One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A. • Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com

Enhanced RS-485 Performance: Receiver Fail-Safe, Hysteresis, Common-Mode Range and Gain Bandwidth Optimized for Long Fieldbus Cables

by Richard Anslow

INTRODUCTION

Industrial automation programmable logic controller (PLC) communication ports, which commonly use RS-485 interfaces, can be subjected to hazards like large common-mode noise, ground potential differences, miswiring faults, and high voltage transients. In particular, over long cable runs with multiple RS-485 nodes, these hazards can either corrupt data communication or cause permanent damage to the RS-485 interface.

Figure 1 shows a robust RS-485 communications network with fieldbus communications running over 1000 m of cabling.

The ADM3095E provides robust protection against high voltage faults to bus power supplies and electromagnetic compatibility (EMC) transients, such as an IEC 61000-4-5 surge.

The ADM3095E data sheet and the user guide for the EVAL-ADM3095EEBZ evaluation board provide a comprehensive summary of the ADM3095E EMC performance.

In addition, the ADM3095E has an extended common-mode input range of ±25 V, which allows ±25 V of potential difference between the RS-485 ground (GND) pins of two or more ADM3095E devices.

ENHANCED RS-485 PERFORMANCE OVER ±25 V COMMON-MODE RANGE

The Telecommunications Industry Association (TIA)/ Electronic Industries Alliance (EIA)-485-A standard for RS-485 communication interfaces specifies transceiver operation with a bus driver differential voltage of at least +1.5 V across a −7 V to +12 V common-mode range.

The ADM3095E offers an extended common-mode input range of ±25 V across a power supply range of +3 V to +5.5 V while still meeting or exceeding compliance with the TIA/EIA-485-A standard. The extended common-mode input range of ±25 V improves system robustness over long cable lengths, where large differences in ground potential between RS-485 transceivers are possible. This application note demonstrates the enhanced RS-485 performance of the ADM3095E over an extended common-mode input range of ±25 V.

In this application note, the Commercial Building Telecommunications Cabling Standard TIA/EIA-568-B.2 is examined, along with ac and dc cable effects on system communication performance. The ADM3095E receiver optimization for lower data rates and long cable lengths, where the cable dc effects dominate, is discussed in the Data Rate and Cable Length section. In particular, the receiver gain bandwidth of the ADM3095E is explained, highlighting the ability to reliably operate at ±200 mV receiver input differential voltage with low data rates is common in RS-485 applications.

The ADM3095E receiver fail-safe and hysteresis features are discussed in the Fail-Safe and Hysteresis section. The ADM3095E bus idle fail-safe, open fail-safe, and short-circuit fail-safe are three elements of performance that make up the fail-safe feature. These elements of the fail-safe feature are guaranteed across a ±25 V common-mode range, with added receiver hysteresis to improve noise immunity on long cable runs.

TABLE OF CONTENTS

REVISION HISTORY

3/2017—Revision 0: Initial Version

RS-485 COMMUNICATIONS NETWORK

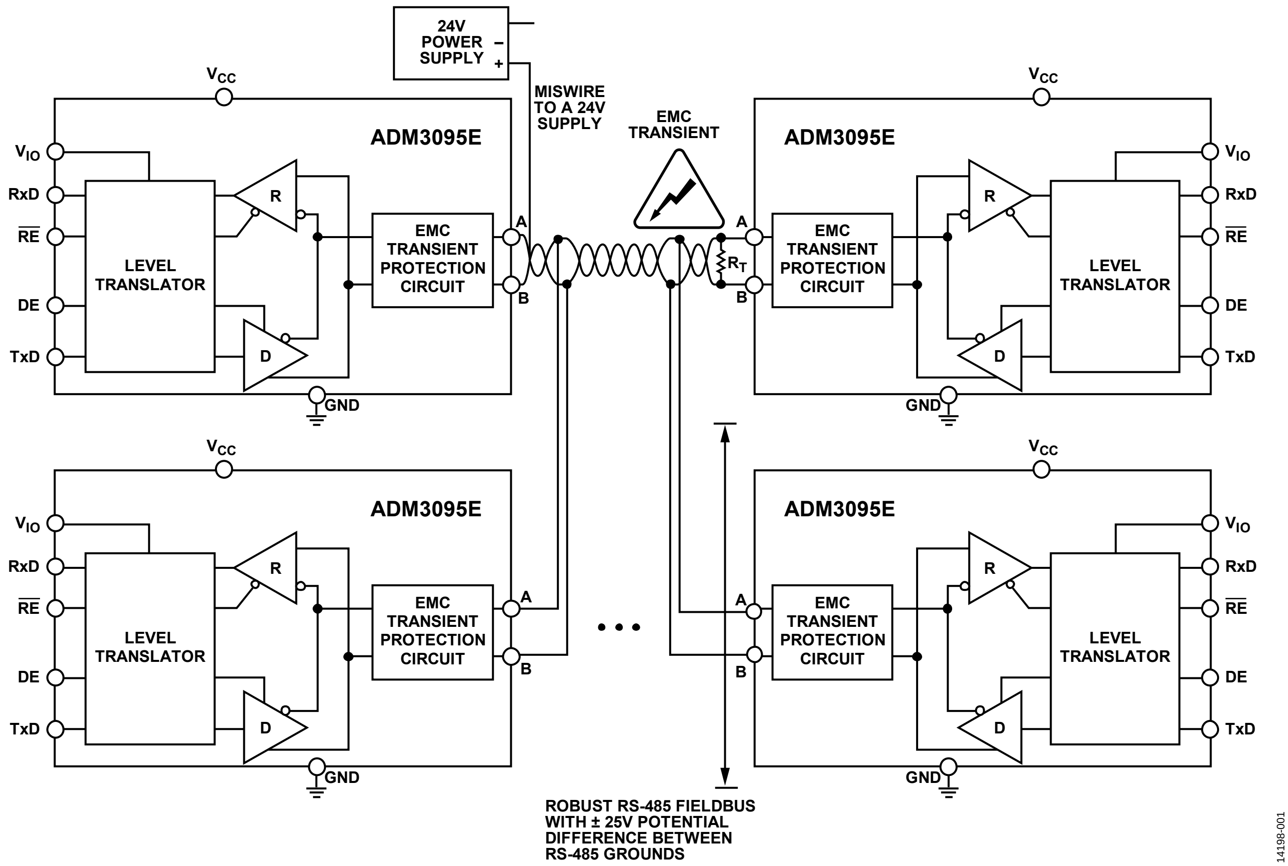

Figure 1. Extended Common-Mode Range of ±25 V for More Robust Communications over Long Cable Runs Using the ADM3095E

DRIVING LONG RS-485 BUS CABLES

When using an RS-485 transceiver on a long cable, a number of factors become important, such as the cable quality and specifications, and the effect of the cable length on the RS-485 signals.

When high data rates are used in an RS-485 fieldbus, cable ac effects dominate, and the RS-485 fieldbus application is limited to short cable lengths, usually less than 100 m. It is possible to extend the cable length to 1200 m at lower data rates, where the dc resistance of the cable dominates. The timing performance of the RS-485 transceivers used in the fieldbus can improve communication reliability. The ADM3095E receiver performance is optimized for lower data rates and long cable lengths.

DATA RATE AND CABLE LENGTH

The TIA/EIA-485-A standard requires compliant RS-485 drivers to generate a differential voltage amplitude, V_{OD}, of at least 1.5 V. The TIA/EIA-485-A standard also requires compliant RS-485 receivers to reliably operate with ±200 mV input differential voltage, V_{ID}.

For long cable applications, the RS-485 bus voltage may be dc attenuated by as much as 1.3 V between the driver node, V_{OD} and the receiver node, V_{ID}.

For applications with shorter cable lengths, the signal dc attenuation is less of an issue, with the RS-485 receiver seeing a large fraction of the amplitude generated by the RS-485 driver.

The TIA/EIA-568-B.2 standard provides background for cable ac and dc effects on RS-485 signal quality. Based on cable effects, the required RS-485 transceiver performance and the RS-485 receiver performance are examined.

Insertion Loss and Signal Attenuation

Use the following equation to determine the insertion loss for any Category 5e cable at any frequency. Figure 2 uses the following equation (noted in the TIA/EIA-568-B.2 standard) and the data provided in Table 4 and Table 5 of the TIA/EIA-568-B.2 standard.

$$Insertion\ Loss_{CABLE,\,100\ m} \leq k1\sqrt{f} + k2 \times f + \frac{k3}{\sqrt{f}}\ \text{dB}/100\,\text{m}$$

where:
k1, *k2*, and *k3* are the constants for cable insertion loss formula.
f is the frequency of data transmission over the Category 5e cable.

See Figure 2 to determine the maximum data rate as a function of cable length. For example, for a 20 MHz data rate, 100 m of cabling is possible with a cable attenuation of −9 dB.

If −9 dB at 20 MHz is chosen as a baseline, then for a 1 MHz data rate, the cable attenuation is −2 dB, which equates to approximately 450 m of cabling.

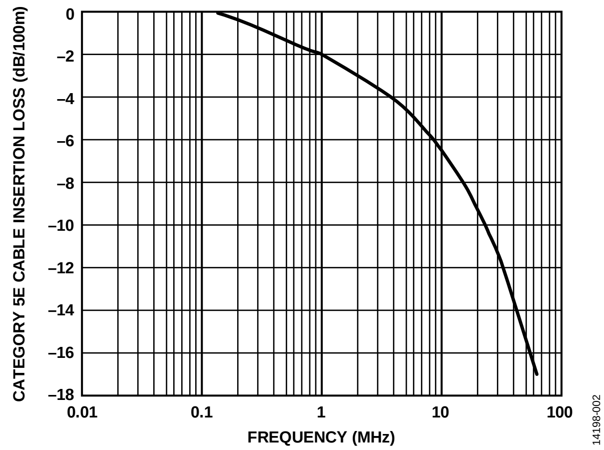

Figure 2. Category 5e Attenuation per TIA/EIA-568-B.2

The attenuation parameters stated in RS-485 data sheets can also be used in estimating the data rate vs. cable length. For example, the Belden 3079A cable for PROFIBUS® applications has the maximum attenuation specifications listed in Table 1.

Table 1. Cable Frequency and Attenuation for the Belden 3079A

Frequency (MHz)	Attenuation (dB) per 100 m
0.2	1.1
4.0	2.65
16.0	5.4

Figure 2 assumes ideal cable conditions for data transmission; however, crosstalk losses and other nonideal cable losses are also discussed in detail in the TIA/EIA-568-B.2 standard. Table 2 lists some ideal cable parameters and the implications of nonideal cable performance on system communication integrity.

In addition to the hazards noted in the TIA/EIA-568-B.2 standard, the system designer must also consider timing and data protocol issues when determining the possible data rate at a particular cable length. Encoding schemes and the data pattern used for the RS-485 bus signals, for example, pseudorandom binary sequence (PRBS) random data, has an effect on intersymbol interference and possible data errors. Protocol requirements, for example, idle time in data transmission, can result in a reduction in the effective transmission data rate.

Consider system jitter, propagation delay, and skew in the transmitted and received signals when testing the system to determine a reliable transmission rate. The TIA/EIA-568-B.2 standard provides the maximum allowable propagation delay and skew. For example, at a frequency of 1 MHz, the maximum allowable cable propagation delay is 570 ns per 100 m, and the maximum allowable cable skew is 45 ns per 100 m.

With these real-world problems considered, Figure 3 provides a conservative estimate of cable length vs. data rate.

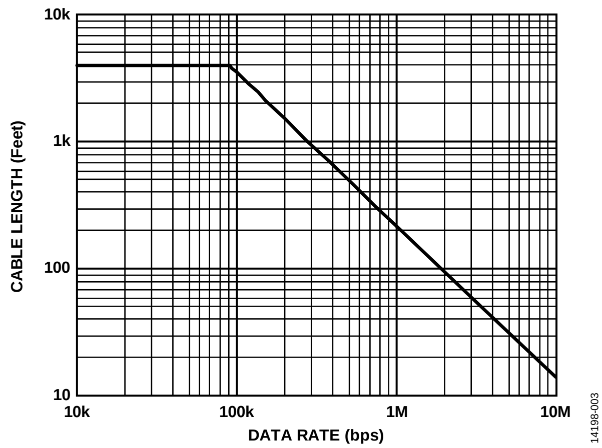

Figure 3. Conservative Estimate for Cable Length vs. Data Rate

Cable Length and DC Resistance

Given a point to point link over a long cable length, it is necessary to examine the effect of cable dc resistance and required RS-485 transceiver performance.

The flat segment of the curve in Figure 3 is for long distance low data rate communication and is based on the cable resistive losses. The TIA/EIA-568-B.2 standard states that the dc resistance of any conductor, measured in accordance with ASTM D4566, must not exceed 9.38 Ω per 100 m (328 ft) at, or corrected to, a temperature of 20°C.

Using the ADM3095E with a long cable length of 1200 m presents a maximum dc resistance of 113 Ω to the ADM3095E RS-485 driver outputs. When using a 1200 m cable on a point to point RS-485 cable link, Figure 4 and Table 3 provide three scenarios for the driver differential voltage amplitude, V_{OD}, at the ADM3095E driver node and the receiver input differential voltage, V_{ID}, at the ADM3095E receiver node. The R2 60 Ω termination resistor is a simplification of a doubly terminated bus with 120 Ω at each end of the 1200 m cable.

Table 3 shows that RS-485 receivers must be able to operate reliably at input differential voltage levels as low as ±300 mV. In fact, the TIA/EIA-485-A standard for RS-485 communication interfaces specifies that transceiver operation to a more stringent ±200 mV receiver input voltage.

Table 2. Cable Conditions and Implications

Ideal Cable Conditions	Implications of Nonideal Cable Conditions on System Performance
No External Noise Interference on the RS-485 Cable Network	Potential sources of noise may reduce system reliability and the effective data rate. The ADM3095E data sheet provides a background for some common system noise sources and high voltage transients, such as IEC 61000-4-2 electrostatic discharge (ESD), the IEC 61000-4-4 electrical fast transients (EFT) and the IEC 61000-4-5 surge. The ADM3095E performance in harsh EMC environments is described and characterized in the ADM3095E data sheet and the user guide for the EVAL-ADM3095EEBZ evaluation board.
Little or No Timing Skew Introduced by Differences Between the Two Wires in a Twisted Pair Cable	Excessively skewed data outputs can result in system data errors. The TIA/EIA-568-B.2 standard states a Category 5e cable propagation delay skew cannot exceed 45 ns per 100 m.
Zero Crosstalk Between the Twisted Cable Pair	Crosstalk is a measure of unwanted signal coupling between the RS-485 transmitter and receiver, measured at near and far ends of cabling. The TIA/EIA-568-B.2 standard provides a number of empirical and statistical models to predict the extent of negative effects of crosstalk on a system. Adding cable shielding can reduce crosstalk and improve the signal-to-noise ratio (SNR).
DC Balanced Data Transfer	Excessive dc unbalance affects signal integrity, in particular, with long cable runs. The TIA/EIA-568-B.2 standard provides guidance for the maximum dc resistance unbalance, with a 5% limit between any two conductors in a pair.
Point to Point RS-485 Cable Links, with No Cable Stubs	Long cable stubs cause significant impedance mismatches, resulting in signal reflections and data errors. Using point to point links increases the effective data rate.

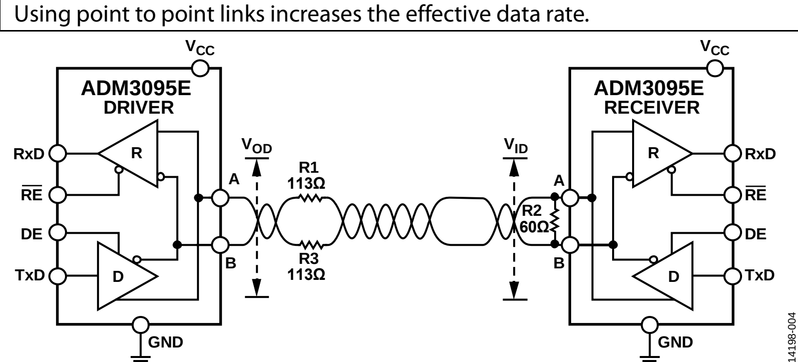

Figure 4. Point to Point RS-485 Cable Link and DC Bus Voltage

RECEIVER GAIN BANDWIDTH

Figure 5 shows the ADM3095E measured receiver performance with input common-mode voltage of +25 V, at V_{ID} of ±600 mV and a data rate of 2.5 Mbps. In this test setup, the ADM3095E clearly exceeds the performance requirement shown in Figure 3. In practical applications, bus differential voltages as low as ±600 mV are usually not observed when operating at data rates as high as 2.5 Mbps.

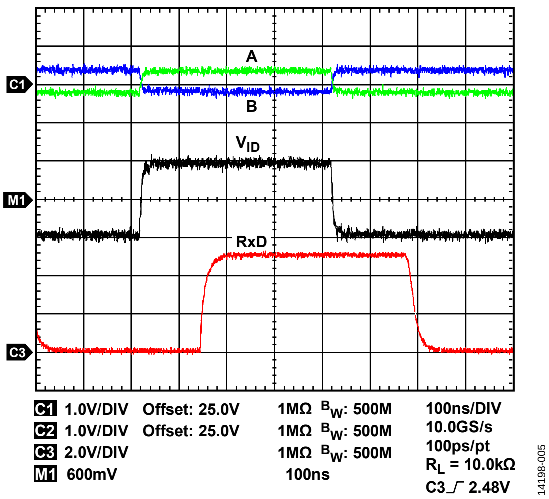

Figure 5. ADM3095E RS-485 Receiver Performance with Input Common-Mode Voltage of +25 V, at ±600 mV, V_{ID}, and 2.5 Mbps Data Rate

Figure 6 shows the ADM3095E receiver gain bandwidth, which is the data rate vs. receiver input differential voltage performance for the transceiver. Long cable runs use low data rates, often less than 0.25 Mbps. At 0.25 Mbps data rate, Figure 6 shows the ability of the ADM3095E receiver to reliably switch at ±200 mV receiver input differential voltage (minimum level set by the TIA/EIA-485-A standard for RS-485 communication).

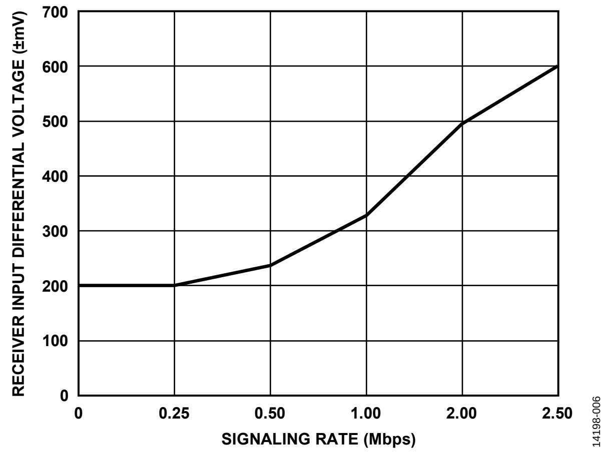

Figure 6. Receiver Input Differential Voltage vs. Signaling Rate

QUALITY OF SIGNAL AT 2.5 MBPS OVER 100 M OF CABLE

Figure 7 shows a quality of signal measurement for the ADM3095E operating on a two node network, operating at 2.5 Mbps data rate, over 100 m of UNITRONIC® PROFIBUS cable. The ADM3095E TxD signal is measured on the transmitting node, with the RS-485 A and B bus signals measured at the receiving node at the far end of the 100 m cable. The oscilloscope measuring the signals is set to infinite persistence, showing the effect of signal jitter added by the cable on the A and B bus signals. Figure 7 shows that the signal jitter and attenuation due to the added 100 m cable does not cause data errors in the RxD signal at the ADM3095E receiver node. In this typical lab measurement, less than 5% jitter is added due to cable effects, and the RxD pulse width is distorted by less than 3% due to cable attenuation.

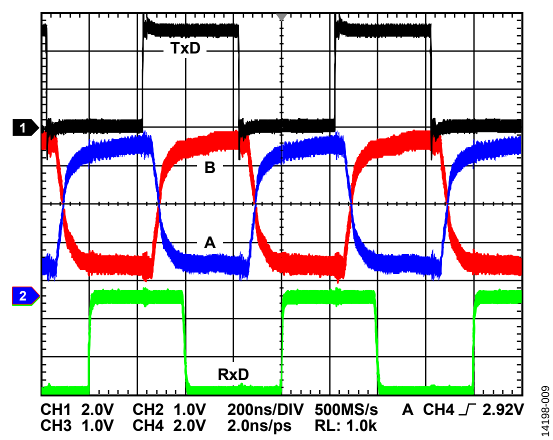

Figure 7. Quality of Signal Operating at 2.5 Mbps over 100 m of RS-485 Cable

Table 3. RS-485 Driver Output Signal DC Attenuation

Pin A (V) at Driver	Pin B (V) Driver	Driver Output Differential Voltage (V), V_{OD}	Receiver Input Differential Voltage (V), V_{ID}
5.0	0	5.0	±1.05
2.1	0	2.1	±0.44
1.5	0	1.5	±0.31

FAIL-SAFE AND HYSTERESIS

BUS IDLE, OPEN, AND SHORT-CIRCUIT FAIL-SAFE

The ADM3095E has a true fail-safe feature, offering a logic high receiver output feature for bus idle, open, and short-circuit across the entire receiver input common-mode range of ± 25 V.

Open circuit fail-safe ensures that the ADM3095E receiver output is high when the RS-485 A pin and B pin are disconnected, with no termination resistor or other nodes present. This feature is present on all Analog Devices, Inc., RS-485 transceivers. There is an internal pull-up resistor on the ADM3095E A pin. If the A pin is disconnected and floating, then this pull-up resistor pulls the A pin to greater than −30 mV. There is a pull-down resistor on the ADM3095E B pin. If the B pin is disconnected and floating, then this pull-down resistor pulls the B pin to less than −200 mV. In this scenario, the A pin voltage is greater than the B pin voltage, which creates a bus differential voltage high, and the receiver output logic is a constant high.

Short-circuit fail-safe ensures that the ADM3095E receiver output is high when two nodes are driving the bus to opposite levels, or when the bus lines are shorted together.

Bus idle fail-safe is more complex and provides a logic high ADM3095E receiver output when no node is driving a signal on the RS-485 bus. There are two main methods of providing this fail-safe. The first is a fail-safe RS-485 transceiver that has an offset receiver threshold, for example, −30 mV rather than the TIA/EIA-485-A RS-485 standard of +200 mV. Analog Devices RS-485 transceivers with bus idle fail-safe also have short-circuit fail-safe. The second method is to use pull-up and pull-down resistors on the bus to ensure a minimum differential voltage, which is also referred to as active or powered termination. Calculate the required resistor value based on the supply voltage and bus load, including the termination resistors and receiver impedances.

The TIA/EIA-485-A RS-485 standard suggests that RS-485 transceivers prevent instability or oscillatory conditions in the receiver device. Receiver hysteresis helps improve receiver stability and provides a measure of noise immunity, which is especially important for long cable runs and harsh fieldbus environments.

See the ADM3095E data sheet specifications table for the typical receiver hysteresis (ΔV_{TH}) of 30 mV, with a receiver differential input threshold voltage (V_{TH}) of −200 mV to −30 mV across an input common-mode range of ±25 V. The V_{TH} is the threshold for the receiver output (V_{OC} or V_{OH}) to change from high to low or low to high.

The ΔV_{TH} is essentially the difference between V_{TH} for high to low (V_{OL} in Figure 8), and V_{TH} for low to high (V_{OH} in Figure 8).

ΔV_{TH} ensures noise around V_{TH} does not result in spurious logic high and low transitions on the receiver output.

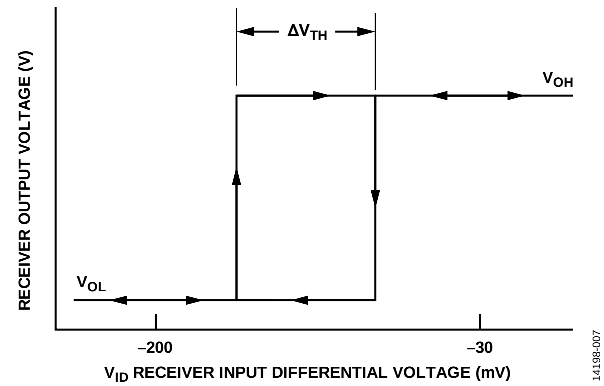

Figure 8. ADM3095E Receiver Hysteresis

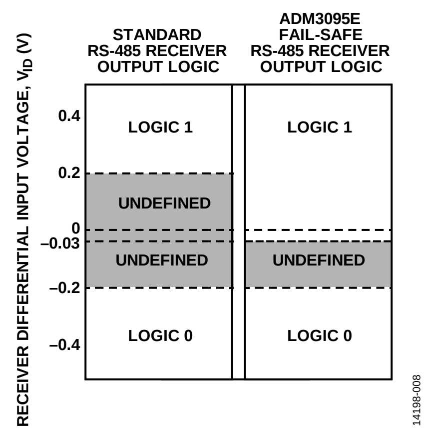

Figure 9. ADM3095E Receiver Fail-Safe Feature

AN14198-0-3/17(0)