

# Using the UCC3580-1 controller for highly efficient 3.3-V/100-W isolated supply design

By Brian M. King (Email: b-king1@ti.com)

Advanced Analog Products

Power-supply modules offer an attractive solution for providing the bulk power conversion in telecom systems. Modules offer a ready-made solution in a single package but can be quite expensive. The alternative, of course, is to build a power supply from discrete components. A discrete design can dramatically reduce production costs but requires a more intense engineering effort. For those willing to invest the effort, Figures 1 and 2 present a discrete solution that provides up to 100 W at 3.3 V from an isolated 48-V input. This design matches or exceeds the performance, consumes less board area, and costs significantly less than many half-brick modules that have the same power requirements.

This design uses a UCC3580-1 to control an active-clamp forward converter with self-driven synchronous rectifiers. The topology allows the circuit to achieve efficiencies of up to 93%. Additional features included in the design are remote sense connections for point-of-load regulation, input undervoltage, input overvoltage, output overvoltage, and overcurrent protection.

## Circuit description

Both an n-channel FET (Q1) and a p-channel FET (Q2) drive the 6-turn, primary winding of the active-clamp transformer. The UCC3580-1 controller provides the drive

for both MOSFETs. The n-channel drive is provided straight from the UCC3580-1, while the p-channel drive is inverted through the circuit of C7, D9, and R100. Figure 3 shows the drain-source waveforms of the primary and secondary MOSFETs.

While Q1 is on, power is delivered to the secondary, and magnetizing energy is being stored in the transformer. During this time, Q2 is off, and the clamp capacitor (C2) is out of the circuit and remains charged at a constant voltage level. When Q1 turns off, the leakage and magnetizing currents charge up the drain-to-source capacitance of Q1. Once the drain-to-source voltage of Q1 exceeds the voltage across the clamp capacitor, the body diode of Q2 begins to conduct. With the body diode of Q2 conducting, the magnetizing current now begins to charge the clamp capacitor.

Some time after the body diode of Q2 has begun to conduct, the controller turns on Q2. This provides zero-current switching for Q2. The clamp capacitor continues to charge until the magnetizing current is reduced to 0 A. At this point, the magnetizing current reverses, and the clamp capacitor begins to discharge until the controller turns off the p-channel FET. After Q2 turns off, the clamp capacitor remains at a fixed voltage. There is a fixed delay before Q1 turns on. During this delay, the energy in the parasitic components discharges the  $V_{DS}$  of Q1 towards

Figure 1. Power stage schematic

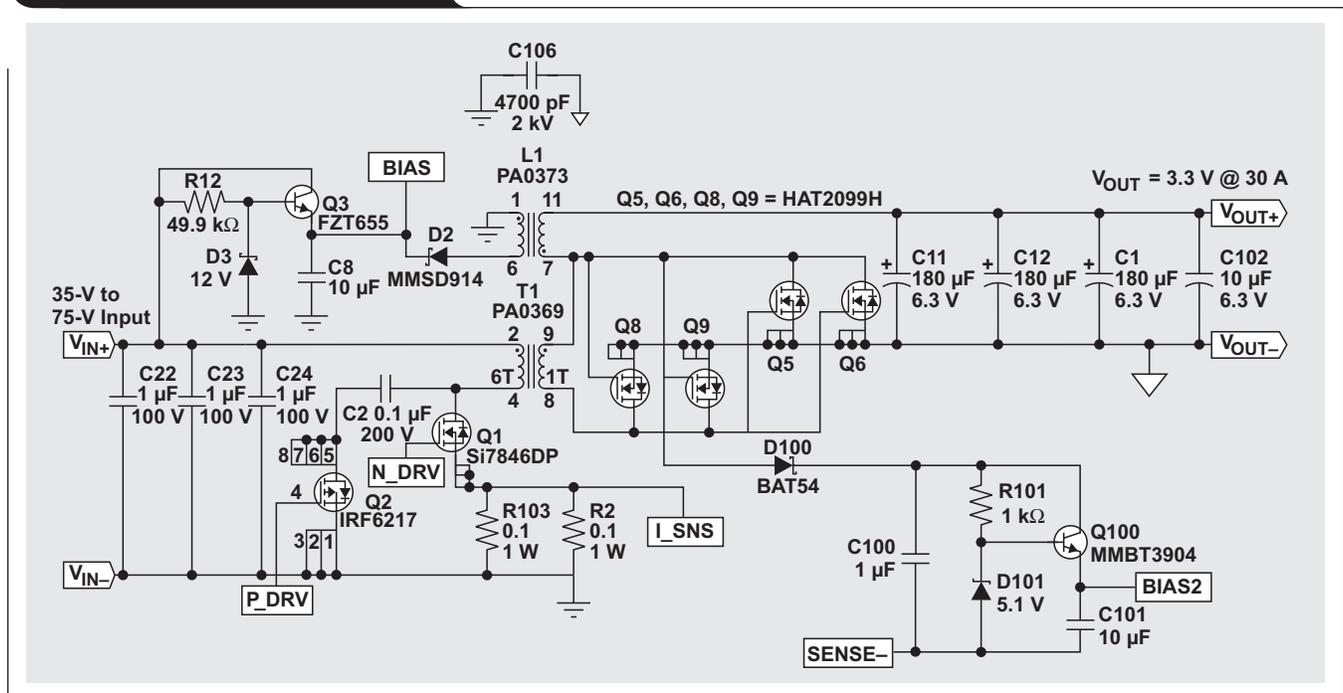
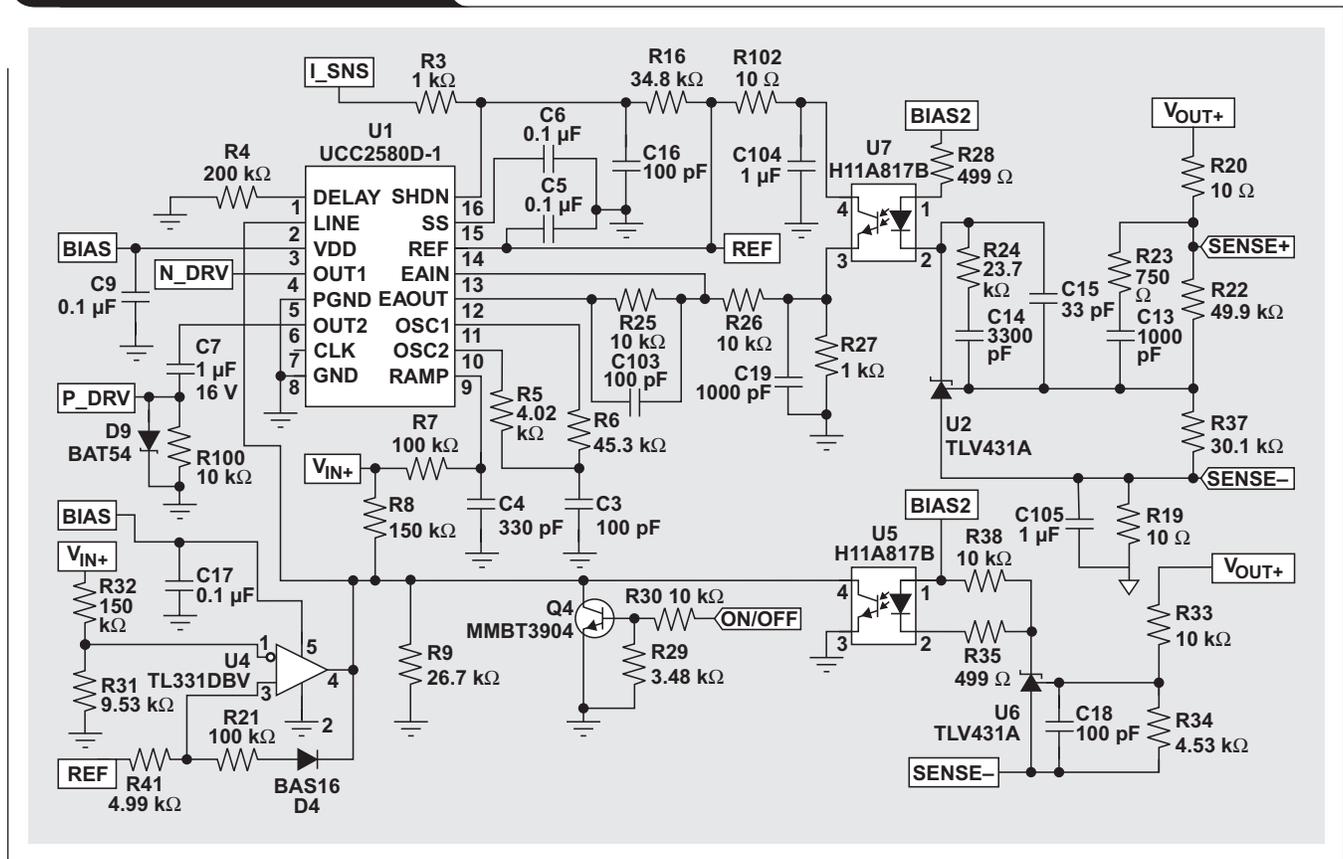


Figure 2. Control stage schematic



$V_{IN}$ . This allows softer turn-on and reduces switching losses in Q1 (see Figure 4).

The secondary power stage consists of the synchronous rectifiers (Q5, Q6, Q8, and Q9) and the output filter (L1, C1, C11, C12, and C102). When Q1 is on, the voltage on the secondary of T1 ensures that both Q8 and Q9 are on, while Q5 and Q6 are off. During this time, a voltage equal to the input voltage divided by the turns ratio of the

transformer is applied across the gate-to-source of Q8 and Q9, and also across the drain-to-source of Q5 and Q6. Also during this time, the gate-to-source voltage of Q5 and Q6 is essentially 0 V and is equal to the inductor current times the  $r_{ds(on)}$  of Q8 and Q9.

When Q2 is off, the voltage on the secondary of T1 reverses, and ensures that both Q5 and Q6 are on, while Q8 and Q9 are off. During this time, the magnitude of the

Figure 3. Power MOSFET drain waveforms

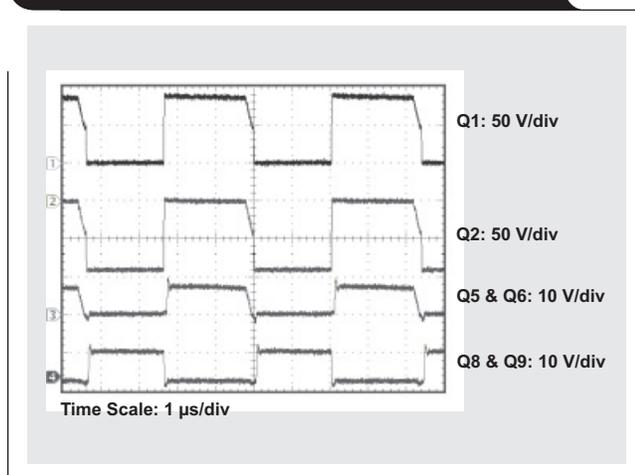
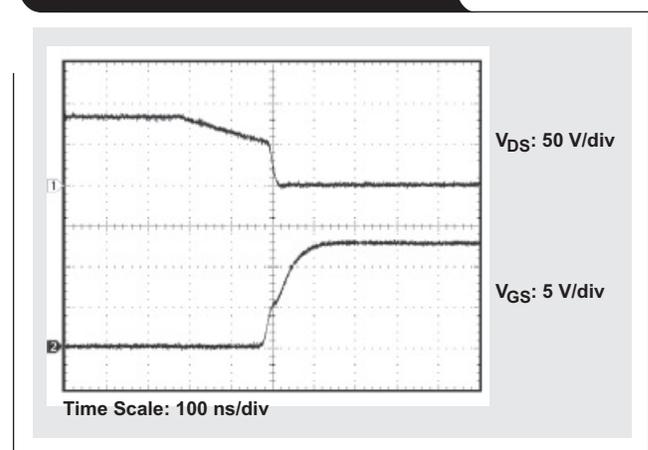


Figure 4. Turn-on of primary-side n-channel MOSFET



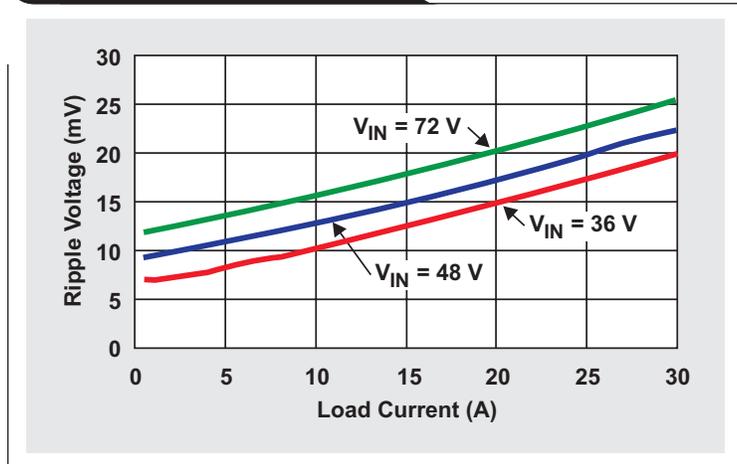
transformer secondary voltage is equal to the clamp capacitor voltage minus the input voltage, divided by the transformer turns ratio. The peak clamp capacitor voltage will determine the maximum voltage stress across the gate-to-source of Q5 and Q6, and also across the drain-to-source of Q8 and Q9. During this time, the gate-to-source voltage of Q8 and Q9 is essentially 0 V and is equal to the inductor current times the  $r_{ds(on)}$  of Q5 and Q6.

Two bias voltages are used in this active-clamp design, one for the primary side and one for the secondary side. The circuit composed of C8, D2, D3, L1, Q3, and R12 produces the primary-side bias. D2, R12, and Q3 form a linear regulator, which is functional only during startup, or during a fault condition. L1 contains an auxiliary winding that is used to produce the primary-side bias during normal operation. The main winding of L1 has 4 turns, while the auxiliary winding has 16 turns. The auxiliary winding charges C8 to a voltage equal to the output voltage times the 16:4 turns ratio of the inductor, minus the diode drop of D3.

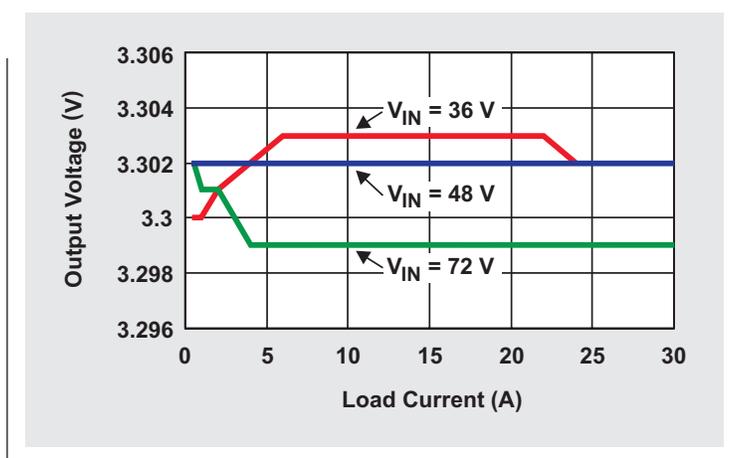
The circuit composed of C100, C101, D100, D101, Q100, and R101 produces the secondary-side bias. This bias is required to drive the feedback optocoupler (U7) and the TLV431 (U2). D100 and C100 peak detect the transformer secondary voltage. R101, D101, and Q100 form a linear regulator. The linear regulator is necessary to ensure that the bias voltage is independent of the input voltage. Without the linear regulator circuit, a second feedback loop is introduced into the compensation circuit, which complicates the compensation design.

Breaking the feedback path with R19 and R20 provides remote sensing. By connecting the remote sense terminals directly to the desired regulation point, the converter compensates for any voltage drops between the output of the supply and the load. The remote sense terminals must always be connected to the converter output and output return. If remote sensing is not required, R19 and R20 may be shorted, in which case regulation will be provided directly at the converter output filter.

**Figure 6. Output ripple voltage**



**Figure 5. Line and load regulation**



The feedback network is typical of most isolated forward converters. The TLV431 (U2) incorporates a voltage reference and transconductance error amplifier into one package. Providing type III compensation around U2 compensates the voltage-mode converter. The current transfer ratio of U7 and the values of R27 and R28 determine the gain of the optocoupler circuit. The error amplifier of the UCC3580-1 is used in an inverting configuration, with a gain of 1 V/V.

The shutdown pin of the UCC3580-1 provides overcurrent protection. The current is sensed at the source of Q1 by resistors R2 and R103. Resistor R16 lowers the shutdown threshold voltage, which improves the converter's efficiency by decreasing the required resistance of R2 and R103.

The UCC3580-1 and resistors R8 and R9 control the input undervoltage protection. The comparator circuit of U4 controls input overvoltage protection. Both input overvoltage and input undervoltage circuits provide hysteresis. The circuit of U5 and U6 provides output overvoltage protection. When the input to U6 exceeds the TLV431 reference voltage, the converter shuts down until the overvoltage condition is gone, at which point a normal soft-start cycle is initiated.

## Performance

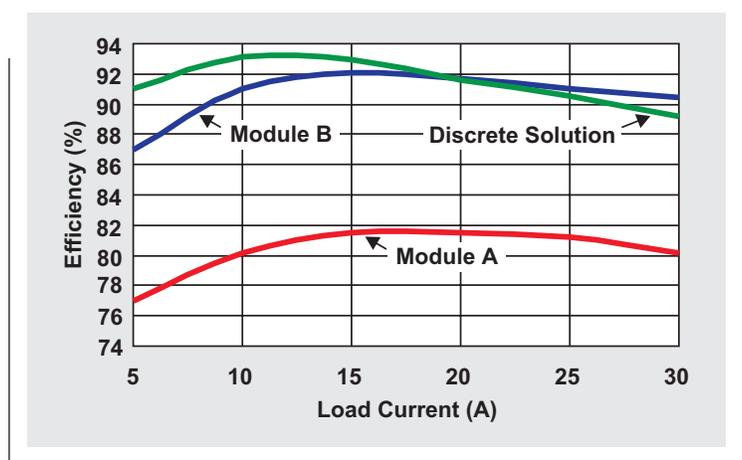
The circuit operates from input voltages between 36 and 75 V and at load currents of up to 30 A. The output voltage typically varies by only 4 mV (0.1%) over the entire line and load range (see Figure 5). Most power modules with similar power requirements list line and load regulations below 0.2%. The output ripple voltage of this design is kept below 26 mV (0.8%) over line and load, as shown in Figure 6. Power modules offer similar ripple performance.

Figure 7 compares the efficiency of this design to the efficiency of modules from two leading module manufacturers. The data are given for a 48-V input and 25°C ambient temperature. Module A is typical of the majority of 3.3-V, half-brick, 100-W modules. Module B is an example of one of the few modules that list efficiency at greater than 90%. The discrete design competes very well with even the most efficient power-supply modules. The efficiency peaks at 93% at around 12 A and drops to 89% at full-rated load.

The efficiency, package, and thermal environment all conspire to limit the maximum load current for an application. While power modules may be rated for 30 A of load current, the current may actually be limited to a fraction of this by the internal device junction temperatures. The same is true of the discrete design. Modules have an advantage in this arena because they often are constructed with materials that provide good heat-sinking properties. With a discrete design, however, the designer has the opportunity to lay out the circuit board to accommodate for the power dissipation of hot components. Even with an excellent layout, at these power levels, both the modules and discrete solution typically require some forced air flow to achieve the maximum rated current.

To compare the thermal performance of the discrete design to that of the power modules, the circuit was constructed on a 2-oz. copper, 4-layer PCB in a half-brick footprint (2.3" x 2.2"). The safe-operating-area (SOA) curves of the modules and the discrete design are shown in Figure 8 for a 48-V input and 300 linear feet per minute (lfm) of air flow. The good heat sinking and high efficiency of Module B allow it to operate at higher currents than both Module A and the discrete design. However, even the good heat sinking of Module A cannot make up for its low efficiency. Incorporating the discrete design into a larger PCB allows more copper to be tied to the hot components (the power MOSFETs) to provide a wider SOA.

**Figure 7. Comparison of typical efficiencies**



### Conclusion

The decision whether to build a discrete power supply or to buy premanufactured modules involves trade-offs involving cost, schedule, and risk. Designing a power supply based on a reference design, such as the one presented here, significantly lowers the risk associated with the discrete approach. In situations where schedule is key, modules are the logical choice. However, migrating to a discrete power supply yields significant cost savings, particularly in high-volume applications.

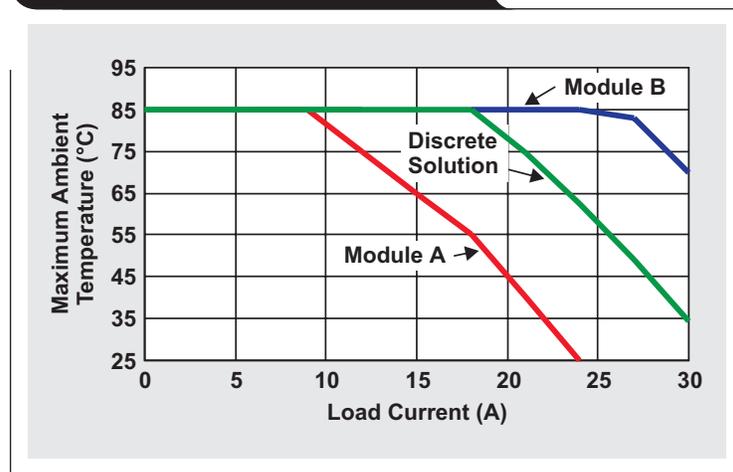
### Related Web sites

[analog.ti.com](http://analog.ti.com)

[www.ti.com/sc/device/partnumber](http://www.ti.com/sc/device/partnumber)

Replace *partnumber* with TL331, TLV431A, UCC2580-1 or UCC3580-1

**Figure 8. Comparison of SOA curves**



## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>

### Applications

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Broadband	<a href="http://www.ti.com/broadband">www.ti.com/broadband</a>
Digital control	<a href="http://www.ti.com/digitalcontrol">www.ti.com/digitalcontrol</a>
Military	<a href="http://www.ti.com/military">www.ti.com/military</a>
Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Telephony	<a href="http://www.ti.com/telephony">www.ti.com/telephony</a>
Video & Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
Wireless	<a href="http://www.ti.com/wireless">www.ti.com/wireless</a>

## TI Worldwide Technical Support

### Internet

**TI Semiconductor Product Information Center Home Page**  
[support.ti.com](http://support.ti.com)

**TI Semiconductor KnowledgeBase Home Page**  
[support.ti.com/sc/knowledgebase](http://support.ti.com/sc/knowledgebase)

### Product Information Centers

#### Americas

Phone	+1(972) 644-5580	Fax	+1(972) 927-6377
Internet/Email	<a href="http://support.ti.com/sc/pic/americas.htm">support.ti.com/sc/pic/americas.htm</a>		

#### Europe, Middle East, and Africa

Phone			
Belgium (English)	+32 (0) 27 45 54 32	Netherlands (English)	+31 (0) 546 87 95 45
Finland (English)	+358 (0) 9 25173948	Russia	+7 (0) 95 7850415
France	+33 (0) 1 30 70 11 64	Spain	+34 902 35 40 28
Germany	+49 (0) 8161 80 33 11	Sweden (English)	+46 (0) 8587 555 22
Israel (English)	1800 949 0107	United Kingdom	+44 (0) 1604 66 33 99
Italy	800 79 11 37		
Fax	+(49) (0) 8161 80 2045		
Internet	<a href="http://support.ti.com/sc/pic/euro.htm">support.ti.com/sc/pic/euro.htm</a>		

#### Japan

Fax			
International	+81-3-3344-5317	Domestic	0120-81-0036
Internet/Email			
International	<a href="http://support.ti.com/sc/pic/japan.htm">support.ti.com/sc/pic/japan.htm</a>		
Domestic	<a href="http://www.tij.co.jp/pic">www.tij.co.jp/pic</a>		

#### Asia

Phone			
International	+886-2-23786800		
Domestic	Toll-Free Number		
Australia	1-800-999-084	New Zealand	0800-446-934
China	800-820-8682	Philippines	1-800-765-7404
Hong Kong	800-96-5941	Singapore	800-886-1028
Indonesia	001-803-8861-1006	Taiwan	0800-006800
Korea	080-551-2804	Thailand	001-800-886-0010
Malaysia	1-800-80-3973		
Fax	886-2-2378-6808	Email	<a href="mailto:tiasia@ti.com">tiasia@ti.com</a>
Internet	<a href="http://support.ti.com/sc/pic/asia.htm">support.ti.com/sc/pic/asia.htm</a>		<a href="mailto:ti-china@ti.com">ti-china@ti.com</a>

### C011905

**Safe Harbor Statement:** This publication may contain forward-looking statements that involve a number of risks and uncertainties. These "forward-looking statements" are intended to qualify for the safe harbor from liability established by the Private Securities Litigation Reform Act of 1995. These forward-looking statements generally can be identified by phrases such as "TI or its management believes," "expects," "anticipates," "foresees," "forecasts," "estimates" or other words or phrases of similar import. Similarly, such statements herein that describe the company's products, business strategy, outlook, objectives, plans, intentions or goals also are forward-looking statements. All such forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those in forward-looking statements. Please refer to TI's most recent Form 10-K for more information on the risks and uncertainties that could materially affect future results of operations. We disclaim any intention or obligation to update any forward-looking statements as a result of developments occurring after the date of this publication.

**Trademarks:** All trademarks are the property of their respective owners.

Mailing Address: Texas Instruments  
Post Office Box 655303  
Dallas, Texas 75265

© 2005 Texas Instruments Incorporated