

Using a Feedforward Capacitor to Improve Stability and Bandwidth of TPS62130/40/50/60/70

Matt Guibord

Battery Power Applications

ABSTRACT

A common method to improve the stability and bandwidth of a power supply is to use a feedforward capacitor, which is a capacitor placed across the high-side feedback resistor. This capacitor adds a zero and a pole ($f_z < f_p$) to the control loop, which can be strategically placed to improve the phase margin and bandwidth. This improvement can be measured in both the transient response and bode plot of the new circuit. This application report details two design strategies for placing the pole and zero at the optimal frequency to improve transient response and circuit stability for the TPS62130/40/50/60/70 DCS-Control™ devices. Additional information may be found in the TI application report *Optimizing the TPS62130/40/50/60/70 Output Filter*.

1 Adding Extra Capacitance

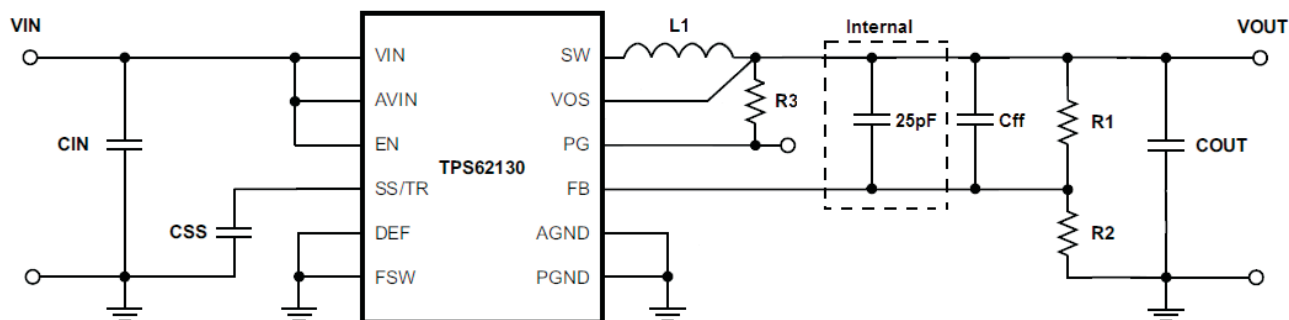


Figure 1. Simplified Schematic With Internal and External Feedforward Capacitors Shown

The traditional method of designing with a feedforward capacitor is to add an external capacitor (C_{ff}) in parallel with the high-side feedback resistor, R_1 in [Figure 1](#). The capacitor value is chosen based on the values of the feedback resistors to place the geometric mean of the pole and zero at the unity gain crossover frequency. The application report *Optimizing Transient Response of Internally Compensated dc-dc Converters With Feedforward Capacitor* ([SLVA289](#)) presents an equation to calculate the optimal feedforward capacitor. Because the TPS6213x/4x/5x/6x/7x family of integrated circuits has an internal 25-pF feedforward capacitor, the equation must be modified as shown in [Equation 1](#).

$$C_{ff} = \frac{1}{2\pi f_{CO}} \sqrt{\frac{1}{R_1} \left(\frac{1}{R_1} + \frac{1}{R_2} \right)} - 25 \text{ pF} \quad (1)$$

Where f_{co} is the unity gain crossover frequency of the control loop without the external feedforward capacitor installed and $R1$ and $R2$ are the high-side and low-side feedback resistors, respectively.

Figure 1 shows the locations of the feedback resistors and feedforward capacitor. This capacitor value places the geometric mean of the zero and pole at f_{CO} , which provides the best phase margin boost. The actual frequencies of the zero and pole are calculated using [Equation 2](#) and [Equation 3](#). Note that the pole is always at a higher frequency than the zero because R_1 is always larger than R_1/R_2 .

$$f_Z = \frac{1}{2\pi R_1 C_{ff}} \quad (2)$$

DCS-Control is a trademark of Texas Instruments.

$$f_P = \frac{1}{2\pi (R_1 // R_2) C_{ff}} \quad (3)$$

As an example, take a 12-Vin, 3.3-Vout TPS62130 design with a 4.7-μH inductor, 200-μF output capacitor, R_1 as 10 kΩ, and R_2 as 3.16 kΩ. First, the loop gain without the feedforward capacitor needs to be measured to find the unity gain crossover frequency. The application report *How to Measure Control Loop of TPS62130/40/50/60/70 DCS-Control™ Devices* (SLVA465) explains how to take a loop measurement on the DCS-Control™ topology and Figure 2 shows the results. The crossover frequency is 33.62 kHz, so Equation 1 is used to calculate that 941 pF of extra capacitance is needed. Figure 3 shows the new loop response with an added 1000-pF C_{ff} compared with the response without the external C_{ff} .

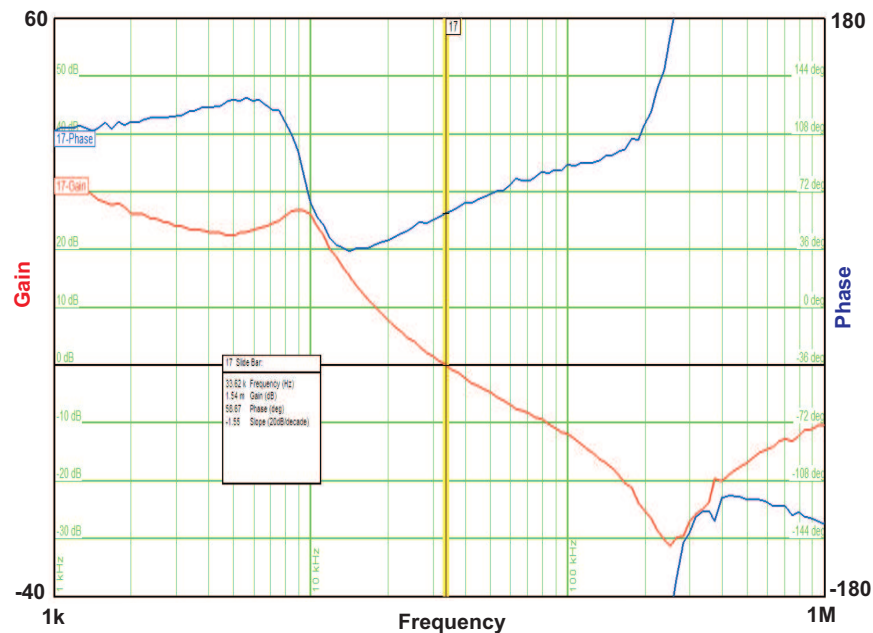


Figure 2. Measuring the Gain Crossover Frequency Without a Feedforward Capacitor

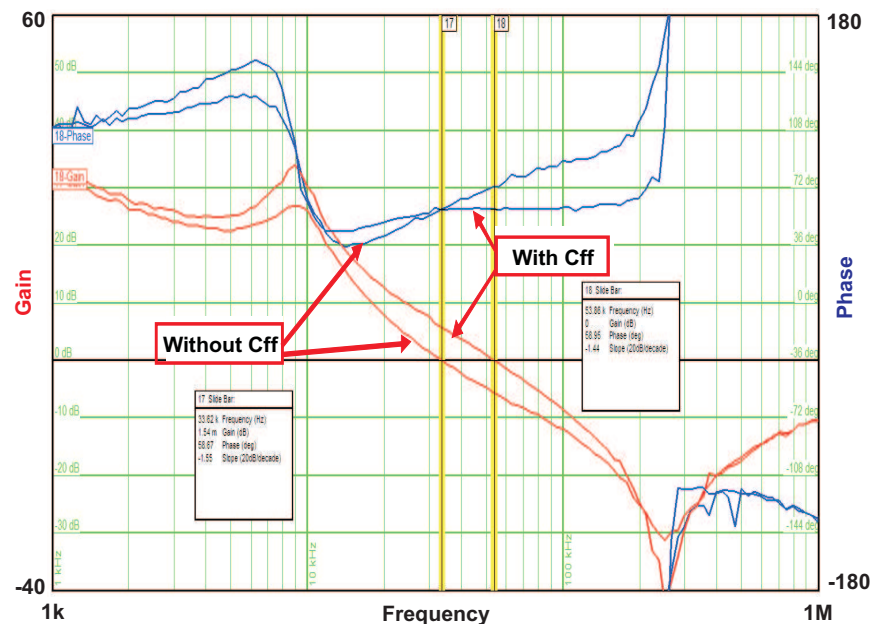


Figure 3. Loop Gain With and Without Feedforward Capacitor

Figure 4 shows the load transient response before and after adding the additional Cff. The increase in loop bandwidth due to the Cff is seen in the bode plot, whereas the transient response shows the tangible benefit of the gain in bandwidth. The transient response is faster and the voltage undershoot is less with the external Cff. In addition, no ringing occurs in the output voltage because the phase is not allowed to dip as low due to the added zero. Note that with the external Cff, the load regulation is reduced somewhat as shown by the different final values of the output voltage in Figure 4. This effect is more pronounced for smaller external Cff values. For this reason, adjusting the resistors and using only the internal 25-pF Cff is the preferred method of loop response optimization as discussed in the next section.

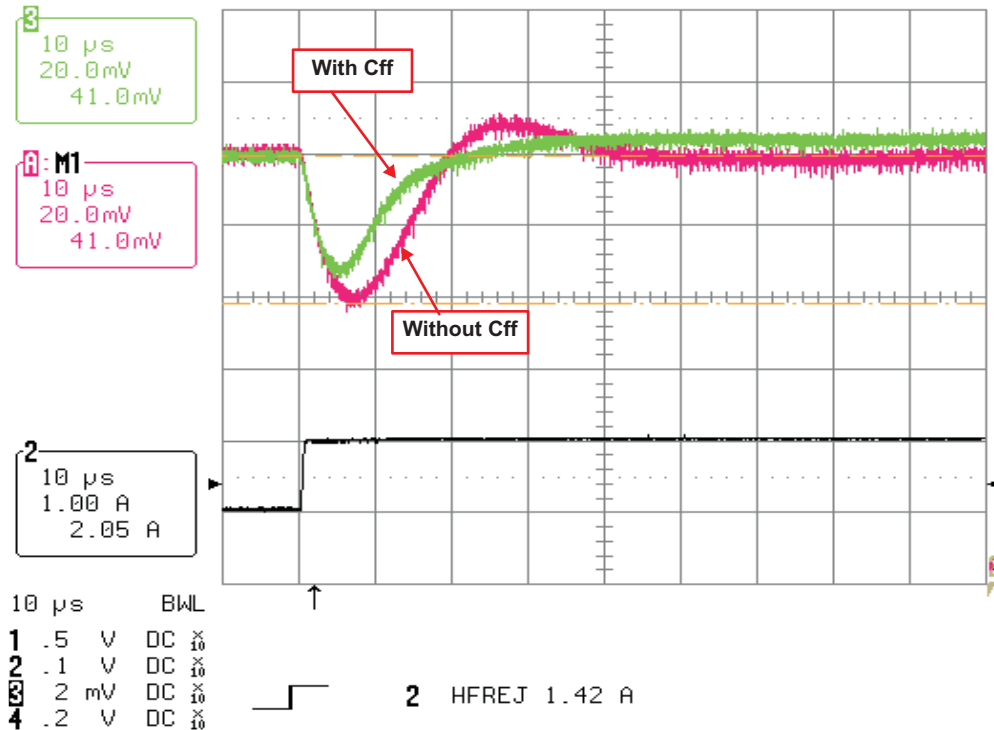


Figure 4. Load Transient Response With and Without Feedforward Capacitor

2 Choosing Feedback Resistors Based on Internal Cff

The second and preferred method of designing a TPS62130/40/50/60/70 power supply with a feedforward capacitor is to choose the feedback resistors based on the internal 25-pF feedforward capacitor. This method is unique to this family of devices because of the internal capacitor. The benefit of using this method is the ability to eliminate one component from the circuit to reduce production costs while keeping superior load regulation in practice.

The first step is to measure the control loop with resistors that place the zero due to the internal feedforward capacitor at a frequency higher than the gain crossover point. Because the feedforward capacitor does not have an effect at frequencies higher than 100 kHz (see Section 3), choose R_1 such that the frequency of the zero is at least greater than 100 kHz. To completely eliminate the effect of the zero's phase response, the zero must be placed one decade above the gain crossover frequency. Therefore, placing the zero at 1 MHz is sufficient for all gain crossover frequencies. Using Equation 2, an appropriate high-side resistor can be calculated as shown by the following equations.

$$R_1 = \frac{1}{2\pi(1 \text{ MHz})(25 \text{ pF})} \approx 6.34 \text{ k}\Omega \quad (4)$$

Therefore, using a 6.34-k Ω resistor is sufficient for any LC combination. R_2 can be chosen for the desired output voltage using Equation 5.

$$R_2 = \frac{R_1 \times V_{REF}}{V_{OUT} - V_{REF}} \quad (5)$$

For example, for a desired output of 3.3 V, R_2 is calculated as:

$$R_2 = \frac{6.34 \text{ k}\Omega \times 0.8 \text{ V}}{3.3 \text{ V} - 0.8 \text{ V}} \approx 2.05 \text{ k}\Omega \quad (6)$$

From Equation 2 and Equation 3, the zero and pole are placed at 1 MHz and 4.194 MHz, respectively. The control loop gain can then be measured to find the unity gain crossover frequency without any effect from the internal Cff. The following equations then can be used to calculate R_1 and R_2 to reposition the geometric mean of the pole and zero to the crossover point, with Cff equal to 25 pF.

$$R_1 = \frac{1}{2\pi C_{ff} f_{CO}} \sqrt{\frac{V_{OUT}}{V_{REF}}} \quad (7)$$

$$R_2 = \frac{R_1 \times V_{REF}}{V_{OUT} - V_{REF}} \quad (8)$$

Continuing with the previous example, for a 3.3-V output and a crossover frequency of 30.3 kHz, R_1 and R_2 are calculated to be 432 k Ω and 137 k Ω , respectively. Figure 5 shows the increased loop bandwidth and phase with the new resistor values. This causes the improved transient response in Figure 6, which also has no ringing and excellent load regulation.

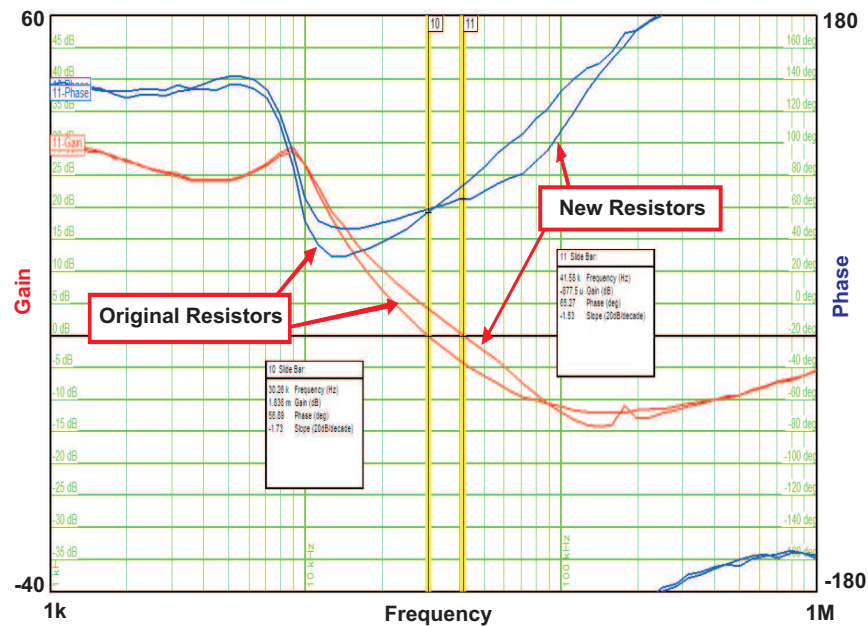


Figure 5. Loop Gain Before and After Optimizing Resistors

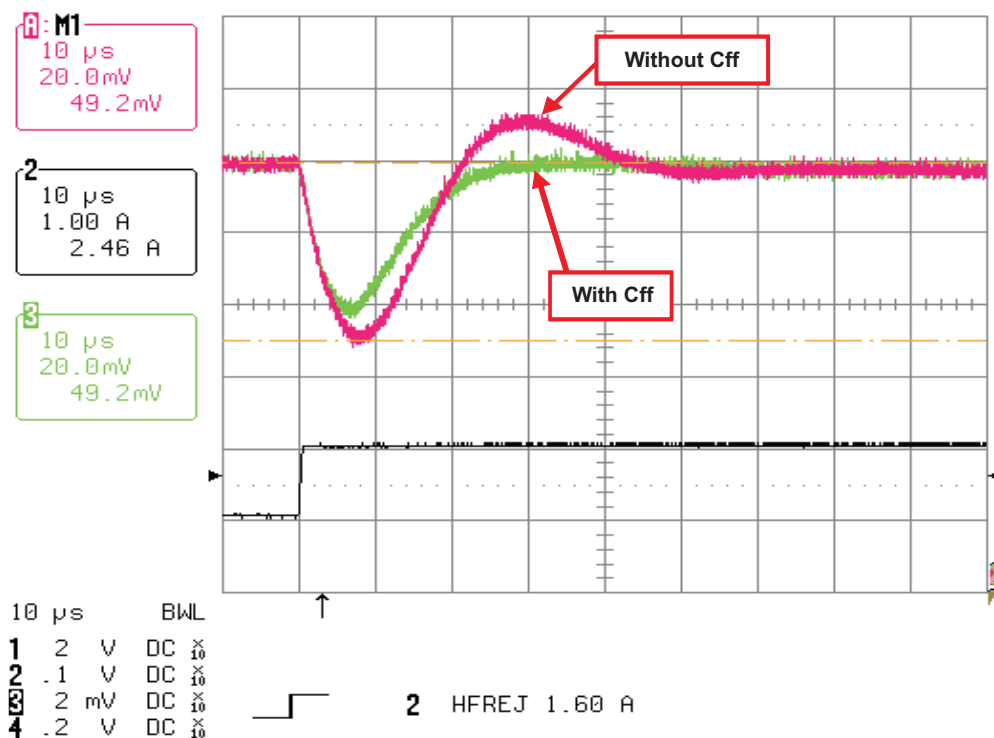


Figure 6. Load Transient Response Before and After Optimizing Resistors

3 Feedforward Capacitor for Gain Crossover Frequencies Above 100 kHz

At loop bandwidths above 100 kHz, the feedforward capacitor has limited or no effect on the response. This is a characteristic of the DCS-Control™ topology as implemented on the TPS62130/40/50/60/70. Figure 7 and Figure 8 show the results of optimizing the feedback resistors for the recommended 2.2-μH inductor and 22-μF output capacitor, which has a unity gain crossover frequency of 298.5 kHz. The lack of any significant change in the bode plot and load transient shows that the Cff has no effect.

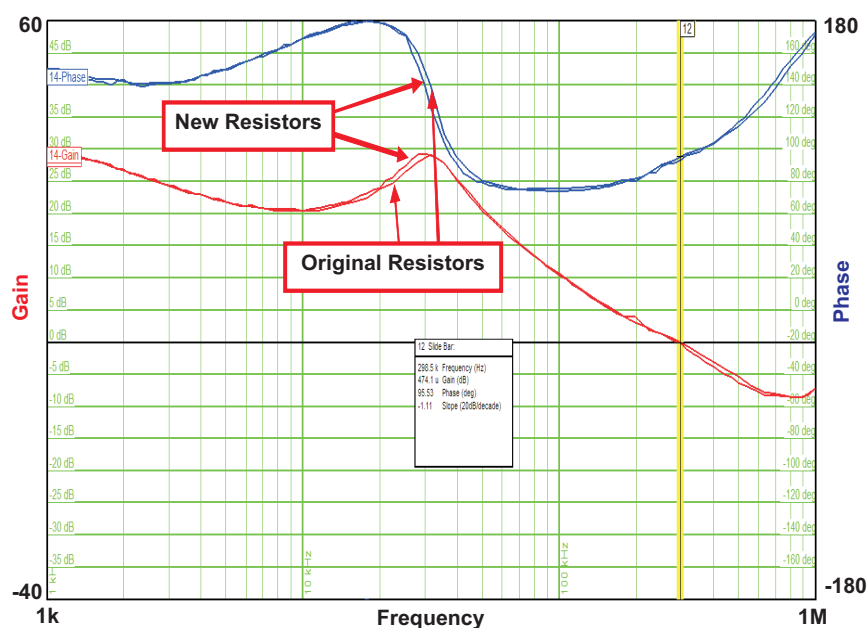


Figure 7. Loop Gain for 2.2-μH Inductor and 22-μF Capacitor

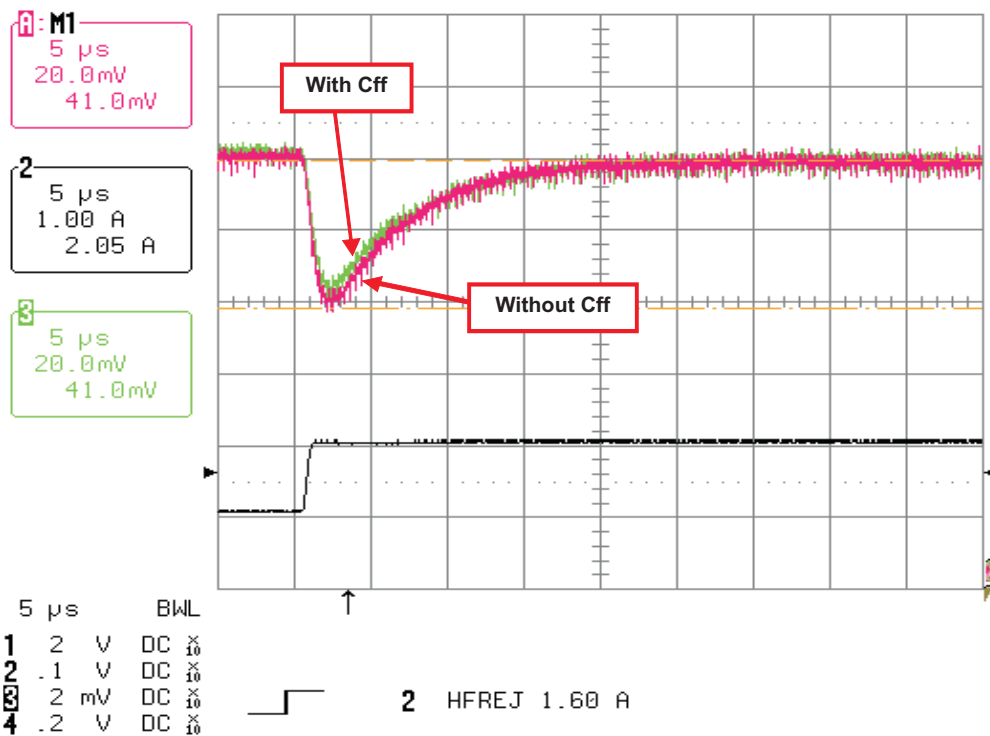


Figure 8. Load Transient Response for 2.2- μ H Inductor and 22- μ F Capacitor

4 Conclusion

This application report presents methods of improving the load transient response of the TPS62130/40/50/60/70 family of devices by using a feedforward capacitor. Either adding an external capacitor or adjusting the feedback resistors are two ways to improve the loop response for loop bandwidths below 100 kHz. For most designs, adjusting the feedback resistors to take advantage of the internal 25-pF Cff provides the best response without any extra components or negative performance effects.

5 References

1. *Optimizing the TPS62130/40/50/60/70 Output Filter* application report ([SLVA463](#))
2. *How to Measure Control Loop of TPS62130/40/50/60/70 DCS-Control™ Devices* application report ([SLVA465](#))
3. *TPS62130, 3-17V 3A Step-Down Converter in 3x3 QFN Package* data sheet ([SLVSAG7](#))
4. *Optimizing Transient Response of Internally Compensated dc-dc Converters With Feedforward Capacitor* application report ([SLVA289](#))

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 TI 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. Information of third parties may be subject to additional restrictions.

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.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

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

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Mobile Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Transportation and Automotive	www.ti.com/automotive
Video and Imaging	www.ti.com/video

TI E2E Community Home Page

e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated