

***PIN Diode Drivers***



Literature Number: SNVA531

# PIN Diode Drivers

National Semiconductor  
Application Note 49  
March 1986



## INTRODUCTION

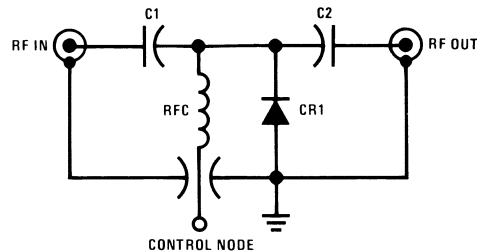
The DH0035/DH0035C is a TTL/DTL compatible, DC coupled, high speed PIN diode driver. It is capable of delivering peak currents in excess of one ampere at speeds up to 10 MHz. This article demonstrates how the DH0035 may be applied to driving PIN diodes and comparable loads which require high peak currents at high repetition rates. The salient characteristics of the device are summarized in *Table 1*.

**TABLE 1. DH0035 Characteristics**

Parameter	Conditions	Value
Differential Supply Voltage ( $V^+ - V^-$ )		30V Max.
Output Current		1000 mA
Maximum Power		1.5W
$t_{\text{delay}}$	PRF = 5.0 MHz	10 ns
$t_{\text{rise}}$	$V^+ - V^- = 20V$ 10% to 90%	15 ns
$t_{\text{fall}}$	$V^+ - V^- = 20V$ 90% to 10%	10 ns

## PIN DIODE SWITCHING REQUIREMENTS

*Figure 1* shows a simplified schematic of a PIN diode switch. Typically, the PIN diode is used in RF through microwave frequency modulators and switches. Since the diode is in shunt with the RF path, the RF signal is attenuated when the diode is forward biased ("ON"), and is passed unattenuated when the diode is reversed biased ("OFF"). There are essentially two considerations of interest in the "ON" condition. First, the amount of "ON" control current must be sufficient such that RF signal current will not significantly modulate the "ON" impedance of the diode. Secondly, the time required to achieve the "ON" condition must be minimized.



**FIGURE 1. Simplified PIN Diode Switch**

The charge control model of a diode<sup>1,2</sup> leads to the charge continuity equation given in *Equation (1)*.

$$i = \frac{dQ}{dt} + \frac{Q}{\tau} \quad (1)$$

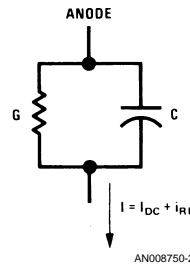
where:  $Q$  = charge due excess minority carriers

$\tau$  = mean lifetime of the minority carriers

*Equation (1)* implies a circuit model shown in *Figure 2*. Under steady conditions  $\frac{dQ}{dt} = 0$  hence:

$$I_{DC} = \frac{Q}{\tau} \text{ or } Q = I_{DC} \cdot \tau \quad (2)$$

where:  $I$  = steady state "ON" current.



$I$  = Total Current  
 $I_{DC}$  = SS Control Current  
 $i_{RF}$  = RF Signal Current

**FIGURE 2. Circuit Model for PIN Switch**

The conductance is proportional to the current,  $I$ ; hence, in order to minimize modulation due to the RF signal,  $I_{DC} \gg i_{RF}$ . Typical values for  $I_{DC}$  range from 50 mA to 200 mA depending on PIN diode type, and the amount of modulation that can be tolerated.

The time response of the excess charge,  $Q$ , may be evaluated by taking the Laplace transform of *Equation (1)* and solving for  $Q$ :

$$Q(s) = \frac{\tau I(s)}{1 + s\tau} \quad (3)$$

Solving *Equation (3)* for  $Q(t)$  yields:

$$Q(t) = L^{-1} [Q(s)] = I\tau (1 - e^{-t/\tau}) \quad (4)$$

The time response of  $Q$  is shown in *Figure 3*. As can be seen, several carrier lifetimes are required to achieve the steady state "ON" condition ( $Q = I_{DC} \cdot \tau$ ).

The time response of the charge, hence the time for the diode to achieve the "ON" state could be shortened by applying a current spike,  $I_{pk}$ , to the diode and then dropping the current to the steady state value,  $I_{DC}$ , as shown in *Figure 4*. The optimum response would be dictated by:

$$(I_{pk})(t) = \tau \cdot I_{DC} \quad (5)$$

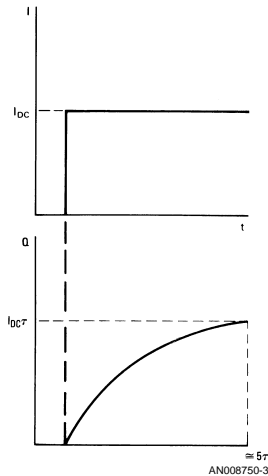


FIGURE 3.

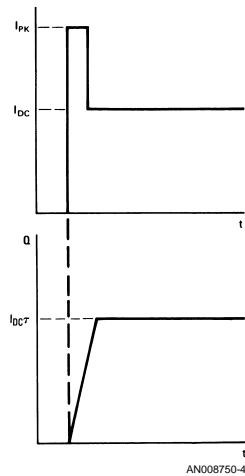


FIGURE 4.

The turn off requirements for the PIN diode are quite similar to the turn on, except that in the "OFF" condition, the steady current drops to the diode's reverse leakage current.

A charge,  $I_{DC} \cdot \tau$ , was stored in the diode in the "ON" condition and in order to achieve the "OFF" state this charge must

be removed. Again, in order to remove the charge rapidly, a large peak current (in the opposite direction) must be applied to the PIN diode:

$$-I_{pk} \geq \frac{Q}{\tau} \quad (6)$$

It is interesting to note an implication of *Equation (5)*. If the peak turn on current were maintained for a period of time, say equal to  $\tau$ , then the diode would acquire an excess charge equal to  $I_{pk} \cdot T$ . This same charge must be removed at turn off, instead of a charge  $I_{DC} \cdot \tau$ , resulting in a considerably slower turn off. Accordingly, control of the width of turn on current peak is critical in achieving rapid turn off.

#### APPLICATION OF THE DH0035 AS A PIN DIODE DRIVER

The DH0035 is specifically designed to provide both the current levels and timing intervals required to optimally drive PIN diode switches. Its schematic is shown in *Figure 5*. The device utilizes a complementary TTL input buffer such as the DM7830/DM8830 or DM5440/DM7440 for its input signals.

Two configurations of PIN diode switch are possible: cathode grounded and anode grounded. The design procedures for the two configurations will be considered separately.

#### ANODE GROUND DESIGN

Selection of power supply voltages is the first consideration. Table I reveals that the DH0035 can withstand a total of 30V differentially. The supply voltage may be divided symmetrically at  $\pm 15V$ , for example. Or asymmetrically at +20V and -10V. The PIN diode driver shown in *Figure 6*, uses  $\pm 10V$  supplies.

When the Q output of the DM8830 goes high a transient current of approximately 50 mA is applied to the emitter of  $Q_1$  and in turn to the base of  $Q_5$ .

$Q_5$  has an  $h_{fe} = 20$ , and the collector current is  $h_{fe} \times 50$  or 1000 mA. This peak current, for the most part, is delivered to the PIN diode turning it "ON" (RF is "OFF").

$I_{pk}$  flows until  $C_2$  is nearly charged. This time is given by:

$$t = \frac{C_2 \Delta V}{I_{pk}} \quad (7)$$

where:  $\Delta V$  = the change in voltage across  $C_2$ .

Prior to  $Q_5$ 's turn on,  $C_2$  was charged to the minus supply voltage of -10V.  $C_2$ 's voltage will rise to within two diode drops plus a  $V_{sat}$  of ground:

$$V = |V^-| - V_f(\text{PIN Diode}) - V_{fCR1} - V_{satQ5} \quad (8)$$

for  $V^- = -10V$ ,  $\Delta V = 8V$ .

Once  $C_2$  is charged, the current will drop to the steady state value,  $I_{DC}$ , which is given by:

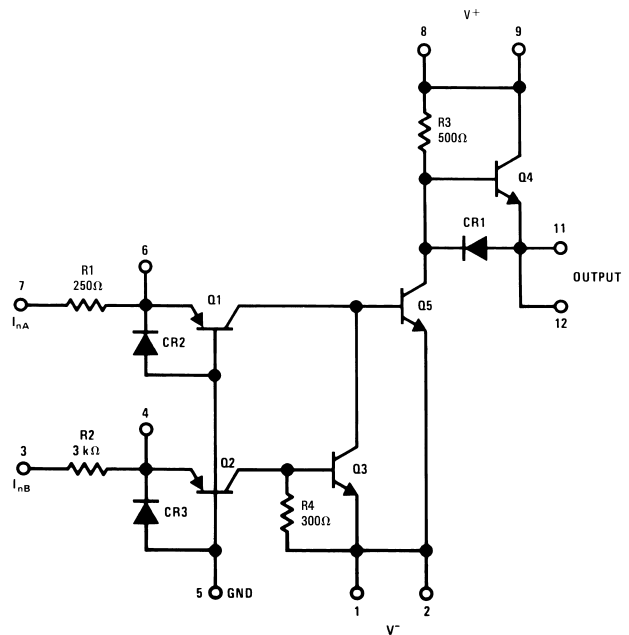
$$I_{DC} = \frac{V}{R_M} - \frac{V^+}{R_3} - \frac{V_{CC}}{R_1} \quad (9)$$

where:  $V_{CC} = 5.0V$

$R_1 = 250\Omega$

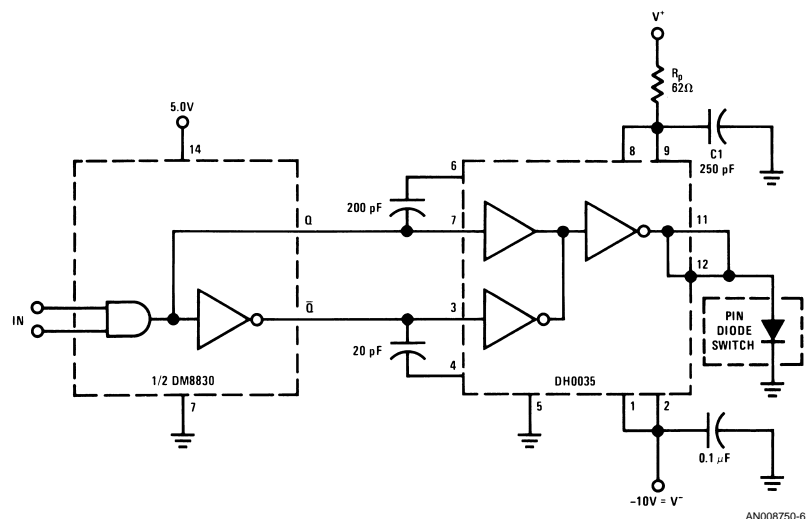
$R_3 = 500\Omega$

$$\therefore R_M = \frac{(R_3 (\Delta V) (R_1))}{R_1 V^+ + I_{DC} R_3 R_1 + V_{CC} R_3} \quad (10)$$



AN008750-5

FIGURE 5. DH0035 Schematic Diagram



AN008750-6

FIGURE 6. Cathode Grounded Design

For the driver of *Figure 6*, and  $I_{DC} = 100 \text{ mA}$ ,  $R_M$  is  $56\Omega$  (nearest standard value).

Returning to *Equation (7)* and combining it with *Equation (5)* we obtain:

$$t = \frac{\tau I_{DC}}{I_{pk}} = \frac{C_2 V}{I_{pk}} \quad (11)$$

Solving *Equation (11)* for  $C_2$  gives:

$$C_2 = \frac{I_{DC} \tau}{V} \quad (12)$$

For  $\tau = 10 \text{ ns}$ ,  $C_2 = 120 \text{ pF}$ .

One last consideration should be made with the diode in the "ON" state. The power dissipated by the DH0035 is limited to  $1.5\text{W}$  (see *Table I*). The DH0035 dissipates the maximum power with  $Q_5$  "ON". With  $Q_5$  "OFF", negligible power is dissipated by the device. Power dissipation is given by:

$$P_{\text{diss}} \cong \left[ I_{DC} (|V^-| - \Delta V) + \frac{(V^+ - V^-)^2}{R_3} \right] \times (\text{D.C.}) \leq P_{\text{max}} \quad (13)$$

where: D.C. = Duty Cycle =

$$\frac{(\text{"ON" time})}{(\text{"ON" time} + \text{"OFF" time})}$$

$$P_{\text{max}} = 1.5\text{W}$$

In terms of  $I_{DC}$ :

$$I_{DC} \leq \frac{\left[ \frac{(P_{\text{max}})}{(\text{D.C.})} - \frac{(V^+ - V^-)^2}{500} \right]}{|V^-| - \Delta V} \quad (14)$$

For the circuit of *Figure 6* and a 50% duty cycle,  $P_{\text{diss}} = 0.5\text{W}$ .

Turn-off of the PIN diode begins when the Q output of the DM8830 returns to logic "0" and the  $\bar{Q}$  output goes to logic "1".  $Q_2$  turns "ON", and in turn, causes  $Q_3$  to saturate. Simultaneously,  $Q_1$  is turned "OFF" stopping the base drive to  $Q_5$ .

$Q_3$  absorbs the stored base charge of  $Q_5$  facilitating its rapid turn-off. As  $Q_5$ 's collector begins to rise,  $Q_4$  turns "ON". At this instant, the PIN diode is still in conduction and the emitter of  $Q_4$  is held at approximately  $-0.7\text{V}$ . The instantaneous current available to clear stored charge out of the PIN diode is:

$$I_{pk} = \frac{V^+ - V_{BE Q4} + V_{f(\text{PIN})}}{R_3} \frac{1}{h_{fe} + 1} \cong \frac{(h_{fe} + 1)(V^+)}{R_3} \quad (15)$$

where:

$h_{fe} + 1$  = current gain of  $Q_4 = 20$

$V_{BE Q4}$  = base-emitter drop of  $Q_4 = 0.7\text{V}$

$V_{f(\text{PIN})}$  = forward drop of the PIN diode =  $0.7\text{V}$

For typical values given,  $I_{pk} = 400 \text{ mA}$ . Increasing  $V^+$  above  $10\text{V}$  will improve turn-off time of the diode, but at the expense of power dissipation in the DH0035. Once turn-off of the diode has been achieved, the DH0035 output current drops to the reverse leakage of the PIN diode. The attendant power dissipation is reduced to about  $35 \text{ mW}$ .

#### CATHODE GROUND DESIGN

*Figure 7* shows the DH0035 driving a cathode grounded PIN diode switch. The peak turn-on current is given by:

$$I_{pk} \cong \frac{(V^+ - V^-)(h_{fe} + 1)}{R_3} \quad (16)$$

=  $800 \text{ mA}$  for the values shown.

The steady state current,  $I_{DC}$ , is set by  $R_p$  and is given by:

$$I_{DC} = \frac{(V^+ - 2V_{BE})}{R_3 + R_p} \frac{1}{h_{fe} + 1} \quad (17)$$

where:  $2V_{BE}$  = forward drop of  $Q_4$  base emitter junction plus  $V_f$  of the PIN diode =  $1.4\text{V}$ .

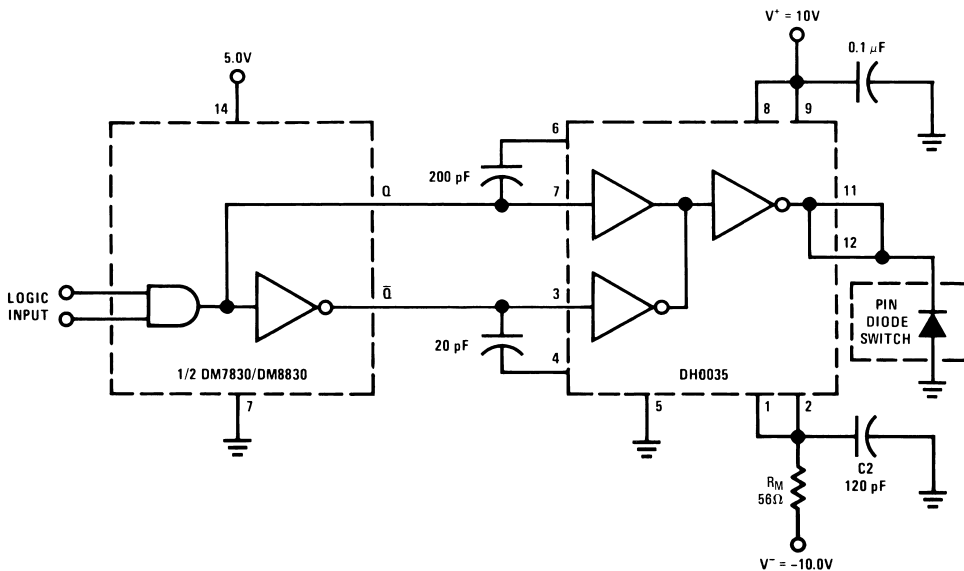


FIGURE 7. Anode Grounded Driver

AN008750-7

In terms of  $R_p$ , Equation (17) becomes:

$$R_p = \frac{(h_{fe} + 1)(V^+ - 2V_{BE}) - I_{DC}R_3}{(h_{fe} + 1)I_{DC}} \quad (18)$$

For the circuit of Figure 7, and  $I_{DC} = 100 \text{ mA}$ ,  $R_p$  is  $62 \Omega$  (nearest standard value).

It now remains to select the value of  $C_1$ . To do this, the change in voltage across  $C_1$ , must be evaluated. In the "ON" state, the voltage across  $C_1$ ,  $V_c$ , is given by:

$$(V_c)_{ON} = \frac{V^+R_3 + R_p(h_{fe} + 1)(2V_{BE})}{R_3 + (h_{fe} + 1)R_p} \quad (19)$$

For the values indicated above,  $(V_c)_{ON} = 3.8\text{V}$ .

In the "OFF" state,  $V_c$  is given by:

$$(V_c)_{OFF} = \frac{V^+R_3 - |V^-|R_p}{R_p + R_3} \quad (20)$$

=  $8.0\text{V}$  for the circuit of Figure 7.

Hence, the change in voltage across  $C_1$  is:

$$\begin{aligned} V &= (V_c)_{OFF} - (V_c)_{ON} \\ &= 8.0 - 3.8 \\ &= 4.2\text{V} \end{aligned} \quad (21)$$

The value of  $C_4$  is given, as before, by Equation (12):

$$C_1 = \frac{I_{DC}\tau}{V^-} \quad (22)$$

For a diode with  $\tau = 10 \text{ ns}$  and  $I_{DC} = 100 \text{ mA}$ ,  $C_1 = 250 \text{ pF}$ . Again the power dissipated by the DH0035 must be considered. In the "OFF" state, the power dissipation is given by:

$$P_{OFF} = \left[ \frac{V^+ - V^-}{R_3} \right]^2 (\text{D.C.}) \quad (23)$$

where: D.C. = duty cycle =

$$\frac{\text{"OFF" time}}{\text{"OFF" time} + \text{"ON" time}}$$

The "ON" power dissipation is given by:

$$P_{ON} = \left[ \frac{(V_c)_{ON}^2}{R_3} + I_{DC} \times (V_c)_{ON} \right] (1 - \text{D.C.}) \quad (24)$$

where:  $(V_c)_{ON}$  is defined by Equation (19).

Total power dissipated by the DH0035 is simply  $P_{ON} + P_{OFF}$ . For a 50% duty cycle and the circuit of Figure 7,  $P_{diss} = 616 \text{ mW}$ .

The peak turn-off current is, as indicated earlier, equal to  $50 \text{ mA} \times h_{fe}$  which is about  $1000 \text{ mA}$ . Once the excess stored charge is removed, the current through  $Q_5$  drops to the diodes leakage current. Reverse bias across the diode =  $V^- - V_{sat} \cong -10\text{V}$  for the circuit of Figure 7.

**REPETITION RATE CONSIDERATIONS**

Although ignored until now, the PRF, in particular, the "OFF" time of the PIN diode is important in selection of  $C_2$ ,  $R_M$ , and  $C_1$ ,  $R_p$ . The capacitors must recharge completely during the diode "OFF" time. In short:

$$4 R_M C_2 \leq t_{OFF} \quad (25)$$

$$4 R_p C_1 \leq t_{OFF} \quad (26)$$

**CONCLUSION**

The circuit of *Figure 7* was breadboarded and tested in conjunction with a Hewlett-Packard 33622A PIN diode.

$I_{DC}$  was set at 100 mA,  $V^+ = 10V$ ,  $V^- = 10V$ . Input signal to the DM8830 was a 5V peak, 100 kHz, 5  $\mu$ s wide pulse train. RF turn-on was accomplished in 10–12 ns while turn-off took approximately 5 ns, as shown in *Figure \*NO TARGET FOR fig NS0292\** and *Figure \*NO TARGET FOR fig NS0292\**.

In practice, adjustment  $C_2$  ( $C_1$ ) may be required to accommodate the particular PIN diode minority carrier lifetime.

**SUMMARY**

A unique circuit utilized in the driving of PIN diodes has been presented. Further a technique has been demonstrated which enables the designer to tailor the DH0035 driver to the PIN diode application.

**REFERENCES**

1. "Pulse, Digital, & Switching Waveforms", Jacob Millman & Herbert Taub, *McGraw-Hill Book Company, Inc.*, New York, N.Y.
2. "Models of Transistors and Diodes", John G. Linvill, *McGraw-Hill Book Company, Inc.*, New York, N.Y.
3. *National Semiconductor AN-18*, Bert Mitchell, March 1969.
4. *Hewlett-Packard Application Note 314*, January 1967.

**LIFE SUPPORT POLICY**

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



**National Semiconductor Corporation**  
Americas  
Tel: 1-800-272-9959  
Fax: 1-800-737-7018  
Email: support@nsc.com

**National Semiconductor Europe**  
Fax: +49 (0) 1 80-530 85 86  
Email: europe.support@nsc.com  
Deutsch Tel: +49 (0) 1 80-530 85 85  
English Tel: +49 (0) 1 80-532 78 32  
Français Tel: +49 (0) 1 80-532 93 58  
Italiano Tel: +49 (0) 1 80-534 16 80

**National Semiconductor Asia Pacific Customer Response Group**  
Tel: 65-2544466  
Fax: 65-2504466  
Email: sea.support@nsc.com

**National Semiconductor Japan Ltd.**  
Tel: 81-3-5639-7560  
Fax: 81-3-5639-7507

www.national.com

## 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	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</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>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

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

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

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