RS-485: Passive failsafe for an idle bus

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Despite the integrated failsafe features of modern RS-485 transceivers, many applications use legacy parts lacking these features. Knowing how to provide failsafe operation, particularly during an idle-bus condition, therefore ranks at the top of the list of customer inquiries to interface-application groups worldwide. This article shows how to apply failsafe biasing for idle buses externally and also suggests low-cost solutions that integrate this feature.

Failsafe operation

RS-485 specifies that the receiver output state should be logic high for differential input voltages of $V_{AB} \geq +200$ mV and logic low for $V_{AB} \leq -200$ mV. For input voltages in between these limits, a receiver's output state is not defined and can randomly assume high or low.

Removing the uncertainty of random output states, modern transceiver designs include internal biasing circuits that put the receiver output into a defined state (typically high) in the absence of a valid input signal.

There are three possible scenarios that can cause the loss of an input signal:

- an open circuit caused by a wire break or the unintentional disconnection of a transceiver from the bus;
- a short circuit due to an insulation fault, connecting both conductors of a differential pair to one another; or
- an idle bus when none of the bus transceivers are active. (This particular condition is not a fault but occurs regularly when bus control is handed over from one driver to another to avoid bus contention.)

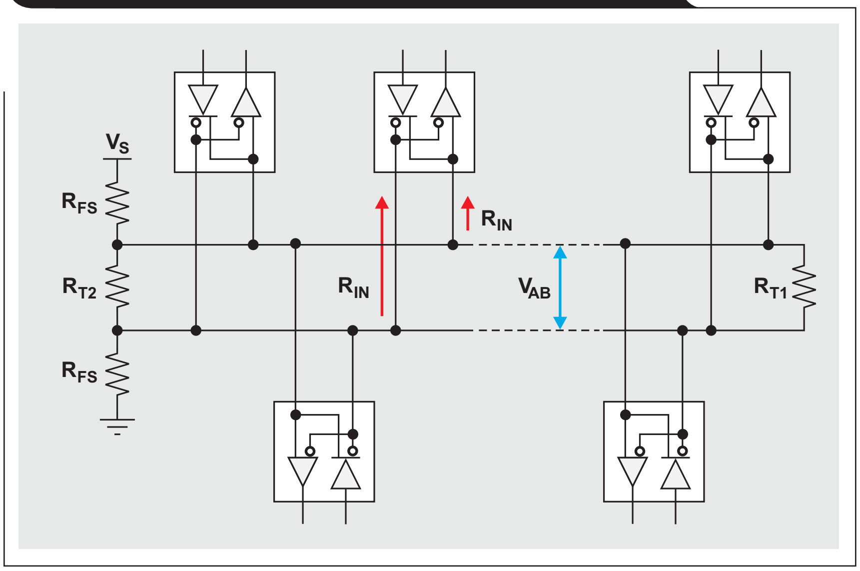
While modern transceiver designs provide failsafe operation for all three categories, legacy designs don't. For these components it is necessary to provide external resistor biasing to ensure failsafe operation during an idle bus.

External idle-bus failsafe biasing

Figure 1 shows an RS-485 bus with its distributed network nodes. If none of the drivers connected to the bus are active, the differential voltage (V_{AB}) approaches zero, thus allowing the receivers to assume random output states.

To force the receiver outputs into a defined state, failsafe biasing resistors, R_{FS}, are introduced that, through voltage-divider action with the terminating resistors, R_{T1} and R_{T2}, must provide sufficient differential voltage to exceed the input-voltage threshold, V_{IT}, of the receiver.

Figure 1. RS-485 network with failsafe bias resistors



For clarity, Figure 2 shows the equivalent circuit of the RS-485 bus with the failsafe biasing resistors, R_{FS}, the terminating resistors, R_{T1} and R_{T2}, and the equivalent input resistance, R_{INEQ}, lumped together to represent the common-mode input resistance of all transceivers connected to the bus.

To find an equation that allows us to calculate the R_{FS} values, we determine the node currents in A and B (Figure 2) and solve for the respective line voltages, V_A and V_B.

Node A:

$$\frac{V_S - V_A}{R_{FS}} = \frac{V_A - V_B}{R_{T2}} + \frac{V_A - V_B}{R_{T1}} + \frac{V_A}{R_{INEQ}} \rightarrow$$

$$V_A = R_{INEQ} \times \left[\frac{V_S - V_A}{R_{FS}} - (V_A - V_B) \times \left(\frac{1}{R_{T1}} + \frac{1}{R_{T2}}\right)\right]$$

Node B:

$$\frac{V_A - V_B}{R_{T2}} + \frac{V_A - V_B}{R_{T1}} = \frac{V_B}{R_{FS}} + \frac{V_B}{R_{INEQ}} \rightarrow$$

$$V_B = R_{INEQ} \times \left[(V_A - V_B) \times \left(\frac{1}{R_{T1}} + \frac{1}{R_{T2}}\right) - \frac{V_B}{R_{INEQ}}\right]$$

Establishing the difference between both line voltages yields the differential input voltage,

$$V_{AB} = \frac{V_S}{R_{FS}} \times \frac{1}{\frac{1}{R_{INEQ}} + \frac{1}{R_{FS}} + 2\left(\frac{1}{R_{T1}} + \frac{1}{R_{T2}}\right)}. \quad (1)$$

The value of R_{FS} is subject to a number of system and standard constraints:

- The RS-485 standard specifies a maximum common-mode loading (or minimum common-mode resistance) of $R_{CM} = 375\ \Omega$. Because the failsafe bias resistors present a common-mode load to both the A and B wires, the parallel combination of R_{FS} and R_{INEQ} must be greater than or equal to 375 Ω, which is expressed as

$$R_{FS} \| R_{INEQ} = R_{CM}, \text{ or } \frac{1}{R_{INEQ}} + \frac{1}{R_{FS}} = \frac{1}{375\ \Omega}. \quad (2)$$

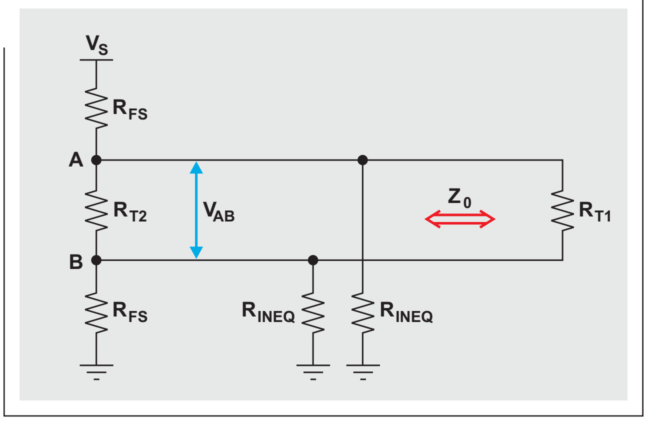
- The cable end without the biasing network is usually terminated with the resistor R_{T1}, whose value matches the line impedance. For RS-485, this is

$$R_{T1} = 120\ \Omega, \text{ or } \frac{1}{R_{T1}} = \frac{1}{120\ \Omega}. \quad (3)$$

- During normal operation, a driver output sees the series of both failsafe bias resistors in parallel to the terminating resistor R_{T2}. Thus, for line impedance matching, the parallel circuit of R_{T2} and $2R_{FS}$ should equal Z_0:

$$R_{T2} \| 2R_{FS} = Z_0, \text{ or } \frac{1}{R_{T2}} = \frac{1}{120\ \Omega} - \frac{1}{2R_{FS}}. \quad (4)$$

Figure 2. Equivalent circuit with transceiver resistances lumped together



Inserting Equations 2, 3, and 4 into Equation 1 simplifies the expression for V_{AB} to

$$V_{AB} = \frac{V_S}{0.036 \times R_{FS} - 1}. \quad (5)$$

Solving for R_{FS} yields

$$R_{FS} = \left(\frac{V_S}{V_{AB}} + 1\right) \times 27.8\ \Omega. \quad (6)$$

Note that Equation 6 is a generic form for calculating the bias resistor value, with the constant of 27.8 Ω representing the common-mode loading and line-matching constraints of an RS-485 system.

Because idle-bus failsafe must work under worst-case conditions, the values of the bias resistors must be calculated for minimum supply voltage at maximum noise. While $V_{S(min)} = 4.75$ V for a standard 5-V supply with ±5% tolerance, the maximum noise is usually subject to measurement. For a well-balanced system, however, we can assume a differential noise of less than 50 mV, so that the sum of receiver input threshold and noise yields a differential input voltage of

$$V_{AB} = V_{IT} + V_{Noise} = 200\text{ mV} + 50\text{ mV} = 250\text{ mV}.$$

Calculating R_{FS} under these conditions provides a theoretical value of

$$R_{FS} = \left(\frac{4.75\text{ V}}{0.25\text{ V}} + 1\right) \times 27.8\ \Omega = 556\ \Omega.$$

Choosing the next lowest value of 549 Ω from the E-96 series allows for a slightly higher voltage drop across R_{T2}.

With R_{FS} in place, we can now determine R_{T2} using the reciprocal of Equation 4 and the actual value of $R_{FS} = 549\ \Omega$:

$$R_{T2} = \frac{1}{\frac{1}{120\ \Omega} - \frac{1}{2R_{FS}}} = \frac{1}{\frac{1}{120\ \Omega} - \frac{1}{2 \times 549\ \Omega}} = 134\ \Omega$$

Choosing the closest E-96 value makes R_{T2} = 133 Ω and the differential impedance of $R_{T1} \parallel R_{T2} \parallel 2R_{FS}$ = 59.7 Ω.

As mentioned earlier, failsafe biasing presents an additional common-mode load to both the A and B wires. To stay below the specified common-mode load of 375 Ω, it is necessary to determine the maximum number of transceivers that can be connected to the bus. For this purpose we solve Equation 2 for R_{INEQ}:

$$R_{INEQ} = \frac{1}{\frac{1}{R_{CM}} - \frac{1}{R_{FS}}} = \frac{1}{\frac{1}{375\ \Omega} - \frac{1}{549\ \Omega}} = 1.183\ \text{k}\Omega$$

The maximum number of transceivers, n_{max}, is determined by dividing the rated number of unit loads (UL) by the value of R_{INEQ}:

$$n_{max} = \frac{UL}{R_{INEQ}} = \frac{12\ \text{k}\Omega}{1.183\ \text{k}\Omega} = 10.14$$

This result indicates that a maximum of 10 standard unit-load transceivers, 10 × UL, which is equivalent to 20 × ½ UL, 40 × ¼ UL, or 80 × ⅛ UL, can be connected to the bus. The final circuit with the actual resistor values is shown in Figure 3.

Conclusion

While the calculation of a failsafe-biased network for legacy transceivers is straightforward, the use of modern RS-485 transceivers such as the SN65HVD308xE family from Texas Instruments eliminates external failsafe biasing. These low-cost devices provide integrated failsafe biasing for open-circuit, short-circuit, and idle-bus conditions as well as a rating of ⅛ UL, thus increasing the possible number of transceivers that can be connected to a bus to 256.

Reference

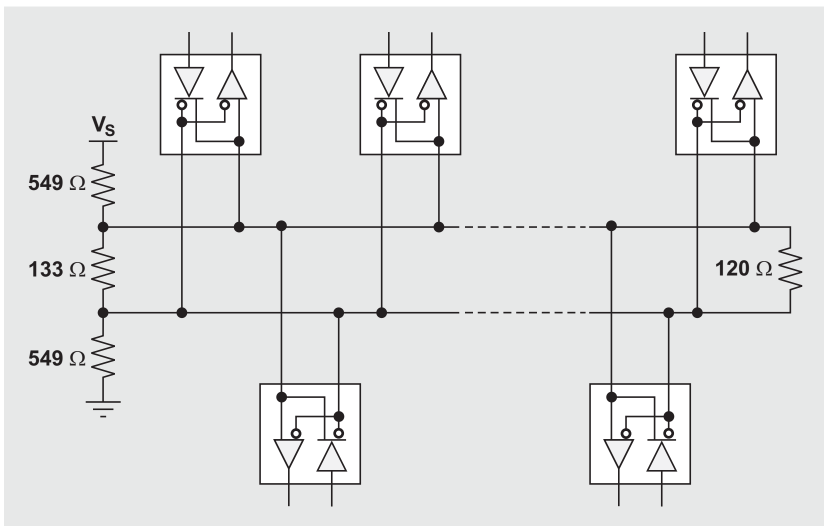
For more information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/*litnumber* and replace "*litnumber*" with the **TI Lit. #** for the materials listed below.

Document Title	**TI Lit. #**
1. "Interface Circuits for TIA/EIA-485 (RS-485)," Application Report.	slla036d

Related Web sites

interface.ti.com
www.ti.com/sc/device/SN65HVD3080E

Figure 3. Final RS-485 network with actual resistor values



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