

## Isolated RS-485 Repeaters

The Backbone of Industrial Long-Haul Networks

AN1988  
Rev.0.00  
Jul 24, 2017

### Abstract

Data transmission networks in Atmospheric Monitors Systems (AMS) of large coal mines, sulfur recovery systems of petrochemical plants, and other, large-scale industrial operations, often use RS-485 as their physical layer. The low equipment, installation, and maintenance cost associated with RS-485 makes it an attractive low-cost alternative to fiber-optics installations, commonly considered for long-haul networks.

Spanning several miles in length, these networks use signal repeaters to connect multiple bus segments together. Minimizing cabling efforts, network nodes, and repeaters must operate in half-duplex mode. With segment length reaching up to one mile (1600m), external failsafe biasing is applied at each repeater input and output. Eliminating the common-mode effects of large ground potential differences between remote network nodes, repeater input and output are galvanically isolated from one another.

To ease the design of long-haul networks, this application note:

- Provides a short overview of the network structure of long distance and wide area RS-485 networks.
- Explains the functional principle of a half-duplex repeater, and shows the design differences between single- and dual-isolated repeaters.
- Discusses the impact of repeater signal skew on the maximum possible data rate.
- Equations for calculating the resistor values of the external failsafe networks

### Contents

1.	<b>Network Structures</b>	3
2.	<b>Repeater Operating Principle</b>	5
3.	<b>Calculation Example 1.</b>	7
4.	<b>Single and Dual Isolated Repeaters</b>	8
5.	<b>Failsafe Biasing Networks</b>	9
6.	<b>Calculation Example 2.</b>	10
7.	<b>Maximum Bus I/O Nodes per Segment</b>	11
8.	<b>Maximum Segment Length</b>	12
9.	<b>Maximum Stub Length</b>	13
10.	<b>Maximum Data Rate.</b>	14
11.	<b>Switching Performance.</b>	15
12.	<b>Conclusion</b>	16

## List of Figures

Figure 1.	Long Distance RS-485 Network Shown Left with Single Bus Segment Shown on the Right. . . .	3
Figure 2.	Large Area RS-485 Network with a Single Branching Bus Segment Shown at the Top . . . . .	3
Figure 3.	Half-Duplex Repeater with Signal Timing Diagram . . . . .	5
Figure 4.	Time Delay Requirement: $t_D = t_{PLH-MAX} + 0.5 t_{R-MAX}$ . . . . .	6
Figure 5.	Dual-Isolated HD Repeater . . . . .	8
Figure 6.	Single-Isolated HD Repeater . . . . .	8
Figure 7.	Single Ground Reference Design of a Repeater Link . . . . .	8
Figure 8.	Failsafe Biasing Networks for Long Data Links . . . . .	9
Figure 9.	TSB-89 Recommended Maximum Cable Length for Low Data Rates is Based on 6dB Voltage Drop. . . . .	12
Figure 10.	20-Mile Long Network with 20 Bus Segments of One-Mile Length and 19 Repeaters . . . . .	14
Figure 11.	$\pm 20\%$ Pulse Distortion Allows for Easy Data Recovery . . . . .	14
Figure 12.	Repeater Waveforms at 20kbps . . . . .	15
Figure 13.	Repeater Waveforms at 100kbps . . . . .	15

# 1. Network Structures

Long distance networks consist of a series of multiple bus segments, connected by half-duplex repeaters (Figure 1). Each bus segment allows for the connection of multiple I/O bus nodes, however, with the requirement for relative short distances between the actual transceiver inputs and the main cable trunk. Thus, the network layout is governed and limited by the locations of the I/O bus nodes it must be connected to.

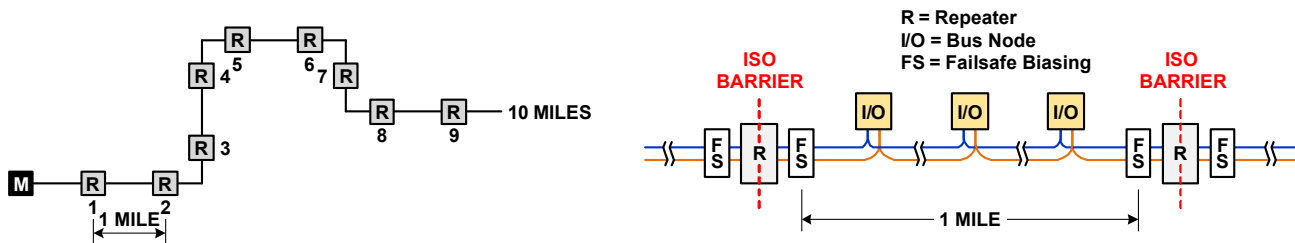


Figure 1. Long Distance RS-485 Network Shown Left with Single Bus Segment Shown on the Right

Overcoming the limitations of purely long distance networks, large area networks utilize a long distance bus as a network backbone, while adding branch capability to each bus segment. An example of a possible network structure is shown in Figure 2.

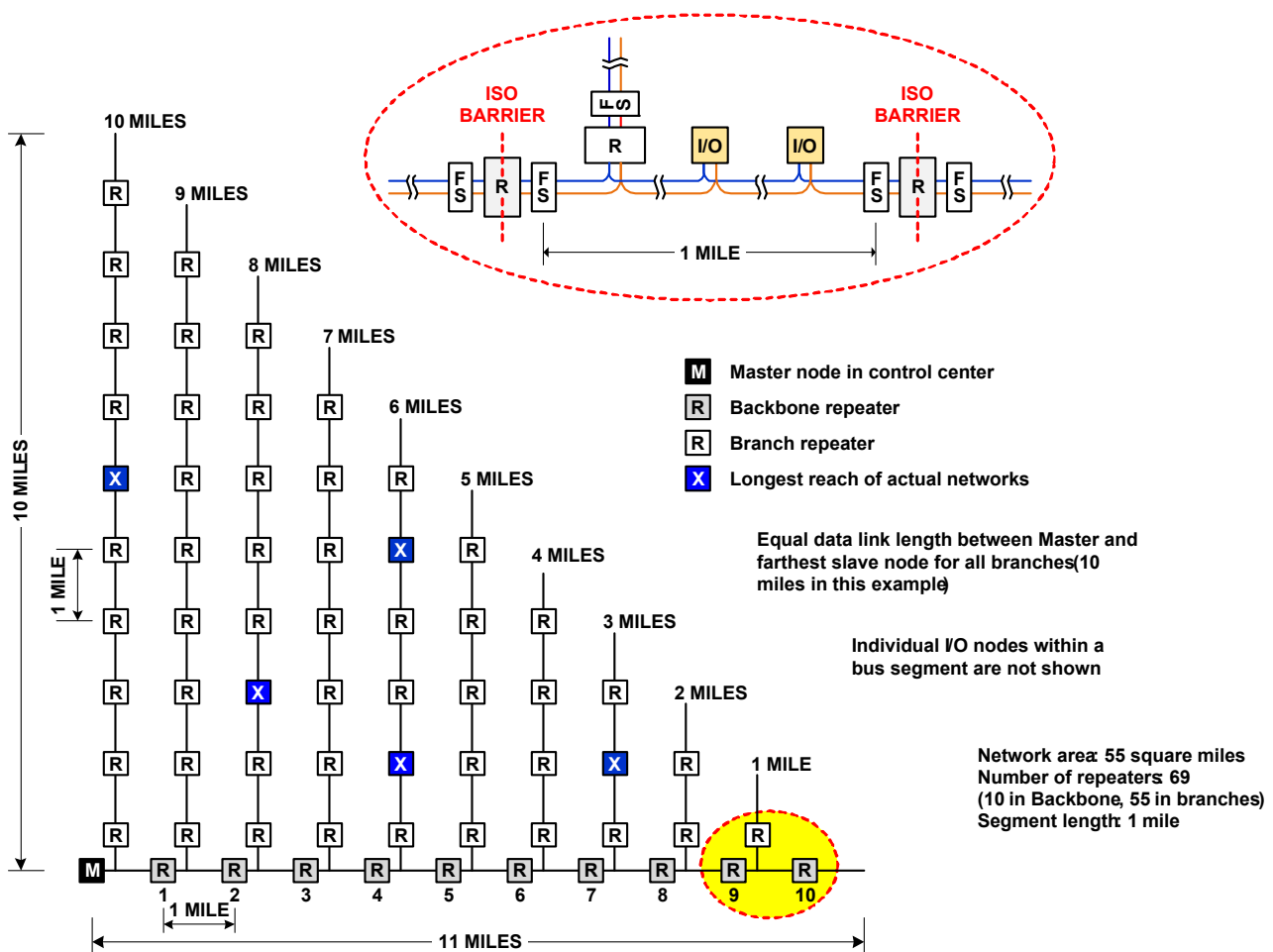


Figure 2. Large Area RS-485 Network with a Single Branching Bus Segment Shown at the Top

While the network of [Figure 2 on page 3](#) is hypothetical, it demonstrates the network layout capabilities when using half-duplex repeaters, commonly available as repeater modules. This approach enables network architects to plan ahead in anticipation of future network growth, an important aspect for many industrial startup enterprises in industrial automation and coal mining that must extend network coverage from an initially smaller network.

Another important aspect of the above network structure is that the distance between the master node and the farthest slave node in any branch is always constant. Thus, the maximum propagation time and propagation skew are fixed, making this RS-485 network deterministic.

## 2. Repeater Operating Principle

A half-duplex repeater consists of two, back-to-back connected, half-duplex transceivers (Figure 3). The driver and receiver enable functions of one transceiver are controlled by the logic states of the other transceiver’s receiver output. Here, the underlying operating principle is to actively drive the bus with a negative bus voltage ( $-V_{AB}$ ) when the driver input is low, and to disable the driver when its input is high. In this case, a positive  $V_{AB}$  (representing a high) in form of the failsafe voltage  $V_{FS}$ , is generated by the external failsafe biasing network. This switching method makes repeater operation largely independent of data rate and packet length.

However, additional time-delay circuits are required, to prevent the receiver output of the active transceiver from glitching. For a better understanding of the repeater’s operating principle, Figure 3 shows the repeater schematic with the corresponding timing diagram for a signal flow port 1 (A1, B1) to port 2 (A2, B2).

After power-up and during an idle-bus condition, both transceivers are in receive mode, and the capacitors,  $C_D$ , fully charged. A negative bus voltage at port 1 drives the output of receiver R1 and the input of driver D2 low. The low potential forward biases diode  $D_D$ , which starts conducting, bypassing resistor  $R_D$ , and immediately discharging  $C_D$  through resistor  $R_S$ . Note that  $R_S$  is only required to limit the large discharge current spike into the output of R1.

When the voltage at  $C_D$  drops below the negative input threshold of the Schmitt-trigger inverter  $V_{TH-}$ , the inverter output turns high, activating D2. Now Port 2 is actively driving its bus with the negative driver output voltage,  $-V_{OD}$ .

When the bus voltage at port 1 turns positive, R1’s output and D2’s input go high and  $C_D$  is slowly charged through  $R_S + R_D$ . This extends D2’s drive time by the time delay,  $t_D$ . With D2 still active, the bus voltage at port 2 assumes the positive driver output voltage ( $+V_{OD}$ ). When the voltage at  $C_D$  reaches the inverter’s positive input threshold,  $V_{TH+}$ , the inverter output turns low, disabling D2 and enabling R2. At this moment, the bus voltage, while remaining positive, drops from its  $V_{OD}$  level to the failsafe level,  $V_{FS}$ .

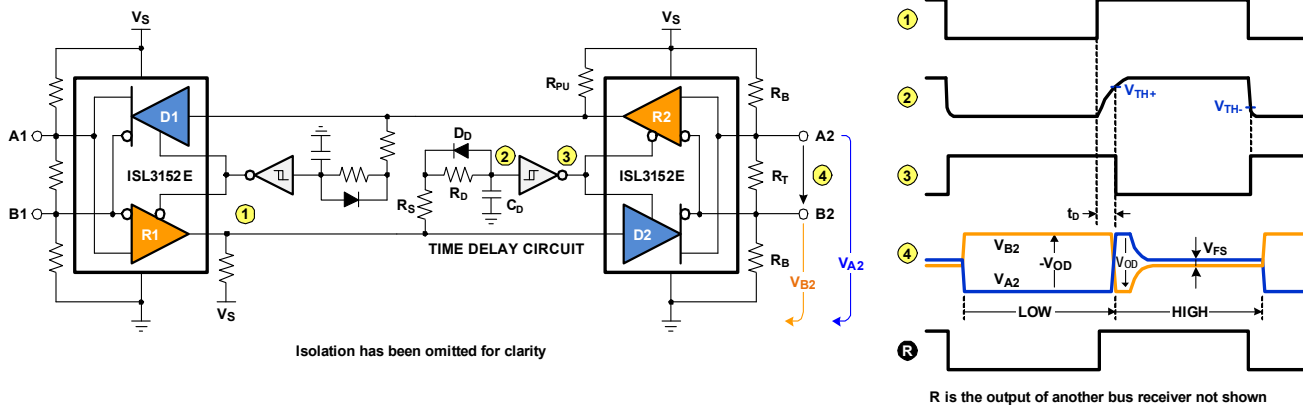


Figure 3. Half-Duplex Repeater with Signal Timing Diagram

The time delay helps prevent bus signal interruption and data errors caused by differences in the driver and receiver switching characteristics. Referring to the above example: without delaying D2’s turn-off time, during the transition from active-low to high-impedance, receiver R2 might detect the receding low condition on the bus, turning its output temporarily low. This low pulse would switch the transceiver at port 1 from receive into transmit mode, thus interrupting the reception of the incoming bus signal and causing data errors.

Therefore, to prevent R2 from glitching, D2 must remain enabled to actively drive the bus high. Once its positive  $V_{OD}$  has been fully established on the bus, D2 can be disabled. This way, R2 never experiences a low condition when port 2 transmits data.

To determine the time constant (T) of the delay circuit, apply the well-known, generic charge equation:  $V_{(t)} = V_{PK}(1 - e^{-t/T})$  and solve for T:

$$T = \frac{-t}{\ln(1 - V_{(t)}/V_{PK})} \tag{EQ. 1}$$

The time constant must be calculated such that for a given peak voltage ( $V_{PK} = V_{CC}$ ), the time for charging  $C_D$  to the inverter's earliest switching threshold, ( $V_{(t)} = V_{TH+MIN}$ ), is at least as long as the time it takes for  $V_{OD}$  to fully establish on the bus, which is the total of the driver's maximum prop-delay plus half of its maximum rise time ( $t_D = t_{PLH-MAX} + 0.5t_{R-MAX}$ ). This is explicitly shown in [Figures 4](#).

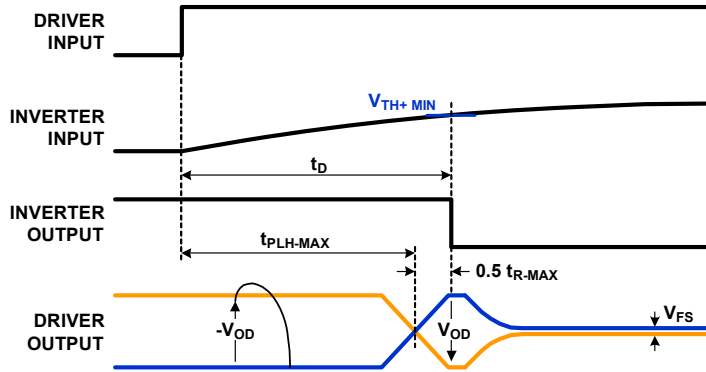


Figure 4. Time Delay Requirement:  $t_D = t_{PLH-MAX} + 0.5 t_{R-MAX}$

With  $C_D (R_S + R_D)$  making up T, [\(EQ. 1\)](#) is rewritten:

$$C_D(R_S + R_D) = \frac{-(t_{PLH-MAX} + 0.5t_{R-MAX})}{\ln(1 - V_{TH+MIN}/V_{CC})} \tag{EQ. 2}$$

Further simplification can be made that reduces [\(EQ. 2\)](#) to an equation that delivers only a single resistor value, namely,  $R_D$ .

- (1) To minimize the impact of the inverter's input capacitance on the time constant while maintaining a low time constant during discharge, set  $C_D$  to a value between 50pF and 100pF:

$$C_D \approx 50pF \dots 100pF \tag{EQ. 3}$$

- (2) Calculate the value of the current limiting resistor,  $R_S$ , limiting the discharge current spike, by dividing the difference between the diode forward voltage,  $V_F$  and the maximum voltage across  $C_D$ ,  $V_{CC}$ , by the specified receiver output current,  $I_O$ :

$$R_S = \frac{V_{CC} - V_F}{I_O} \tag{EQ. 4}$$

Inserting EQs. [3](#) and [4](#) into [\(EQ. 2\)](#) and solving for  $R_D$  results in:

$$R_D = \frac{-(t_{PLH-MAX} + 0.5t_{R-MAX})}{C_D \cdot \ln(1 - V_{TH+MIN}/V_{CC})} - R_S \tag{EQ. 5}$$

### 3. Calculation Example 1

For a new repeater design, Intersil's powerhouse transceiver ISL3152E has been selected because of its large driver output voltage, capable of driving segment lengths of up to 2 miles (3200m). The major device parameters are:

- Supply voltage:  $V_{CC} = 5V$
- Maximum data rate:  $DR_{MAX} = 115\text{kbps}$
- Driver minimum output voltage:  $V_{OD-MIN} = 2.4V$
- Driver maximum prop-delay:  $t_{PLH-MAX} = 1300\text{ns}$
- Driver maximum rise-time:  $t_{R-MAX} = 1600\text{ns}$
- Receiver rated output current:  $I_{O-MAX} = 8\text{mA}$

The positive input threshold of the selected Schmitt-trigger inverter is specified such that  $V_{TH+MIN} = 1.58V$ , and the diode forward voltage with  $V_F = 0.65V$ .

The following steps explain how to calculate the delay circuit's component values:

- (1) Making  $C_D = 100\text{pF}$
- (2) Calculating  $R_S$  using [\(EQ. 4\)](#) yields:

$$R_S = \frac{5V - 0.65V}{8\text{mA}} = 544\Omega$$

From the E-96 series of 1% resistor values choose  $R_S = 549\Omega$ .

- (3) Calculating  $R_D$  using [\(EQ. 5\)](#) results:

$$R_D = \frac{-(1300\text{ns} + 800\text{ns})}{100\text{pF} \cdot \ln(1 - 1.58V/5V)} - 549\Omega = 54.74\text{k}\Omega$$

From the E-96 series, choose  $R_D = 55.6\text{k}\Omega$ .

### 4. Single and Dual Isolated Repeaters

Long-haul networks possess large Ground Potential Differences (GPDs) between remote network nodes, which in non-isolated data links manifest themselves as large common-mode voltages between a transceiver’s bus terminals and local ground. In noisy electrical environments these voltages can exceed a transceiver’s Common-Mode Voltage Range (CMVR), causing data errors and even device damage. To eliminate the common-mode effects of large GPDs, repeater input and output must therefore be, galvanically isolated from each other.

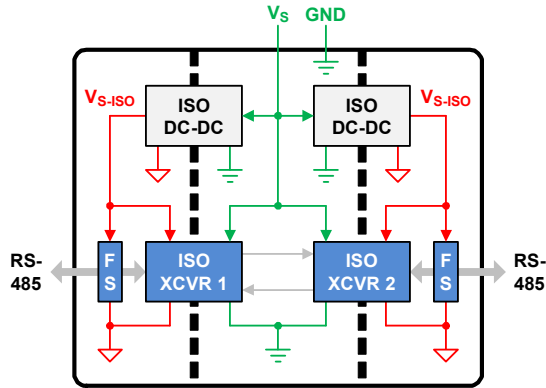


Figure 5. Dual-Isolated HD Repeater

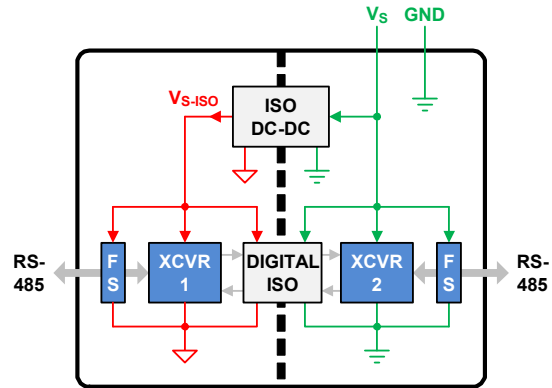


Figure 6. Single-Isolated HD Repeater

In applications with high isolation voltage requirements, the use of dual-isolated repeaters might be necessary (Figure 5). The repeaters often utilize two RS-485 transceivers with integrated isolation barriers and two isolated DC/DC converters that provide the transceiver supplies across the barriers. A third supply, powering the central repeater logic as well as the DC/DC converters, is referenced to local Earth-ground. High component count combined with the use of dedicated, isolated RS-485 transceivers make the dual-isolated repeater a rather expensive design.

Most long-haul networks however, rely on basic insulation, thus only requiring a single isolation barrier (Figure 6). A single isolated repeater has an isolated port and a non-isolated port that is referenced to local Earth ground. The non-isolated port is always located on the repeater’s downstream side, facing away from the master node. This port drives a bus segment of isolated bus nodes, including the isolated port of a remote repeater at the other cable end. The concept of a grounded signal source driving an isolated bus is referred to as a single ground reference design (Figure 7). It is used to keep repeater cost low as its design requires only two standard transceivers, a digital signal isolator and an isolated DC/DC converter.

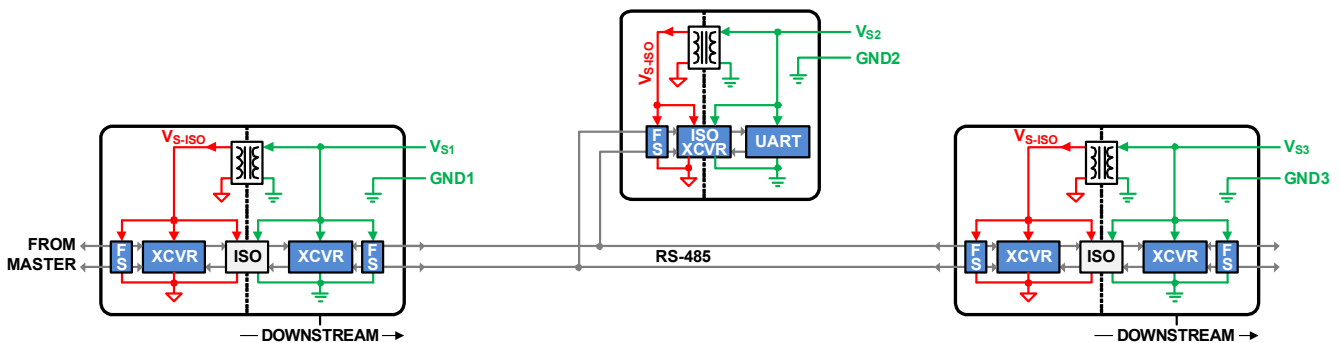
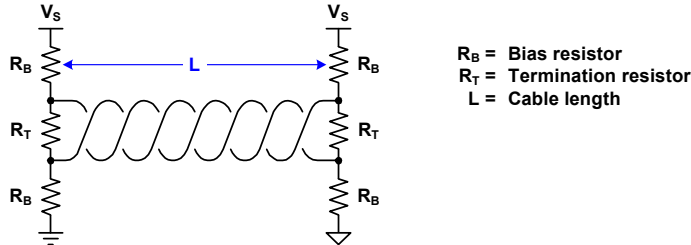


Figure 7. Single Ground Reference Design of a Repeater Link



## 5. Failsafe Biasing Networks

Long distance buses use two failsafe biasing networks, one at each cable end, to maintain a relative constant bus failsafe voltage ( $V_{FS}$ ) during bus idling ([Figure 8](#)).



**Figure 8. Failsafe Biasing Networks for Long Data Links**

Here, the biasing resistors are calculated for maximum differential loading ( $R_L = 54\Omega$ ):

$$R_B(k\Omega) = \frac{V_S/V_{AB}}{L/1296 + 18.52} \tag{EQ. 6}$$

where:

$R_B$  = Failsafe bias resistor (k $\Omega$ )

$V_S$  = Transceiver supply voltage (V)

$V_{FS}$  = Failsafe voltage (V)

$L$  = Bus segment length (m)

For line impedance matching, the series combination of the two biasing resistors in parallel with the termination resistor,  $R_T$ , must match the characteristic cable impedance of  $Z_0 = 120\Omega$ . Thus, for a given value of  $R_B$ ,  $R_T$  becomes:

$$R_T = \frac{2R_B \cdot 120\Omega}{2R_B - 120\Omega} \tag{EQ. 7}$$

For detailed information on the derivation of EQs [6](#) and [7](#), refer to application note [AN1987](#) “External Failsafe Biasing for Isolated Long-Haul Buses”.

## 6. Calculation Example 2

Assuming a bus segment length of  $L = 1600\text{m}$  (1 mile) with maximum differential loading of  $R_{\text{INEQ}} = 540\Omega$ , while assuring a minimum failsafe voltage of  $V_{\text{AB}} = 200\text{mV}$ , at a nominal supply of  $V_{\text{S}} = 4.5\text{V}$  requires a minimum  $R_{\text{B}}$  value of  $1.14\text{k}\Omega$ :

$$R_{\text{B}}(\text{k}\Omega) = \frac{V_{\text{S}}/V_{\text{AB}}}{L/1296 + 18.52} = \frac{4.5/0.2}{1600/1296 + 18.52} = 1.14\text{k}\Omega$$

The termination resistor required to match the line impedance is  $127\Omega$  as calculated with [\(EQ. 2\)](#):

$$R_{\text{T}} = \frac{2R_{\text{B}} \cdot Z_0}{2R_{\text{B}} - Z_0} = \frac{2 \cdot 1.14\text{k}\Omega \cdot 120\Omega}{2 \cdot 1.14\text{k}\Omega - 120\Omega} = 127\Omega$$

## 7. Maximum Bus I/O Nodes per Segment

Calculate the maximum number of bus transceivers per segment by dividing the single transceiver input impedance through the equivalent input impedance:

$$n_{\text{XCVR}} = \frac{R_{\text{IN}}}{R_{\text{INEQ}}} \quad (\text{EQ. 8})$$

For the ISL3152E, the differential input impedance  $R_{\text{IN}} = 192\text{k}\Omega$ . Using [\(EQ. 8\)](#), the maximum possible number of transceivers to be connected to the bus is 355:

$$n_{\text{XCVR}} = \frac{192\text{k}\Omega}{540\Omega} = 355$$

## 8. Maximum Segment Length

In TSB 89 “Application Guidelines for RS-485” the recommended maximum cable length for data rates up to 100kbps is 1200m or 4000ft (Figure 9). At this length, the cable DC resistance approaches the value of the termination resistor, thus attenuating the bus voltage by about 6dB (or half). This means that a standard compliant driver with a minimum output of  $V_{OD} = 1.5V$  causes a minimum input voltage of  $V_{ID} = 750mV$  at the receiving end, which often provides sufficient noise margin for a standard compliant receiver of  $\pm 200mV$  input sensitivity.

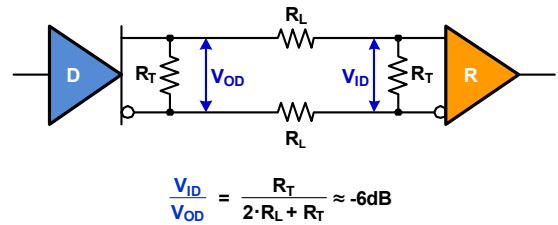
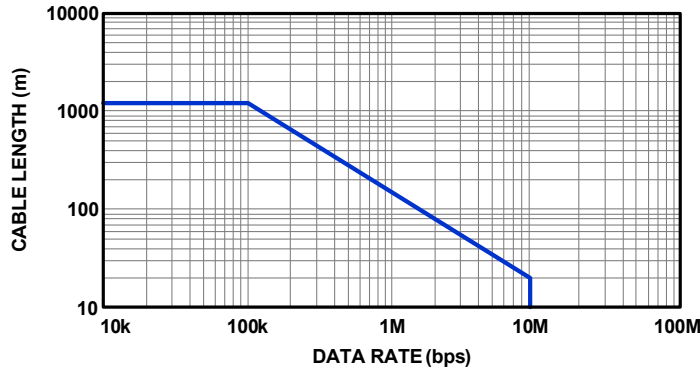


Figure 9. TSB-89 Recommended Maximum Cable Length for Low Data Rates is Based on 6dB Voltage Drop

Many industrial networks aim for segment lengths of up to one mile (1600m) by tolerating even lower  $V_{ID}$  levels of 650mV. Applying the same  $V_{ID}$  limit to the ISL3152E transceiver with -50mV to -200mV input sensitivity yields 700mV of noise margin, which is 150mV more than for a standard compliant receiver. However, the ISL3152 also has a significant higher  $V_{OD}$  of 2.4V minimum, thus allowing for much longer cable runs. Use the equation in Figure 8 on page 9 to calculate the maximum cable length for  $R_L$ .

$$R_L = \frac{R_T}{2} \cdot \left( \frac{V_{OD}}{V_{ID}} - 1 \right) \tag{EQ. 9}$$

Since the line resistance,  $R_L$  ( $\Omega$ ), is the product of cable length,  $L$  (m), and the specific cable DC resistance, DCR ( $\Omega/m$ ):

$$R_L = L \cdot DCR \tag{EQ. 10}$$

We can insert (EQ. 9) into (EQ. 10) and solve for  $L$ . Using the above values of  $V_{OD} = 2.4V$  and  $V_{ID} = 0.65V$ , and applying an RS-485 cable, such as Belden 3105A with a DCR of 48.2m $\Omega/m$ , the maximum segment length is 3351m (2.1 miles):

$$L = \frac{R_T}{2DCR} \cdot \left( \frac{V_{OD}}{V_{ID}} - 1 \right) = \frac{120\Omega}{2 \cdot 0.0482\Omega/m} \cdot \left( \frac{2.4V}{0.65V} - 1 \right) = 3351m \text{ (2.1 miles)} \tag{EQ. 11}$$

## 9. Maximum Stub Length

The distance between the actual transceiver inputs and the main cable trunk is known as a stub. As a stub presents a piece of unterminated transmission line, its length must be limited to avoid signal reflections. A common rule of thumb is to limit a stub's one-way signal delay, (electrical length), to one tenth of the driver's minimum rise time:

$$L_S \leq \frac{t_{R-MIN}}{10} \cdot v \cdot c \quad (\text{EQ. 12})$$

where:

- $L_S$  is the stub length (m),
- $c$  is the speed of light ( $3 \cdot 10^8$ m/s)
- $v$  is the signal velocity of the transmission medium as a factor of  $c$

For example, if connecting an ISL3152E transceiver with a minimum rise time of 700ns through a stub using a Belden 3105A cable with 78% velocity, the maximum stub length must not exceed 16.4m (54 ft):

$$L_S \leq \frac{700\text{ns}}{10} \cdot 0.78 \cdot 3 \cdot 10^8 \text{m/s} = 16.4\text{m (54 ft)}$$

## 10. Maximum Data Rate

The maximum applicable data rate depends on the pulse distortion of the entire data link, which is from the driver input in the master node to the receiver output of the farthest slave node. Pulse distortion is caused by the multiple driver and receiver skews within the data link. Pulse skew is the difference in propagation delays for the rising and falling edges of drivers and receivers ( $t_{SKEW} = |t_{PLH} - t_{PHL}|$ ). The pulse distortion of a single repeater is the sum of its driver and receiver skews. [Figure 10](#) depicts a 20-mile long network with 20 bus segments of one-mile length and 19 repeaters.

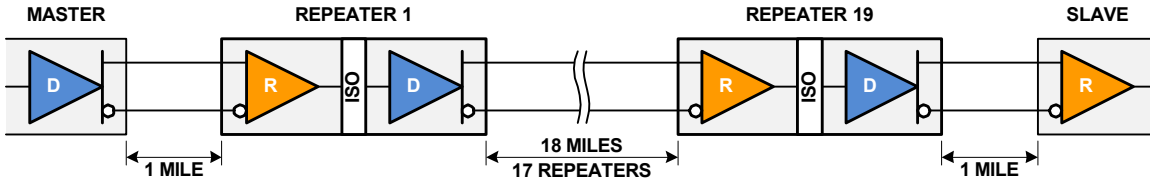


Figure 10. 20-Mile Long Network with 20 Bus Segments of One-Mile Length and 19 Repeaters

As RS-485 uses asynchronous data transmission, data recovery at the receiving end is accomplished with UARTs oversampling the receive signal by eight to sixteen times the data rate. To ease data recovery, the recommended limit for pulse distortion is about 20% of the pulse width or the time unit interval,  $t_{ui}$  ([Figure 11](#)).

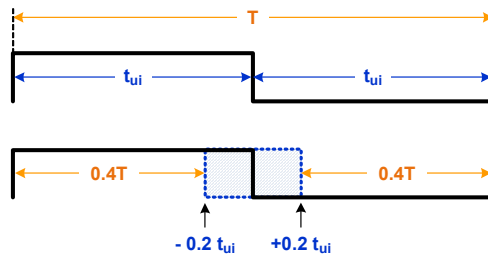


Figure 11. ±20% Pulse Distortion Allows for Easy Data Recovery

To determine the maximum pulse distortion of the data link, identify the distortion of a single repeater and multiply it with the number of repeater stations in the link.

Using ISL3152 transceivers, the skew of a single repeater is 70ns (10ns receiver skew, 10ns isolator skew, and 50ns driver skew). Multiplied by 20 repeater stations yields a total skew of 1.4µs for the entire data link, which according to the pulse distortion limits, equals  $0.2 t_{ui}$ . Thus, the minimum pulse width,  $t_{ui-MIN} = 1.4\mu s / 0.2 = 7\mu s$ , and the maximum data rate  $DR_{max} = 1 / t_{ui-MIN} = 1 / 7\mu s = 143\text{kbps}$ , which exceeds the transceiver’s maximum data rate of 115kbps.

The 20-mile network can therefore be operated at maximum transceiver speed without exceeding the pulse distortion limit.

## 11. Switching Performance

Figures 12 and 13 show the switching waveforms of an actual half-duplex repeater at 20kbps and 100kbps, respectively. These real-world signals confirm the operating principle described in Figure 3 on page 5 and Figure 4 on page 6.

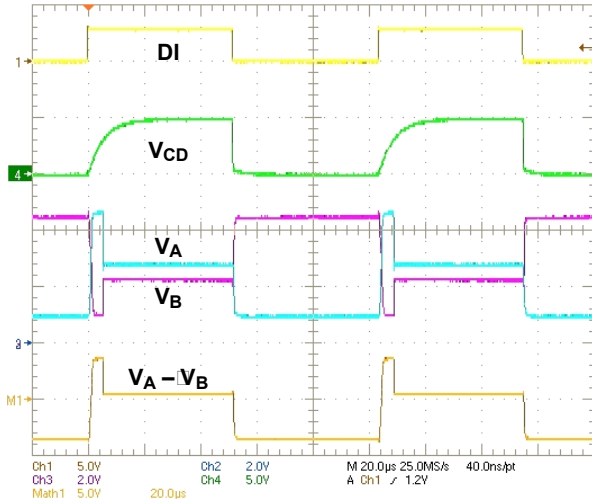


Figure 12. Repeater Waveforms at 20kbps

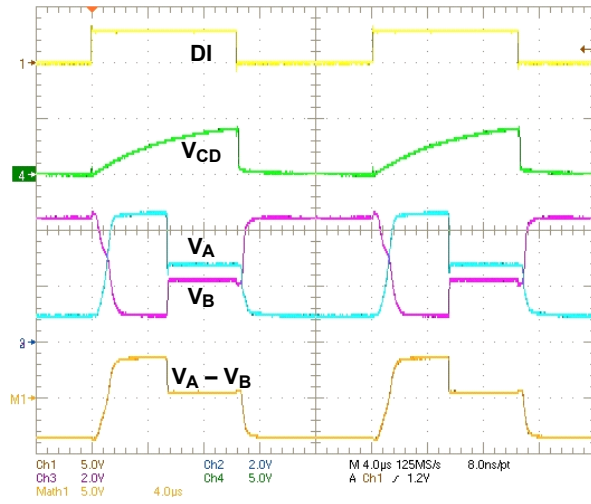


Figure 13. Repeater Waveforms at 100kbps

## 12. Conclusion

Isolated half-duplex RS-485 repeaters using the ISL3152E transceiver enable the design of the fastest and longest RS-485 networks ever accomplished, with more than twenty two-mile bus segments and up to 355 bus nodes per segment, while operating at data rates of up to 115kbps.



## Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.  
"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.  
"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.  
Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.
6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.  
(Note 1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.  
(Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)



### SALES OFFICES

Renesas Electronics Corporation

<http://www.renesas.com>

Refer to "<http://www.renesas.com/>" for the latest and detailed information.

**Renesas Electronics America Inc.**  
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.  
Tel: +1-408-432-8888, Fax: +1-408-434-5351

**Renesas Electronics Canada Limited**  
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3  
Tel: +1-905-237-2004

**Renesas Electronics Europe Limited**  
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K.  
Tel: +44-1628-651-700, Fax: +44-1628-651-804

**Renesas Electronics Europe GmbH**  
Arcadiastrasse 10, 40472 Düsseldorf, Germany  
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

**Renesas Electronics (China) Co., Ltd.**  
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China  
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

**Renesas Electronics (Shanghai) Co., Ltd.**  
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China  
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

**Renesas Electronics Hong Kong Limited**  
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong  
Tel: +852-2265-6688, Fax: +852-2886-9022

**Renesas Electronics Taiwan Co., Ltd.**  
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan  
Tel: +886-2-8175-9600, Fax: +886-2-8175-9670

**Renesas Electronics Singapore Pte. Ltd.**  
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949  
Tel: +65-6213-0200, Fax: +65-6213-0300

**Renesas Electronics Malaysia Sdn.Bhd.**  
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia  
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

**Renesas Electronics India Pvt. Ltd.**  
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India  
Tel: +91-80-67208700, Fax: +91-80-67208777

**Renesas Electronics Korea Co., Ltd.**  
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea  
Tel: +82-2-558-3737, Fax: +82-2-558-5338