Technical Article

THVD8010: Simplified and stable RS-485 communication over power line with OOK modulation

Len, Zhang *Qing Dao*

Summary

This document was translated from a simplified Chinese source. (ZHCTA10)

In traditional commercial air conditioning systems, wired communication methods such as UART and RS-485 buses are commonly used for communication between remote controllers and indoor units. These solutions require separate wiring, resulting in high installation and maintenance costs. They are also susceptible to electromagnetic interference from high-voltage power lines over long distances, and troubleshooting can be difficult. To address these challenges, this paper introduces RS-485 transceiver THVD8010 with On-Off Keying (OOK) modulation. Supporting power line communication, it modulates data onto existing DC power lines, enabling the power supply and communication to share the same pair of cables, thereby significantly reducing system complexity and cabling costs. THVD8010 offers good noise immunity due to the advantages of the differential bus combined with OOK modulation, and guarantees that the signal will demodulate properly even with severe attenuation after transmission over long distances. This paper will delve into how it addresses system-level design challenges and provide implementation guidelines, layout recommendations, and actual test data.

System design challenges: Simplified cabling, noise immunity, long-distance communication and cost reduction

Sensors, actuators and controllers are widely distributed in many industrial automation, building automation, and commercial air conditioning control systems. Laying both power and data communication cables for each node is a costly and complex task, especially when retrofitting existing facilities. The primary challenges currently faced are described as follows.

Challenge 1: Independent cable costs. Additional power cables increase material (cable itself) and labor (laying) costs.

Challenge 2: Space constraints and noise immunity. Inside narrow ducts or equipment, it becomes difficult to add cables, and entanglement with other cables, such as blowers, can also affect the quality of communication.

Challenge 3: Long-distance communication. In scenarios requiring long-distance communication, such as in buildings or shopping malls, there is a risk of signal loss.

Challenge 4: System complexity. Separate power and communication networks add complexity to connectors, interfaces and cabling.

THVD8010 directly addresses these challenges with its innovative OOK modulation technology.

THVD8010: RS-485 solution with OOK modulation integrated

THVD8010 is not a standard RS-485 transceiver. Its core value lies in its built-in modem that converts digital data into OOK signals suitable for transmission on DC power lines and recovers it to digital data at the receiving end.

OOK modulation core features and benefits

OOK modulation and demodulation: This is the basis of THVD8010. In transmit mode (TX), a logic low level is modulated to a carrier signal of a specific frequency, while a logic high level causes the driver to output a zero differential voltage, as shown in Figure 1. In receive mode (RX), the built-in peak detector demodulates the OOK signal extracted from the power cable into original data, as shown in Figure 2.

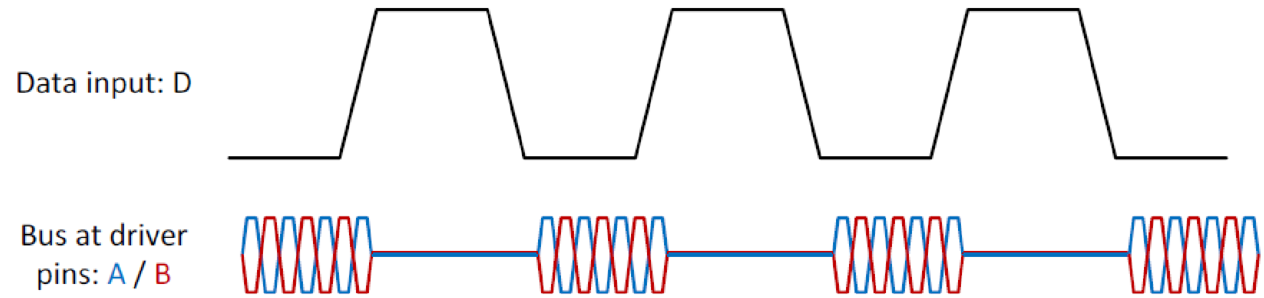

Figure 1. OOK modulation

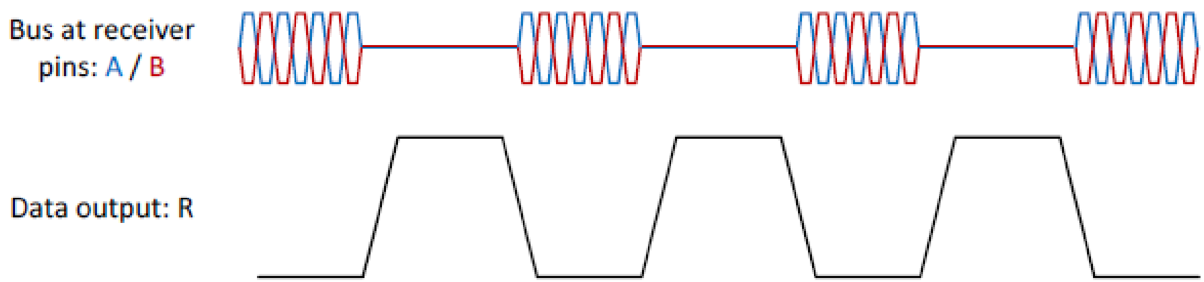

Figure 2. OOK demodulation

No need to consider polarity: This is a key advantage that simplifies installation. In OOK mode, the receiver only detects the input signal amplitude and ignores its polarity. This means that there is no need to worry about reversing the bus A and B lines when wiring in the field, greatly simplifying the installation process, avoiding debugging problems due to polarity errors, and improving the reliability of the system.

Pin programmable carrier frequency: The carrier frequency (125kHz~300kHz) can be set by a single external resistor (“RF_SET”), as shown in Figure 3. This provides flexibility in the system design to optimize the selection of external passive components (inductors, capacitors) and avoid noise interference in specific frequency bands.

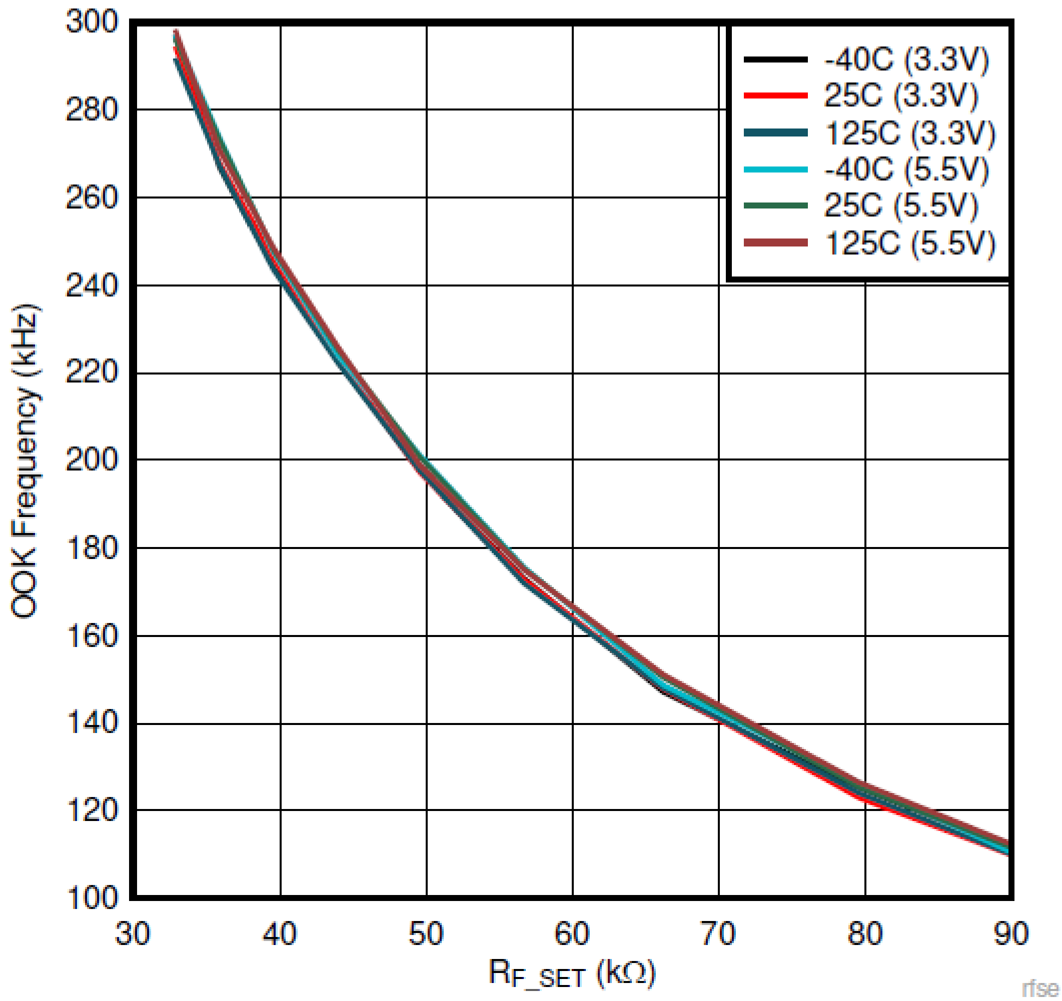

Figure 3. Correlation curve between RF_SET and OOK Frequency

Spread Spectrum Clocking (SSC): The internal oscillator uses spread spectrum techniques to spread the carrier energy across a narrow band rather than concentrating it at a single frequency. This significantly reduces the peak of electromagnetic interference (EMI), helping the system easily meet EMC regulations.

Integrated robust protection features:

- IEC ESD protection: Integrated IEC 61000-4-2 ESD protection of ±8 kV (contact discharge) and ±15 kV (air discharge), and IEC 61000-4-4 electrical fast transient (EFT) immunity of ±4 kV. This provides robust resilience against surges and transient events in industrial environments, reducing the need for external TVS diodes.
- ±18V bus fault protection: The bus pins are resistant to persistent high-voltage faults, preventing the device from being damaged if the power line is accidentally shorted to the high-voltage line.

Transmitter timeout function: To prevent the bus from being consumed indefinitely by a single node while the D input signal remains stable due to a fault, ensuring the reliability of a multi-node network.

Typical application and implementation

System block diagram: power line communication network

For communication between indoor units and remote controllers in commercial spaces, traditional UART suffers from issues such as short communication range and susceptibility to interference. Typically, data is lost at the UART receiver end beyond a distance of 40m. Additionally, when the air conditioner is operating, the fan cables and communication cables can become entangled, which also interferes with UART communication and leads to abnormal data transmission. To address these issues, THVD8010, leveraging the advantages of a differential bus combined with OOK modulation, offers excellent noise immunity. Even when signals are severely attenuated after long-distance transmission, they can still be demodulated normally, perfectly addressing the shortcomings of UART communication between indoor units and remote controllers.

Figure 4 demonstrates a typical application of a commercial air conditioning indoor unit and a remote controller. The indoor unit and the remote controller correspond to two nodes, respectively; each node connects THVD8010 to a shared power and data bus via an RC circuit.

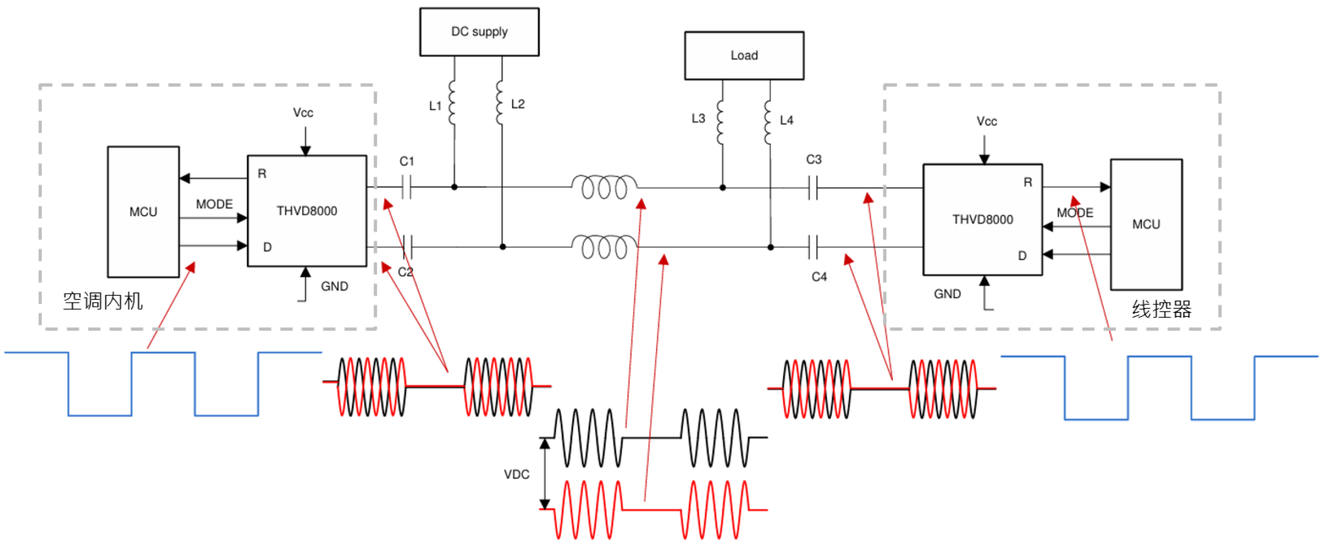

Figure 4. THVD8010 power line communication network

Power supply (DC supply): Provide DC power to the entire network.

Inductors (L1, L2, L3, L4): Present low impedance to low-frequency DC power but high impedance to high-frequency data signals, preventing data signals from being short-circuited by the power supply.

Capacitors (C1, C2, C3, C4): Present low impedance to high-frequency data signals, allowing them to pass through, while blocking the DC power supply to protect THVD8010's bus pins.

Design steps: select inductor and capacitor

First, select the appropriate values for L and C to provide the correct impedance path for both data and power at the corresponding carrier frequency, as follows:

1. Select the carrier frequency (f_0): select it based on data rate and noise immunity needs. It is recommended that the data rate does not exceed $f_0/10$. For example, for a data rate of 20kbps, select carrier frequencies more than 200KHz;
2. Calculate the inductance value (L): the impedance of the inductance

   $ZL=2\pi f_0 L$. To ensure that the data signal does not attenuate excessively across the inductor, the total parallel impedance of all node inductors should be significantly greater than the differential impedance of the RS-485 terminator (typically 60Ω). For a network with N nodes, the impedance of each inductor should be at least 60Ω*N. The inductance value is then calculated based on $L=ZL/(2f_0)$.

   Example: For a 2-node and 300kHz network, if ZL of each inductor is ≥ 120Ω, L ≥ 120/(2π*300e3) ≈ 63.5μH. Choose a standard value, such as 68μH, and ensure that it can withstand the maximum DC current of the node.
3. Calculate the capacitance value (C): impedance of the capacitor $ZC = 1/(2\pi f_0 {*} C)$. To ensure that the data signal is effectively coupled to the bus, the impedance of the capacitor should be sufficiently low (typically recommended as ZC ≤ 5Ω).

Example: For 300kHz, C ≥ 1/(2π*300e3*5) ≈ 106nF. Select a standard value, such as 100nF or 220nF, and make sure it is rated well above the DC voltage on the bus.

Measured waveforms of communication between commercial indoor unit and remote controller

THVD8010 enables long distance communication

Based on THVD810 carrier communication solution, the indoor unit and remote controller are connected via a 100m long power line. The indoor unit sends commands to the remote controller, and the remote controller sends commands to the indoor unit. By measuring the waveforms of the transmitted and received signals, we determine whether THVD8010 can achieve bidirectional communication over a 100m power line.

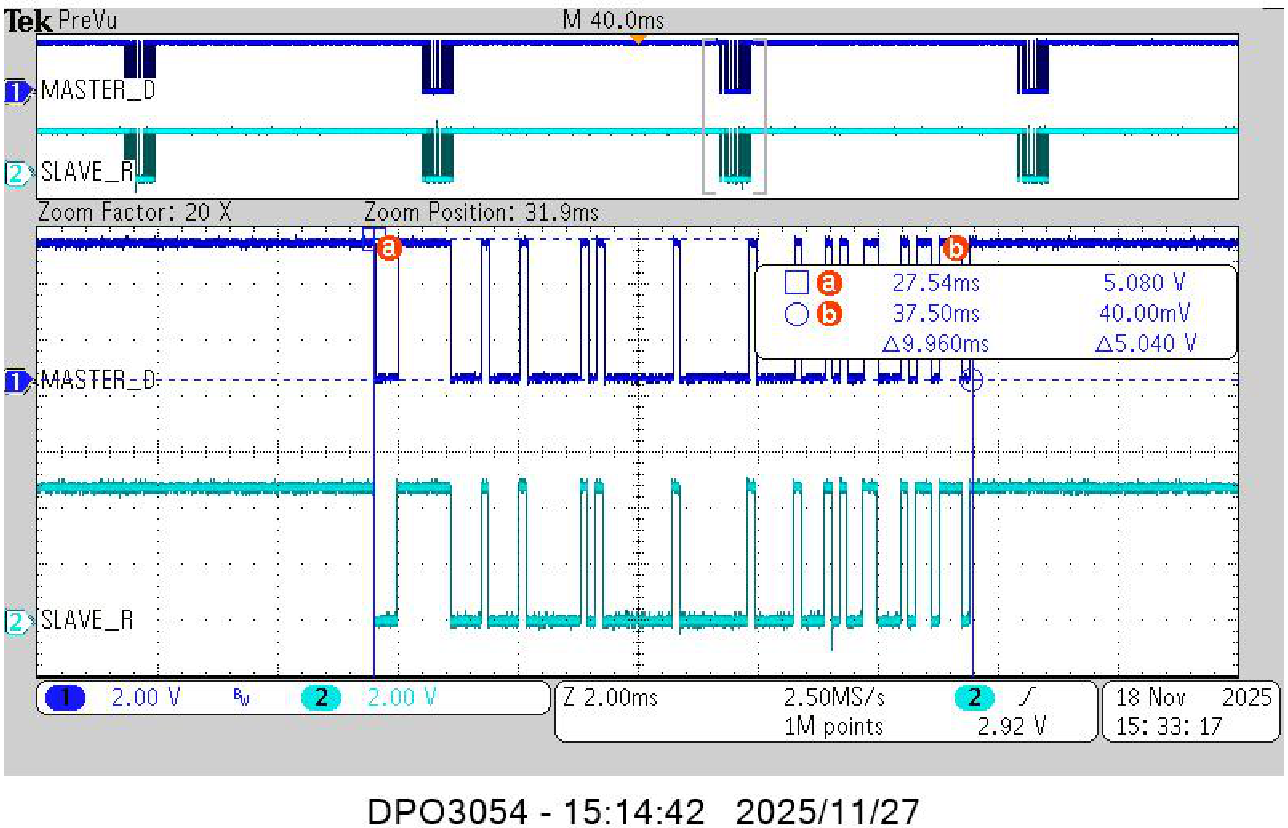

Figure 5. 100m communication - signal waveforms that indoor unit transmits and remote controller receives

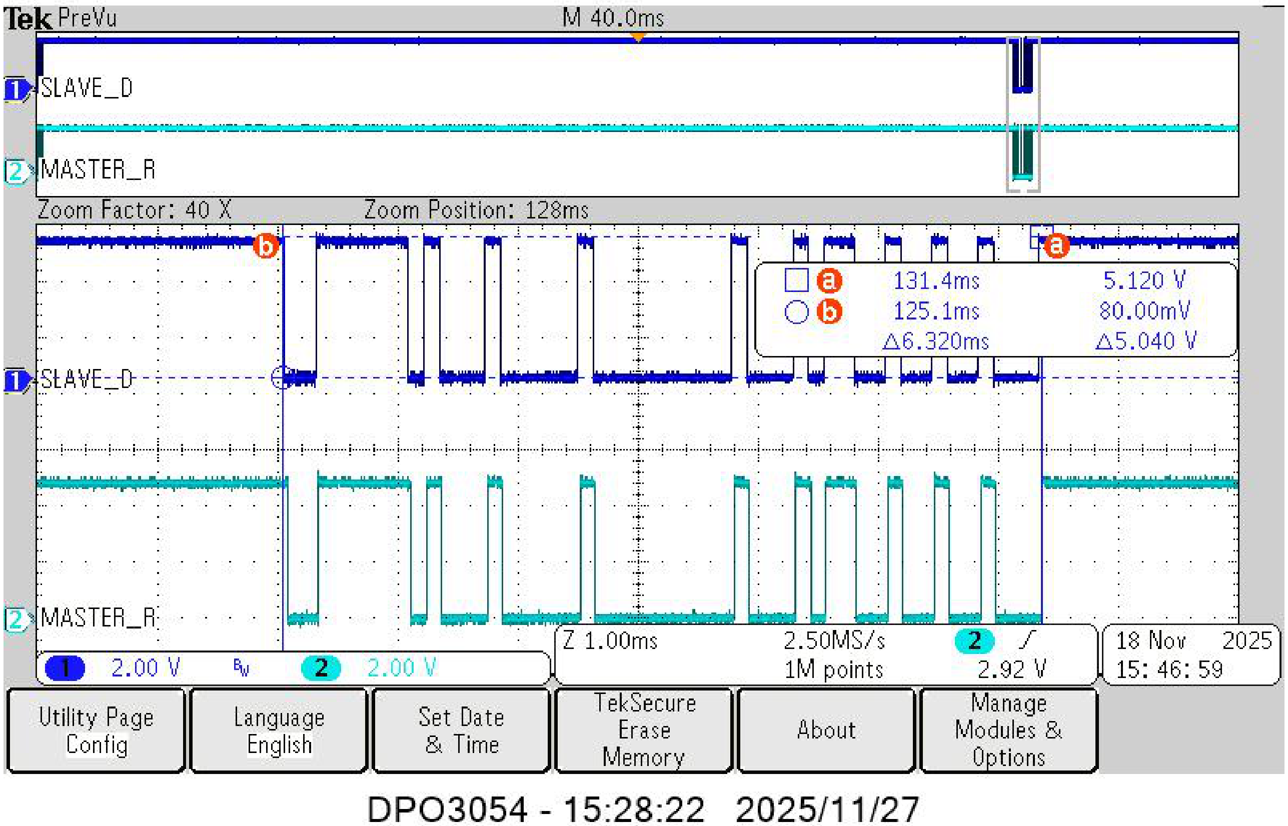

Figure 6. 100m communication - signal waveforms that remote controller transmits and indoor unit receives

As shown in Figure 5, MASTER_D is the signal transmitted by the indoor unit, and SLAVE_R is the signal received by the remote controller. It can be seen that THVD8010 enables the remote controller to receive signals normally even with a 100m long power line. The remote control can still receive signals normally. Similarly, as shown in Figure 6, the indoor unit can also receive signals normally over a 100m power line. This not only enables customers to communicate over longer distances but also eliminates the need for an additional 100m power cable, significantly reducing system design costs.

THVD8010 communication under fan disturbance

When the air conditioner is running, the fan's three-phase output cables often become entangled with the power lines. This can cause high currents and voltages in the fan cables to couple into the power lines, thereby interfering with normal communication between the indoor unit and the remote controller. To verify the noise immunity of THVD8010, start the air conditioner to run the fan, then entangle THVD8010's power lines with the fan's three-phase output cables. Measure the waveforms of the transmitted and received signals to determine whether THVD8010's communication is affected by the fan cables.

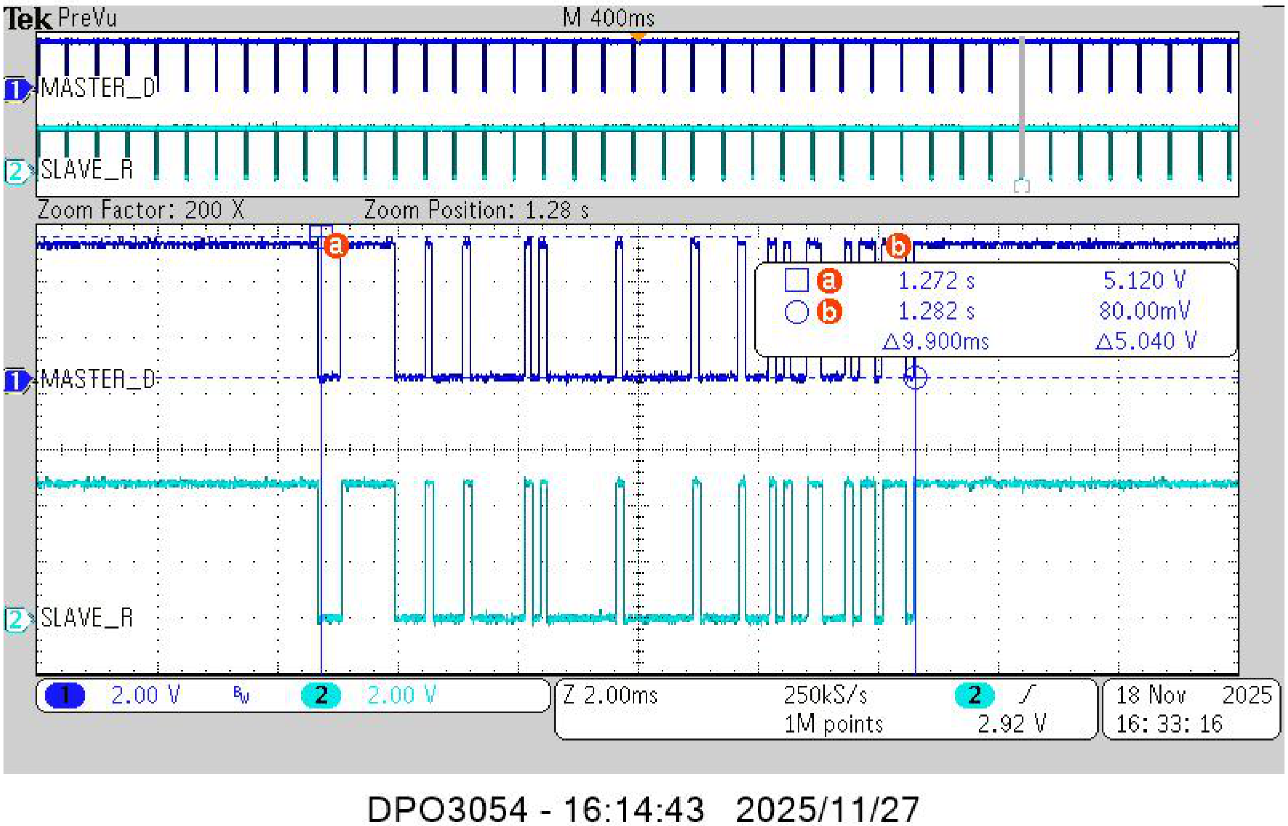

Figure 7. Fan interference - signal waveforms that indoor unit transmits and remote controller receives

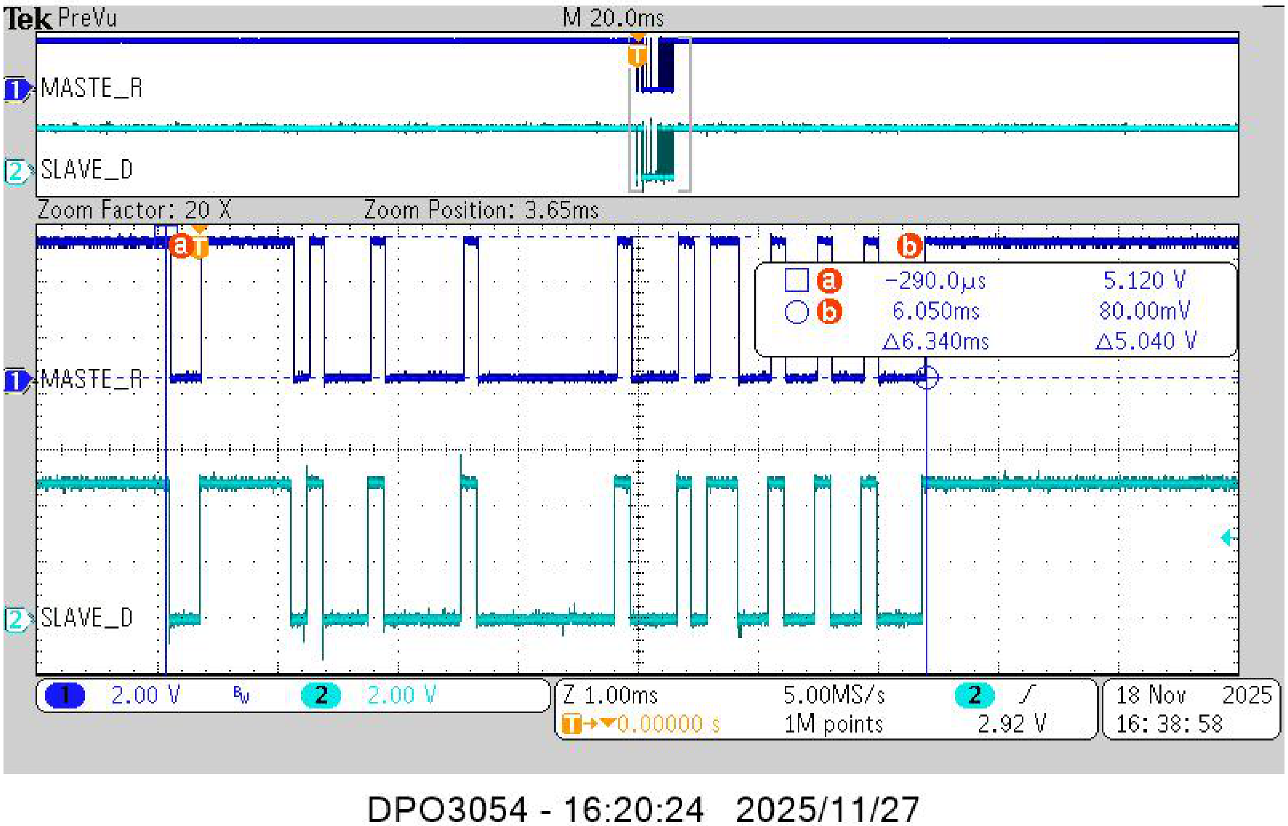

Figure 8. Fan interference - signal waveforms that remote controller transmits and indoor unit receives

As shown in Figure 7, MASTER_D represents the signal transmitted by the indoor unit, and SLAVE_R represents the signal received by the remote controller. It can be seen that even under interference from the fan cables, THVD8010's power lines allow the remote controller to receive signals normally. Similarly, as shown in Figure 8, the indoor unit can also receive signals normally under fan cable interference, thereby improving the quality and reliability of communication between the air conditioner's indoor unit and the remote controller.

Layout guidelines

Decoupling capacitor: Place 100nF and 1µF decoupling capacitors as close as possible to the device's VCC and GND pins;

F_SET resistor: Place the frequency-setting resistor "RF_SET" close to F_SET pin and minimize lead capacitance to ensure frequency accuracy;

Bus pins: Traces leading to A and B pins should be as short and symmetrical as possible; traces connecting decoupling capacitors C1 and C2 should also be kept short and direct.

Grounding: Prioritize laying a continuous ground plane to provide a path for high-frequency return currents.

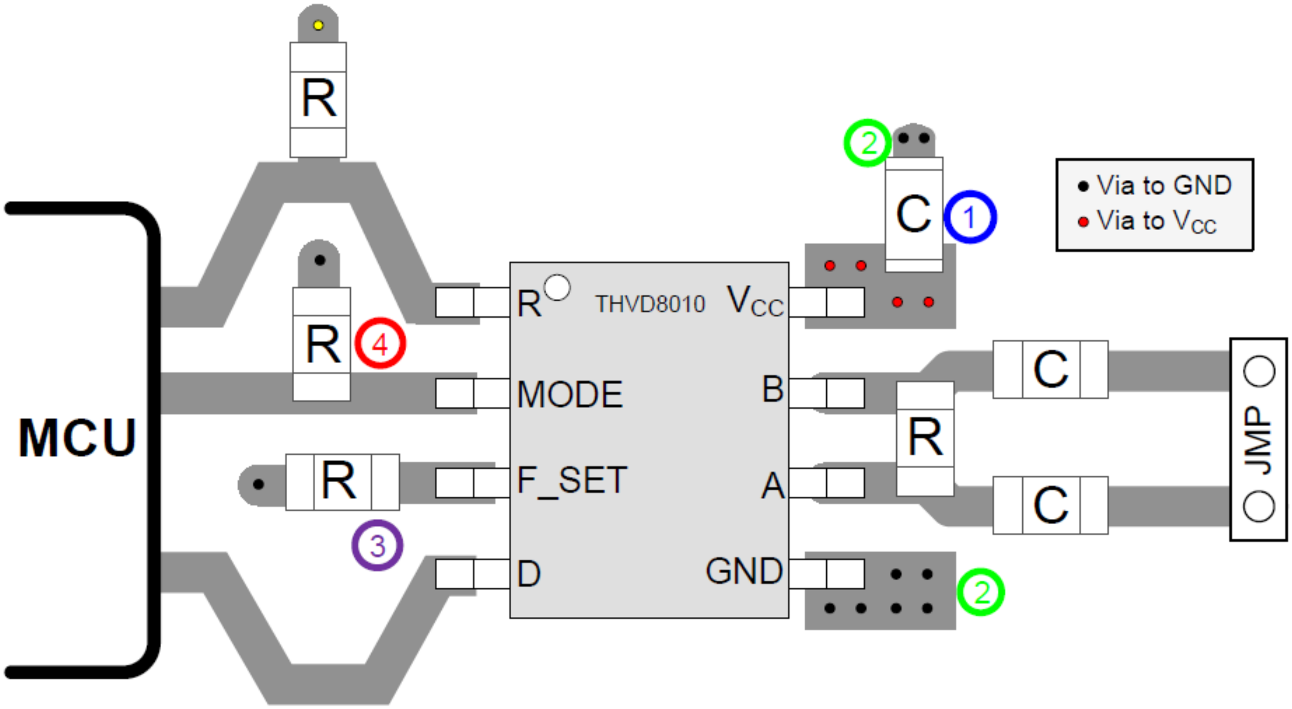

Figure 9. Layout recommendations

Conclusion

By integrating RS-485 communication with DC power transmission over a single pair of cables, THVD8010 offers system designers a revolutionary solution. Its integrated OOK modem, polarity adaptation, programmable carrier frequency, and robust built-in protection features provide excellent noise immunity and long-distance communication capabilities. Together, these features address critical cabling challenges in industrial, building, and commercial air-conditioning applications, resulting in significant reductions in BOM costs and installation complexity. By following the design and layout guidelines outlined in this application note, engineers can quickly and reliably build robust and efficient power line communication networks.

References

1. THVD8010 data sheet: https://www.ti.com/lit/gpn/thvd8010
2. How to Properly Set Up THVD1505 and SN65HVD888 in Applications