20A to 30A. These advantages include: reduced input-ripple current, substantially decreasing the number of input capacitors; reduced output-ripple voltage due to an effective multiplication of the ripple frequency; reduced component temperature achieved by distributing the losses over more components; and reduced-height external components.

Multiphase converters are essentially multiple buck regulators operated in parallel with their switching frequencies synchronized and phase shifted by 360/n degrees, where n identifies each phase. Paralleling converters makes output regulation slightly more complex. This problem is easily solved with a current-mode control IC that regulates each inductor current in addition to the output voltage.

Input-ripple current

The key issue designers face when selecting input capacitors is input-ripple-current handling. Input-ripple current is substantially reduced by using a multiphase topology—the input capacitor of each phase conducts a lower amplitude input-current pulse. Also, phase shifting increases the effective duty cycle of the current waveform, which results in a lower RMS ripple current. The ripple-current levels shown in **Table 1** demonstrate the ripple-current reduction and the input-capacitor savings.

High-k dielectric ceramic capacitors provide the best ripple-current handling and the smallest PCB footprint. Ceramic devices housed in an 1812 form factor exhibit ripple-current ratings of 2A to 3A per capacitor. Electrolytic capacitors are a good choice for cost-sensitive designs.

Output-ripple-voltage reduction

Accuracy requirements of <2% are commonly required for core voltage supplies. For a 1.2V supply, this translates to a ±25mV output-voltage window. A technique for using the output-voltage window more effectively is called active voltage positioning. At light loads, the converter regulates the output voltage above the midpoint of the output-voltage window and, at heavy loads, regulates the output voltage below the midpoint of the output-voltage window. In the case of a ±25mV window, regulating at the high end (low end) of the range during light loads (heavy loads) allows the entire output-voltage window to be used for a step-load increase (decrease).

Large load-current steps require both extremely low-ESR capacitors to minimize transients and large enough capacitance to absorb the stored energy of the main inductor during a step-load decrease. Organic polymer chemistries have improved low-ESR tantalum capacitors. Polymer capacitors provide the most capacitance with the lowest ESR. Ceramic capacitors have excellent high-frequency characteristics, but the total capacitance per device is one-half to one-quarter that of tantalum and polymer capacitors. Typically, ceramic capacitors are, therefore, not the best choice as output capacitors.

Low-side MOSFETs

A 12V to 1.2V converter requires 90% on-time from a low-side MOSFET; conduction losses dominate switching losses in this case. For this reason, two or three MOSFETs are often paralleled. Operating several MOSFETs in parallel effectively reduces $R_{DS(ON)}$ and thus lowers conduction losses. When the MOSFET is turned off, inductor current continues to flow through the MOSFET's body diode. Under this condition, the MOSFET drain voltage is essentially zero, reducing switching losses substantially. Table 1 shows the losses for several multi-phase configurations. Note that the low-side MOSFET's total losses decrease as the number of phases increases, thus reducing the MOSFET's temperature rise.

High-side MOSFETs

With a duty cycle of 10 percent, high-side MOSFET-switching losses dominate conduction losses. Because the high-side MOSFET conducts for a small percentage of time, conduction losses are less significant. Thus, low on-resistance is not as important as low switching losses. During the switching intervals (both t_{ON} and t_{OFF}), the MOSFET has to withstand voltage and conduct current. The product of this voltage and current determines the MOSFET peak-power dissipation; therefore, the shorter the switching interval, the lower the power dissipation. When selecting a high-side MOSFET, choose a MOSFET with low gate charge and gate-drain capacitance, both of which are more important than low on-resistance. Table 1 illustrates how the total MOSFET losses decrease as the number of phases increases.

Inductor selection

The inductor value determines the peak-to-peak ripple current. Allowable ripple current is typically calculated as a percentage of maximum DC-output current. In most applications, an optional ripple current is 20% to 40% of the maximum DC-output current.

At low core voltages, the inductor current cannot decrease as quickly as it can increase. During a load decrease, the output capacitor can be overcharged, causing an over-voltage condition. By using an inductor of smaller value (allowing higher ripple current—closer to 40%), a lower amount of stored energy is transferred to the output capacitor, which minimizes voltage surge.

Thermal design

Table 1 provides estimates of heat-sinking requirements for the number of phases used. In a forced-convection cooling system that can provide 100LFM to 200LFM, a single-phase design would require a fairly large heatsink to achieve a 0.6˚C/W thermal resistance. In the four-phase design, the thermal resistance can increase to 2˚C/W. This thermal resistance is easily achieved without a heatsink and 100LFM to 200LFM airflow.

Design example

Figure 1 illustrates the MAX5038 configured as a four-phase DC-DC converter. The MAX5038 master remote-voltage-sense input (VSP to VSN pins) provides a signal (DIFF) to both the master and the slave EAN inputs, enabling parallel operation. The MAX5038 master also provides a clock (CLKOUT) to the MAX5038 slave controller. By floating the PHASE pin, the slave locks on to the CLKIN signal with a 90˚ phase shift. The error amplifier also performs the active voltage-positioning

Table 1. Comparison of critical parameters and the number of phases used for the design of synchronous buck regulators. Example is a 12V to 1.2V, 100A buck regulator.

	Number of Phases			
	1	**2**	**4**	**8**
Current per phase	100A	50A	25A	12.5A
Input capacitor, 3A rated				
Ripple current	31.6A	22A	15.8A	11.2A
Number required	11	8	6	4
H/S MOSFET				
RMS ripple current	31.6A	15.8A	7.9A	3.9A
Package size	DPAK	DPAK	SO-8	SO-8
Number required	2	2 (1/ph)	8 (2/ph)	8 (1/ph)
Power dissipation (each)	22W	1.8W	0.32W	0.22W
Total power dissipation	4.4W	3.6W	2.5W	1.76W
L/S MOSFET				
RMS ripple current	94.8A	47.4A	23.7A	11.9A
Package size	DPAK	DPAK	SO-8	SO-8
Number required	3	2 (1/ph)	8 (2/ph)	8 (1/ph)
Power dissipation (each)	6W	12W	1.4W	1W
Total power dissipation	18W	24W	11.2W	8W
C_{OUT} 470µF, 10mΩ				
Number required	7	7	7	7
V_{SS} ripple	22mV	11mV	5mV	1mV
Heatsink capacity	0.6°C/W	1°C/W	2°C/W	4°C/W
Estimated efficiency	69	77	85	89

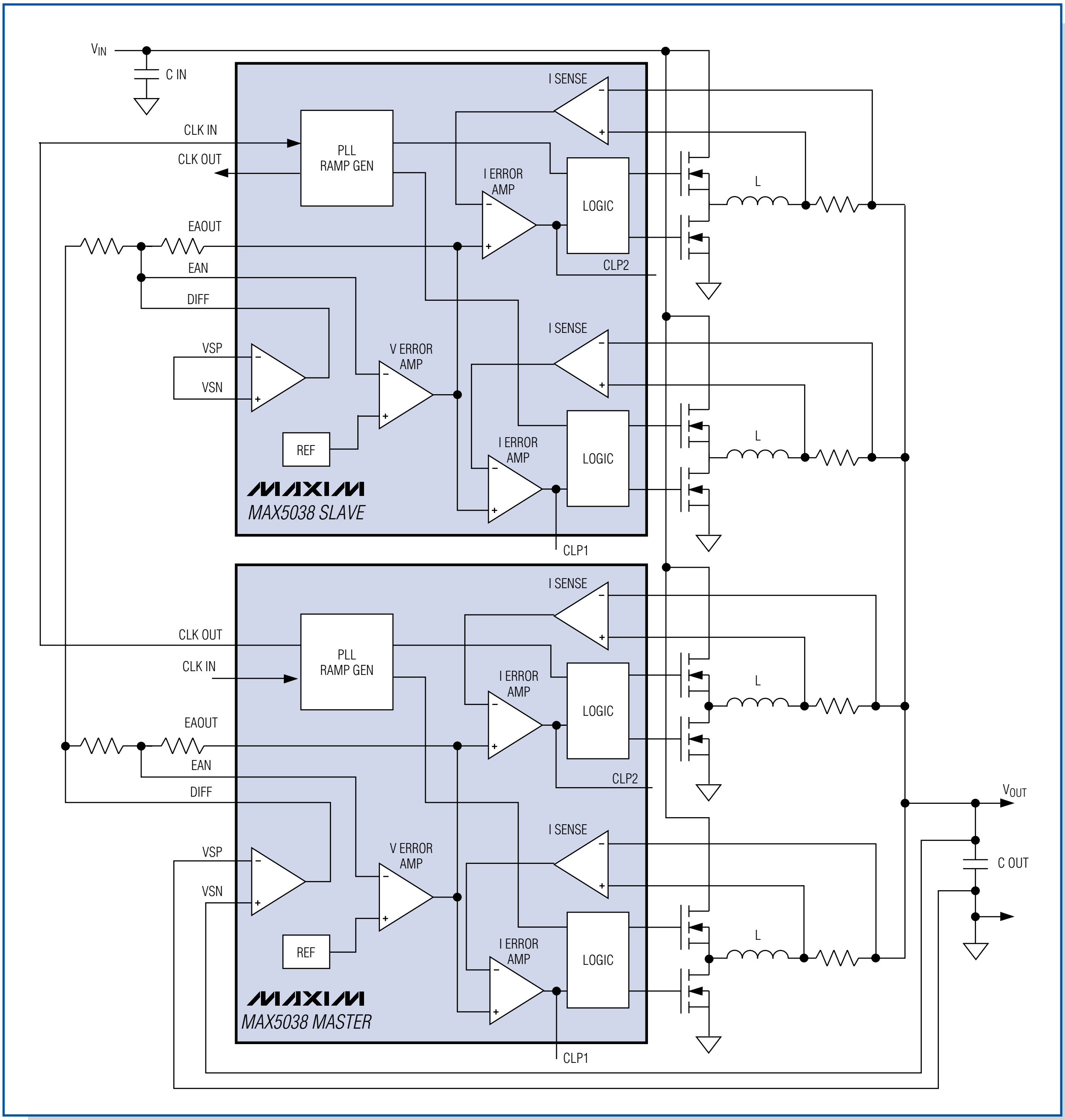

Figure 1. A four-phase example using two MAX5038s. The master performs the remote voltage-sense function and the clock-generation function, which the slave controller uses to increase output current and synchronize the operating frequency.

function by setting the gain of the voltage-error amplifier. Using precision gain-setting resistors ensures accurate load sharing. The output of the voltage-error amplifier (EAOUT) programs the load current of each phase. Compensation (not shown) is provided for each current loop at the CLP1 and CLP2 pins, providing a very stable output for most line and load conditions.

Conclusion

Multiphase synchronous DC-DC converters effectively power ASICs and processors that require 1V to 1.5V at 100A or more. They solve basic problems involving capacitor ripple current, MOSFET power dissipation, transient response, and allowable output-ripple voltage.

Extended-range temperature-sensing ICs

Measuring at silicon's limits

Using remote temperature sensors to monitor die temperature of high-performance microprocessors and graphics processors is a common technique for managing power and thermal operating characteristics. As clock speeds, circuit densities, and power levels increase, die operating temperatures can exceed the limits of conventional temperature sensors. New temperature sensors can measure temperatures previously beyond the range of older devices. This article discusses extended-range temperature sensors, their theory, and applications.

Digital, remote temperature sensors that use an external bipolar transistor as the sensing element are widely relied on for monitoring die temperature on high-speed, high-performance ICs like microprocessors, graphics processors, and FPGAs. Monitoring temperature accurately is critically important for ensuring best performance and protecting against catastrophic failure. A temperature monitor lets the system perform fan control and clock-throttling functions to keep high-performance ICs within the necessary operating temperature ranges. At higher temperatures, it can be used to shut the system down to prevent failure. As performance and power levels increase, the remote temperature-monitoring function becomes even more important, yet is more difficult to perform.

Virtually all conventional digital temperature-sensor ICs have upper measurement limits of less than 128°C; many are limited to 100°C. Frequently, a conventional temperature range is sufficient. However, there are times when it is important to measure temperatures as high as 150°C. In such cases, extended-range temperature sensors are necessary.

Sensing extended temperatures

The typical digital temperature-sensor IC represents temperature data using one sign bit and seven magnitude bits with an LSB of 1°C and an MSB of 64°C. Although some digital sensors have a few additional bits to express temperature with more resolution, the 64°C MSB limits the highest measured temperature to less than 128°C.

An extended-range temperature sensor can measure values well above this 128°C limit—often as high as 150°C. The most convenient way of performing this task is by providing an MSB with a weight of 128°C. In this case, the temperature data range extends to 255°C, which is well beyond the useful range as it is unlikely that temperatures over 127°C will be encountered. Accuracy degrades rapidly at temperatures above approximately 150°C because of the limitations in semiconductor junctions used to measure temperature.

The maximum operating temperature for some high-power ICs depends on clock speed, process, device package, and various design factors. Often, signal integrity degrades with increasing temperature until the circuit no longer meets its specifications. In many CPUs and graphics processors, this happens around 100°C; but in some high-performance circuits, normal operation can extend to 145°C. If the device can function properly at an extended temperature, accurately measuring the temperature is important for keeping it within the correct operating range. Since the absolute maximum temperature of the die is near the top of this range, it is even more critical to monitor temperature to avoid failure and subsequent shutdown (**Figure 1**).

In some high-performance processors, the physics of the thermal diode adds an "offset" to the measured temperature. In other words, the measured temperature can be significantly higher than the real temperature. In this case, the temperature sensor needs to measure *apparent* temperatures that are much higher than the normal operating range. Although the measured temperature might be 150° or higher, the diode's real temperature can still be within the processor's normal operating temperature range.

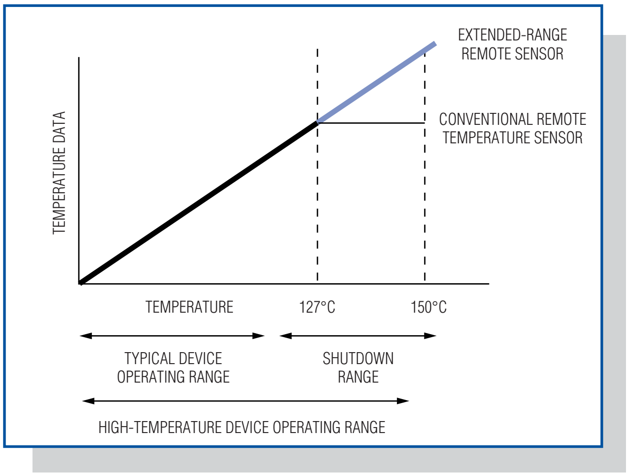

Figure 1. Extended-range remote temperature sensors can monitor high-performance devices through their full operating ranges.

Remote temperature-sensing basics

The most common approach to measuring temperature with a remote-diode temperature sensor forces two different currents through the diode, typically with a current ratio of about 10:1. (The diode is not a two-lead device like a 1N4001. Instead, it is a diode-connected bipolar transistor. The ideality factor of a two-lead diode is incompatible with remote-diode temperature sensors.) The diode's voltage is measured at each current level and the temperature is calculated based on the equation,

$$V_H - V_L = n\frac{kT}{q}\left[ln\ \frac{I_H}{I_L}\right]$$

where:
I_H is the larger diode bias current
I_L is the smaller diode bias current
V_H is the diode voltage caused by I_H
V_L is the diode voltage caused by I_L
n is the ideality factor of the diode
k is Boltzmann's constant (1.38 x 10^{-23}joules/°K)
T is the temperature in °K
q is the charge of an electron (1.60 x 10^{-19}°C)

If $\frac{I_H}{I_L}$ = 10, this can be simplified to:

$$V_H - V_L = 1.986 \times 10^{-4} \times nT$$

The term "n" is called the ideality factor and is process-dependent. The value is quite close to 1.0 for most transistors. For example, Pentium® III microprocessors have an ideality factor of about 1.008, while Pentium IV microprocessors are about 1.002. A remote-diode temperature sensor generates currents with precise ratios, measures the resulting voltages, and then scales and level-shifts the voltage measurement to produce temperature data. The internal analog-to-digital converter (ADC) must be able to accurately measure small voltages with rather large common-mode values; a 1°C temperature change corresponds to approximately 200µV.

An extended-range temperature sensor is similar to a conventional sensor, but with a slightly larger ADC input-voltage range to accommodate the larger voltage differentials between the low and high current levels. Also, the temperature data must be organized differently. Maxim's extended-range temperature sensors add a higher-weighted MSB to permit temperature measurements above 128°C. This is usually done by replacing the sign bit with the larger MSB.

To produce a reliable, accurate, extended-range remote-diode temperature sensor, precise manufacturing test techniques must be employed to trim the sensor and verify its accuracy. Maxim's proprietary thermal-management test systems measure the temperature of the sensor and the thermal diode and trim the sensor's internal circuitry for accuracy that is unmatched in the industry.

Remote temperature sensors measure to 150°C

Maxim's first extended-range remote temperature sensor was the MAX6627, introduced in 2001. The MAX6627 is unique among remote temperature sensors because it has a 3-wire (clock, serial data out, and chip select) digital interface. It is available in the small, 8-pin SOT-23 package, which allows it to be located near critical components.

In 2003, Maxim introduced the MAX6646/MAX6647/MAX6649, three extended-range remote temperature sensors with a 2-wire, I^2C^{TM}-/SMBus™-compatible interface, which makes them particularly well suited for desktop, notebook, and server applications. These sensors have 1°C accuracy up to 145°C (**Figure 2**), making them the world's most accurate extended-range temperature sensors. They are pin-compatible with the industry-standard MAX6692, and are register-compatible as well. However, at 128°C and above, the temperature data registers have an additional data bit to allow higher temperature measurements. These sensors also include features such as thermal comparator outputs to indicate over- and undertemperature conditions, which are useful for monitoring and protecting high-performance ICs.

Another new extended-range sensor introduced in 2003 is the MAX6642 (**Figure 3**), the smallest extended-range temperature sensor available with an SMBus interface. It is packaged in a 6-pin TDFN with a 3mm x 3mm footprint of only 0.8mm thickness. Accuracy is guaranteed within ±1°C from 60°C to 100°C, and ±3.5°C from 100°C to 150°C.

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SMBus is a trademark of Intel Corporation.

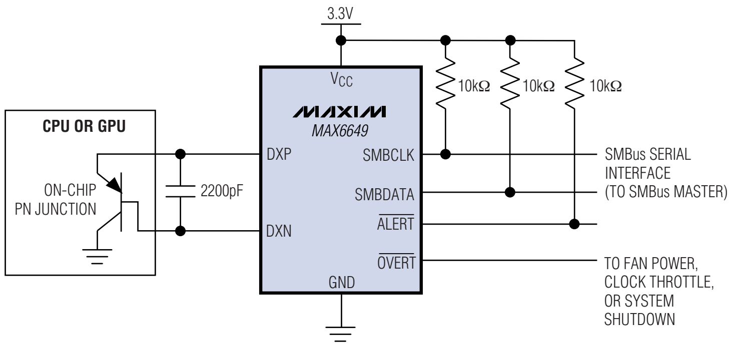

Figure 2. The MAX6649 measures thermal diodes on CPUs or graphics processors with 1°C accuracy from 60°C to 145°C. Temperatures up to 150°C can be measured with reduced accuracy.

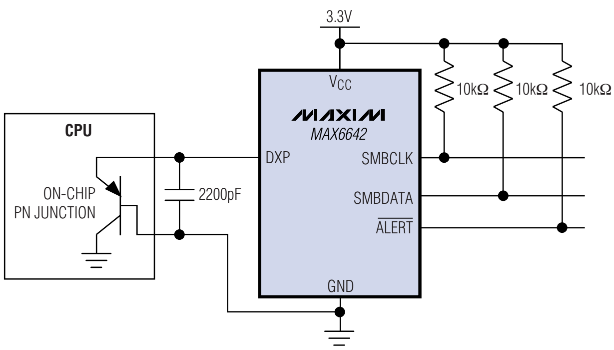

Figure 3. The MAX6642 is the world's smallest remote temperature sensor, measuring temperatures up to 150°C.

Summary

Although extended-range remote temperature sensors are new to the market, their need in a variety of current and future systems is clear. Maxim is committed to supplying the highest precision extended-range sensors in the industry and will continue to introduce innovative extended-range products that keep pace with emerging system requirements.

A similar article appeared in the January, 2004 issue of ECN.

802.11b WLAN transceiver shrinks circuit board and bill of materials

IEEE 802.11b wireless networks have become a key element of enterprise networks. To serve this fast-growing, emerging market, Maxim developed a complete RF solution (RF transceiver and power amplifier) that meets the requirements of the IEEE 802.11b WLAN (wireless local area network) standard.

Wireless networks provide convenient access to network resources for workers carrying portable computers and handheld devices, and for guests or temporary workers. Those networks are finding wide application in public environments such as hotels, airports, and coffee shops. They also provide a cost-effective alternative to relocating physical Ethernet jacks in environments where facilities are moved or changed frequently.

The MAX2820 and MAX2821 are single-chip zero-IF (intermediate-frequency) transceivers designed for 802.11b (11Mbps) applications operating in the 2.4GHz to 2.5GHz ISM (industrial-scientific-medical) band. The transceivers are nearly identical, except that the MAX2821 provides low-power shutdown and analog-voltage reference-output, while the MAX2820 does not. The transceivers include all circuitry required to implement an 802.11b RF-to-baseband transceiver solution, providing a fully integrated receive path, transmit path, VCO, frequency synthesis, and baseband/control interface. To complete the radio front-end solution, only an 802.11b dedicated PA like the MAX2242, an RF switch, an RF BPF (bandpass filter), and a small number of passive components are needed. The devices are suitable for the full range of 802.11b data rates (1Mbps, 2Mbps, 5.5Mbps, and 11Mbps), and also the higher rate 22Mbps PBCC™ (Packet Binary Convolutional Code) standard from Texas Instruments. The MAX2820 and MAX2821 are available in the very small, 7mm x 7mm, 48-pin QFN/thin QFN packages.

The MAX2820-MAX2242 chipset complements Maxim's capabilities in other wireless areas, including cdma2000/W-CDMA chipsets, multimode transmitter ICs for GSM/GPRS, and enhanced data rates for global evolution (EDGE), zero-IF (ZIF) direct satellite receivers and transmitters.

PBCC is a trademark of Texas Instruments Incorporated.

The ZIF transceiver

The homodyne (ZIF) approach used in today's highest performing solutions results in a typical receive sensitivity of -87dBm at 11Mbps (-97dBm Rx sensitivity at 1Mbps) with Maxim's reference designs. This sensitivity is 2dB to 3dB better than other homodyne solutions and 1dB to 2dB better than other heterodyne solutions.

The surface acoustic wave (SAW) filter from a heterodyne transceiver might appear to provide an advantage in power consumption, because passive filters seem to allow lower supply currents. One must not forget, however, that heterodyne architectures need an RF mixer with additional power gain to compensate for the SAW filter's insertion loss. Active filters integrated within the transceiver are attractive as they allow a very low, 4.5dB worst-case noise figure for the whole receiver chain at a maximum gain condition (34dB at minimum gain condition). The on-chip-receive low-pass filters provide the necessary steep filtering that attenuates the out-of-band (>11MHz) interfering signals to sufficiently low levels, thus preserving receiver sensitivity.

Maxim's RF BiCMOS™ (Bipolar Complementary Metal Oxide Semiconductor) process allows the MAX2820 to achieve low power consumption without sacrificing the high performance demanded by the end customer. Because this part employs a ZIF receiver and transmitter architecture, it is best suited to respond to the 802.11b market's continuing demand for reduced prices. The MAX2820's ZIF architecture attains the suppression of a transmit-and-receive IF SAW filter, saving the cost and design space of an external SAW filter. The entire RF front end with the MAX2820 and a MAX2247 PA only needs 4 inductors, 33 capacitors, and 4 resistors. A MAX2820 802.11b solution, with MAC/baseband DSP included, is easily laid out in a 20mm x 40mm form factor (26.5mm x 12mm for the RF only).

The MAX2820 receive-path gain is varied through an external voltage applied to the RX_AGC pin. The continuous variable-gain control range in the I and Q sections is typically 70dB. The differential, 100Ω input-impedance front-end LNA (low-noise amplifier) is easily matched using a 2:1 balun. The LNA also offers a 30dB gain step. In most applications, the LNA-gain select-logic input is connected directly to a CMOS output of the baseband IC, which controls the LNA gain based on the detected signal amplitude.

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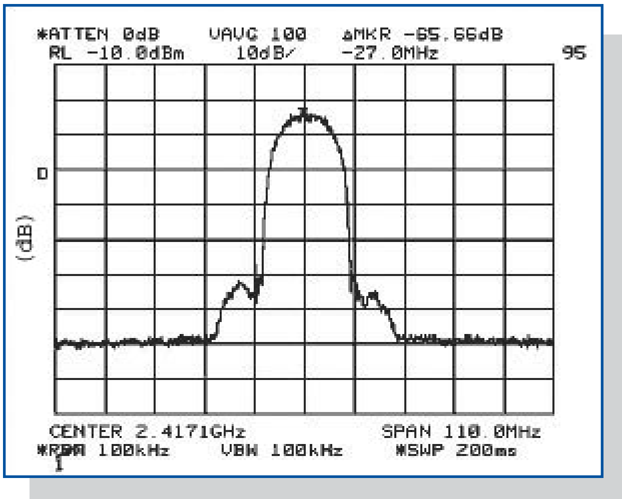

Figure 1. The MAX2820 transmitter output spectrum offers low adjacent-channel power.

When in the receive mode, the MAX2820 consumes just under 85mA of current with a 2.7V supply. The MAX2820 transmitter RF outputs have a high-impedance differential configuration directly connected to the driver amplifier. The outputs are essentially open collector with an on-chip inductor connected to V_{CC}. The power-amplifier driver outputs require external impedance matching and differential-to-single-ended conversion. The balanced 20Ω-to-single-ended-50Ω conversion is achieved through use of a low-cost, off-chip balun transformer available from Murata or Toko.

The transmit gain of the MAX2820 is controlled by an external voltage at the TX_GC input, offering a 30dB gain-control range. At maximum gain, the power delivered at the balun transformer output is +2dBm for an 11Mbps data rate, with -37dBc first side-lobe and -59dBc second side-lobe rejection (**Figure 1**).

The MAX2820 on-chip transmit lowpass filters provide the filtering necessary to attenuate the unwanted, higher frequency, spurious signal content that arises from digital-to-analog converter (DAC) clock feed-through and sampling images. In addition, the filter provides additional attenuation of the second side lobe of the signal's spectrum. The filter-frequency response requires no user adjustment.

To achieve low LO leakage at the RF output in a ZIF system, the DC offset of the Tx baseband signal path must be reduced as near to zero as possible. As the amplifier stages, baseband filters, and TX DAC possess a finite DC offset too large for the required LO leakage specification, it is necessary to null the DC offset. The MAX2820 accomplishes this through an on-chip calibration sequence. During this sequence, the net-transmit baseband-signal-path offsets are sampled and canceled in the baseband amplifiers. This calibration occurs in the first ~2.2µs after TX_ON is taken high.

The MAX2820 ZIF quadrature modulator needs approximately 75mA of current with a 2.7V supply for all the active transmit functions. The MAX2820 baseband interface is compatible with several baseband/MACs, giving the user the option of choosing the one most appropriate for a specific application. Baseband inputs and outputs are differential and both require a +1.2V common-mode voltage. They are designed to be DC-coupled to the I/Q inputs and outputs of the baseband IC.

The MAX2242 power amplifier

The MAX2242 low-voltage, three-stage linear power amplifier (PA) is a highly efficient linear amplifier that delivers the maximum allowable output power with high efficiency and greater margin to meet spectral-mask requirements. The MAX2242 is optimized for 802.11b WLAN (wireless local area network) applications. Integrated with an adjustable bias control, power detector, and shutdown mode, this device is packaged in the tiny, 3 x 4 chip-scale package (UCSP™), measuring only 1.5mm x 2mm. The MAX2242 features 28.5dB of power gain and delivers up to +22.5dBm of linear output power with a single +3.3V supply. It achieves less than -33dBc of first side-lobe suppression and less than -55dBc of second side-lobe suppression under 802.11b modulation. It has harmonic output (2f, 3f, 4f) rejection better than -40dBc without a harmonic trap. In addition, the device can be matched for optimum efficiency and performance at output power levels from +10dBm to +22.5dBm. It also possesses high +26.5dBm saturated output power.

The combination of the MAX2820 and the MAX2242 forms a complete chipset to implement an IEEE 802.11b physical-layer solution (**Figure 2**). Both ICs are in high-volume production. The chipset is supported by several complete reference designs.

A complete stand-alone MAX2820 evaluation kit is also available (**Figure 3**) with a schematic, lay-out diagrams, and a bill of materials (BOM). The evaluation kit provides 50Ω SMA connectors for all RF and baseband inputs and outputs. Differential-to-single-ended and single-ended-to-differential line drivers are provided to convert the differential I/Q baseband inputs and outputs to single ended.

UCSP is a trademark of Maxim Integrated Products, Inc.

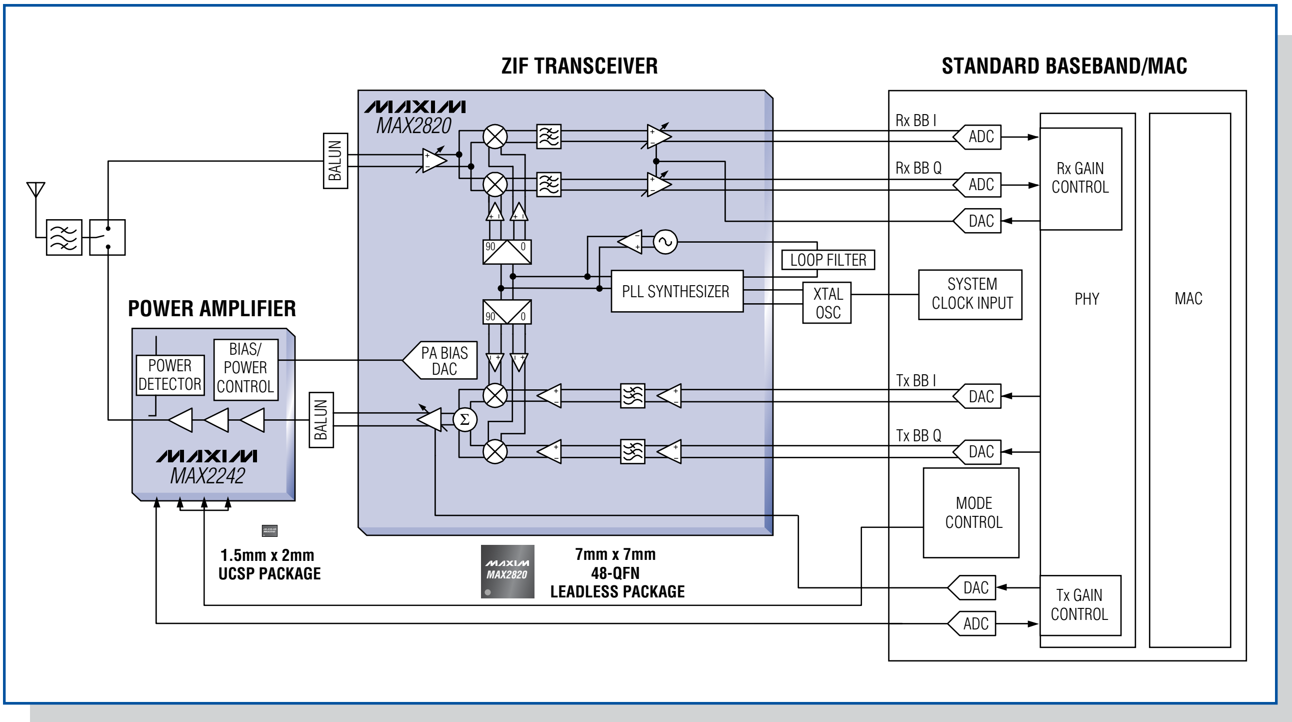

Figure 2. Maxim's complete IEEE 802.11b solution includes the MAX2820 single-chip ZIF transceiver and the MAX2242 linear power amplifier.

Conclusion

A common method for estimating the cost of a solution is by determining the number of interconnect pins, passive components, and layout vias needed to integrate several packaged ICs (**Figure 4**). The three-chip WLAN solution (including baseband/MAC chip) from Maxim provides a small-form-factor, low passive-component-count solution. The highly integrated programmable transceiver supports a WLAN solution with a high degree of flexibility at a low cost.

This highly integrated, 802.11b, 2.4GHz WLAN chipset solution offers outstanding performance for CCK and PBCK modulation schemes. It is small (**Figure 5**), is the lowest cost solution available on the market, and offers an easy +20dBm output power at the antenna. This chipset is available now in high-volume production for access and client applications, and has been designed in for a number of enterprise and consumer products available in the marketplace today. Part of this chipset, the MAX2822, was recently introduced. As a client-dedicated, second-generation chip, it contains a +17dBm-output, power-integrated power amplifier. While maintaining a high level of performance, it offers a significant reduction in the power consumption, size, and BOM cost when compared to competitors' alternatives.

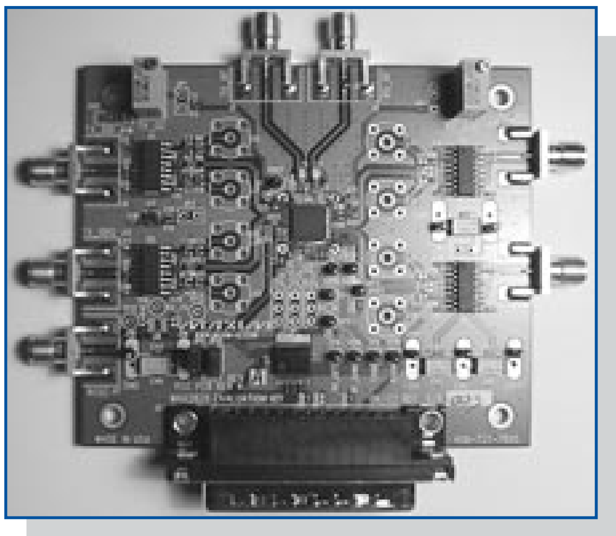

Figure 3. The MAX2820 stand-alone evaluation kit includes 50Ω SMA connectors, schematics, layout diagrams, and a BOM.

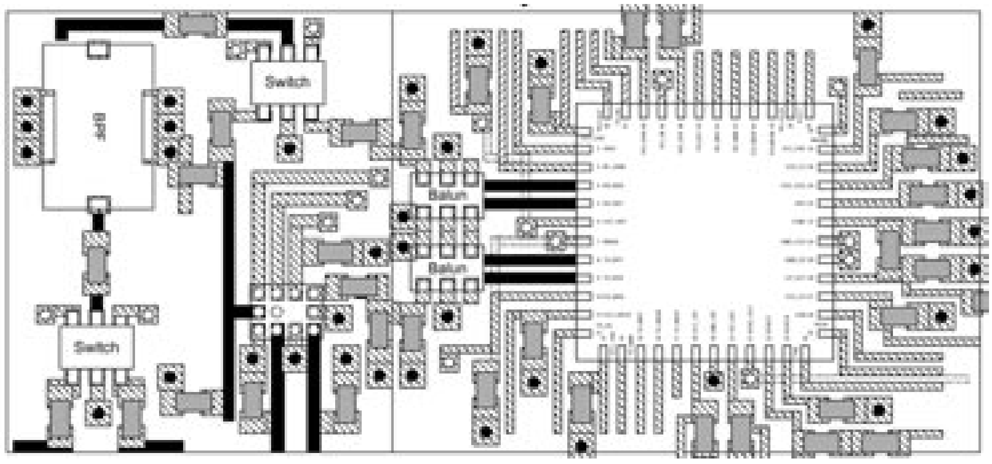

Figure 4. This diagram of the MAX2820/MAX2242 radio interface shows approximate PCB layout (26.5mm x 12mm) and low passive-component count.

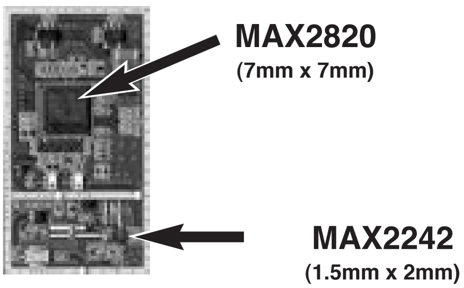

Figure 5. This small 802.11 RF transceiver offers excellent performance for CCK- and PBCK-modulation schemes.

DESIGN SHOWCASE

Standby current for RS-422 repeater is less than 3µA

The RS-422 interface is an excellent choice for communicating in noisy environments and over a distance. However, when the distance exceeds the RS-422 capability for reliable data transfer, you must add a repeater. The repeater circuit in **Figure 1**, which must operate from batteries when no power supply is available, draws less than 3µA of current from a 3V supply.

Low standby power and true fail-safe operation are the key features in this application. U1 and U2 drive their receiver outputs (RO) high when the RS-422 inputs are open circuited or terminated and undriven. An incoming data byte on the differential inputs A1 and B1 forces a transition on RO of U1, and a state machine (right half of the Figure 1 schematic) is latched ON by the falling edge of RO. The state machine asserts a high level at U2's driver-enable pin, causing the incoming data byte to be retransmitted from U2 at full RS-422 levels.

The state machine watches for transitions on RO. When a data-byte transfer is complete (as indicated by no falling edges within a time delay internal to the state machine), the state machine resets itself in anticipation of the next data byte from either side of the interface.

An incoming data burst (**Figure 2**, top) is retransmitted as outputs A2 (bottom trace) and B2 (middle trace). U2 de-asserts those outputs 700µs after the final transition. Other delays can be implemented by adjusting R1/C1 and R2/C2 as shown in Figure 1.

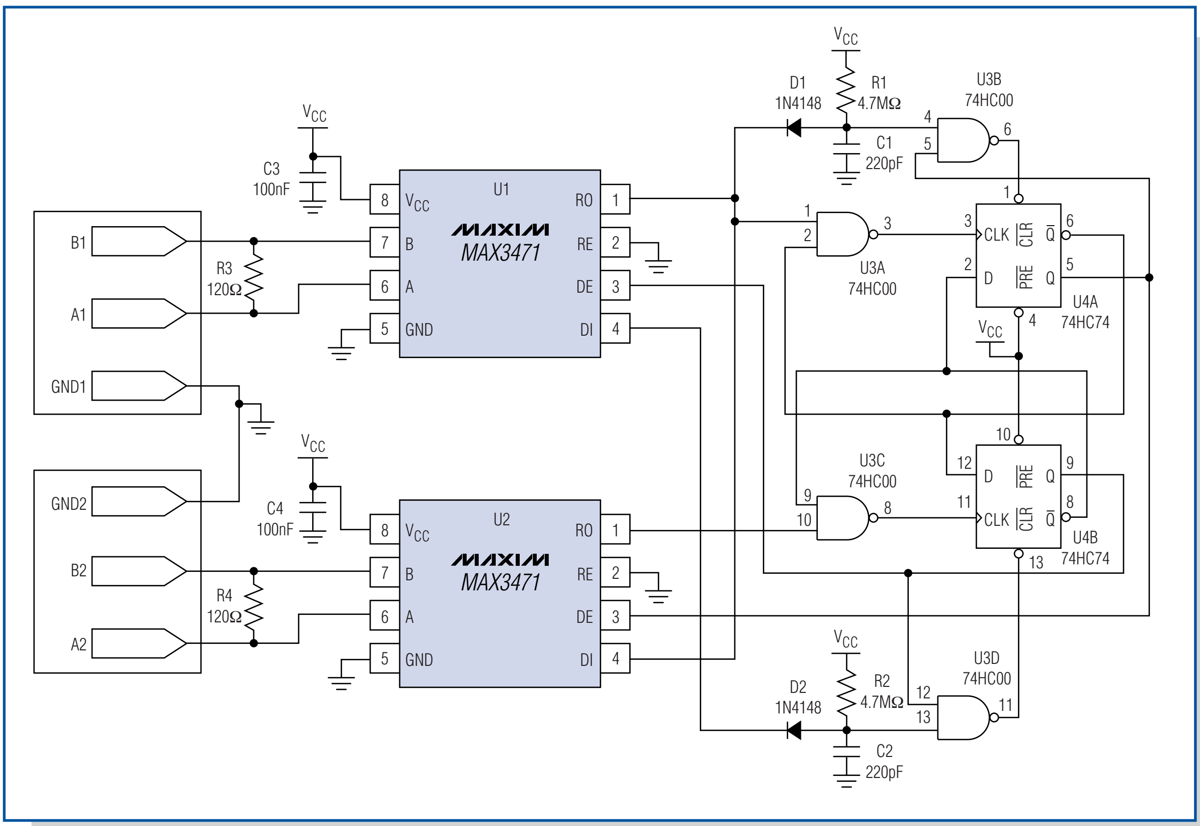

Figure 1. This RS-422 repeater draws only 3µA of standby current.

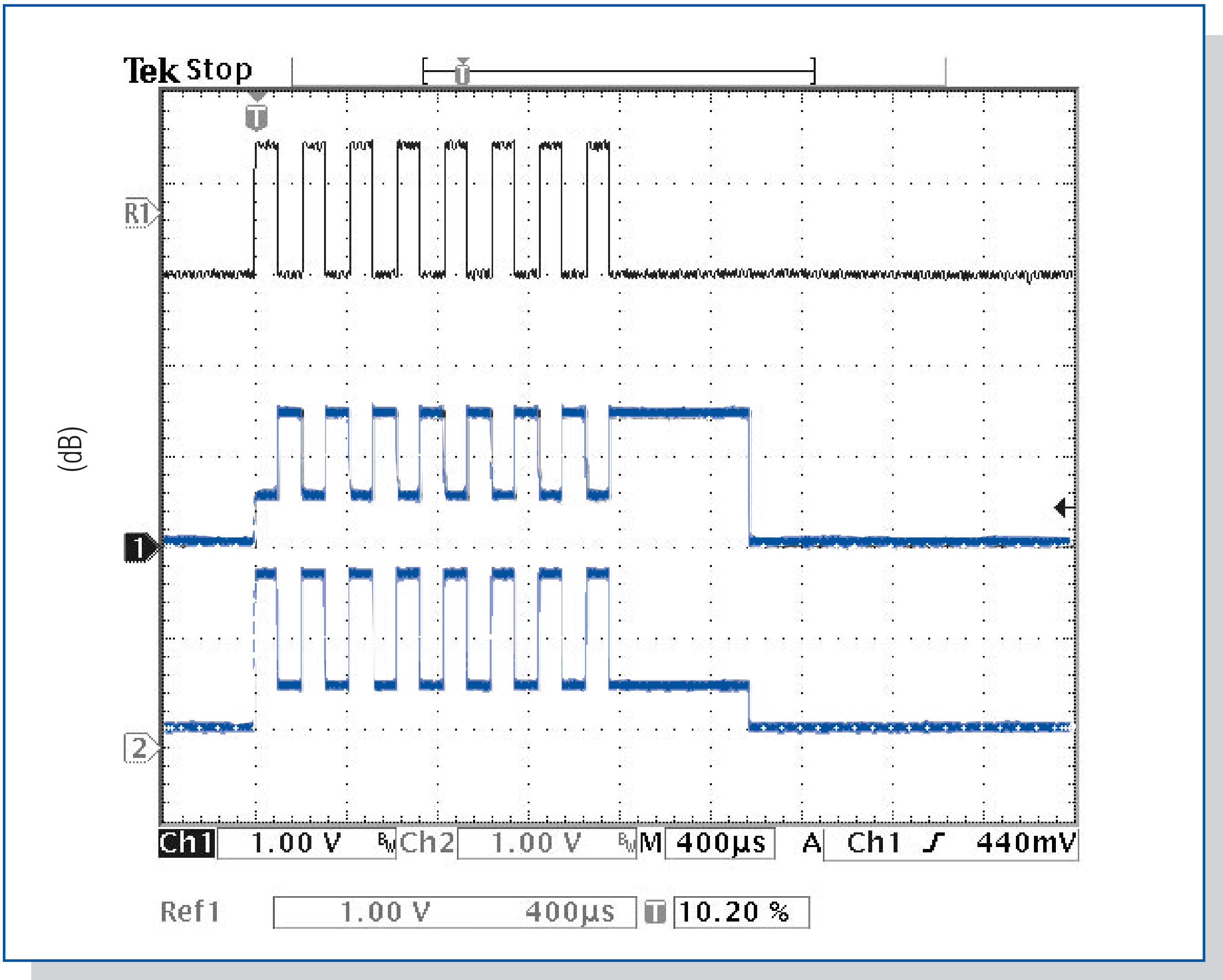

Figure 2. An input data byte causes the repeater to transmit the byte, then go to standby. Vertical scale is 1V per division; horizontal scale is 400µs per division.

DESIGN SHOWCASE

3V supply delivers $12V_{P-P}$ to piezoelectric speaker

Low-profile piezoelectric speakers can provide quality sound for portable electronics devices, but they require voltage swings greater than $8V_{P-P}$ across the speaker element. Most portable devices, however, include only a low-voltage power source, and conventional amplifiers operating from batteries cannot provide enough voltage swing to drive a piezoelectric speaker. One solution is IC1 in **Figure 1**, which can be configured to drive a piezoelectric speaker with as much as $12V_{P-P}$ while operating from a single 3V supply.

IC1 (the MAX4410) is a specialized device that combines a stereo headphone driver with an inverting charge pump that derives a negative 3V supply from the positive 3V supply. Providing the drive amplifiers with such an internal ±3V supply allows each output of IC1 to swing $6V_{P-P}$. Configuring IC1 as a bridge-tied load driver (BTL) further doubles the maximum swing at the load to $12V_{P-P}$.

In the BTL configuration, IC1's right channel serves as the master amplifier. It sets the gain of the device, drives one side of the speaker, and provides a signal to the left channel. Configured as a unity-gain follower, the left channel inverts the output of the right channel and drives the other leg of the speaker. To ensure low distortion and good matching, set the left-channel gain using precision resistors.

The circuit was tested with a Panasonic® WM-R57A piezoelectric speaker, yielding the THD+N curves shown in **Figures 2** and **3**. Note that THD+N increases as the frequency increases in both graphs. Because the speaker appears as a capacitor to the amplifier, the speaker impedance decreases as the frequency increases, drawing larger currents from the amplifier.

IC1 remains stable with the speaker used in **Figure 4**, but a speaker with different characteristics might cause instability. In that case, the speaker's capacitance can be isolated from the amplifier by adding a simple inductor/resistor network in series with the speaker (shown within the dotted lines in Figure 1). The network remains stable by maintaining a minimum high-frequency load of about 10Ω at the device output.

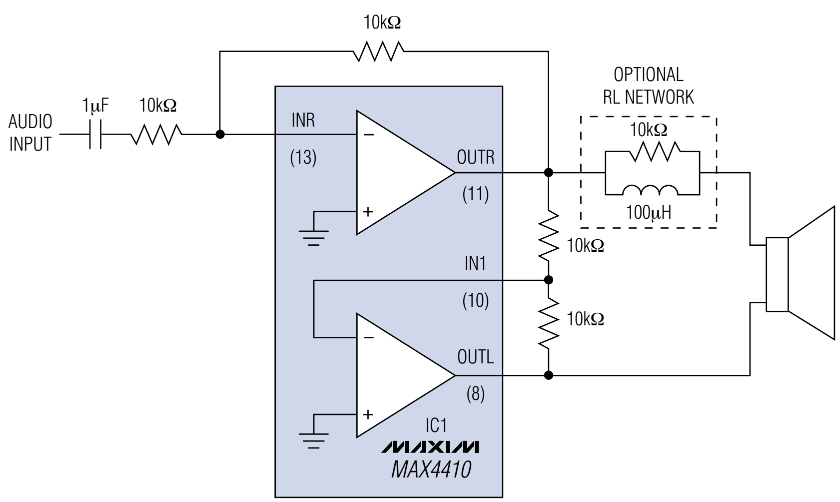

Figure 1. This bridge-tied-load (BTL) configuration multiplies the amplifiers' voltage-swing capability.

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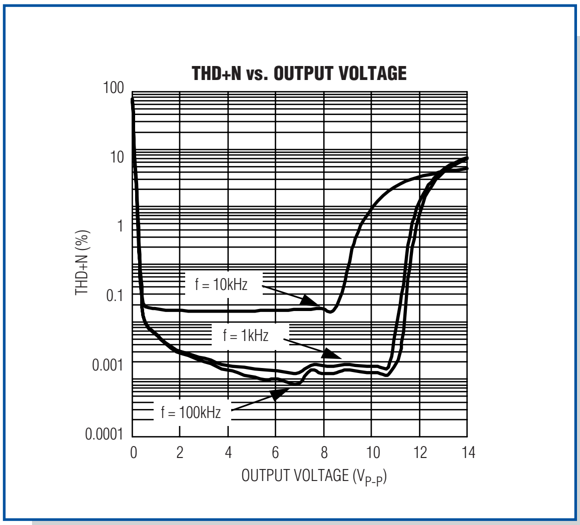

Figure 2. THD+N vs. output voltage is shown for the Figure 1 circuit, as tested with a WM-R57A piezoelectric speaker.

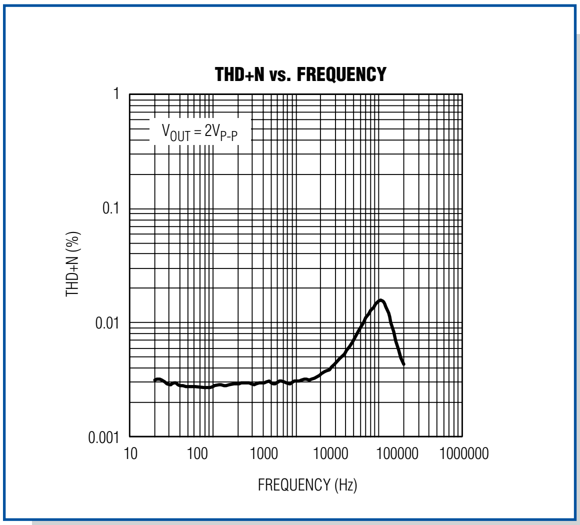

Figure 3. THD+N vs. frequency graph for the Figure 1 circuit shows the increase of THD+N as frequency increases. This is also seen in Figure 2.

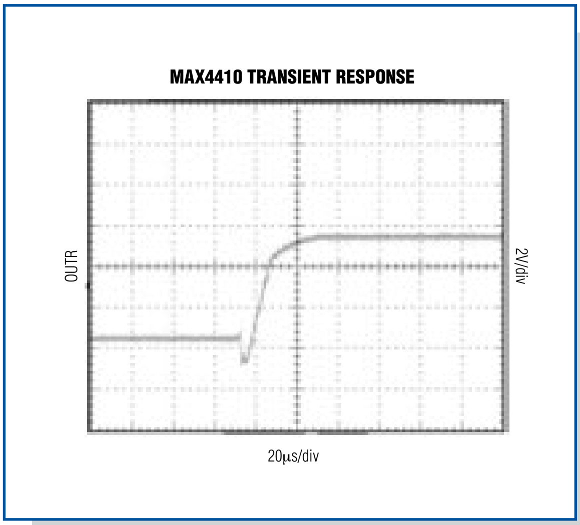

Figure 4. This graph shows the step response at the OUTR output of IC1 in Figure 1 while that device is driving a WM-R57A piezoelectric speaker.

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