

Application Report

THVD8000 Design Guide



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ABSTRACT

This design guide presents design guidelines for engineers new to data-over-power implementations. The discussion helps accomplish a robust and reliable data- and power-transmission design in the shortest time possible.

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1 Introduction and Device Overview

The RS-485 standard is a differential interface that has been widely used in industrial, medical, and consumer applications. The THVD8000 device enables power line communication using RS-485 physical layer signaling. Built-in on-off keying (OOK) modulation enables input Transistor-Transistor Logic (TTL) data to be directly coupled onto shared power cables via series capacitors without any updates to the microcontroller (MCU). A two-wire cable is required to transmit both power supply and RS-485 signals. To be more specific, OOK modulation converts a logic-low input to a high-frequency clock signal, while a logic-high input results in a DC voltage (Figure 1-1). The receiver of the THVD8000 extracts the data from the power cables after AC-coupling by utilizing a precise bandpass filter and a demodulator. The power on the bus is decoupled by series inductors that show high impedance at the frequency of OOK data.

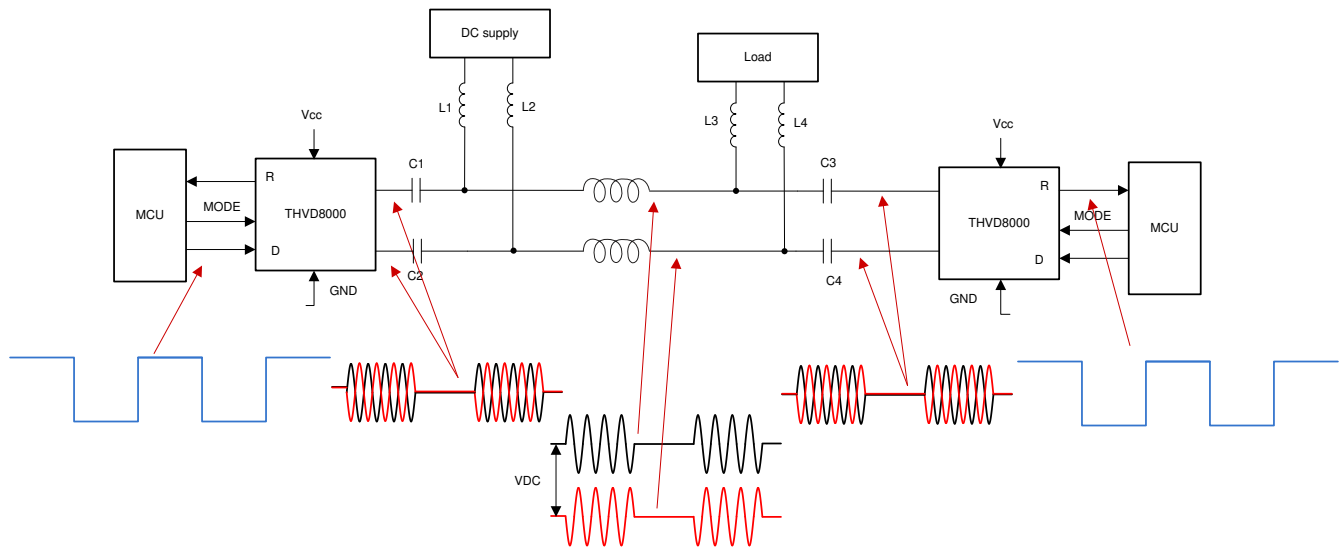


Figure 1-1. THVD8000 OOK Modulation Signal

2 Comparison With RS-485

In this guide, the RS-485 standard is frequently referred to or compared with. Since the THVD8000 device leverages RS-485 signaling, the device inherits some RS-485 features like balanced multipoint transmission and common-mode noise immunity (Table 2-1). Also, just like RS-485 transceivers, the THVD8000 is a physical-layer-only device. This makes the THVD8000 simple to implement and flexible in various applications requiring different higher-layer data communication protocols. The device works with universal asynchronous receiver-transmitter (UART) signaling from the MCU and can directly replace the existing RS-485 signal link in the system.

Table 2-1. THVD8000 and RS-485 Comparison

Feature	RS-485 Transceiver	THVD8000
Vod	1.5 V over 54 Ω	1.5 V over 54 Ω
RX threshold	200 mV	115 to approximately 225 mV
Transmission direction	Half or full duplex	Half duplex
Multipoint communication	Yes	Yes
Common-mode noise immunity	Yes	Yes
Topology	Daisy chain	Daisy chain
Termination	Yes	Preferred
Polarity free	No	Yes
TTL interface to MCU/UART	Yes	Yes
Maximum node count	256	256

3 Cable Type

RS-485 applications benefit from the use of twisted-pair cabling, because noise from external sources couples equally into both wires as common-mode noise that is rejected by the differential receiver. In THVD8000 applications, twisted-pair cabling is preferred due to the same reason. Also, the cable should have enough current rating and low enough series resistance to deliver power without excessive voltage drop. Many power cables in the applications may not be the twisted-pair type. In this case, the coupled common-mode noise could be presented differentially on the bus. Therefore, extra attention needs to be paid on minimizing the noise coupling in the system design, which is discussed in the following sections. Similarly, use of length-matched cabling is critical when transmitting higher-speed differential signals. Length mismatches would lead to phase imbalance between the inverting and non-inverting lines, and this would result in a portion of the differential signaling to common mode. The mode conversion could result in higher EMI, and in more severe cases could result in a loss of communication.

4 Data Rate, Carrier Frequency and Communication Distance

In the system design, the carrier frequency of the OOK modulation is selected based on the desired data rate and the expected AC losses through the cabling. Usually it is recommended to choose the carrier frequency at least 10 times faster than the data rate. In other words, there are more than 10 cycles in one bit period of the data. For example, for 19200 baud rate application, the carrier frequency of 300 kHz can be used. For 115200 baud, a carrier frequency of at least approximately 1.2 MHz is preferred. This helps to minimize bit timing distortion due to asymmetries in rising and falling signal transitions that can occur during modulation and demodulation.

There are some tradeoffs in the carrier frequency selection, though. With higher carrier frequencies, the signal suffers more loss from the cable, thus less transmission distance can typically be supported. Generally, the implementation cost might be less due to smaller inductors. The details about inductor selection are discussed in the next section.

Similarly to RS-485 transmission, the maximum bus length is limited by the transmission line losses at a given carrier frequency. Jitter is a common parameter for signal integrity, which shows the deviation from the ideal signal edges in time. In THVD8000 applications, other than the cable loss, the duty cycle distortion due to the modulation theme and reversed polarity connection may also contribute to the total jitter.

In [Table 4-1](#), the maximum achievable cable length for each carrier frequency is listed based on lab data. The measurement is carried on 20-AWG UL2464 power cables. If the received signal has a jitter of 20% or more or below the threshold of the receiver, the communication is considered not applicable (marked as 'n' in the table).

Table 4-1. Cable Length Versus Carrier Frequency

		fo (kHz) (data rate = 1/10 fo)				
		125	300	500	750	1000
Cable Length (Meter)	300	y	y	y	y	y
	600	y	y	y	y	y
	900	y	y	y	y	n
	1200	y	y	y	n	n
	1500	y	y	n	n	n

5 Inductor and Capacitor Selection

The inductor and capacitor value selection is based on the impedance at the carrier frequency of OOK modulation. A general rule is that the total inductor impedance should remain larger than $375\ \Omega$, and the impedance of each capacitor is less than $5\ \Omega$. The reasoning behind this stems from the RS-485 standard, where a minimum 1.5-V differential voltage is required from each output driver when considering a $54\text{-}\Omega$ load. As [Figure 5-1](#) shows, with two $120\text{-}\Omega$ terminations, the remaining bus load has to be larger than $375\ \Omega$ to make the strongest (lowest-resistance) load less than $54\ \Omega$ ($120\ \parallel\ 120\ \parallel\ 375 \times 2 = 54\ \Omega$). The input impedance of the receiver is relatively high and negligible in the loading calculation, and the $375\text{-}\Omega$ budget is all assigned to the inductors.

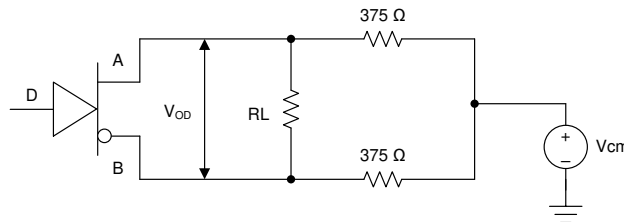


Figure 5-1. RS-485 Bus Load

Suppose there are $2n$ inductors on the bus (the differential load from each node consists of two series inductances). Assume the DC source has low impedance and the loads have large filter capacitance, making the inductors AC grounded ([Figure 5-2](#)).

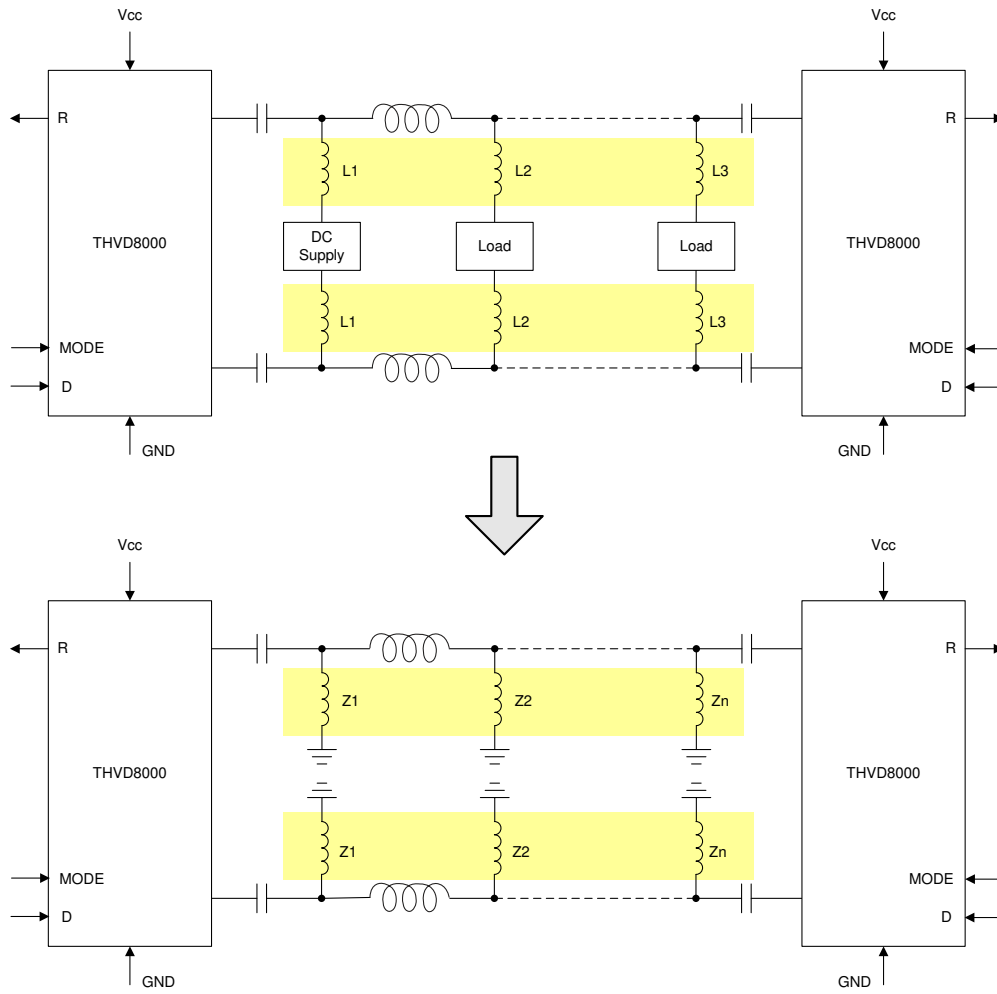


Figure 5-2. THVD8000 Inductor Load

The total equivalent differential impedance is approximated by the parallel combination of each inductor value (fo is the carrier frequency of OOK), while the total value is equal to Equation 5.

$$Z_1 || Z_2 || \dots || Z_n \tag{5}$$

$$Z_n = 2\pi f_0 L_n \tag{6}$$

Use the reference chart in Figure 5-3 to find the recommended inductor value at each carrier frequency. This is the reason mentioned in the last section that the inductance could be smaller with higher carrier frequency. Please note the guide is based on the first-order estimation. In a real system, take other factors into account, like the phase, cable loss, and so forth.

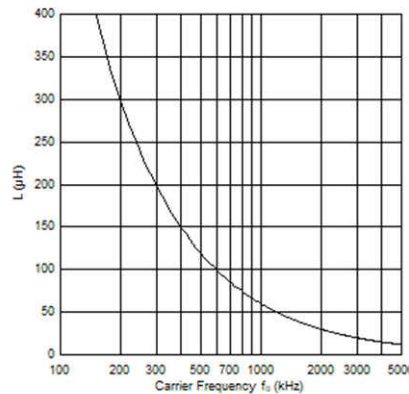


Figure 5-3. THVD8000 Inductance Recommendation Chart

Other than the inductance, other parameters need to be considered for inductor selection. One of them is the current rating depending on the power delivery capability requirement. Another parameter is DCR (DC resistance). As Figure 5-4 shows, the source and load in the network goes through 4 inductors in total. If the resistance is not small, the voltage drop could be significant when drawing larger currents.

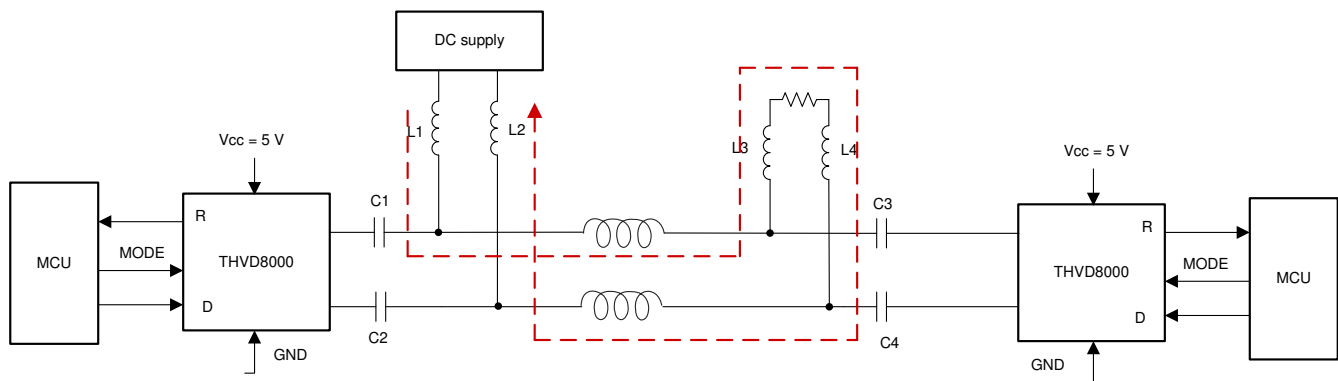


Figure 5-4. THVD8000 Load Current Flow Path

Similarly for each decoupling capacitor, the impedance at the carrier frequency is (Equation 7).

$$Z_c = \frac{1}{2\pi f_0 C} \tag{7}$$

The capacitor impedance is placed in series with the OOK signaling path, so it can act to attenuate the received signal (Figure 5-5). Unlike the inductor, the capacitor impedance is considered point-to-point within a multi-node system. The capacitor isolates the lower-frequency bus voltage components from the THVD8000 device. The voltage rating and leakage needs to be considered in the selection.

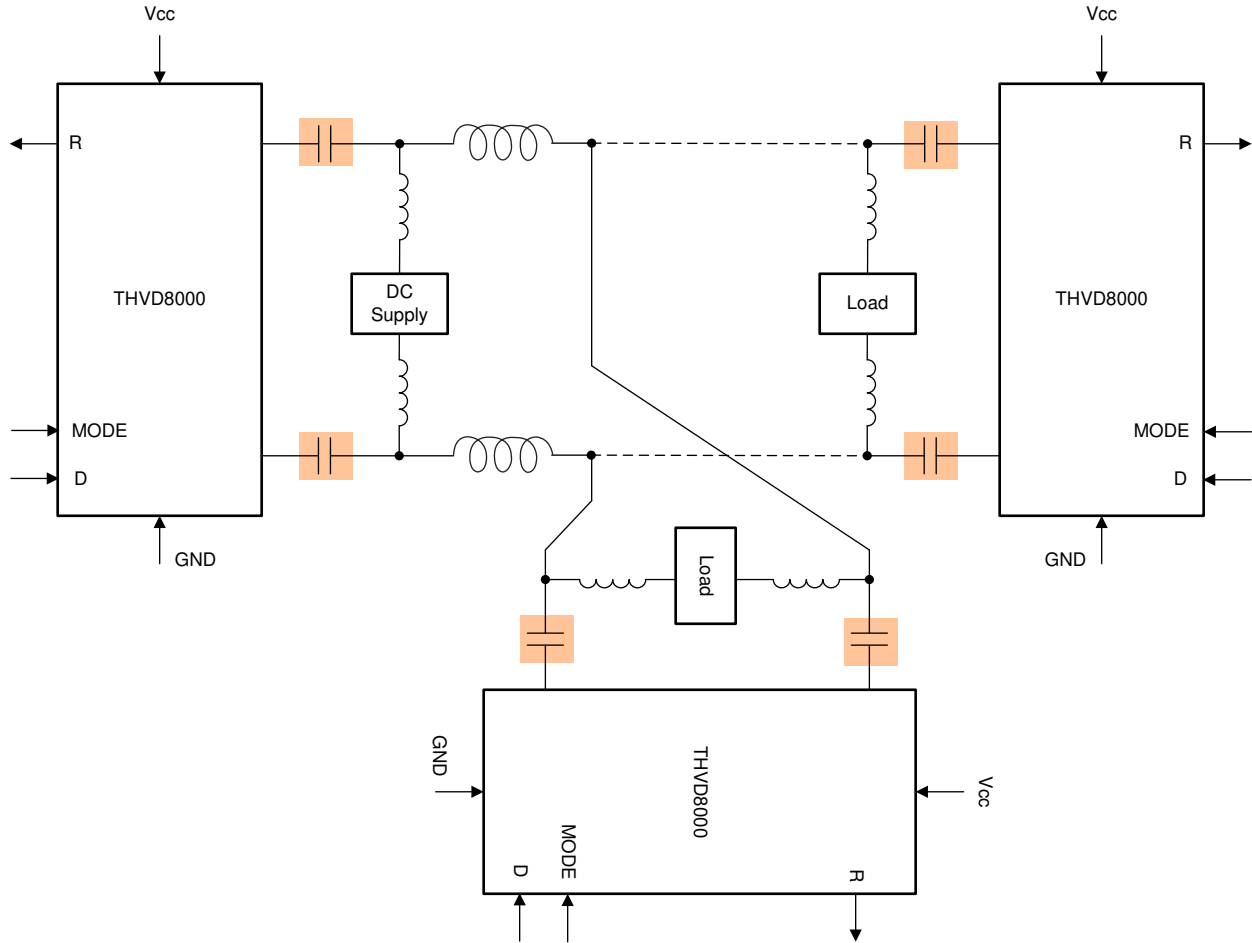


Figure 5-5. THVD8000 Capacitor Load

Figure 5-6 shows the chart for capacitor value selection, in which the recommended capacitor values are above the curve in the upper region.

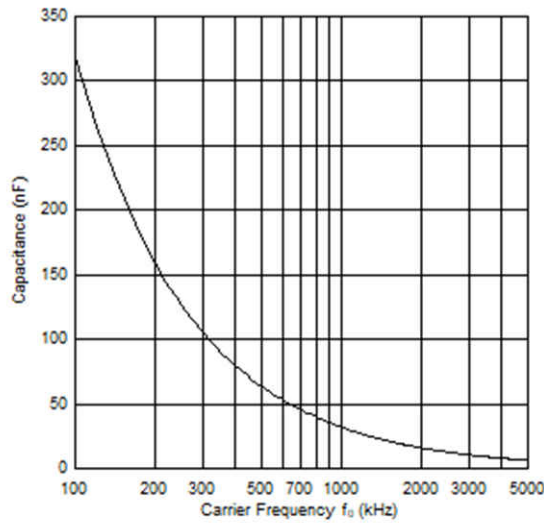


Figure 5-6. THVD8000 Capacitance Recommendation Chart

6 Network Topology

Just like an RS-485 system, daisy chain is the recommended topology with two terminations installed on the farthest ends of the bus. With proper termination that matches the characteristic impedance of the cable, the bus reflections are minimized to provide the best signal integrity.

Nevertheless, other topologies could possibly be implemented depending on the data rate and distance. The signal integrity needs to be studied carefully for each system. For example, running the THVD8000 with a long cable without termination could end up having standing waves along the bus. The reason is that the open end generates a nearly full reflection. The reflected waves travel backward and superimpose upon the transmitting waves. If the phases of two waves are 180 degree apart, the amplitude of the transmitted signal can be largely reduced. In the unterminated system, usually the minimum amplitude happens at about $\frac{1}{4}$ wavelength (λ) of the transmission signal. Figure 6-1 shows the transmitted waves, reflected waves and the superposition at $N \times \frac{1}{4} \lambda$ ($N = 0, 1, 2, 3, 4$) positions of a cable.

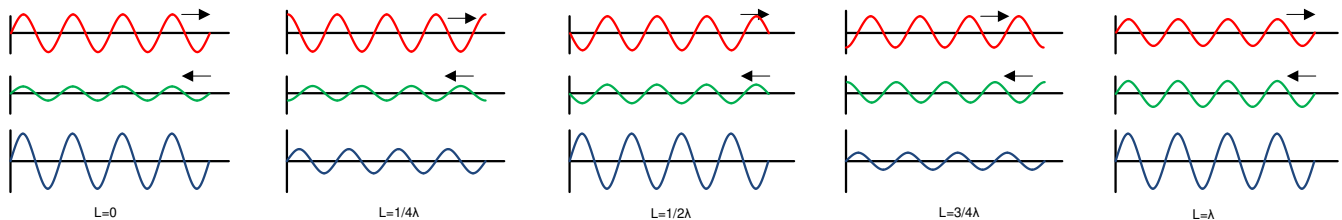


Figure 6-1. Standing Waves Along Bus

The same concern applies to the stubs (unterminated cable branches) in the system. As a general rule, if the stub is longer than $\frac{1}{10}$ of the output rise time of the driver, the reflection should be taken into account from the signal integrity point of view. Use Equation 8 for the maximum stub length:

$$L_{stub} \leq \frac{t_r}{10} v c \quad (8)$$

where

- t_r = drivers 10/90 rise time (ns)
- v = signal velocity of the cable
- c = speed of light

7 Termination and Fail-safe

As discussed in the previous section, daisy chain with terminations matching the cable characteristic impedance is the preferred topology. The characteristic impedance of a cable is a complex value dependent on the per-unit-length capacitance, inductance, series resistance, and shunt conductance of the cabling (Figure 7-1). For low-loss cables, it can often be approximated as a real value (dominated by the parasitic capacitance and inductance terms) and can therefore be matched with a simple resistance. However, note that this is an approximation and may not provide a perfect match at all signal frequencies and cable lengths.

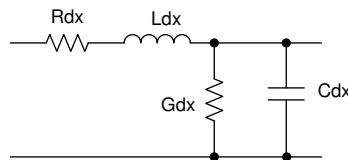


Figure 7-1. Equivalent Circuit of a Unit-length Cable

In practice, it might be hard to measure the characteristic impedance of the cable in many applications. With handy equipment like a Vector Network Analyzer (VNA), the response of the cable in the complex domain on different frequencies can be checked and the results are shown on the Smith chart. The complex impedance for the frequency range is circled around the nominal load impedance (resistance only).

In an S-parameter measurement, S11 is the return loss showing the reflected energy. The Voltage Standing Wave Ratio (VSWR) of S11 should be close to 1 in the frequency range of interest. If VSWR has the smallest variation over the frequency range of the application, the resistance is considered to match the cable well. A 1000-ft. CAT5 cable is measured by a VNA by open termination (Figure 7-2) and a 100-Ω resistor termination (Figure 7-3). Other than the Smith chart, the results show that S11 is smaller and has smaller variation with the proper termination.

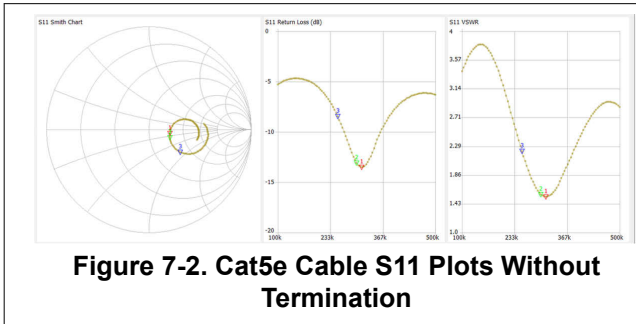


Figure 7-2. Cat5e Cable S11 Plots Without Termination

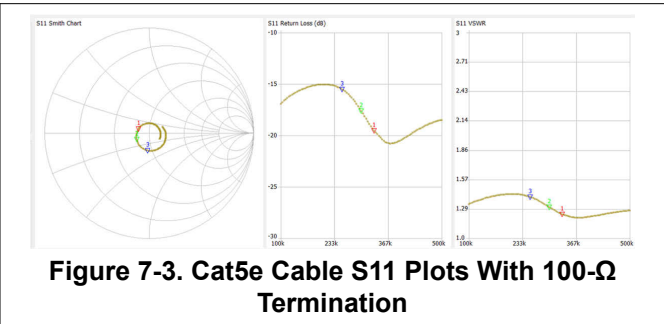


Figure 7-3. Cat5e Cable S11 Plots With 100-Ω Termination

Without a VNA, it is harder but still possible to search the impedance. For example, a signal generator can be used to drive the cable. The reflection of the signal at the end of the cable can be observed with various termination resistors. In the same test mentioned in the previous paragraph, with open end, the signal takes time to die down and ripples can be observed (Figure 7-4).

With 100-Ω termination, the signal travels to the end of the cable and settles down quickly (Figure 7-5).

The THVD8000 device has symmetric thresholds due to OOK modulation. Adding pullup or pulldown resistors on the bus would not generate the fail-safe feature like the RS-485 system. However, the THVD8000 works with fail-safe network on the bus, since the receiver retrieves the frequency information and the DC bias is blocked. On the same note, the receiver does not rely on the DC voltage for decisions. If for some reason the received signal shows some DC offset, the modulation scheme still works.

The THVD8000 device has polarity-free functionality, which means that communication works no matter how A and B wires are connected among nodes. Miswiring would affect the power delivery as well and that power-line polarity immunity can be achieved at the system level through use of a full bridge rectifier.

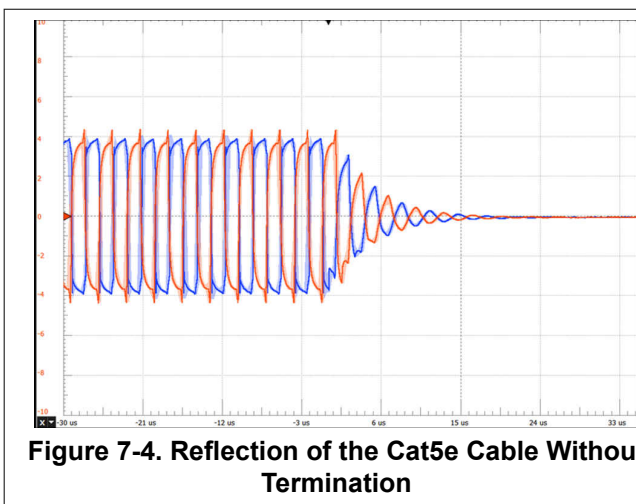


Figure 7-4. Reflection of the Cat5e Cable Without Termination

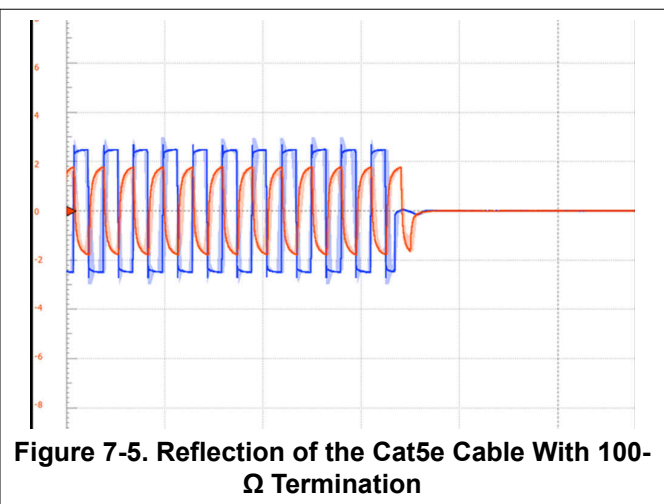


Figure 7-5. Reflection of the Cat5e Cable With 100-Ω Termination

8 Bus Loading

As previously mentioned, the THVD8000 has both similar driving strength and similar receiver sensitivity comparing to an RS-485 transceiver. To evaluate signal attenuation on the bus, include all cable loss and loading on the bus due to termination, decoupling inductances and input impedances of multiple nodes. The cable loss and inductor loading were previously discussed in this application report. The input impedance of the THVD8000 receiver is about 1/8 unit load (UL) measured in RS-485 standard. Any other external components attached to the bus like TVS diodes could have an impact with multiple nodes and at high carrier frequency. Among all the nodes, not all have to function as delivering both data and power. Some nodes can be self-powered and have data transmission only, like node 3 in [Figure 8-1](#).

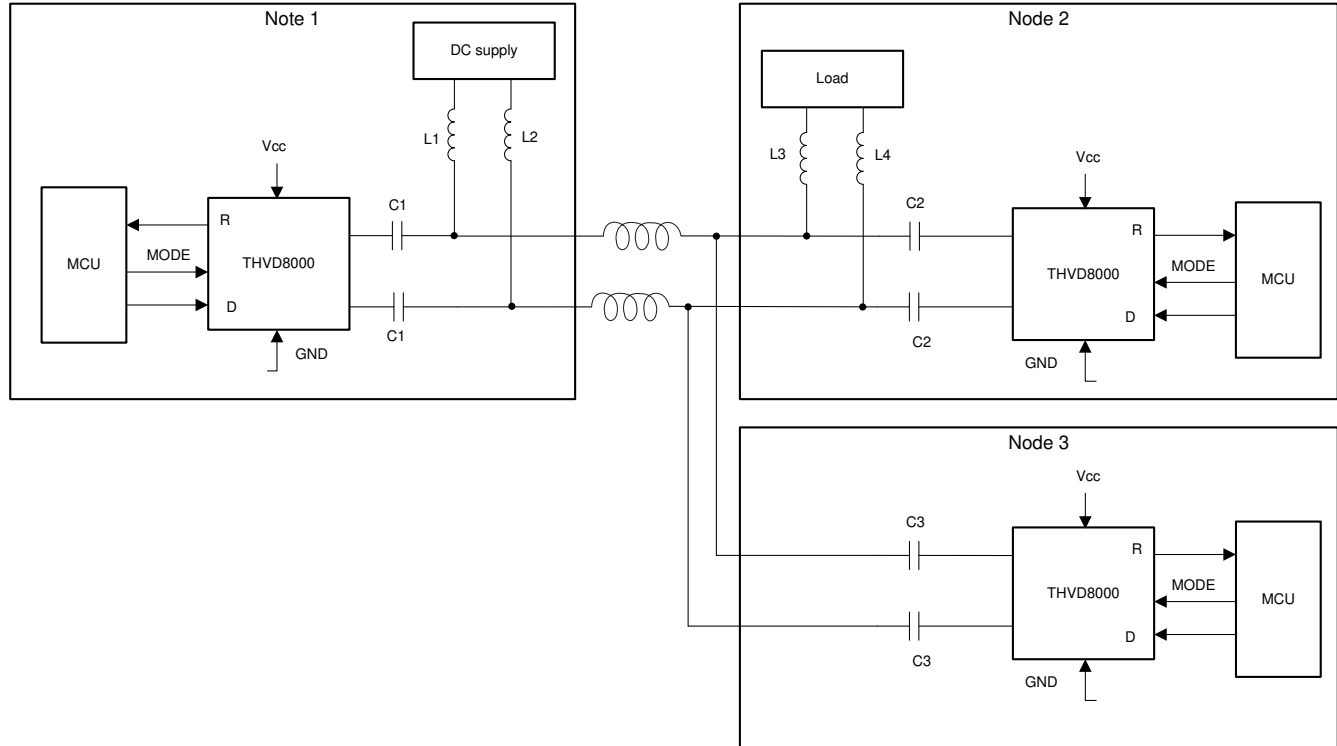


Figure 8-1. THVD8000 Multiple Nodes Setup

9 Grounding and Common-Mode Noise

When designing a remote data link, the designer must assume that large ground potential differences may exist. These voltages show as common-mode noise to the transmitter output. Even if the total superimposed signal is within the input common-mode range of the receiver, the local earth ground may not be a reliable path for the return current. In other words, the nodes in a multi-node network have isolated local grounds that are connected through some high-impedance path (Figure 9-1). To help create stronger current return path, an easy way is to put all transceiver grounds on the same potential by connecting them by a third wire or the shield of the cable. If this method is not practical for the system, a capacitor and a large resistor like 10-M Ω can be applied to connect the transceiver ground with the protective earth (PE). The intention is to create a high-frequency current path via PE, while the effectiveness depends on the application environment.

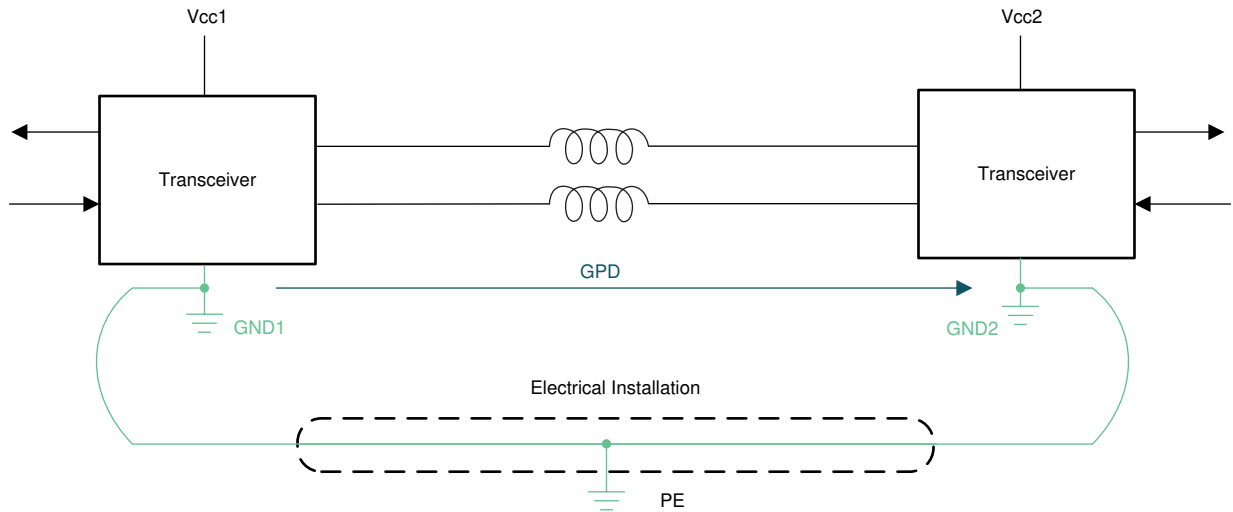


Figure 9-1. Grounding of two Transceivers

Although the THVD8000 device has good common-noise immunity like RS-485 transceivers, the noisy environment could be problematic if the coupled common noise has large amplitude. In these applications, the 120- Ω resistors can be replaced by two 60- Ω , low-pass filters to provide additional common-mode noise filtering (Figure 9-2).

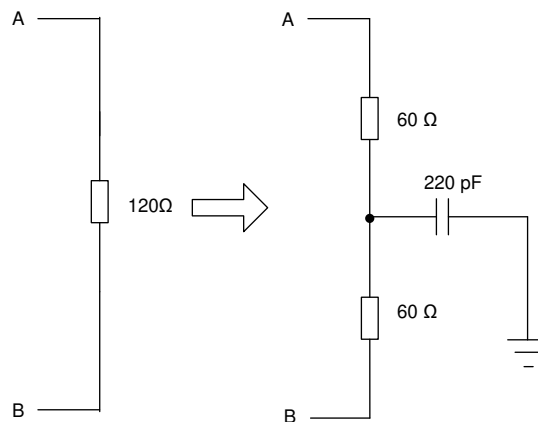


Figure 9-2. Split Termination

10 Conclusion

This application report covers the main aspects of a data-over-power system design with the THVD8000 device.

Following the discussions presented in this document and consulting the detailed application reports in the reference section can help accomplish a robust system design in a short time.

10.1 References

1. Signal integrity and reflection:
 - Texas Instruments, [AN-806 Data Transmission Lines and Their Characteristics Application Report](#)
 - Texas Instruments, [AN-807 Reflections: Computations and Waveforms Application Report](#)
 - Texas Instruments, [AN-808 Long Transmission Lines and Data Signal Quality Application Report](#)
2. RS-485 design guide:
 - Texas Instruments, [The RS-485 Design Guide Application Report](#)
3. Ground noise:
 - Texas Instruments, [Removing Ground Noise in Data Transmission Systems Application Report](#)
4. Power over data simulation:
 - Texas Instruments, [Power Line Communication Using RS-485 Simulation Reference Design, Design Guide](#)

11 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (June 2020) to Revision A (July 2021)

Page

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- Updated the numbering format for tables, figures and cross-references throughout the document.....2
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