

PROFIBUS Electrical-Layer Solutions

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ABSTRACT

PROFIBUS is an industrial networking standard with multiple electrical-layer options. In automation applications, the most common PROFIBUS electrical layer is a variant of RS-485 with additional requirements that improve data transmission performance. This application report discusses the basics of this networking technology in PROFIBUS applications and presents the key characteristics of transceivers. Design tradeoffs are discussed with regard to implementation topics, such as signaling levels, bus capacitance, fault tolerance, and isolation schemes.

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1 Introduction

Industrial communication, whether in process automation, factory automation, or motion control, is achieved through a field bus. Field-bus networks are used at the lower levels of the industrial hierarchy as illustrated in [Figure 1](#). At the lowest level, referred to the actuator/sensor level, the field bus directly

connects to the automation process via actuators and sensors. An example of this lower level field bus is PROFIdrive. One level above the actuator/sensor level, the field or cell level, the communication is about coordinating the different steps or stages that make up the entire automation process. An example of this type of field bus is PROFIBUS FMS. Both PROFIBUS FMS and PROFIdrive are part of the larger field-bus family **PROcess FieldBUS**, simply referred to as PROFIBUS.

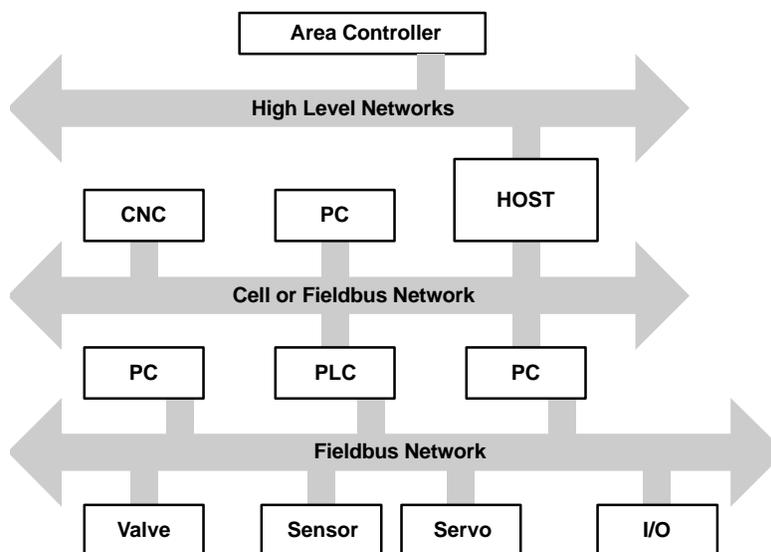


Figure 1. Industrial Network Hierarchy

Developed in Germany, PROFIBUS was established as a national standard (DIN 19245) in 1989. The standard was later ratified as a European Standard in 1996 (EN 50170). PROFIBUS was adopted internationally in IEC 61158 and IEC 61784, along with other competing field-bus standards.

Over time, the term *PROFIBUS* has become a broad term, encompassing many different applications. Originally, the only PROFIBUS application was PROFIBUS FMS (field management system). Now, other applications such as PROFIBUS DP⁽¹⁾ (factory automation), PROFIBUS PA (process automation), and PROFIdrive (motor control) have become available and have grown in popularity. Each of these PROFIBUS protocols can be realized with fiber optic, MBP (Manchester encoding bus powered), TIA/EIA-485 (RS-485), or RS-485IS (intrinsic safety) electrical/optical layers.

PROFIBUS compliance is application-dependent, and several components of the design contribute to overall compliance. One of these components is the TIA/EIA-485 transceiver. To select a transceiver, one must understand the physical layer and how the transceiver is part of that layer.

⁽¹⁾ Decentralized peripheral

2 Choosing a PROFIBUS Transceiver

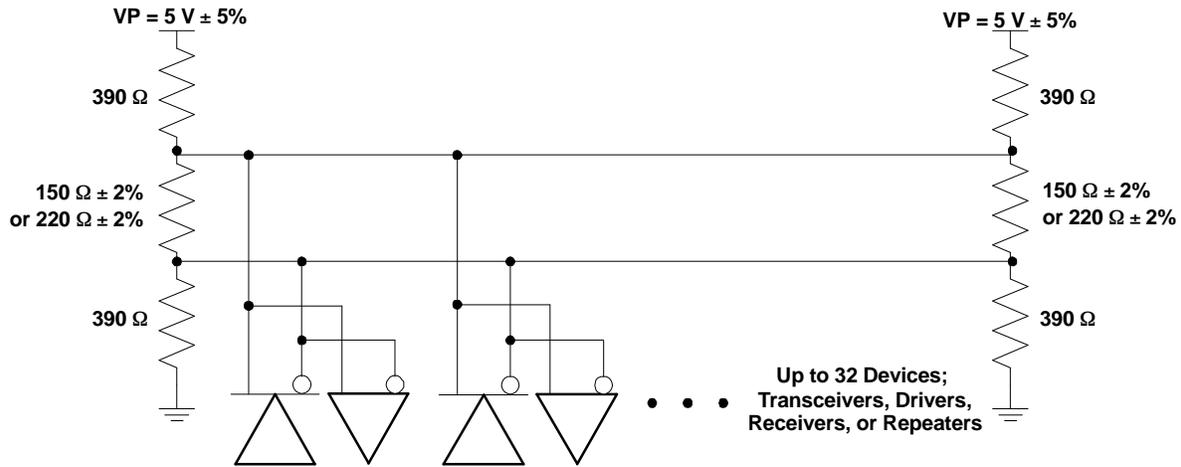


Figure 2. PROFIBUS Network

Two key characteristics differentiate a PROFIBUS from a standard RS-485 transceiver. The first and most important characteristic is the differential output of the driver. This pertinent feature applies specifically to PROFIBUS DP applications and is included in the Test Specifications for PROFIBUS DP Masters and Slaves (PROFIBUS Test Specifications for PROFIBUS DP Masters, Version 3.0, November 2005 and PROFIBUS Test Specifications for PROFIBUS DP Slaves, Version 3.0, November 2005). The second key characteristic is the differential output capacitance. The differential output capacitance is part of the total station capacitance, which limits the maximum signaling rate allowed per the IEC 61158-2 standard.

2.1 Differential Output Voltage (V_{OD})

The standard RS-485 definition of V_{OD} is the differential output voltage found across a $60\text{-}\Omega$ resistor over a common-mode voltage range of -7 V to 12 V , as shown in Figure 3. The test specifications for both PROFIBUS DP masters and slaves require that the differential output voltage, peak-to-peak ($V_{OD(PP)}$) be greater than 4 V and less than 7 V . Most data sheets do not specify the peak-to-peak value but the zero-to-peak voltage. For example, most PROFIBUS data sheets specify a minimum zero-to-peak V_{OD} of 2.1 V , meaning that the actual value measured in Figure 3 can be either -2.1 V or 2.1 V depending on the polarity of the driver. The minimum of 2.1 V_{0-P} is equivalent to 4.2 V_{PP} [$2.1\text{ V} - (-2.1\text{ V})$].

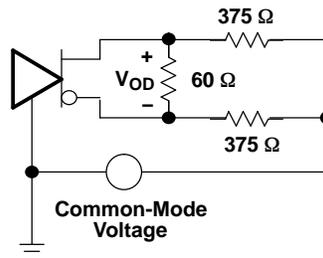


Figure 3. V_{OD} Test Over a Common-Mode Load

2.1.1 Applying the V_{OD} Definition to a PROFIBUS Load

The equivalent circuit shown in Figure 3 is not representative of the PROFIBUS network in Figure 2, but an RS-485 bus with 32 unit loads. A PROFIBUS system can have as many as 32 stations per segment, which is similar to the worst-case loading in Figure 3. However, the PROFIBUS standard requires that a pullup and pulldown be provided at both ends of the bus in order to maintain a differential voltage in the event of an idle bus. Figure 4 illustrates the recommended PROFIBUS termination.

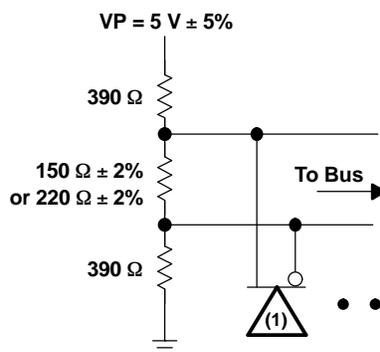


Figure 4. PROFIBUS Termination

Two options for the center termination resistor are possible. Typical applications use the 220-Ω resistor option in Figure 4. Choosing a termination of 150 Ω should only be done when the characteristic impedance of the cable is less than 125 Ω [$150 \Omega / ((390 + 390))$]. A termination resistance that is less than the characteristic impedance of the transmission line results in negative reflections, which reduces noise margin.

Figure 5 is the combination of Figure 3 and Figure 4 and results in an equivalent load for the PROFIBUS driver. The 195-Ω pullup and pulldown resistors are the parallel equivalent of the 390-Ω pullup and pulldown resistors located at both ends of the PROFIBUS driver. The 110-Ω differential impedance is the parallel combination of the two 220-Ω resistors.

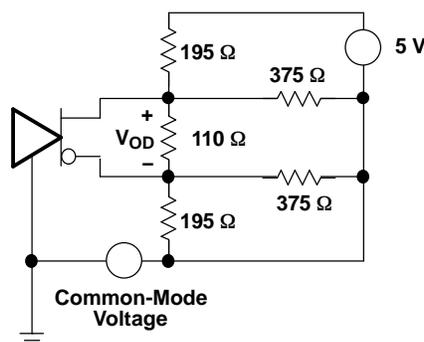


Figure 5. PROFIBUS Transceiver Loading

2.1.1.1 An Increased V_{OD} Provides Added Noise Margin

The 5-V termination voltage creates a positive offset or shift in the V_{OD} . The significance of this shift is threefold. First, asymmetry in the waveform may translate into duty-cycle distortion at the output of the receiver. The degree to which the duty cycle is distorted is based on the rise and fall time of the signal and the threshold of the receiver. Second, asymmetry in the waveform means that one logic state has less noise margin than the other does. This second point is of particular interest because most PROFIBUS applications are in noisy industrial environments. Third and finally, the driver must overcome the offset in order to meet the PROFIBUS DP test guidelines, which require that the bus voltages do not differ in amplitude by more than 0.5 V.

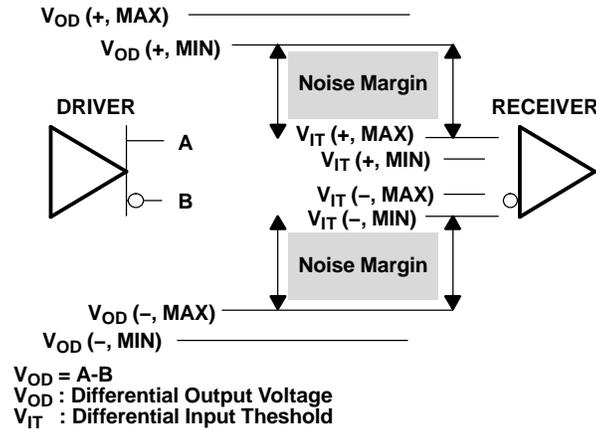


Figure 6. Definition of Noise Margin

Figure 7 illustrates the offset introduced by the unbalanced PROFIBUS load and the resulting change in noise margin. The noise margin on the left side of Figure 7 is symmetrical, and assuming receiver threshold voltages of -200 mV for $V_{IT(-,MIN)}$ ⁽²⁾ and $+200\text{ mV}$ for $V_{IT(+,MAX)}$ ⁽³⁾, then the noise margin would be 1.9 V ($2.1\text{ V} - 0.2\text{ V}$). However, on the right side, the noise margin is not symmetrical.

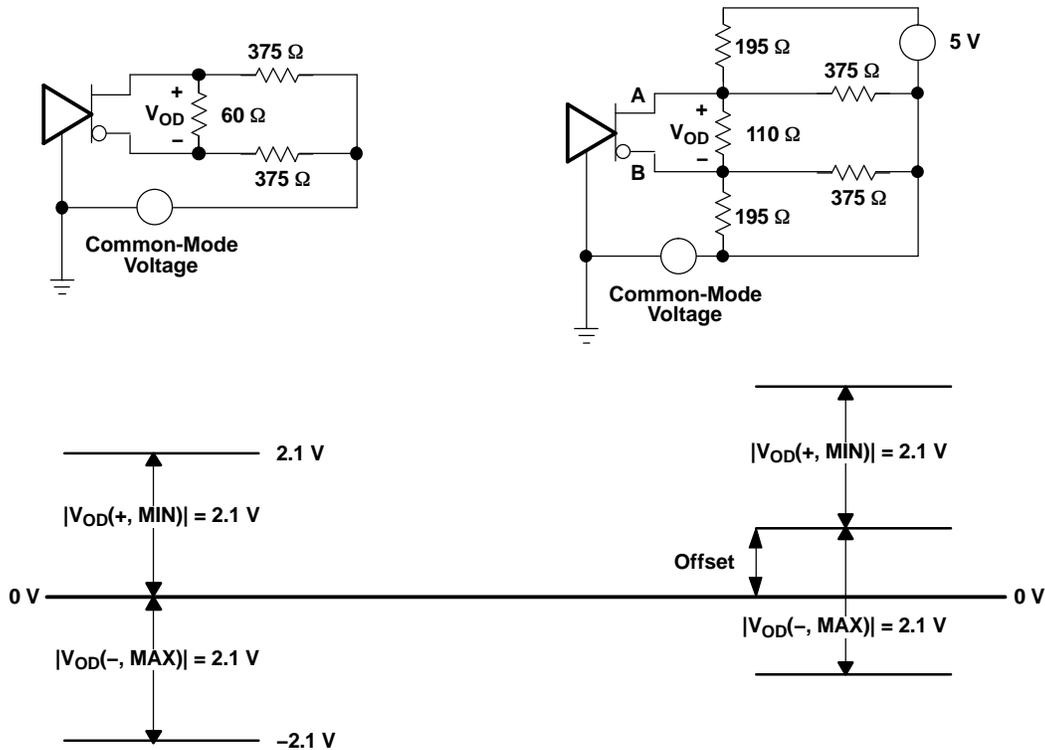


Figure 7. Resulting Offset of PROFIBUS Termination

Figure 7 illustrates the importance of having a minimum V_{OD} that is greater than the typical values found in RS-485 applications. Assuming that the V_{OD} in Figure 7 is reduced to 1.5 V and a 800-mV offset, then the noise margin would be only 700 mV and 2.3 V . Although the $V_{OD(min)}$ found in the data sheet is determined with the balanced common-mode load in Figure 3, a minimum V_{OD} of 2.1 V is necessary to meet the $V_{OD(PP)}$ requirement in the test guidelines and maintain a sufficient amount of noise margin in the presence of the PROFIBUS termination.

(2) V_{IT-} : Negative-going differential input voltage threshold
 (3) V_{IT+} : Positive-going differential input voltage threshold

2.1.1.2 V_{OD} and PROFIBUS DP Test Guidelines

Both the slave and master PROFIBUS DP test specifications state that the differential voltage between A- and B-lines shall be a minimum of 4 V and a maximum of 7 V. The signals of the A- and B-line are measured against DGND. The difference of the amplitudes shall be less than 0.5 V. Figure 8 shows the A and B waveforms of the SN65HVD1176 for the loading of Figure 5 and a common-mode voltage of 0 V.

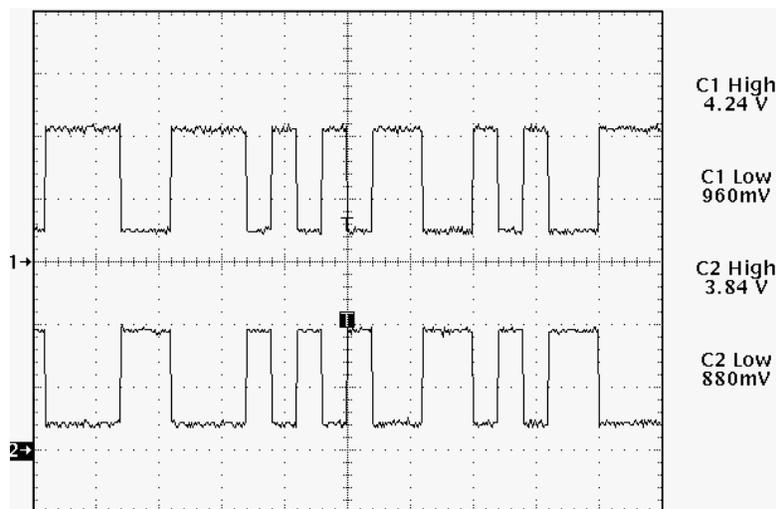


Figure 8. A (CH1) and B (CH2) Outputs With a 0-V Common-Mode Voltage Load

The sum of amplitudes is 6.24 V (>4 V) and the difference in the amplitudes is 0.32 V (<0.5 V). $V_{OD(PP)} = (A+ - B-) - (A- - B+) = (4.24 - 0.880) - (0.960 - 3.84) = 6.24$ V (between 4 V and 7 V). The offset voltage created by the termination is 0.24 V. Table 1 shows the A and B voltages for -7 and +7 common-mode voltages.

Table 1. PROFIBUS Voltages With Varying Common-Mode Voltage (CMV)

CMV	CH1 (A) V_{OH}	CH1 (A) V_{OL}	CH2 (B) V_{OH}	CH2 (B) V_{OL}	Amplitude Sum (V)	Amplitude Difference (V)	V_{OD} (peak-to- peak)	V_{OD} Offset
-7	1.92	-1.04	1.28	-2.08	6.32	0.40	6.32	0.84
0	4.24	0.96	3.84	0.88	6.24	0.32	6.24	0.24
7	5.12	2.16	4.88	1.52	6.32	0.40	6.32	0.44
Requirements in Test Guidelines					>4	<0.5	4 < < 7	NA

2.1.1.3 Larger V_{OD} Due to Reflections and V_{CC} Variation

The equivalent circuit shown in Figure 5 does not account for the distributed nature of the PROFIBUS network and does not take into account reflections. The PROFIBUS standard defines Type A cable specifications (Table 100 of IEC 61158-2), which is to be used with the termination found in Figure 4 when the differential termination is 220 Ω . The characteristic impedance of this medium can range from 135 Ω to 165 Ω ($f = 3$ –20 MHz). The equivalent differential termination is 171 Ω , and a typical PROFIBUS cable has a characteristic impedance of 150 Ω . This reflection adds to the already high $V_{OD(PP)}$ values, and in the nominal 5-V case, the $V_{OD(PP)}$ value increases to 6.65 V (6.24×1.07).

The discussion thus far has not identified a violation of the PROFIBUS DP test guidelines with a typical PROFIBUS environment. Although no violations were found in the typical PROFIBUS environment, by allowing V_{CC} and cable impedance to vary within acceptable ranges found in both the 61158-2 standard and transceiver data sheets, a combination can be found which violates the PROFIBUS DP test guidelines (see Table 2). Limiting V_{CC} to less than 5 V (but greater than 4.75 V) and choosing a cable that is closer to 165- Ω characteristic impedance ensures compliance.

Table 2. Variation in V_{OD} With V_{CC}

V_{CC}	CMV	V_{OD} (peak-to-peak)	V_{OD} (peak-to-peak) With 0.07 Reflection
5.25 VDC	0 V	6.57	7.03
5.0 VDC	0 V	6.24	6.65
4.75 VDC	0 V	5.8	6.21

2.2 Bus Capacitance per Station

The PROFIBUS standards EN 50170 and IEC 61158-2 explicitly state the maximum amount of bus capacitance for a given signaling rate (kbps). For example, at a signaling rate of 500 kbps, the total capacitance of all bus nodes cannot exceed 0.6 nF. This total capacitance includes the differential capacitance of all connectors, stubs, and devices on the bus, but not the capacitance of the cable itself (see Figure 9). Using the SN65HVD1176 as an example, the node capacitance⁽⁴⁾ calculation could be 10 pF+20 pF+2 pF (device, connector, and stub). A node capacitance of 32 pF times 8 stations is 256 pF. A total capacitance of 256 pF allows signaling up to 1.5 Mbps per the standard. If the node capacitance were 25 pF, then the total capacitance for an 8-node bus would be 200 pF and the maximum signaling rate of 12 Mbps would be allowed.

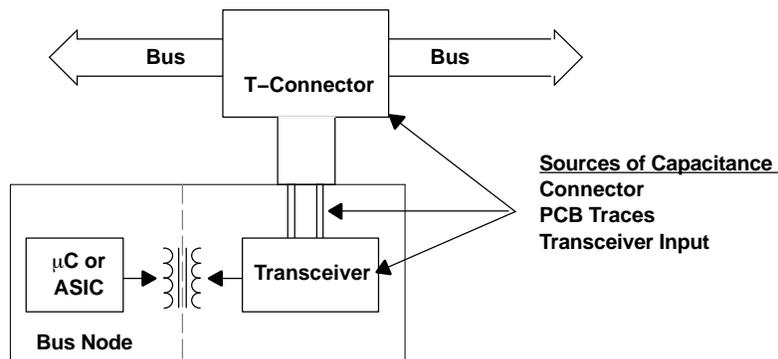


Figure 9. Total Node Capacitance

In order to achieve higher signaling rates and remain PROFIBUS-compliant, the transceiver output capacitance has to be kept to a minimum. Only the SN65HVD1176 specifically guarantees an output capacitance less than or equal to 10 pF. The closest competitor only offers a typical capacitance value and no maximum limit.

⁽⁴⁾ The EN 50170 standard does not make a distinction between differential and single-ended capacitance; however, the transceiver capacitance is specified as differential by vendors with PROFIBUS-compliant devices.

2.3 Robustness

Robustness is an important quality in industrial applications, and PROFIBUS is no exception. In this application report, robustness is the degree to which a transceiver can handle electrical overstresses (EOS), which can take the form of electrostatic discharge (ESD), transient voltage, and common-mode voltages. These measures of robustness are differentiated by their peak voltages and durations. The lowest peak voltage and the longest duration is the absolute maximum rating. ESD ratings represent the highest peak voltages and the shortest duration. Transient voltages fall between ESD and the absolute maximum ratings.

2.3.1 Absolute Maximum Rating / Recommended Operating Conditions

The absolute maximum rating (AMR) of the bus pins is the maximum voltage that can be applied with a slow rise time (sine wave) without causing damage. The recommended operating condition (ROC) is a subset of the AMR. Because most PROFIBUS transceivers are based on RS-485, the ROCs for the bus I/O are consistent with the RS-485 standard: -7 V to +12 V. AMRs vary from vendor to vendor, but are generally a 1-V to 2-V expansion of the range found in the ROC.

2.3.1.1 Common-Mode Voltage Range

Just as the absolute maximum rating bounds the recommended operating condition, the ROC bounds the common-mode voltage range of a receiver. A large common-mode voltage range is valuable in applications where the driver and receiver operate at different ground potentials. This is common in cabled applications where multiple return currents may pass through the same return line or external signals couple onto the bus line. Figure 10 shows a typical PROFIBUS block diagram of the RS-485 interface. The grounds of the different nodes are connected via the cable, and therefore any voltage drop across that ground return results in a ground potential difference. The microprocessor is protected from ground potential differences via the isolation barrier. However, the PROFIBUS transceiver must be able to withstand what is seen as a shift in the common-mode voltage of the input signal.

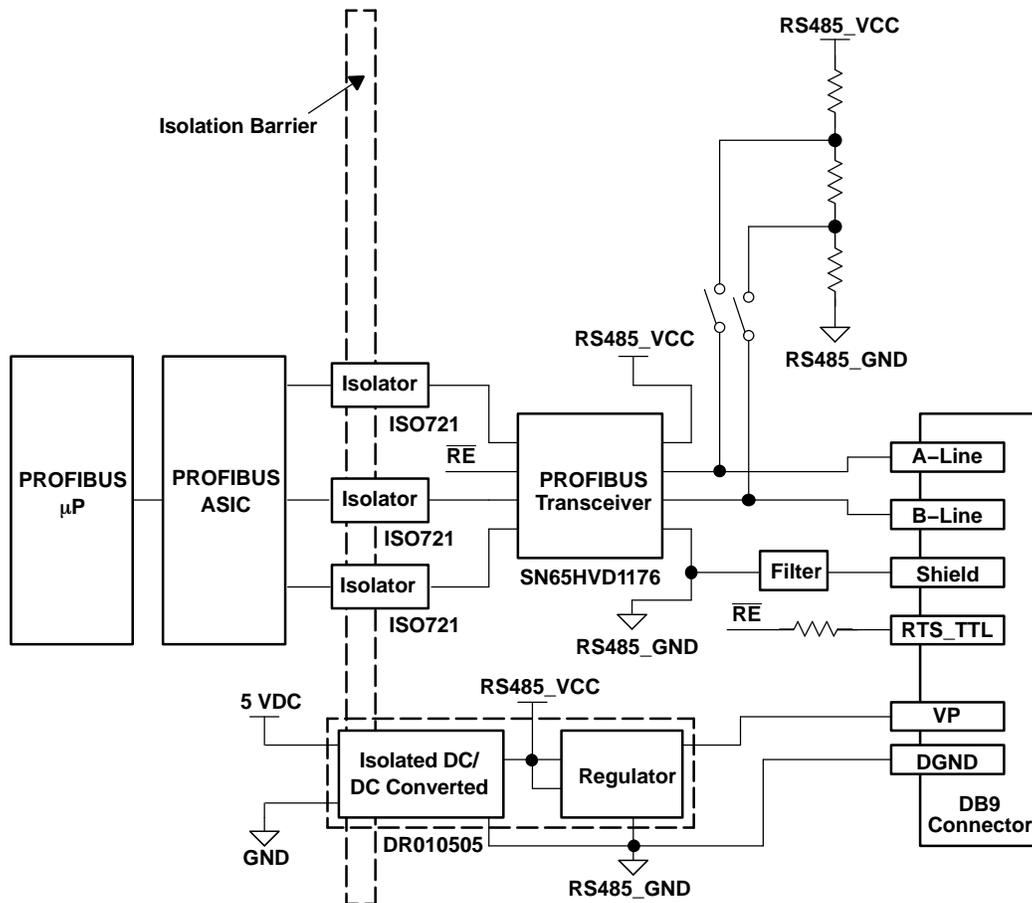


Figure 10. PROFIBUS Node Block Diagram

2.3.1.2 Common-Mode Voltage Rejection

Up to this point, the idea of a large absolute maximum rating and, consequently, a large common-mode voltage range, has been in the context of survivability. Beyond survivability is the ability to communicate accurately even with the presence of a large common-mode voltage. Figure 11 shows the test circuit developed for testing the ability of the SN65HVD1176 to reject common-mode inputs that vary in magnitude and rise time. Because the differential voltage is 0 V, the output should remain in a fail-safe state. No output changes during the test demonstrated the receiver's ability to reject common-mode noise voltage.

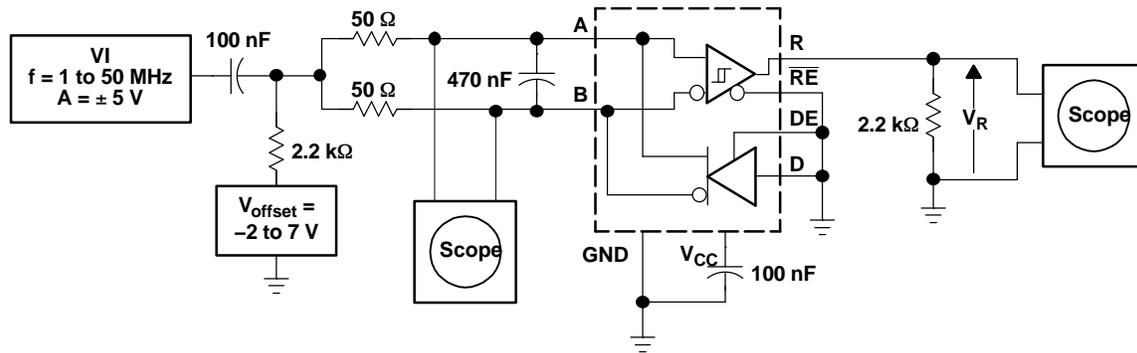


Figure 11. Common-Mode Rejection Test Circuit

2.3.2 ESD Protection

If the absolute maximum rating is at one end of the EOS spectrum, small magnitude and long duration, then ESD is at the opposite end. ESD events are typically measured in terms of kV magnitudes and ns rise times. ESD testing is defined in JEDEC standard 22, test method A114-A (also test method 3015.7 of MIL-STD-883D). This particular standard defines the human body model (HBM). Figure 12 shows the schematic of the HBM simulator and the HBM current waveform.

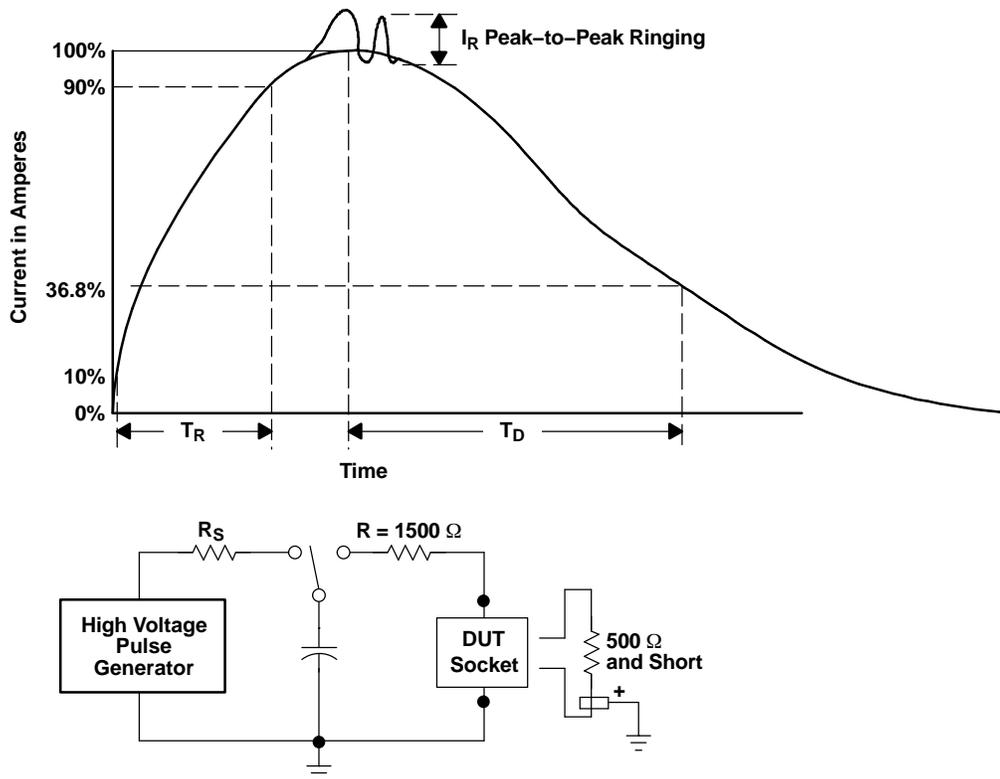


Figure 12. HBM Waveform Description and Simulator

In order to survive such large transients, the SN65HVD1176 uses protection diodes, which can quickly react to such large voltages. Figure 13 shows the equivalent schematic diagram of the A and B outputs, highlighting the ESD protection circuitry that turns on when the voltage exceeds 16 V. It is important to note that the 16 V indicated in the Figure 13 and the 16-kV ESD rating of the SN65HVD1176 is different from the -9 V to 14 V absolute maximum rating of the device.

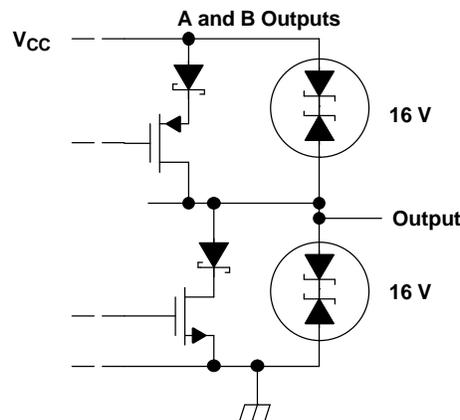


Figure 13. Equivalent Output Schematic of SN65HVD1176

2.3.3 Transient Overvoltage Protection

Transient overvoltage is defined in the TIA/EIA-485 standard. The definition and requirement found in the standard provides *protection for transients that may occur on a line when the high current due to a single contending pair is interrupted.*⁽⁵⁾ The duration is significantly longer than an ESD event (μs vs ns), and the voltage level is diminished significantly ($\pm 25\text{ V}$ vs kV). The transient overvoltage test circuit in Figure 14 is taken from TIA/EIA-485. In the specification, the test voltages are 25 V and -25 V . As shown in Figure 14, the SN65HVD1176 can withstand transient overvoltages of $\pm 40\text{ V}$.

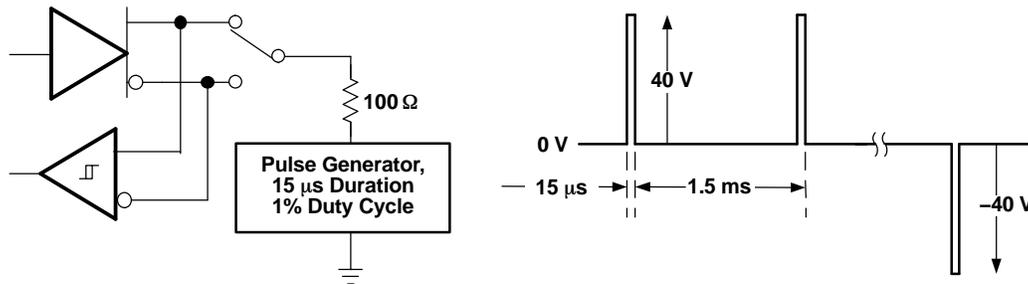


Figure 14. Transient Overvoltage Test of the SN65HVD1176

These three points do not represent all of the possible overstress conditions a device may face in an industrial environment, but these points do provide a qualitative measure as to the robustness of a device. The larger the absolute maximum rating, transient overvoltage protection, and the ESD rating, the more robust the interface is.

⁽⁵⁾ TIA/EIA-485A Section 4.26 Transient Over Voltage Tolerance: Note that this specification addresses survivability and does not imply data accuracy during the overvoltage event.

3 Conclusion

The IEC 61158-2 standard defines the physical layer for both DP and non-DP applications. This standard puts a strict limitation on the capacitance a node can place on the bus and consequently limits the bus capacitance of the transceiver. This standard also defines the cable media, bus terminations to be used, and the number of nodes allowed per segment.

In addition to the 61158-2 requirements, devices used in PROFIBUS DP applications must also meet the requirements of the PROFIBUS DP guidelines. These guidelines define a field-level testing that place additional requirements on the transceiver, specifically the differential output voltage. Section 2.1.3 shows that care must be taken in controlling the device V_{cc} and the cable medium so that a PROFIBUS system compliant with 61158-2 is also compliant with the PROFIBUS DP guidelines.

PROFIBUS is designed for industrial applications, and the interface therefore needs to be robust. The measure of robustness is seen in the absolute maximum rating, transient overvoltage protection, and ESD ratings of the transceiver bus pins. Table 3 shows that the SN65HVD1176 provides a superior degree of robustness when compared to the data sheets of other PROFIBUS transceivers. The SN65HVD1176 also provides a low bus capacitance in order to meet the capacitance requirements in IEC 61158-2 for higher speed applications.

Table 3. Characteristics of Profibus Transceivers

KEY CHARACTERISTIC	SN65HVD1176	ADM1486	MAX3463	IL485W
Differential output voltage VOD	2.1 V (min)	2.1 V (min)	2.1 V (min)	1.5 V (min)
Bus capacitance (C _{in})	10 pF (<i>max</i>)	Not specified	8 pF (<i>typical</i>)	Not specified
Absolute maximum rating of bus pins A and B	-9 V to +14 V	-9 V to +14 V	-8 V to +13 V	-7 V to +12 V
Transient voltage immunity ⁽⁶⁾	±40 V	Not specified	Not specified	Not specified
ESD protection	4 kV (HBM) ⁽⁷⁾	Not specified	Not specified	2 kV (HBM) ⁽²⁾
Common-mode rejection (CMR)	4 V (typical)	Not specified	Not specified	Not specified

⁽⁶⁾ The RS485 standard specifies a minimum voltage immunity of ±25 V; data sheet claims of standard compliance implies the minimum requirement although not explicitly stated in the data sheet.

⁽⁷⁾ HBM = Human body model

4 References

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