

RS-485 Unit Load and Maximum Number of Bus Connections

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ABSTRACT

The TIA/EIA-485 (RS-485) standard defines a *Unit Load* and confines bus configurations to 32. This report explains the Unit-Load concept and how it relates to the maximum number of bus connections. Fractional Unit-Load devices, such as the 1/8th Unit-Load SN65HVD21 and SN65HVD06, allow up to 256 devices on a single bus segment.

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Introduction

TIA/EIA-485 (RS-485) is a popular electrical standard for data interchange over a multipoint differential bus. Multipoint buses are three or more stations connected to a common transmission media that allow bidirectional data communication between any two nodes. Figure 1 schematically shows an example of a multipoint bus.

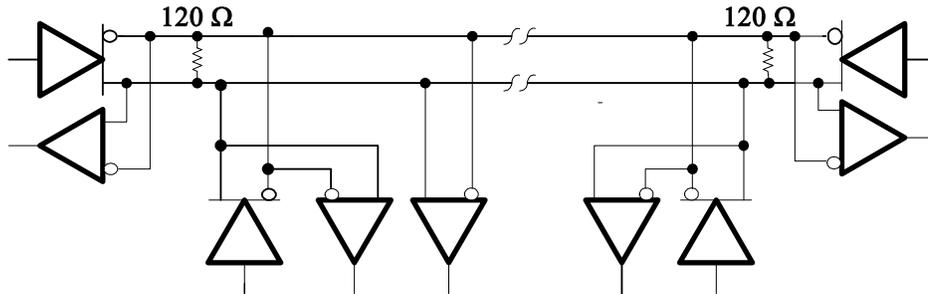


Figure 1. Example Schematic of a Multipoint Bus

Maintaining a practical limit to the output drive capability of an RS-485 driver requires that a limit be imposed on the steady-state load presented by the bus. In turn, this constrains the input resistance of stations and, ultimately, the maximum number of connections.

RS-485 does not specify the maximum number of bus connections. Instead, the standard defines the steady-state electrical load presented by a bus connection in *Unit Loads*. The following paragraphs explain the Unit Load and how it is used to determine the maximum number of nodes connected to an RS-485 bus segment.

The Unit Load

TIA/EIA-485-A defines a Unit Load as a 15-kΩ resistor connected to a -3-V or 5-V source (see Figure 2). The -3-V case applies for positive input current and the 5-V case for negative bus current. The definition and model are valid for input voltages from -7 V to 12 V to account for driver outputs between 0 V and 5 V with up to ±7 V of common-mode noise voltage between a driver and receiver.

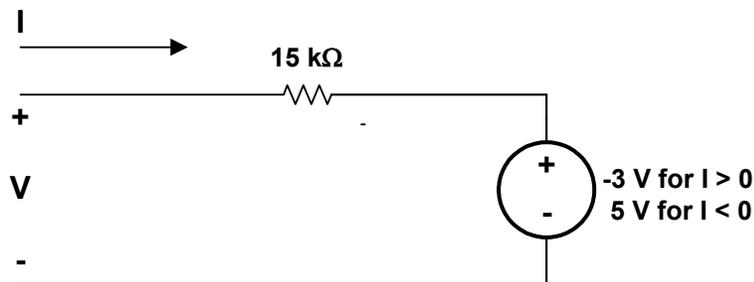


Figure 2. Electrical Model of One Unit Load

The number of Unit Loads (nUL) presented by any proposed connection to the RS-485 bus is then determined as the ratio of its measured input current and that of one Unit Load. Because one Unit Load's current is a function of voltage, the input current must be measured and the ratio determined throughout the entire -7-V-to-12-V input voltage range with the highest ratio determining the Unit-Load rating.

Figure 3 shows a hypothetical example where the measured input current of a circuit is non-linear. It can be shown (see the Slope Ratio Proof at the end of this section) that, at its maximum value, the ratio of the measured and Unit-Load current is equal to the ratio of the slopes of the two functions and lies on a line with an intercept at -3 V for positive current and 5 V for negative current. Conceptually, this amounts to rotating a line pivoted at $I = 0$ mA and $V = -3$ V until tangent to the measured positive current versus voltage curve. For negative currents, the line is pivoted at $I = 0$ mA and $V = 5$ V. In our example, the maximum ratio occurs at measured input currents of 0.65 mA and -0.72 mA.

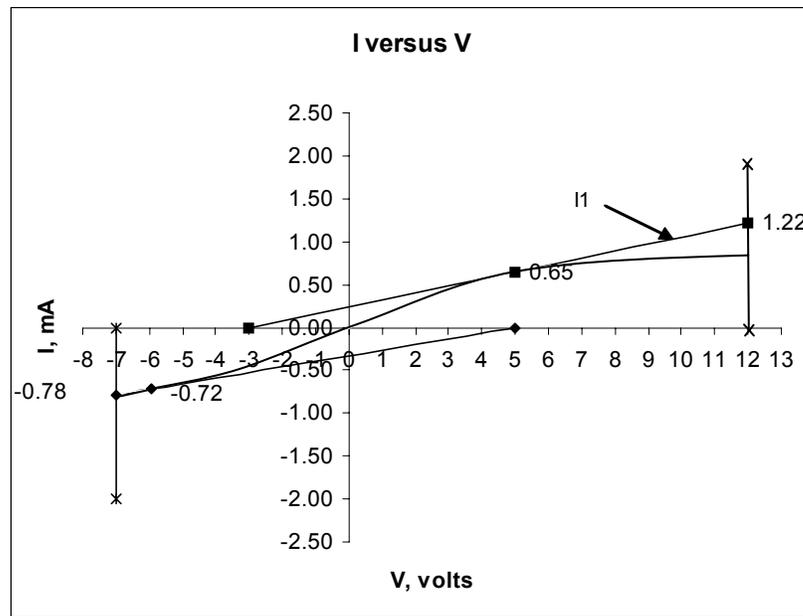


Figure 3. Example Unit-Load Analysis

The ratio, and nUL, may be calculated by dividing the measured value at the intercept by the value derived from solving the Unit-Load circuit or, for convenience, the lines are often extended to the 12-V or -7-V intercept. Because the slopes for one Unit Load and the tangential lines are constants, their ratios are constant and may be determined at any voltage. The current into one Unit Load at 12 V is 1 mA and at -7 V, is -0.8 mA. These values are respectively divided into the current-intercept values of the tangential lines at 12 V and -7 V and the maximum number determines the number of Unit Loads for the circuit. In the example, the input current versus voltage characteristics of the hypothetical circuit results in 1.22 Unit Loads.

Slope Ratio Proof: Let the input current of a Unit Load be defined by $f_1(V)$ and the measured circuit be $f_2(V)$. The number of Unit Loads is then:

$$nUL = \frac{f_2(V)}{f_1(V)} \text{ for } -7 \text{ V} > 12 \text{ V}$$

The maximum of the function nUL occurs when the first derivative equals zero or

$$\frac{d}{dV} \frac{f_2(V)}{f_1(V)} = \frac{1}{f_1(V)} \frac{d}{dV} f_2(V) - \frac{f_2(V)}{f_1(V)} \frac{d}{dV} f_1(V) = 0$$

$$\frac{d}{dV} f_2(V) = \frac{f_2(V)}{f_1(V)} \frac{d}{dV} f_1(V)$$

$$\frac{f_2(V)}{f_1(V)} = \frac{\frac{d}{dV} f_2(V)}{\frac{d}{dV} f_1(V)}$$

Therefore, the maximum nUL value is equal to the ratio of the first derivative (slopes) of the input current function at that voltage.

Solving the Unit-Load circuit, $f_1V = \frac{V+3}{15} \text{ mA}$

Or $f_1(V) = \frac{V-5}{15} \text{ mA}$ and $\frac{d}{dV} f_1(V) = \frac{1}{15} \text{ mho}$

Substituting these into the equation above yields:

$$\frac{f_2(V)}{\frac{(V+3)}{15}} = \frac{\frac{d}{dV} f_2(V)}{\frac{1}{15}} \text{ or } \frac{f_2(V)}{(V-5)} = \frac{\frac{d}{dV} f_2(V)}{\frac{1}{15}}$$

$$f_2(V) = \frac{d}{dV} f_2(V) \times (V+3) \qquad f_2(V) = \frac{d}{dV} f_2(V) \times (V-5)$$

These are line equations and mean that the input current where the nUL is maximum, lies on a line with the points $I=-0 \text{ mA}$ and $V=-3 \text{ V}$ for positive current and $I=0 \text{ mA}$ and $V= 5 \text{ V}$ for negative current.

Maximum Unit Loads

The minimum output drive capability of a standard RS-485 driver is established in clause 4.2.3 of TIA/EIA-485-A with the specification of at least a 1.5-V differential output voltage magnitude with a common-mode load. The schematic diagram in Figure 4 reproduces this test circuit.

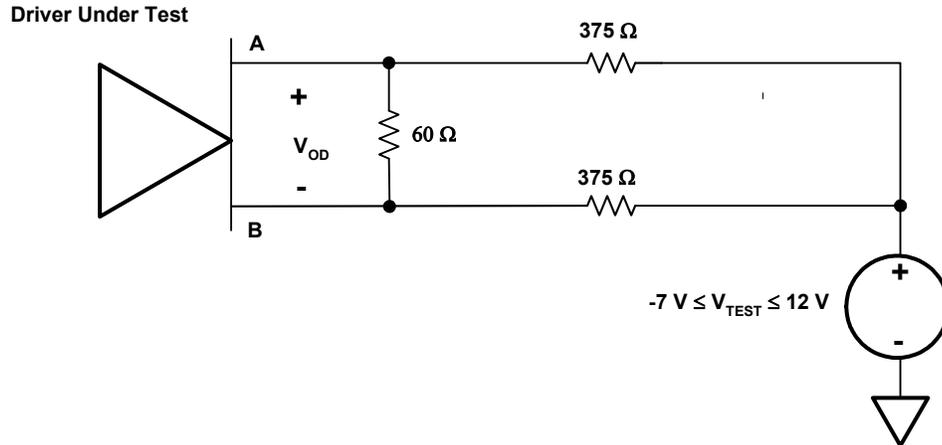


Figure 4. Differential Output Voltages With Common-Mode Loading

The 375-Ω resistors are certainly part of the common-mode load. What is not obvious is the test voltage of -7 V to 12 V actually represents a ±7-V common-mode-noise source and a 0-V to 5-V local supply voltage at the load(s). This is important in that the local supply is included in the Unit-Load determination for this test circuit. Figure 5 shows the common-mode test circuit with the insertion of a “local” ground used as the reference for the Unit-Load calculation.

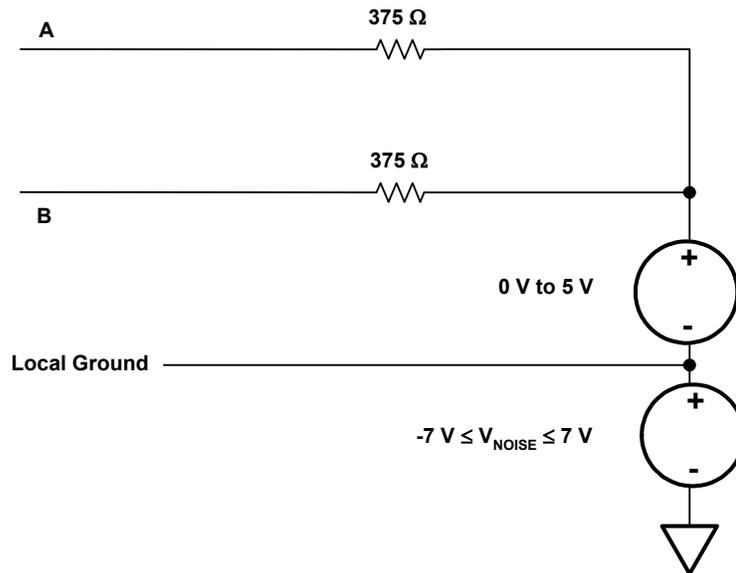


Figure 5. Physical Representation of the Test Circuit

To determine the Unit Loading of this test circuit, we plot the input current versus voltage function between point A or B and the “Local” ground of Figure 5 and apply the Unit-Load definition previously described. This is illustrated in Figure 6, and we find that the current at the intercepts of the tangential lines are 32 mA at $V= 12\text{ V}$ and -32 mA at $V= -7\text{ V}$. By definition, this represents 32 Unit Loads and 40 Unit Loads, respectively.

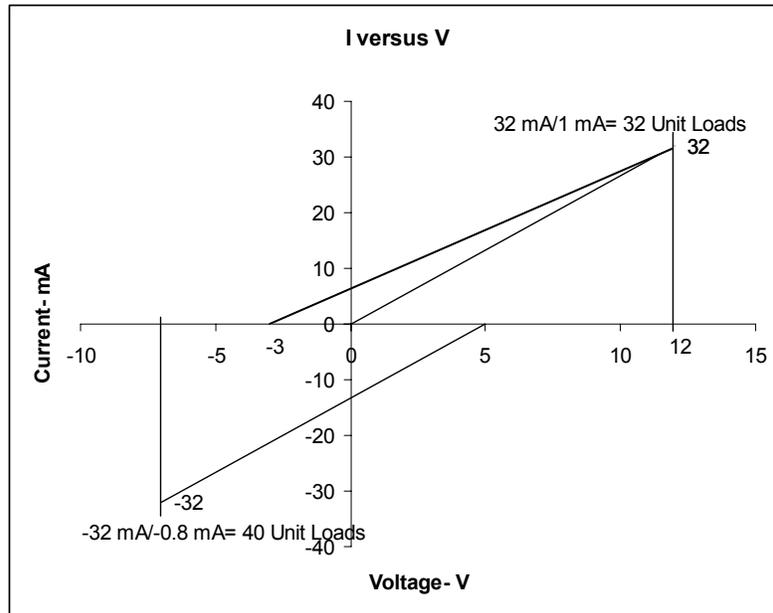


Figure 6. Unit Loading of Common-Mode Test Circuit

The reader may have noted the discrepancy between the Unit-Load model and the driver test circuit. One can only assume that this was an oversight or compromise by the authors of TIA/EIA-485. As tested, the Unit-Load model should consist of a 12-kΩ resistor to a 0-V to 5-V source rather than 15 kΩ to a -3-V to 5-V source. Using this modified definition, the differential output voltage with common-mode load test of TIA/EIA-485-A ensures that a standard driver will work with 32 Unit Loads.

Using the Unit Load

Other than a refresher on analytic geometry, of what use is the Unit-Load concept to the designer of a data interchange circuit? Primarily, it provides a single standard parameter for calculating the maximum number of connections and for specifying the input characteristics of possible line circuits for use. Because a driver supports 32 Unit Loads in a standard bus configuration, divide 32 by the total number of nodes (N) to derive the maximum Unit-Load rating for each of the line circuits. For example, if 48 nodes were to be connected, each line receiver or transceiver would have to have no more than a 0.67-Unit-Load rating (32/48).

The Unit Load can also be useful when implementing nonstandard bus configurations. Often and in addition to the differential termination of the differential signal pair, pullup and pulldown resistors are connected to the lines to provide a known bus state when all of the connected drivers are idle. The resistor values used for this fail-safe termination are approximately 1 kΩ. If so, this termination consumes 12 Unit Loads (12 mA at 12 V) out of the budget of 32 Unit Loads. This leaves 20 Unit Loads for the line circuits and, if 48 nodes are still to be connected, each of the line circuits must now be no more than 0.42 Unit Loads (20/48).

Texas Instruments offers numerous options for supporting a large number of RS-485 bus connections. Table 1 lists some of these.

Table 1. Fractional Unit-Load Devices from TI

Unit Loads	Maximum No. of Devices on a Single Bus Segment	Part Number
0.5	64	SN65HVD05
		SN65HVD10
		SN65HVD20
		SN65HVD23
0.25	128	SN65LBC182
		SN65LBC184
0.125	256	SN65HVD06
		SN65HVD07
		SN65HVD08
		SN65HVD11
		SN65HVD12
		SN65HVD21
		SN65HVD22
		SN65HVD24

Conclusion

The Unit Load is a relative parameter that provides a basis for determining the maximum number of connections to an RS-485 bus segment or specifying the input characteristics of line circuits. A standard RS-485 driver will handle 32 Unit Loads that could consist of 256 one-eighth Unit-Load devices.

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