

# Data-rate independent half-duplex repeater design for RS-485

By Thomas Kugelstadt

Applications Engineer

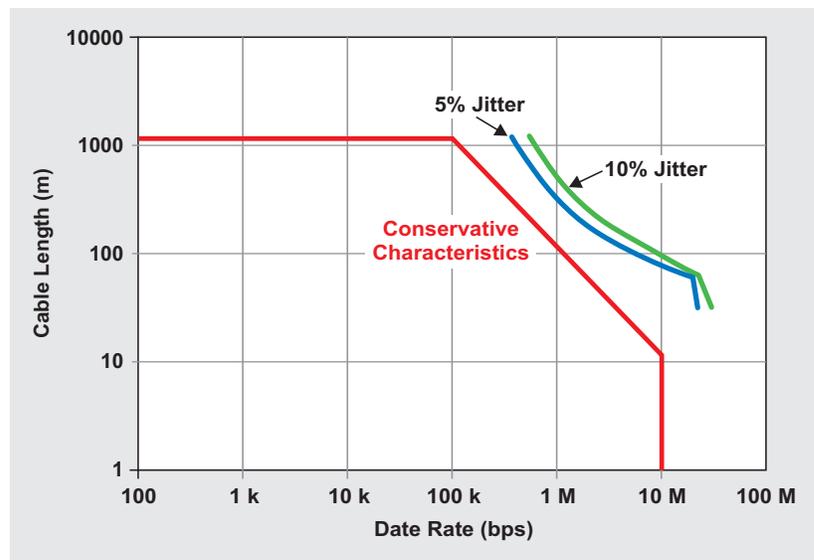
A question frequently posed by engineers is how to design a data-rate independent half-duplex repeater for RS-485 applications. Examples include designing a long-haul network beyond the suggested maximum cable length of 1200 m, adding long stubs to an existing network, or designing a network using a star topology. The data rates applied can vary between systems from 10 kbps up to 200 kbps.

Ground-potential differences (GPDs) between remotely located nodes can assume voltages exceeding the maximum common-mode voltage range of most bus transceivers, making galvanic isolation necessary between the network node electronics and the bus.

In Reference 1, the characteristic for cable length versus data rate suggests that a maximum cable length of 1200 m, or about 4000 ft, should be used (Figure 1). At this length, the resistance of the commonly applied 120- $\Omega$ , AWG24 unshielded twisted-pair (UTP) cable approaches the value of the termination resistor and reduces the bus signal swing by half, or 6 dB.

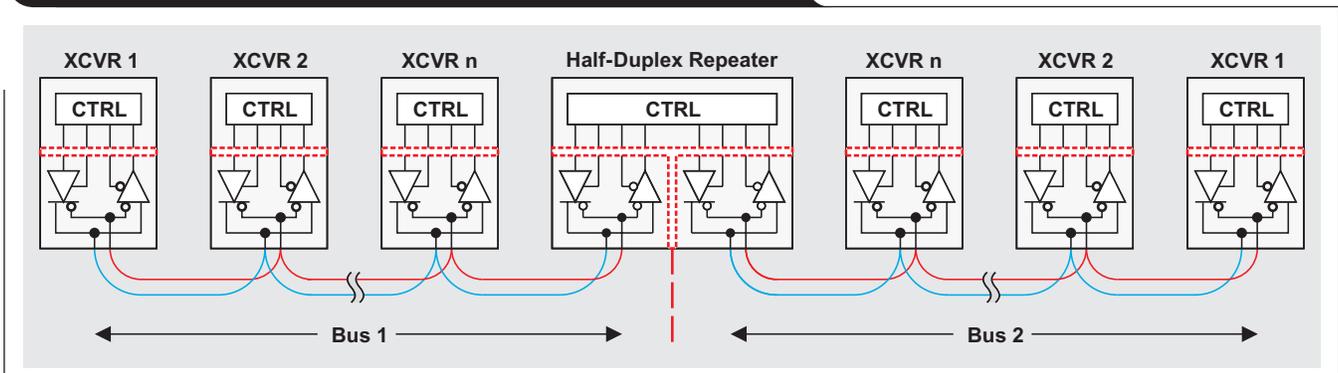
In RS-485 literature, transceiver datasheets often show a full-duplex repeater design for simplicity's sake. In long-haul networks, however, it is undesirable to run a full-duplex cable for thousands of meters because cable and wiring are very expensive.

Figure 1. Cable length versus data rate



To operate an extended long-haul network in half-duplex mode, implementing a half-duplex repeater is a must. A system block diagram is shown in Figure 2. Because a half-duplex repeater interfaces to two bus segments, the repeater must comprise two separate transceivers, each connecting to its respective bus via signal isolators, and a control logic isolated from both transceiver sections. The control logic performs timely enabling and disabling of the repeater's driver and receiver sections. This is initiated by the incoming data signal from either direction.

Figure 2. Bus extension with dual isolated half-duplex repeater



The two most commonly applied timing-control methods are the one-shot circuit in Figure 3 and the inverting buffer with a time delay in Figure 4. To ensure correct switching behavior, both methods require defined start conditions after power up and bus idling. This is accomplished through fail-safe biasing resistors,  $R_{FS}$ , which create a fail-safe voltage,  $V_{FS}$ , above the receiver input sensitivity of  $V_{FS} > +200$  mV when no transceiver is actively driving the bus.

A run-through of the one-shot circuit's functional sequence (numbered here and in Figure 3) clarifies the repeater operation:

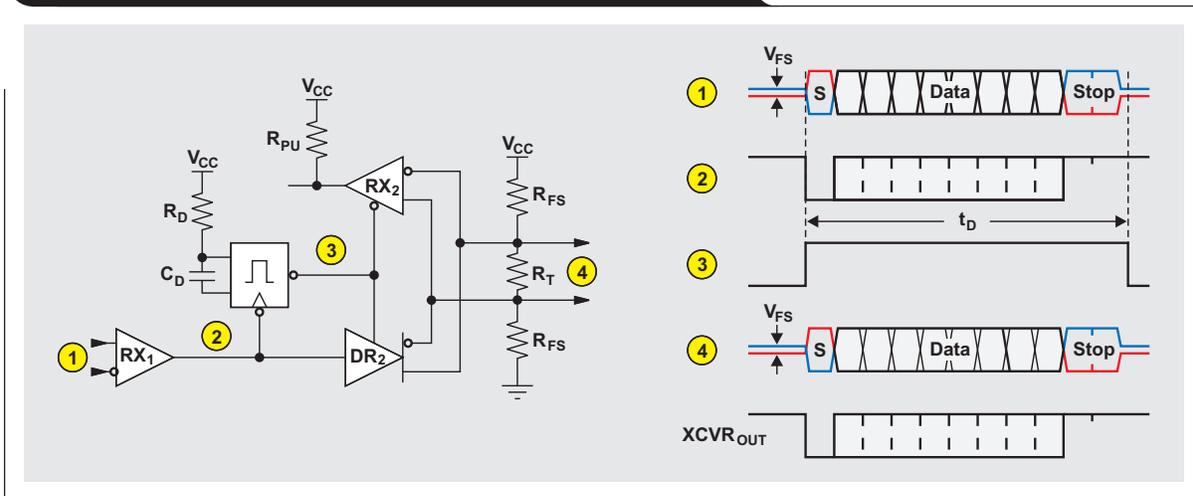
1. During bus idling, the receiver outputs of both repeater ports are high due to  $V_{FS}$ . Thus, both transceivers hold each other in receive mode.
2. Next, the arriving start bit of an incoming data packet on port 1 drives the output of  $RX_1$  low. This transition

triggers the one-shot circuit, driving its output high and enabling driver  $DR_2$ .

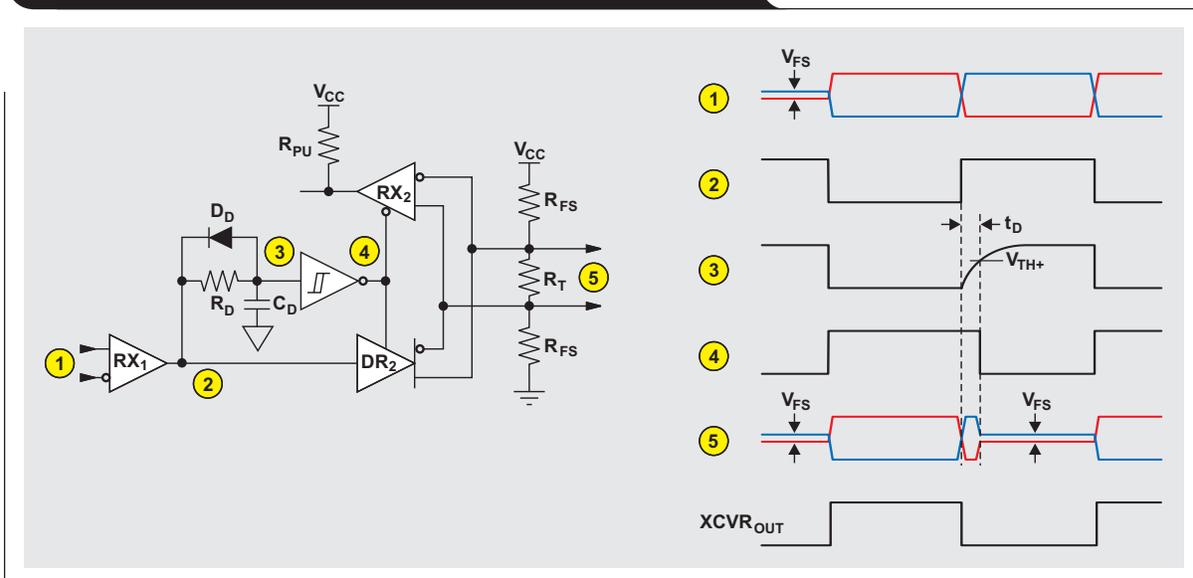
3. The time constant,  $R_D \times C_D$ , must be so calculated that the one-shot circuit's output remains high for the entire time of the data packet.
4.  $DR_2$  continues driving bus 2 for the duration of the one-shot time constant.  $XCVR_{OUT}$  represents the receiver output state of a remote transceiver on bus 2. Note that while  $DR_2$  is enabled, the pull-up resistor,  $R_{PU}$ , pulls the disabled receiver's ( $RX_2$ 's) output high in order to keep  $RX_1$  enabled.

A drawback of this solution is that the R-C time constant depends on the data-packet length and the data rate at which the signal is transmitted. Also, one-shot circuits are sensitive to noise transients, which can cause false triggering and repeater breakdown.

**Figure 3. Transceiver timing control with a one-shot circuit**



**Figure 4. Transceiver timing control with an inverting buffer**



Nevertheless, one-shot circuits are used often in interface bridges such as RS-232 to RS-485 converters. These converters directly connect an RS-485 network to the RS-232 ports of older PCs or RS-232-controlled machinery.

A more robust and data-rate-independent alternative to the one-shot circuit is timing control through an inverting Schmitt-trigger buffer with different charge and discharge times. The underlying principle is to actively drive a bus during logic-low states and to disable the driver during logic-high states. The enabling and disabling sequences then occur on a per-bit basis, which makes the repeater function independent of data rate and packet length.

A run-through of the inverter-controlled repeater's functional sequence (numbered here and in Figure 4) clarifies its operation:

1. During bus idling, the receiver outputs of both repeater ports are high due to  $V_{FS}$ . The delay capacitor,  $C_D$ , is fully charged, driving the inverter output low to maintain the transceiver in receive mode.
2. Then a low bit on bus 1, driving the output of  $RX_1$  low, rapidly discharges  $C_D$  and enables driver  $DR_2$ .
3. When the bus voltage turns positive ( $V_{Bus} > 200$  mV), the output of  $RX_1$  turns high, which drives  $DR_2$ 's output high and slowly charges  $C_D$  via  $R_D$ . The minimum time constant ( $R_D \times C_D$ ) must be so calculated that at the maximum supply voltage,  $V_{CC(max)}$ , and the minimum positive inverter input threshold,  $V_{TH+(min)}$ , the delay time,  $t_D$ , exceeds the maximum low-to-high propagation delay,  $t_{PLH(max)}$ , of the driver by, say, 30%. For example, given a capacitance of  $C_D = 100$  pF, the required resistor value for  $R_D$  is

$$R_D = \left\lceil \frac{1.3 \times t_{PLH(max)}}{C_D \times \ln \left( 1 - \frac{V_{TH+(min)}}{V_{CC(max)}} \right)} \right\rceil$$

4. The driver enable time is extended by the delay time ( $t_D$ ) versus the actual data-bit interval to establish a valid high signal on the bus. This is done prior to switching from transmit to receive mode in order to keep the receiver output continuously high. Because the propagation delays of receivers are shorter than those of drivers, it is impossible for the receiver to turn low, not even for a short instant. Once the driver is disabled, the external fail-safe resistors bias bus 2 to above 200 mV, which is seen by the active receiver as a defined high.
5. The differential output voltages on bus 2 are  $V_{OD} = V_{FS} > +200$  mV during an idle bus,  $V_{OD} < 1.5$  V for a low bit, and  $V_{OD} > 1.5$  V for the time delay ( $t_D$ ) at the beginning of a high bit. Afterwards,  $V_{OD} = V_{FS} > +200$  mV for the remainder of a high bit.

Again,  $XCVR_{OUT}$  represents the receiver output state of a remote transceiver on bus 2. While legacy repeater designs typically were limited to data rates of 10 kbps, modern transceivers with shorter propagation delays allow for higher data rates of up to 100 kbps and more.

For simplicity, the repeater discussion has so far excluded the important aspect of galvanic isolation. However, in long-haul networks—the main application field of repeaters—large ground-potential differences (GPDs) between network nodes are common. These GPDs present themselves as large common-mode voltages across the transceiver inputs and can damage a device if not eliminated through galvanic isolation. When a transceiver's bus circuitry is isolated from its control circuitry, the bus system is floating and independent from a local node's ground potential.

Figure 2 shows the driver and receiver section of a bus node being isolated from the node's control circuitry. However, in the case of the repeater, dual isolation is required because the inner control logic must be isolated from bus 1 and bus 2. Furthermore, the two buses must

be isolated from each other. A repeater circuit accomplishing this is shown in Figure 5, accompanied by its bill of material (BOM) in Table 1. The circuit uses two isolated RS-485 transceivers, each requiring a separate, isolated supply,  $V_{ISO}$ , derived from the central 3.3-V supply of the control section (Figure 6).

**Conclusion**

A repeater can be used as a bus extender or a stub extender. For a bus extender, a repeater builds the end of one bus and the beginning of another. This allows a fixed installation of fail-safe and termination resistors at both ports. When a repeater is used as an extender for long stubs, however, it can be located anywhere in the network. In this case the resistors at the port side connecting to the bus should be removed, while the resistors at the stub port can remain installed.

**Reference**

1. "Application Guidelines for TIA/EIA-485-A," TIA TSB-89, January 1, 2006. Available at [www.global.ihs.com](http://www.global.ihs.com)

**Table 1. BOM for the repeater's signal path**

DESIGNATOR	FUNCTION	DEVICE/VALUE	SUPPLIER
U1, U2	Isolated half-duplex transceiver	ISO15DW	Texas Instruments
U3	Dual Schmitt-trigger inverter	SN74LVC2G14DBV	
R <sub>PU</sub>	Pull-up resistor	4.7 kΩ	Vishay
R <sub>FS</sub>	Fail-safe resistor	348 Ω	
R <sub>T</sub>	Termination resistor	120 Ω	
R <sub>D</sub>	Delay resistor	10 kΩ	
C <sub>S</sub>	Storage capacitor	10 μF	
C <sub>B</sub>	Bypass capacitor	0.1 μF	
C <sub>D</sub>	Delay capacitor	100 pF	
D <sub>D</sub>	Discharge diode	1N4448	

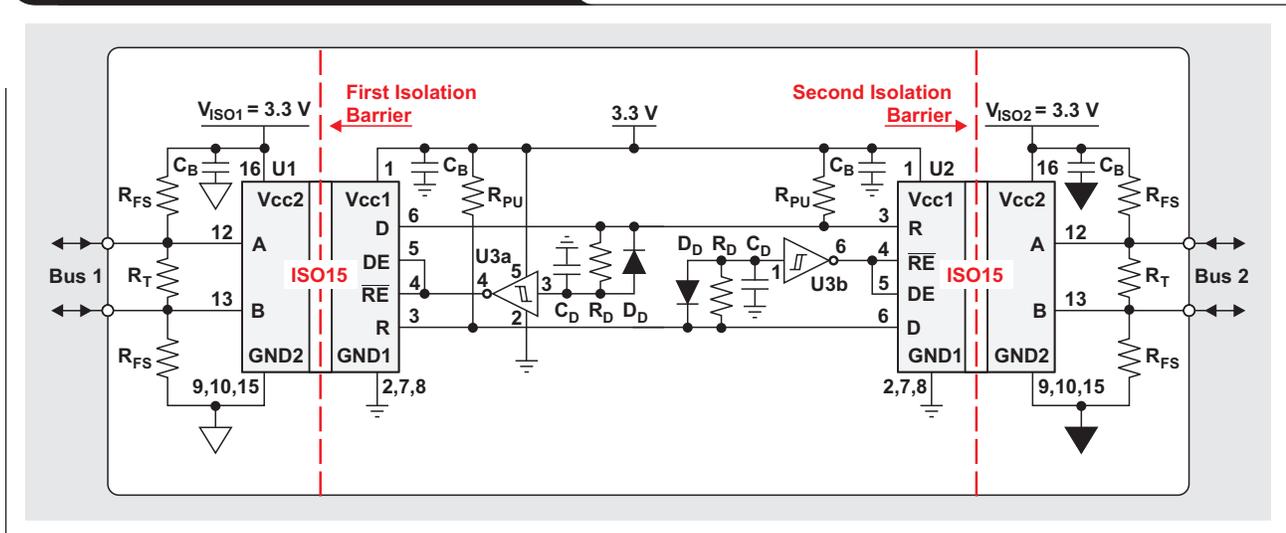
**Related Web sites**

[www.ti.com/interface](http://www.ti.com/interface)

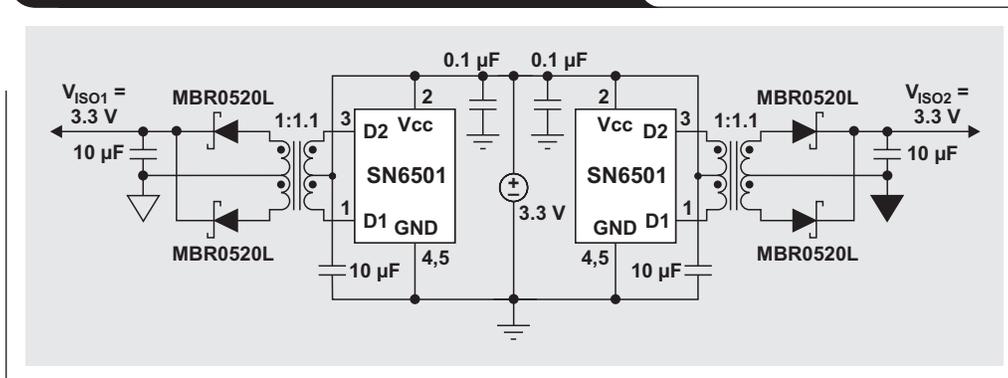
[www.ti.com/product/partnumber](http://www.ti.com/product/partnumber)

Replace *partnumber* with ISO15, SN6501, or SN74LVC2G14

**Figure 5. Dual isolated half-duplex repeater**



**Figure 6. Design for dual isolated power supplies**



# TI Worldwide Technical Support

---

## Internet

### TI Semiconductor Product Information Center Home Page

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

### TI E2E™ Community Home Page

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

## Product Information Centers

<b>Americas</b>	Phone	+1(972) 644-5580
<b>Brazil</b>	Phone	0800-891-2616
<b>Mexico</b>	Phone	0800-670-7544
	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	
European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
Russian Support	+7 (4) 95 98 10 701

**Note:** The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax	+ (49) (0) 8161 80 2045
Internet	<a href="http://www.ti.com/asktexas">www.ti.com/asktexas</a>
Direct Email	<a href="mailto:asktexas@ti.com">asktexas@ti.com</a>

### Japan

Phone	Domestic	0120-92-3326
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	+91-80-41381665
Domestic	<u>Toll-Free Number</u>
<b>Note:</b> Toll-free numbers do not support mobile and IP phones.	
Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	1-800-425-7888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010
Fax	+8621-23073686
Email	<a href="mailto:tiasia@ti.com">tiasia@ti.com</a> or <a href="mailto:ti-china@ti.com">ti-china@ti.com</a>
Internet	<a href="http://support.ti.com/sc/pic/asia.htm">support.ti.com/sc/pic/asia.htm</a>

**Important Notice:** The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

A011012

E2E is a trademark of Texas Instruments. All other trademarks are the property of their respective owners.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46C and to discontinue any product or service per JESD48B. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

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

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

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license 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 significant portions 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. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

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

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components which meet ISO/TS16949 requirements, mainly for automotive use. Components which have not been so designated are neither designed nor intended for automotive use; and TI will not be responsible for any failure of such components to meet such requirements.

### 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

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
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>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

**TI E2E Community** [e2e.ti.com](http://e2e.ti.com)