RS-485 for E-Meter Applications

Clark Kinnaird High Performance Linear Products

ABSTRACT

This application report discusses the best practices for designing energy meter communication circuits using the RS-485 standard. Component selection and performance tradeoffs are covered with reference to relevant standards such as IEC 61036 and DL/T 645. Reference design details are provided to help energy meter engineers successfully complete their own circuit designs.

Contents

Introduction **1**
RS-485 Interface **2**
Balanced Signaling 3
Signal Levels and Bus Loading 3
Bus Length 4
Interface Isolation 4
Failsafe Biasing 7
Transient Voltage Protection 9
ESD Protection **10**
Transceiver Selection **10**
Additional References **11**

Figures

Figure 1. Half-Duplex 485 Network With Single Master and Multiple Slave Nodes **3**
Figure 2. Typical Isolated RS-485 Circuit Using Digital Isolators **5**
Figure 3. Typical Isolated RS-485 Interface Circuit Using Optocouplers **6**
Figure 4. Typical Terminal Node With Termination and Failsafe Biasing Resistors **8**
Figure 5. Waveforms for Transient Voltage testing **9**

Tables

Table 1. Failsafe Biasing Options **9**
Table 2. Texas Instruments 485 Transceivers for E-Meter Applications **10**

Introduction

Energy meters (e-meters) are used worldwide to account for individual usage of electricity at the location of delivery. Historically these meters have been electromechanical in nature, and periodic on-site reading of the meters was necessary to collect usage information for customer billing. The latest generation of meters is electronic and provides new features including networked communications, self-test, and intelligent accounting for various time periods.

These meters monitor, analyze, and store information on energy usage. Because many utilities promote off-peak consumption, there may be several defined time segments for different energy costs. Therefore, not only total energy consumption is tabulated, but also energy consumption during each of several time segments.

A network connection between meters allows a centralized data collection. This becomes a significant advantage due to the economics of labor-intensive manual meter reading, especially as both the number of installed meters and the cost of labor increase. Networked automatic meter reading (AMR) systems further reduce problems with safety and security, as human access to distributed meters is less important. Installation costs may also be lower, as networked meters have more flexibility in terms of possible locations.

The architecture of the connecting network can be one of several types; a bus, a daisy-chain, or a tree structure are examples. One of the more efficient architectures in terms of interconnection is the bus architecture. Each meter attaches to the main bus through a stub, which is kept as short as possible. Signals on the bus are available to all the nodes. Typically, a master node controls the communications on the common bus, indicating when each node has permission to transmit.

The information that must be communicated to and between meters includes set-up, energy usage, and diagnostic data. Set-up data is communicated to a meter during initial installation, after a repair, or when tariff or time segment data must be updated. Energy usage data is collected from each meter on a periodic basis, and may include the power, voltage, and current data for a set of time segments, as well as peak, average, or other statistics. Diagnostic data may be communicated to indicate not only samples of the state of the distributed power, but also the state of the meters themselves.

There are several choices for communication with meters. One popular method is through a twisted pair of wires, using RS-485 differential signaling as defined by the TIA/EIA-485 and ISO-8482 standards. This method has the advantages of high noise immunity, fast signaling rate, many nodes on a single bus, and a wide base of proven transceivers available. Other methods include various wireless technologies, signaling over the power lines, and local infrared (IR) links. Because of its advantages, this application report focuses here on the 485-based solutions.

RS-485 Interface

The RS-485 can be either half-duplex or full-duplex. In a full-duplex implementation, four wires are required, and a node can simultaneously drive one pair of wires while receiving data on the second pair of wires. In half-duplex, a single pair of wires is used for both driving and receiving. In either case, the operation of all the nodes on the bus must be controlled so that, at most, one driver is active on each pair of lines at any time.

Having two or more drivers simultaneously active on the same pair of wires causes errors in data transmission and is called bus contention. Bus contention can be avoided by several control strategies. One method is to have a single permanent master node in control. The drivers on the bus transmit only with permission from the master node. Another strategy is to have any node temporarily take on master responsibilities, as determined by a priority scheme. Another strategy is to allocate distinct time segments to each of the nodes on the bus. Choosing a bus control strategy is the responsibility of the system designer and may be constrained by available processing power, or by the need to communicate with an existing network with predetermined protocol.

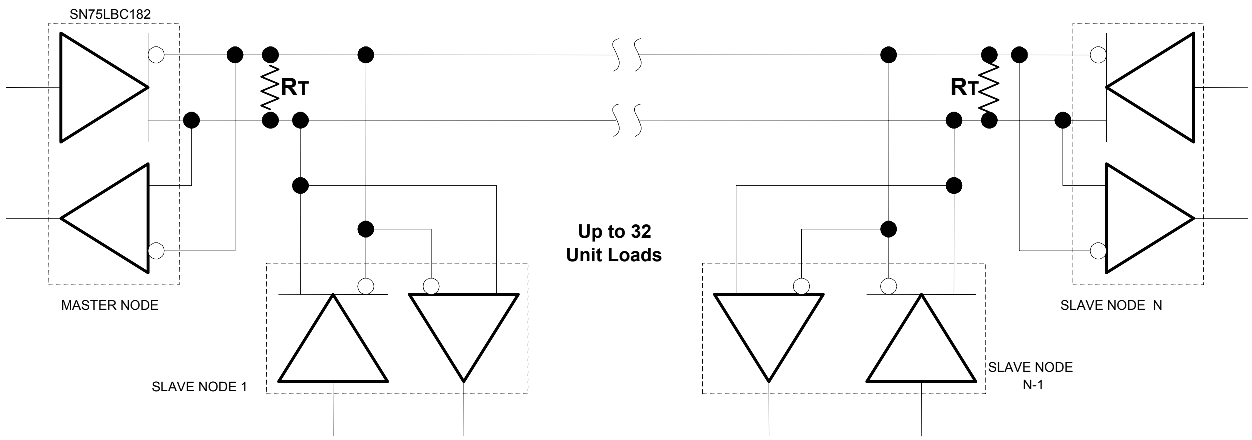

Figure 1. Half-Duplex 485 Network With Single Master and Multiple Slave Nodes

Balanced Signaling

RS-485 signaling has several advantages for energy meter applications. Because differential drivers and receivers are used, external noise sources, such as 50/60 Hz ac and high-frequency (HF) interference, are rejected. Ideally, noise is coupled equally onto both lines (common mode), and therefore the differential noise signal is zero. Similarly, if meter network lines must be routed through an industrial plant or residential community, this noise immunity and rejection is important when considering noise sources such as industrial machines, home appliances, and atmospheric noise. The IEC 61036 standard[1], for example, specifies testing meters in fields of strength 10 V/m for frequencies from 80 MHz to 1000 MHz. Texas Instruments transceivers are designed to be immune to HF noise at these frequencies, while maintaining sensitivity to differential signals within the signaling frequencies.

When designing equipment using RS-485 communication, this balanced signaling approach must be considered. Cable selection, connector pin assignment, and circuit board layout should keep the two signaling lines close to each other to maintain similar electrical characteristics. Cables with twisted-pairs of conductors, either shielded or unshielded, with characteristic impedance of 100 Ω to 120 Ω, are best for RS-485. Connector signal pin assignments must be adjacent. Traces for differential signal paths on circuit boards should be of equal length, with no discontinuities which can cause reflections or impedance mismatch between the two signals.

Signal Levels and Bus Loading

Drivers that conform to the 485 standard must be capable of producing a differential voltage with a magnitude of at least 1.5 V into a load of 54 Ω. Receivers that conform to the 485 standard must be capable of detecting a differential voltage with a magnitude as low as 200 mV. These two criteria give a considerable margin for reliably communicating between nodes, even when significant degradation of the signal occurs across the cable and connectors. For this reason,

[1] IEC 61036 *Alternating Current Static Watt-Hour Meters for Active Energy (Classes 1 and 2)),* International Electrotechnical Commission

RS-485 is well suited to applications requiring long cables between nodes, such as networking meters located around an industrial site or a residential community.

The actual differential output from a driver depends on the current it must supply into the load. Because each receiving node requires some bus current, the total current that an active driver must supply increases as nodes are added to a bus. The 485 standard defines a unit load (UL) which can be approximated by a 12-kΩ resistance over the full range of bus voltage (-7 V to 12 V) specified for 485 communication. Standard-compliant drivers can generate the required output signal with 32 of these unit loads on the bus plus a 120-Ω termination resistor on each end of the bus. These considerations are reflected in industry standards such as DL/T 645[2], which specifies an interface capable of handling at least 32 loads.

Transceivers such as the SN65HVD12 and the SN65HVD3082E are available with reduced unit loading, meaning they require less current from the bus. Therefore, a network using these 1/8 unit load transceivers can connect up to 256 nodes without overloading any 485-compliant driver.

Bus Length

As the length of the bus increases, several factors degrade the differential signal transmitted. The resistance of the copper wire reduces the signal level, although this is typically not significant.[3] More significant is the attenuation of high-frequency components of the signal. This can produce rounded edges on signal pulses, and can lead to inter-symbol interference (ISI) and bit timing jitter. Because of these effects, the combination of bus length and signaling rate must be considered. For most energy meter applications, signaling rates below 250 kbps are adequate. The standard DL/T 645 specifies signaling rates below 100 kbps. At these rates, the effect of high-frequency signal attenuation is negligible for bus lengths of even 1200 meters. Transceivers such as the SN65HVD12 and the SN65HVD3082E have driver outputs optimized for these signaling rates, and thereby have reduced levels of electromagnetic interference (EMI) and reduced problems due to stub reflections on the bus.

Interface Isolation

In many applications, it is desirable to electrically isolate the various nodes on a bus from each other. This can eliminate problems due to ground loops, conducted noise, or high common-mode voltages that exceed the RS-485 common-mode voltage range. An example of an isolated interface is shown in Figure 2. Three digital isolators are required for the single-ended signals connecting the transceiver with the node controller. An isolated voltage supply, denoted here by V_{BUS}, powers the transceiver and its associated bias components. The rest of the node is powered by the supply V_{NODE}, which is typically developed from a separate transformer winding. As long as electrical isolation is maintained throughout the interface, the communication is not affected by voltage differences between the local node and bus grounds.

---

[2] DL/T 645 - 1997 *Multi-Function Watt-Hour Meter Communications Protocol,* People's Republic of China, Ministry of Electricity

[3] For typical 485 twisted-pair cable, the dc resistance is approximately 7 to 10 Ω per 100 meters. Therefore, cable lengths on the order of 1000 meters reduce the signal by about half. Shorter cable lengths have a smaller effect in reducing the dc signal.

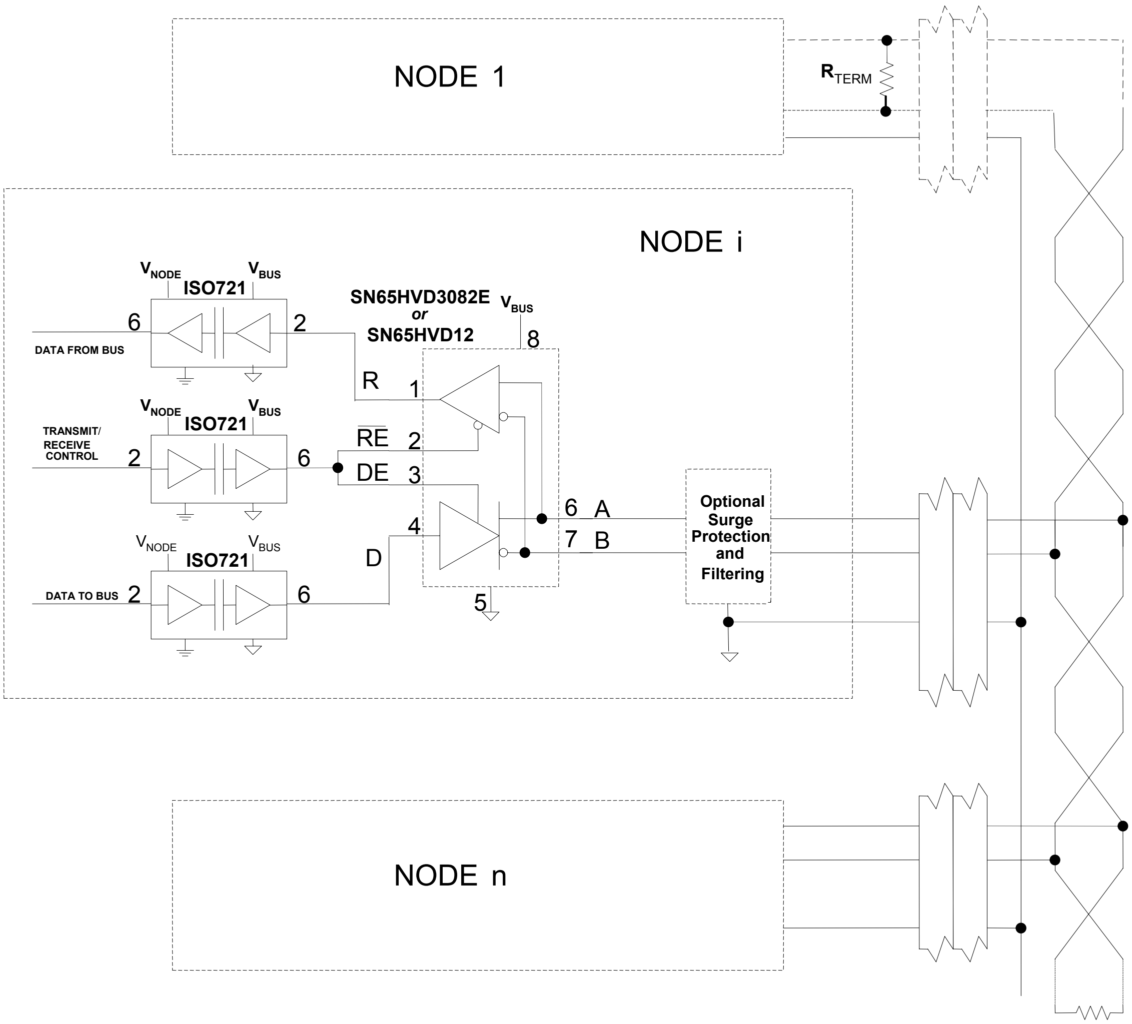

Figure 2. Typical Isolated RS-485 Circuit Using Digital Isolators

This implementation shows the connections between the transceiver and the digital isolators. Note that the driver enable (DE) and receiver enable (/RE) are connected to form a single direction control. In other implementations, these two signals may be separately controlled, to put the transceiver in a low-power state, for example. This requires one additional digital isolator.

Note that although the electronics at the various nodes are galvanically isolated from each other by the digital isolators, a ground wire connects the transceivers on all the nodes. This grounding scheme is needed to keep the transceivers referenced to a common voltage potential and is necessary for isolated and non-isolated networks.

Another implementation of the isolated interface is shown in Figure 3. In this Illustration, optocouplers are used to transmit the digital signals across the isolation barrier. Optocouplers are commonly used in applications where the superior performance of digital isolators is not needed.

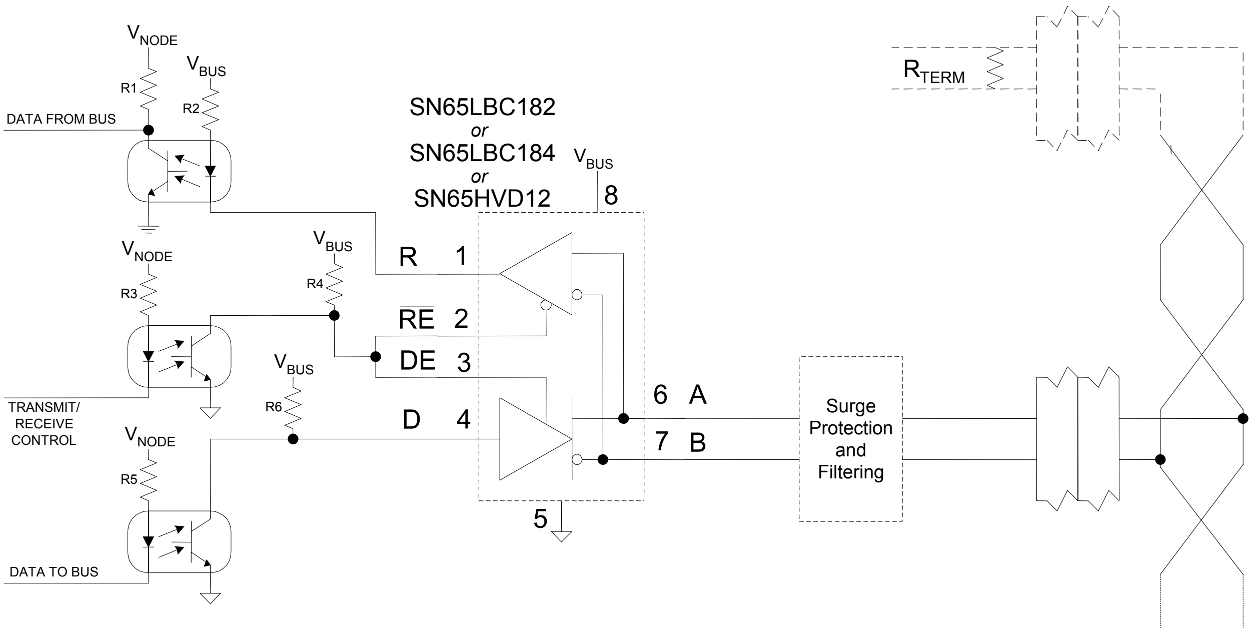

Figure 3. Typical Isolated RS-485 Interface Circuit Using Optocouplers

Component selection for this circuit is relatively simple. The significant parameters for selection of the optocouplers[4] are rise and fall times and current transfer ratio. Rise and fall times are related to the signaling rate. Adopting the signal-quality requirements of the 485 standard, the rise (or fall) time for any signal transition must not exceed 30% of the bit time. (The bit time is the reciprocal of the signaling rate.) For the maximum signaling rate specified by DL/T 645 of 100 kbps, this gives maximum rise/fall time of 3 microseconds.

$$\{t_{rise}, t_{fall}\} \leq \mathbf{30\%}\left(\frac{\mathbf{1}}{\text{signalingrate}}\right) = \mathbf{0.3} \cdot \left(\frac{\mathbf{1}}{\mathbf{100}\text{kbps}}\right) = \mathbf{3}\mu\,\textbf{sec}$$

Therefore, when selecting an optocoupler, the designer must make sure the rise and fall times are fast enough for the required signaling rate.

The current transfer ratio (CTR) is the ratio of output current to input current and relates to the drive capabilities and logic thresholds of the circuit. The optocoupler must be efficient enough to switch to valid logic levels under all conditions. Typical values of CTR range from 75% to 300%.

The pullup resistors (R2, R3, and R5) limit the current through the LED. A value of R2 that is too large does not allow enough current for reliable switching. A value too low saturates the output stage of the driving logic stage. A value of 330 Ω for R2 allows an LED current of approximately 10 mA, which is appropriate for most optocouplers.

The phototransistor biasing resistors (R1, R4, and R6) set the voltage levels for the isolated logic outputs. For a typical optocoupler with CTR greater than 50% and LED current of 10 mA, a value of 5.1 kΩ has abundant margin for switching logic levels.

[4] Manufacturers of optocouplers include NEC, Agilent, Toshiba, and others.

$$phototransistor\_output_{LOW} = V_{NODE} - (I_{LED} \cdot CTR)R_{BIAS} \approx 0V$$

$$phototransistor\_output_{HIGH} = V_{NODE} - (I_{LED} \cdot CTR)R_{BIAS} \approx V_{NODE}$$

Failsafe Biasing

Under normal operation, the 485 bus has a valid signal applied by an active driver, giving a differential voltage with magnitude exceeding the 485 threshold of 200 mV. When a node is disconnected from the bus, and the receiver inputs detect an open circuit, the bus state is not determined. This condition (open-bus circuit) can cause some 485 receivers to output a random state. Transceivers such as the SN65LBC182 and SN65LBC184 have an open-bus failsafe feature, which applies a small bias (12 μA) to the bus pins, causing a known receiver output state (logic high) under open-bus circuit conditions. The small bias has an insignificant effect during normal operation.

Another problem situation is called the idle-bus condition. This occurs when the node is connected to a bus with termination resistors, but no active driver. The bus is not actively driven to a valid 485 state, and the termination resistors tend to decrease the differential voltage to near zero volts. The 485 standard does not specify this bus condition to be a known logic state. However, many protocol standards, such as DL/T 645, require that an idle bus must take on a logic high state. Some transceivers, such as the SN65HVD12, have receiver thresholds, which are offset from zero, and therefore detect a zero differential bus voltage as a known bus state, and output a logic high. For transceivers without a threshold offset, in order to comply with the requirements of DL/T 645, bus-biasing resistors can be added, as shown by R7 and R8 in Figure 4. These resistors supply a bias to generate a valid bus logic state under idle-bus conditions.

For a bus terminated at each end with a 120-Ω resistor (60-Ω total termination load), a bias current of 4 mA produces a differential voltage exceeding the 200-mV threshold specified by the 485 standard. This 4-mA current requires bias resistors R7 and R8 of 600 Ω, given a 5-V supply. You cannot do this at every node. A hard-wired failsafe such as this must be such that the total effective pullup/down resistance is 600 Ω or so. Because the number of nodes is often variable, the usual recommendation is to have the pullup/down resistors at only one location on the bus (usually the master). Another approach is to add the termination resistor and biasing resistors to the two terminal nodes, one at each extreme end of the E-meter network. This approach, illustrated in Figure 4, shows the termination resistors and failsafe biasing resistors inserted via switches. This allows each node to be field-configurable as terminal nodes or intermediate nodes on the bus.[5]

[5] Additional discussion of failsafe biasing design is contained in *Interface Circuits for TIA/EIA-485 (RS-485)*, Texas Instruments design note (SLLA036).

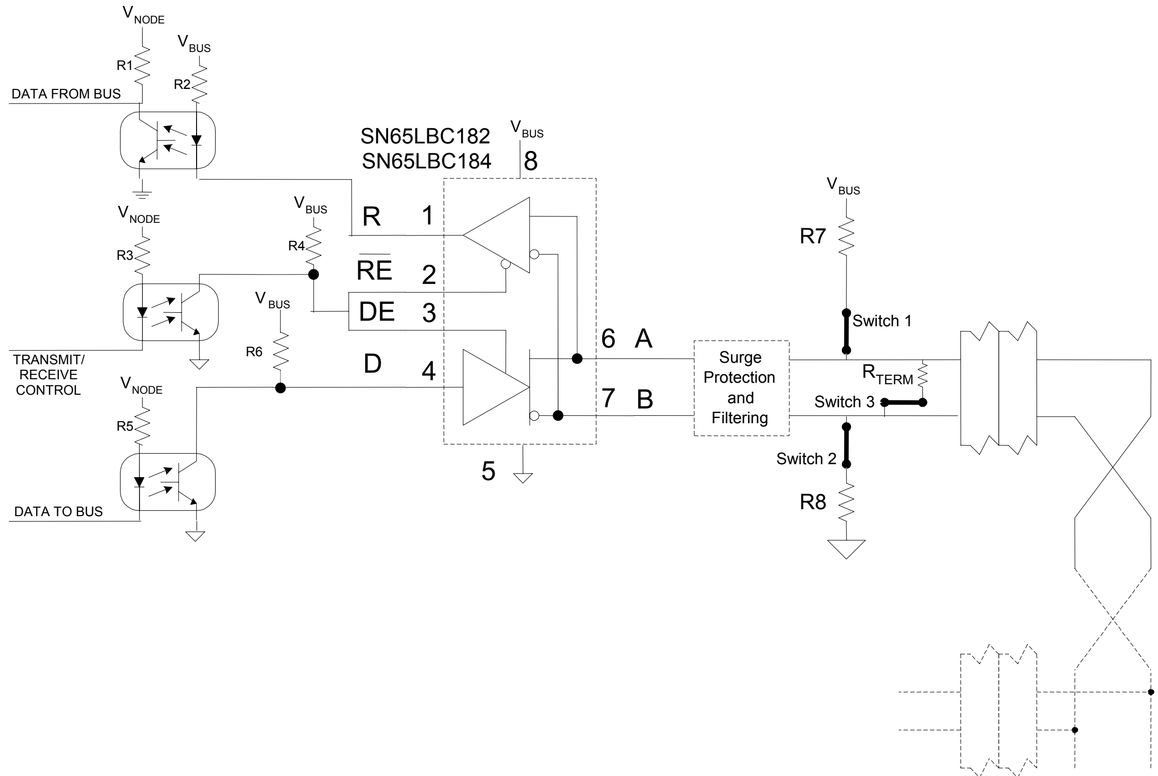

Figure 4. Typical Terminal Node With Termination and Failsafe Biasing Resistors

The biasing network also acts as a current load on the bus when any node is driving the bus to a low state. Under worst-case common-mode offsets, the effective load of the biasing circuit is approximately 20 unit loads. Using 1/4-unit-load transceivers such as the SN65LBC182 or SN65LBC184, this biasing approach allows a connection of up to 48 nodes on a single bus, in addition to the failsafe biasing resistors.

$$\text{maximum number of transceivers} = \frac{32 \text{ unit loads} - 20 \text{ unit loads}}{\text{unit load per transceiver}}$$

For example, given the 'LBC182,

$$\text{maximum number of 'LBC182} = \frac{12 \text{ unit loads}}{1/4 \text{ unit load per transceiver}} = 48 \text{ transceivers}$$

Bus designers often ask whether or not they should terminate. Termination current does increase the overall power used by the network. However, terminating the bus at each end with a resistor equal to the characteristic impedance of the cable reduces the signal reflections generated by the impedance discontinuities. For relatively long cable length, such as E-meter applications, termination resistors are recommended to ensure data signal integrity.

Table 1. Failsafe Biasing Options

Network	Transceiver	Bus Biasing	Maximum Transceivers
Terminated R_{TERM}= 120 Ω, 5%, 1/4 W	1/4 unit load without idle-bus failsafe	R7 = R8 = 600 Ω, 5%, 1/4 W on master node only	48
Terminated R_{TERM}= 120 Ω, 5%, 1/4 W	1/4 unit load without idle-bus failsafe	R7 = R8 = 1.2 kΩ, 5%, 1/4 W on two terminal nodes only	48
Terminated R_{TERM}= 120 Ω, 5%, 1/4 W	1/8 unit load with idle-bus failsafe	R7 and R8 not needed	256

Transient Voltage Protection

Transient voltage surges are caused by lightning strikes, sudden equipment stops, inductive load switching, and other sources. The ISO standard IEC 61000-4-5[6] describes methods to test circuits with a waveform that simulates these conditions, as shown in Figure 5.

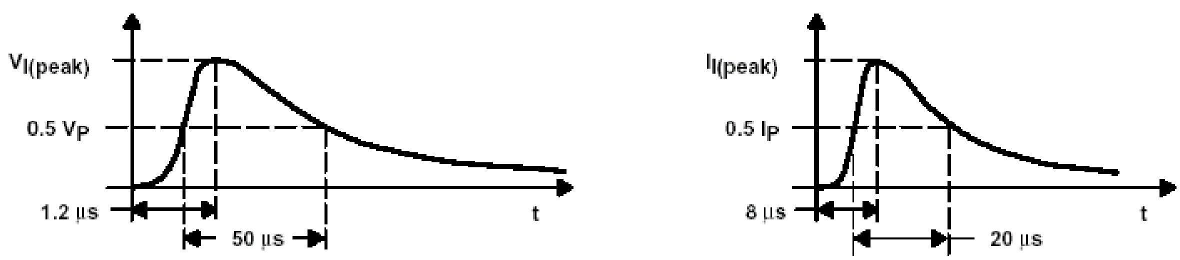

Figure 5. Waveforms for Transient Voltage testing

A fully isolated bus has some protection from surge voltages if both differential lines experience the same surge. For example, lightning induced transients are typically generated with respect to earth ground. If fully isolated, this potential is developed across the isolation barrier and not between the bus lines and the isolated ground. However, other reasons for transient suppression include protection from surges in case of mis-wiring, faulty grounding, and other fault conditions. Additional transient voltage protection is available by using discrete transient voltage suppression (TVS) Zener diodes[7], or by selecting a transceiver with integrated transient voltage suppression. If specifying TVS components, the key parameters are clamping voltage and power dissipation.

The clamping voltage is the level at which the Zener diodes hold the line, and it must be low enough that no damage occurs to the protected circuits. However, if the clamping voltage is *too* low, the Zener diodes break down within the working voltage range of the transceiver; this range is specified as -7 V to 12 V by the 485 standard.

[6] IEC 61000-4-5 *Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 5: Surge ImmunityTest*

[7] Manufacturers of TVS Zener diodes include General Semiconductor, American Microsemiconductor, Fagor Electronica, and others.

The power dissipation rating shows the peak power that the TVS diodes can manage without being harmed. This is the product of the clamping voltage and the peak current through the device.

$$P_{PEAK} = V_{CLAMP} \cdot I_{PEAK}$$

The SN65LBC184 has integrated TVS Zener diodes on each bus pin. This protects the node against circuit damage due to surge voltages, safely dissipating 400 W of peak power. The clamping voltage is selected at 16 V, which is outside the normal 485 operating range, and sufficient to protect the transceiver's circuitry. The integration of the TVS provides additional board space and cost savings over discrete Zener diodes.

ESD Protection

Electrostatic discharge (ESD) can damage interface integrated circuits during handling or during cable connection. Selection of a transceiver with high values of ESD protection on the bus pins ensures a robust circuit for energy meter applications. Several standards are available to specify ESD protection values, including JEDEC standards (HBM[8]), which model the ESD of a human body, and ISO standards[9] that model both air discharge and contact discharge events from charged objects. The IEC 61036 standard requires testing to contact discharge of 8 kV for metallic surfaces (such as interface connectors). The DL/T 645 standard requires meter communication components to tolerate 15-kV HBM ESD discharges.

Transceiver Selection

Texas Instruments manufactures several transceivers well-suited for energy meter applications. Selection of a specific transceiver depends on requirements and constraints for each individual application. Several choices appropriate for these applications are listed in Table 2.

Table 2. Texas Instruments 485 Transceivers for E-Meter Applications

Transceiver SN65… or SN75…	Supply Voltage	Signaling Rate	Integrated 400W TVS	Failsafe Receiver	Unit Loading	ESD Protection
LBC182	5 V	up to 250 kbps	No	Open-bus	1/4	±8 kV (Contact) ±15 kV (Air) ±15 kV (HBM)
LBC184	5 V	up to 250 kbps	Yes	Open-bus	1/4	>±30 kV (Contact) >±15 kV (Air) >±15 kV (HBM)
HVD12	3.3 V	up to 1 Mbps	No	Open-bus, idle-bus, shorted-bus	1/8	>±16 kV (HBM)
HVD3082E	5 V	up to 200 kbps	No	Open-bus, idle-bus, shorted-bus	1/8	±15 kV (HBM))

[8] EIA/JEDEC Standard Test Method A114-A *Electrostatic Discharge Sensitivity Testing Human Body Model*
[9] IEC 61000-4-2 *Electromagnetic Compatibility - Part 4-2 Testing And Measurement Techniques - Electrostatic Discharge Immunity Test*

Additional References

- *Interface Circuits for TIA/EIA-485 (RS-485)*, Texas Instruments design note (SLLA036)
- *422 and 485 Standards Overview and System Configurations*, Texas Instruments application report (SLLA070)
- TIA/EIA-485-A, *Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems*
- TIA/EIA-TSB 89, *Application Guidelines for TIA/EIA-485-A*
- ISO/IEC 8482, *Information technology - Telecommunications and information exchange between systems - Twisted pair multipoint interconnections*
- Texas Instruments Web site, www.ti.com
- DL/T 645-1997 *Multi-function watt-hour meter communication protocol*, People's Republic of China, Ministry of Electricity
- CEI/IEC 61036:1996+A1:2000, *Alternating current static watt-hour meters for active energy (classes 1 and 2)*, International Electrotechnical Commission