APPLICATION NOTE

RS-485 Interfaces

Isolating RS-485 Interfaces with High-Speed Digital Optocouplers

AN1991
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Abstract

Opto-isolators (also known as optocouplers, photocouplers, or optical isolators), have been used in the design of isolated RS-485 networks for the past four decades. Despite the availability of transceivers with integrated magnetic or capacitive isolation barriers, the demand for optocouplers in network applications remains high, often due to their low-cost advantage, but also because they offer a freedom of choice with regard to isolation voltages.

This application note discusses the design of isolated RS-485 interfaces using Renesas digital high-speed optocouplers.

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1. Functional Principle and Construction of Optocouplers

An optocoupler provides signal transfer between an isolated input and output using an infrared Light Emitting Diode (LED) and a silicon phototransistor (Figure 1). The LED sends a beam of infrared energy to an optical receiver inside a single package with a light conducting medium between the emitter and the detector. This mechanism provides complete electrical isolation of electronic circuits from input to output, while transmitting information from one side to the other, and from one voltage potential to another.

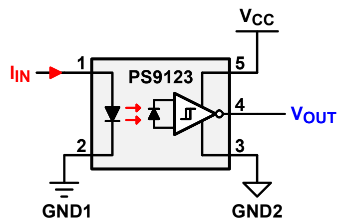

Figure 1. Functional Block Diagram

The manufacturing process and structure of an optocoupler varies between manufacturers. Renesas optocouplers are constructed based on single or double mold processes (Figure 2), and rated at Moisture Sensitivity Level (MSL) 1.

Typically, the lead frame material is either Cu alloy or Alloy 42 with the plating being either SnBi or AuNiPd. The silicone resin that covers the surface of an LED die is used to extract more light by better matching the index of refraction.

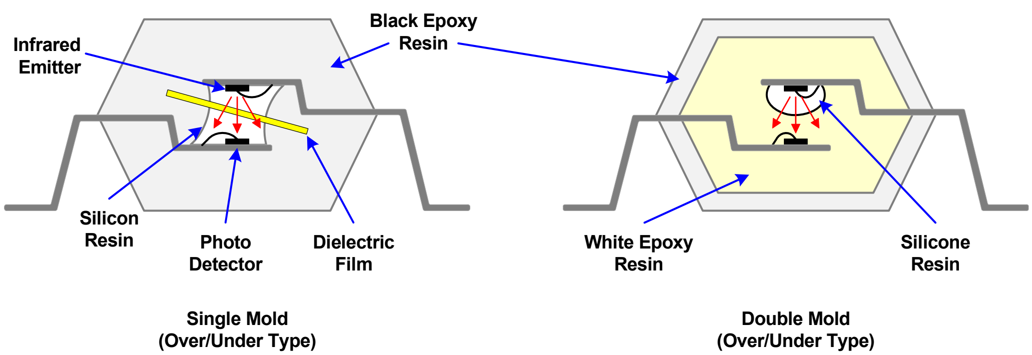

Figure 2. Optocoupler Constructions

The single molded over/under technique provides the best light coupling efficiency because a silicone resin is used as a medium for direct contact between the LED and the Si detector die. To further improve the common mode noise rejection and isolation voltage, glass or polyamide film is inserted in between the LED and the detector die. A black epoxy resin is used to house the device.

The double molded device is similar to the single molded version but it has an additional inner mold with high dielectric white epoxy resin acting as a light pipe to provide the best reliability.

2. LED Drive Circuit and Common-Mode Rejection (CMR)

Figure 3 shows a typical drive circuit for optocouplers using a single resistor (R_S) that sets the forward current of the LED. Its value is calculated using Equation 1:

(EQ. 1)
$$R_S = \frac{V_{CC1} - V_F - V_{OL}}{I_F}$$

Where V_F and I_F are the typical forward voltage and current of the LED, and V_{CC1} and V_{OL} are the typical supply voltage and low output voltage of the input buffer (B). This buffer ensures a reliable LED drive that is independent of the output drive capability of the local controller (MCU or UART).

Due to the optocoupler's internal construction, leakage capacitances (C_{LA} and C_{LC}) exist that allow common-mode transients to capacitively couple from the LED anode and cathode to the output-side ground (Figure 4). This coupling can cause forward current to be shunted away from the LED, which could momentarily turn off the LED during an ON condition, or conversely cause current to be injected into the LED, which could momentarily turn on the LED during an OFF condition. In both cases output glitches can occur that lead to data errors.

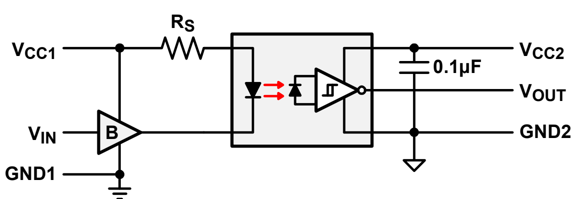

Figure 3. Typical LED Drive Circuit

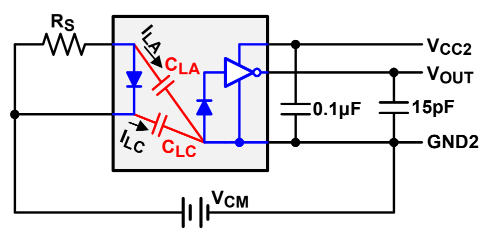

Figure 4. AC Equivalent Circuit

To reduce the risk of output glitches and thus improve common-mode rejection, it is necessary to balance the common-mode impedance at the LED anode and cathode. This is achieved by using two current setting resistors, each with a value of $R_S/2$. Figure 5 shows the recommended drive circuit for optimum CMR and Figure 6 shows its AC equivalent circuit.

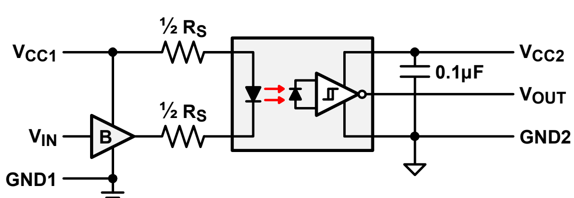

Figure 5. Recommended LED Drive Circuit

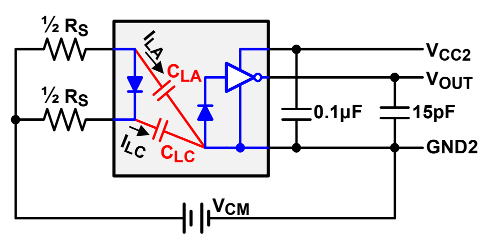

Figure 6. AC Equivalent Circuit

3. Isolated RS-485 Interface (Dominant/Recessive Mode)

Figure 7 shows an isolated RS-485 interface using PS9924 optocouplers rated for 7.5kV isolation and up to 10Mbps data rate. The RS-485 transceiver ISL3155 is specified with a minimum data rate of 1Mbps and a typical output voltage of 3.1V across a differential load of 54Ω, which is about 60% more than that of standard transceivers.

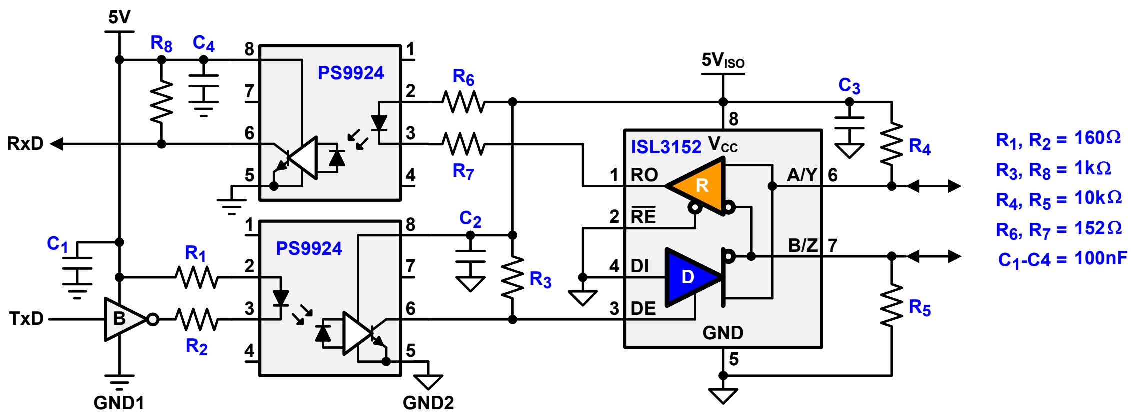

Figure 7. 7.5kV Isolated RS-485 Interface

3.1 Transceiver Operating Mode

The ISL3155 is configured for dominant/recessive operation, meaning a logic low state at the transmit channel input (TxD) enables the driver at DE, thus actively driving the bus low ($V_A < V_B$). A high at TxD disables the driver, thus establishing a bus-high through the pull-up/down resistors, R_4 and R_5.

The receive channel is permanently enabled, which allows the immediate verification of the transmit data and the detection of bus contentions, if two or more transceivers try to access the bus at the same time. For example, if a transceiver outputs a high, its receiver should also read a high. If the receiver reads a low instead, the transceiver knows that another driver is pulling the bus low and that it must stop its transmission immediately.

This detection method can be used for arbitration, a negotiation procedure between network nodes to gain bus access. However, this process is time critical and requires short propagation delays and small pulse width distortion.

3.2 PS9924 Optocoupler Features

The PS9924 satisfies these requirements with prop-delays of 45ns and a Pulse Width Distortion (PWD) of 5ns. Its high isolation voltage of 7.5kV is supported through an 8 Ld LSDIP package, which has a minimum creepage distance of 14.5mm.

Figure 8. 8 Ld LSDIP Package

3.3 Calculating the Current Setting Resistor Values

To ensure reliable operation across a wide temperature range, the LED forward current (I_F) should be set to the typical value in the datasheet, using the nominal input supply and the typical forward voltage at +25°C. Commonly, the datasheet lists these values in table form. If not, use the forward-current vs forward-voltage characteristic in the datasheet's Typical Characteristics section.

Table 1. Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Low Level Forward Voltage	$V_{F(OFF)}$	-2		0.8	V
High Level Forward Current	$I_{F(ON)}$	8	10	12	mA

Table 2. Electrical Characteristics

(T_A = -40 to +110°C, unless otherwise specified)

Parameter		Symbol	Conditions	MIN	TYP	MAX	Unit
Diode	Forward Voltage	V_F	I_F = 10mA, T_A = 25°C	1.3	1.56	1.8	V

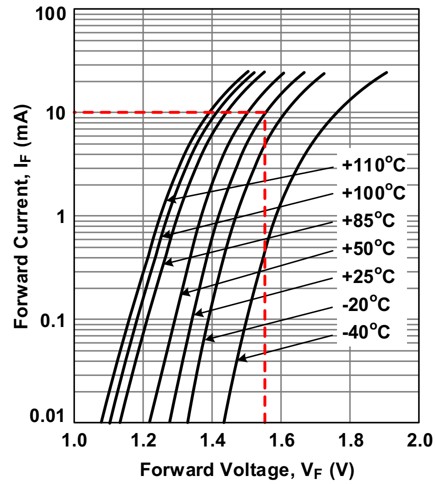

Figure 9. Establishing the I_F and V_F Values from Tables or the Typical Characteristics

First, calculate the current setting resistance for the PS9924 in the transmit path, using a typical V_{OL} of 0.25V for the input buffer (TC7SZU04F). Use Equation 2:

(EQ. 2) $$R_{S(TX)} = \frac{V_{s(nom)} - V_{F(typ)} - V_{OL(typ)}}{I_{F(typ)}} = \frac{5V - 1.56V - 0.25V}{10mA} = 319\Omega$$

For optimum CMR make R_1, $R_2 = R_{S(TX)}/2$, choosing either 160Ω from the E-192 series, or 162Ω from the E-48 series of standard resistor values.

Then calculate the current setting resistance for the PS9924 in the receive path, using a typical V_{OL} of 0.4V for the receiver output of the ISL3155:

(EQ. 3) $$R_{S(RX)} = \frac{V_{s(nom)} - V_{F(typ)} - V_{OL(typ)}}{I_{F(typ)}} = \frac{5V - 1.56V - 0.4V}{10mA} = 304\Omega$$

For optimum CMR make R_7, $R_8 = R_{S(RX)}/2$, choosing either 152Ω from the E-192 series, or 154Ω from the E-48 series of standard resistor values.

3.4 Determining the Collector Resistor Values

The PS9924 has an open collector output that requires a pull-up or load resistor (R_L) between the collector and the V_{CC} supply. Although the datasheet allows for a wide range of resistor values (from 350Ω to 4kΩ), it is important to notice that R_L interacts with the inherent capacitances of the output transistor. A large resistor value reduces the collector current, but increases the propagation delay and Pulse Width Distortion (PWD). Conversely, a low resistor value increases current flow but keeps the delay and distortion parameters at a minimum.

Because RS-485 commonly uses asynchronous data transmission, limit PWD to equal or less than 20% of the bit time. Unfortunately the PS9924 datasheet only specifies a maximum PWD of ±35ns for R_L = 350Ω. However, from bench testing we know that the PWD for R_L = 1kΩ is only slightly increased to less than 100ns. As a compromise between current saving and increased PWD, the collector resistors R_3 and R_9 are therefore selected with 1kΩ. This reduces the collector current by a factor of 3 (1kΩ/350Ω) and keeps the PWD below 10% of the 1µs bit time at 1Mbps data rate.

3.5 Signal Waveforms

Figure 10 shows the signal waveform of the isolated interface circuit in Figure 7 on page 4.

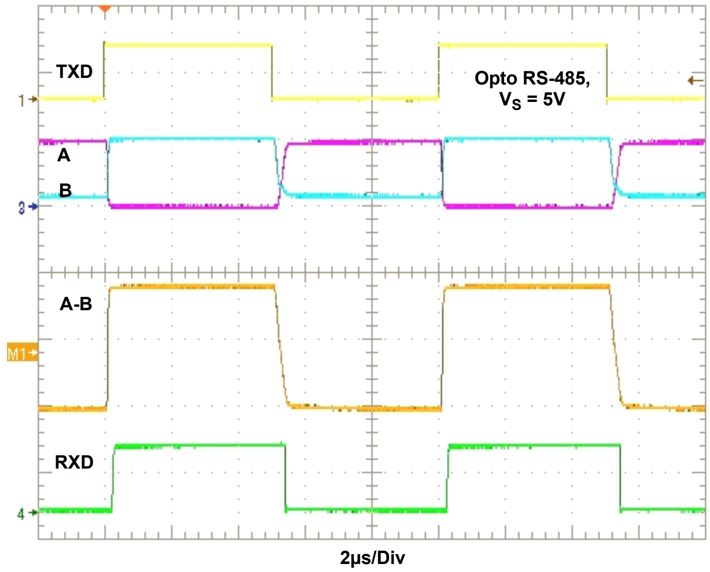

Figure 10. Signal Waveforms of the Circuit in Figure 7

4. Low-Cost, Small-Board Space, 3.75kV Isolated RS-485 Interface

Figure 11 shows the low-cost design of an isolated interface using PS9123 optocouplers with push-pull outputs, thus requiring no collector/load resistors. To further reduce component count, both LED drive circuits use only single current setting resistors, yet still provide a high common-mode rejection of 15kV/µs minimum. The PS9123 has maximum prop-delays of 60ns and a maximum PWD of 30ns, thus easily supporting data rates up to 1Mbps.

For space constrained designs the PS9123 comes in a small 3.4mmx4.4mm SO-5 package, while the ISL3155 is available in a small 3mmx3mm, 8 Ld MSOP package.

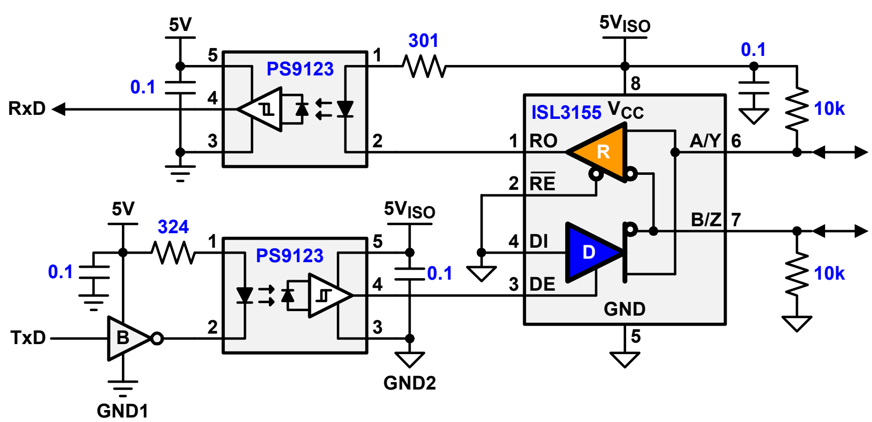

Figure 11. 3.75kV Isolated RS-485 Interface using Dominant/Recessive Mode

5. Low-Volt, 2.5kV Isolated RS-485 Interface (Transmit/Receive Mode)

This interface operates the transceiver in the usual RS-485 transmit/receive mode, which makes the use of three optocouplers necessary. Two optocouplers isolate the data channels in transmit and receive (TxD and RxD), while the third one controls the direction of the data flow (DIR) by switching the transceiver enable functions between receive and transmit mode.

All components are 3V compatible and can be directly connected to low-voltage UARTs. Although the PS9121 is rated for 3.75kV isolation, V_{ISO} of the PS9821-2 is only 2.5kV and thus, determines the maximum isolation voltage of the interface isolation barrier.

The ISL3175 is a slew rate limited half-duplex transceiver with a maximum data rate of 500kbps. Its failsafe biasing network is designed to provide a minimum failsafe voltage of 400mV on a fully loaded bus with up to 350 bus transceivers.

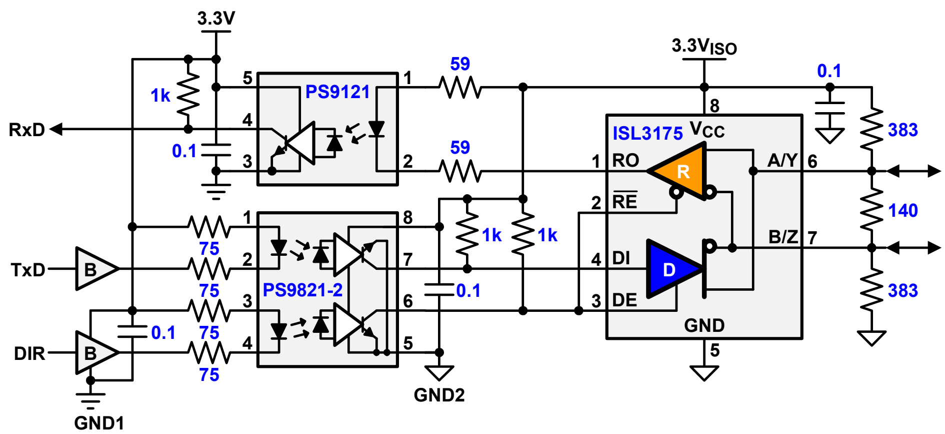

Figure 12. Low-Supply, 2.5kV Isolated RS-485 Interface (Tx/Rx Mode)

6. References

For more information on digital isolated interfaces visit our website.

- PS9924 datasheet: High CMR, 10Mbps Open Collector Output Photocoupler with 14.5mm Creepage Distance
- PS9123 datasheet: High CMR, 15Mbps Totem Pole Output Photocoupler
- PS9121 datasheet: High CMR, 15Mbps Open Collector Output, 3.3V Photocoupler
- PS9821-2 datasheet: High CMR, 15Mbps Open Collector Output, 3.3V Dual Photocoupler
- TC7SZU04F datasheet: CMOS Inverting Buffer (Toshiba Electronic Devices & Storage Corporation)
- ISL3155 datasheet: ±16.5kV ESD, Large Output Swing, 5V, Full Fail-Safe, 1/8 Unit Load, RS-485 Transceiver
- ISL3175 datasheet: ±15kV ESD, Low Power, 3.3V, Full Fail-Safe, Slew Rate Limited, RS-485 Transceivers
- Application note AN3020: A Guide to Designing with Optocouplers
- Application note AN1987: External Failsafe Biasing for Isolated Long Haul Buses

7. Revision History

Rev.	Date	Description
0.00	Mar 19, 2018	Initial release

SALES OFFICES Renesas Electronics Corporation http://www.renesas.com

Refer to "http://www.renesas.com/" for the latest and detailed information.

Renesas Electronics America Inc.
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.
Tel: +1-408-432-8888, Fax: +1-408-434-5351

Renesas Electronics Canada Limited
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3
Tel: +1-905-237-2004

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-651-700, Fax: +44-1628-651-804

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

Renesas Electronics Hong Kong Limited
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2265-6688, Fax: +852 2886-9022

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics India Pvt. Ltd.
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India
Tel: +91-80-67208700, Fax: +91-80-67208777

Renesas Electronics Korea Co., Ltd.
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5338