

RS-422 and RS-485 Application Note

INTRODUCTION

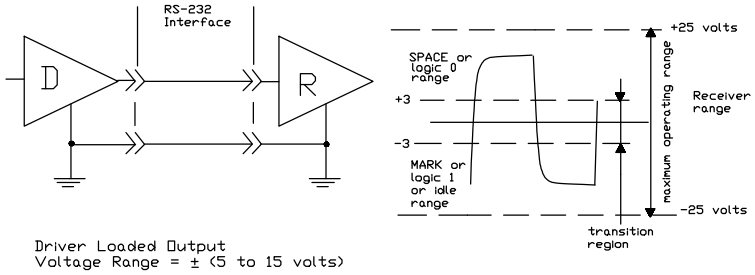
The purpose of this application note is to attempt to describe the main elements of an RS-422 and RS-485 system. This application note attempts to cover enough technical details so that the system designer will have considered all important aspects in his data system design. Since both RS-422 and RS-485 are data transmission systems that use balanced differential signals, it is appropriate to discuss both systems in the same application note.

DATA TRANSMISSION WITH BALANCED DIFFERENTIAL SIGNALS

Balanced Line Drivers

Each signal that transmits in an RS-232 unbalanced data transmission system appears on the interface connector as a voltage with reference to a signal ground. For example, the transmitted data (TD) from a DTE device appears on pin 2 with respect to pin 7 (signal ground). This voltage will be negative if the line is idle and alternate between that negative level and a positive level when data is sent. The RS-232 receiver operates within the voltage range shown in Figure 1. The magnitude will vary from 3 to 12 volts (see Figure 1). The RS-232 driver produces an output voltage within the range of + or -5 to 15 volts.

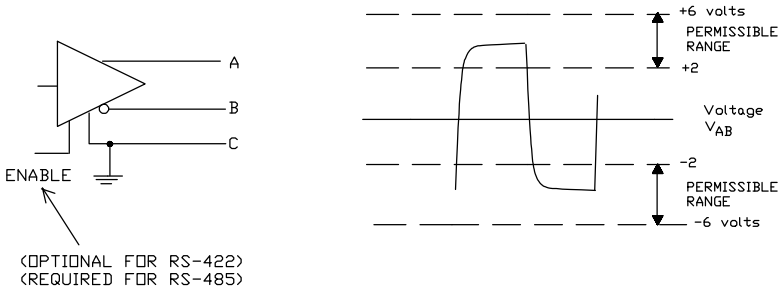
In a balanced differential system the voltage produced by the driver appears across a pair of signal lines that transmit only one signal. Figure 2 shows a schematic symbol for a balanced line driver and the voltages that exist. A balanced line driver will produce a voltage from 2 to 6 volts across its A and B output terminals. A balanced line driver will have signal ground (C) connection. Although proper connection to the signal ground is important, it isn't used by a balanced line receiver in determining the logic state of the data line. A balanced line driver can also have an input signal called an "Enable" signal. The purpose of this signal is to connect the driver to its output terminals, A and B. If the "Enable" signal is OFF, one can consider the driver as disconnected from the transmission line. An RS-485 driver must have the "Enable" control signal. An RS-422 driver may have this signal, but it is not always required. The disconnected or "disabled" condition of the line driver usually is referred to as the "tristate" condition of the driver.



RS-232 Interface Circuit

FILENAME: 232CKT

Figure 1



BALANCED DIFFERENTIAL OUTPUT
LINE DRIVER

FILENAME: BALDRV

Figure 2

Balanced Line Receivers

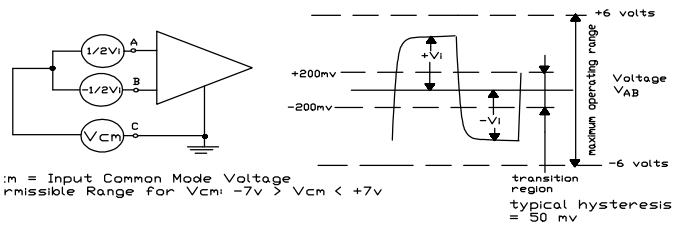
A balanced differential line receiver senses the voltage state of the transmission line across two signal input lines, A and B. It will also have a signal ground (C) that is necessary in making the proper interface connection. Figure 3 is a schematic symbol for a balanced differential line receiver. Figure 3 also shows the voltages that are important to the balanced line receiver. If the differential input voltage V_{ab} is greater than +200 mv the receiver will have a specific logic state on its output terminal. If the input voltage is reversed to -200 mv the receiver will create the opposite logic state on its output terminal. The input voltages that a balanced line receiver must sense are shown in Figure 3. The 200 mv to 6 V range is required to allow for attenuation on the transmission line.

EIA STANDARD RS-422 DATA TRANSMISSION

The EIA Standard RS-422-A entitled "Electrical Characteristics of Balanced Voltage Digital Interface Circuits" defines the characteristics of RS-422 interface circuits. Figure 4 is a typical RS-422 four-wire interface between Data Terminal Equipment (DTE) and Data Circuit - Terminating Equipment (DCE). Each generator or driver can drive up to ten (10) receivers. The two signaling states of the line are defined as follows:

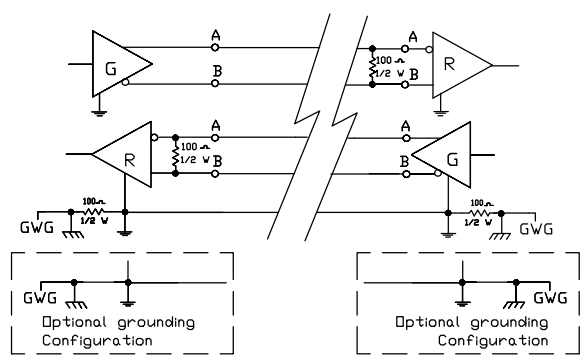
- a. When the "A" terminal of the driver is negative with respect to the "B" terminal the line is in a binary 1 (MARK or OFF) state.
- b. When the "A" terminal of the driver is positive with respect to the "B" terminal the line is in a binary 0 (SPACE or ON) state.

Figure 5 shows the condition of the voltage of the balanced line for an RS-232 to RS-422 converter when the line is in the "idle" condition or OFF state. It also shows the relationship of the "A" and "B" terminals of an RS-422 system and the "-" and "+" terminal markings used on many types of equipment. The same relationship shown in Figure 5 also applies for RS-485 systems.



BALANCED DIFFERENTIAL INPUT
LINE RECEIVER

Figure 3

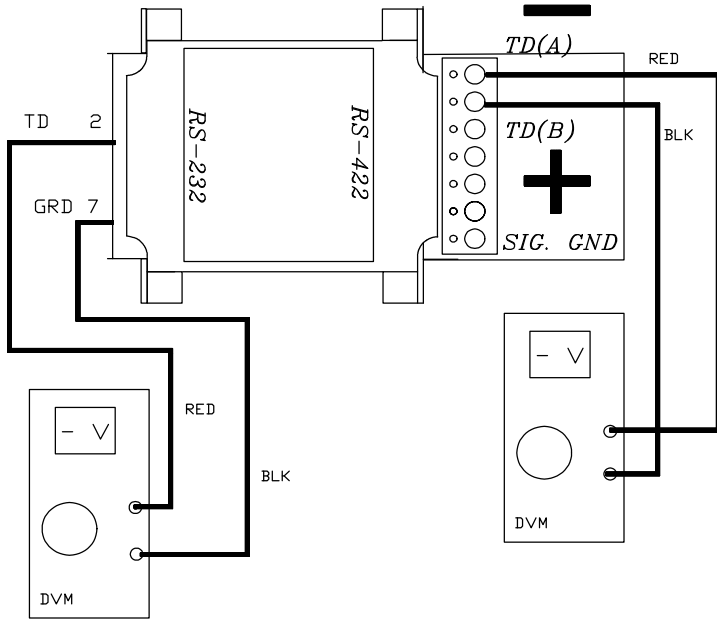


- G — Generator
- R — Receiver
- ⏏ — Circuit ground or circuit common
- ⏏ — Protective ground or frame ground
- GWG — Green wire ground or power system ground

Typical RS-422 Four Wire Network

FILENAME: 482FVNET

Figure 4



NOTE: UNDER "IDLE" CONDITIONS IT IS POSSIBLE TO DETERMINE WHICH TERMINAL IS "A" AND WHICH IS "B"

RELATIONSHIP BETWEEN EIA STANDARD "A" AND "B" TERMINALS ON AN RS-422 OR RS-485 DEVICE AND "+" AND "-" IDENTIFICATION CONVENTION

FILENAME: 482POL

Figure 5

For high data rates it is recommended that the transmission line be terminated. A typical termination resistor of 100 ohms 1/2 watt is shown in Figure 4. The transmission line's characteristic impedance should be used in selecting this resistor. A terminating resistor of less than 90 ohms should not be used. If the line is driven by an RS-422 driver that is never "tristated" or disconnected from the line, there is no need to terminate the line at the driver. The driver provides a low internal impedance that terminates the line at that end. Note that the signal ground line is also connected in the system shown in Figure 4. This connection is necessary to keep the V_{cm} common mode voltage at the receiver within the -7 V to +7 V range. This interface circuit may operate without the signal ground connection, but may not be reliable.

Other aspects of RS-422 such as cable selection and data rates will be discussed in the RS-485 section of this application note. The technical aspects of these topics are the same for RS-422 and RS-485.

EIA STANDARD RS-485 DATA TRANSMISSION

The RS-485 Standard permits a balanced transmission line to be shared in a party line mode. As many as 32 driver/receiver pairs can share a two-wire party line network. Many characteristics of the drivers and receivers are the same as RS-422. The range of the common mode voltage V_{cm} that the driver and receiver can tolerate is expanded to +12 to -7 volts. Since the driver can be disconnected or tristated from the line, it must withstand this common mode voltage range while in the tristate condition. Some RS-422 drivers, even with tristate capability, will not withstand the full voltage range of +12 to -7 volts.

Figure 6 shows a typical two-wire multidrop or party line network. Note that the transmission line is terminated on both ends of the line but not at drop points in the middle of the line. The signal ground line is also recommended in an RS-485 system to keep the common mode voltage that the receiver must accept within the -7 to +12 volt range.

An RS-485 network can also be connected in a four-wire mode (see Figure 7). In a four-wire network it is necessary that one node be a master node and all other be slaves. The network is connected so that the master node communicates to all slave nodes. All slave nodes communicate only with the master node. This network has some advantages with equipment with mixed protocol communications. Since the slave nodes never listen to another slave response to the master, a slave node cannot reply incorrectly to another slave node.

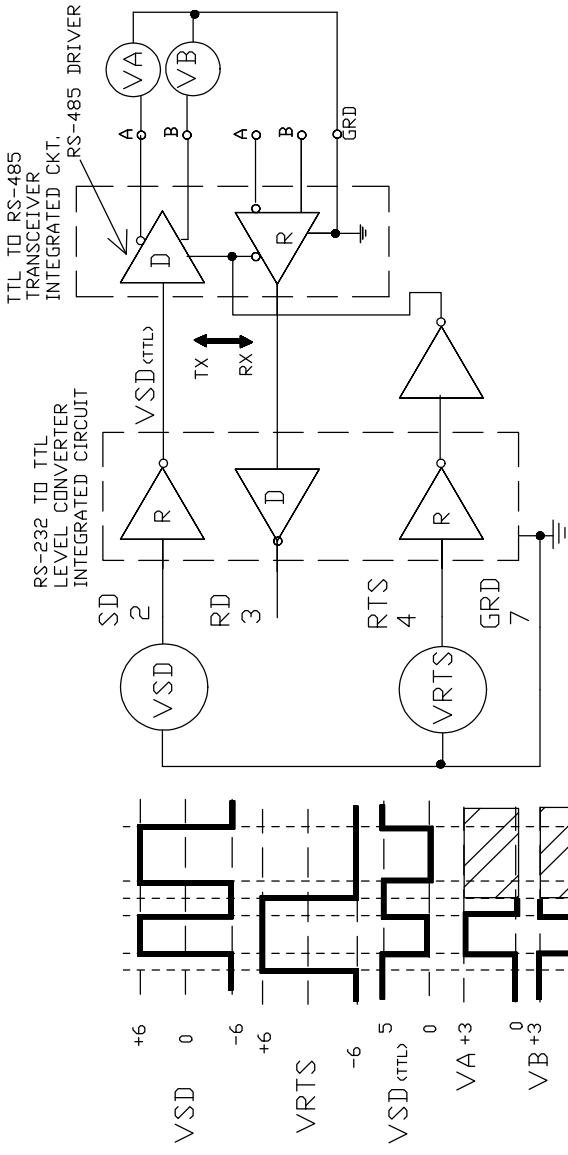
RTS Control of an RS-485 Converter

As discussed previously, an RS-485 system must have a driver that can be disconnected from the transmission line when a particular node is not transmitting. In an RS-232 to RS-485 converter, this is most often implemented by using the RTS control signal from an asynchronous serial port to enable the RS-485 driver. Figure 8 shows a timing diagram for a typical RS-232 to RS-485 converter. The waveforms show what happens if the VRTS waveform is narrower than the data VSD. This is not the normal situation, but is shown here to illustrate the loss of a portion of the data waveform. When RTS control is used, it is important to be certain that the "RTS" active signal happens before data is sent. Also, the "RTS" inactive signal must happen after the last data bit is sent. This timing is done by the software used to control the serial port and not by the converter.

When an RS-485 network is connected in a two-wire multidrop party line mode, the receiver at each node will be connected to the line (see Figure 6). If B & B Electronics converters are used in the system, it is possible to connect the receivers so they receive when the driver (at the same node) is transmitting. Some of B & B Electronics converters can be configured to receive all of the time. Be sure to check the data sheet for your converter to determine how the receiver "enable" function is connected.

SD Send Data Control of an RS-485 Converter

An RS-232 to RS-485 converter can also be controlled by triggering from the data signal to enable the RS-485 driver. Figure 9 is a timing diagram of the important signals used to

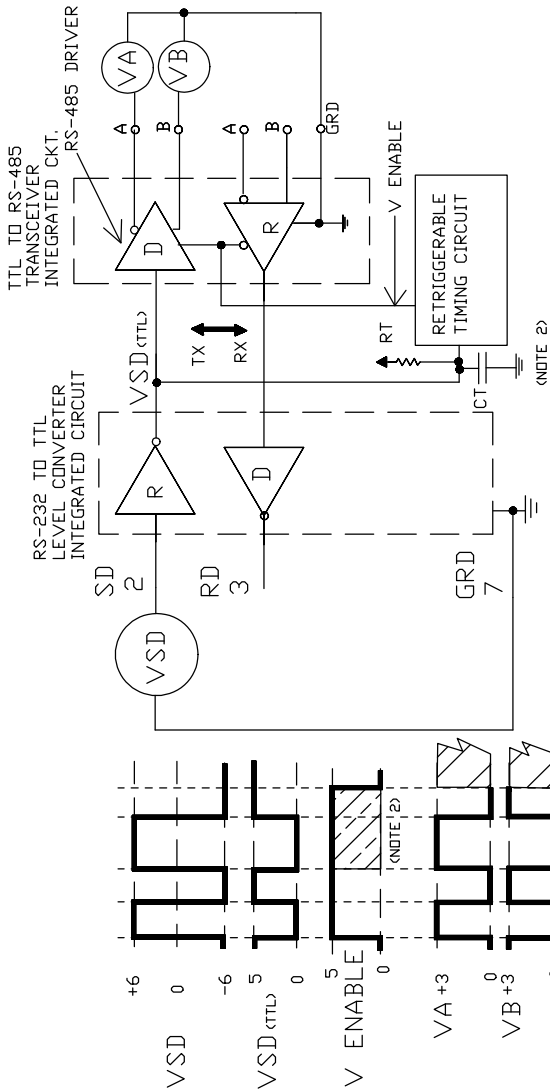


TIMING DIAGRAM FOR RS-232 TO RS-485 CONVERTER WITH RTS CONTROL OF RS-485 DRIVER AND RECEIVER

Note: 1) Voltage here is determined by other devices on the line.
 2) All peak values of voltages are approximate.

FILENAME: 485TMD

Figure 8



TIMING DIAGRAM FOR RS_232 TO RS-485 CONVERTER WITH SEND DATA (SD) CONTROL OF THE RS-485 DRIVER AND RECEIVER

Figure 9

FILENAME: 485SDTMD

control a converter of this type. It is important to note that the transmitted data line is "disabled" after a fixed interval, after the leading edge of the last bit. If this interval is too short, you can miss parts of each character being sent. If this time is too long, your system may try to turn the data line around from transmit to receive before the node (with the SD converter) is ready to receive data. If the latter is the case, you will miss portions (or complete characters) at the beginning of a message.

Transmission Line Termination

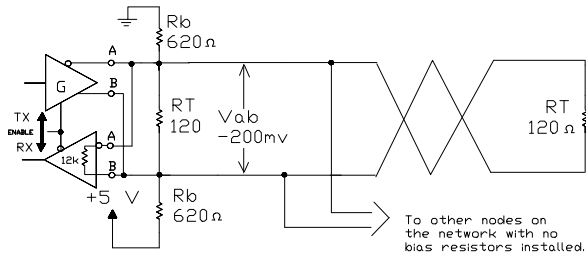
A common method of terminating a two-wire party line RS-485 network is with terminating resistors installed at the ends of the multidrop network (see Figure 6). The termination resistor should match the characteristic impedance of the transmission line. This characteristic impedance will usually be in the range of 100 to 120 ohms. Check the manufacturer's data sheets on the cable you are using in your system.

Idle or Off State Biasing on an RS-485 Network

When all nodes finish transmitting, the network is at an idle condition with all nodes in listen or receive mode. Under this idle condition, the state of the balanced line can be indeterminate because all drivers are tristated. If the voltage level at the A and B inputs is less than +/- 200 mv the logic level at the output of the receivers will be the value of the last bit received. It is often necessary to force to state of the line to be in an idle condition where V_{ab} is less than -200 mv. This can be done with bias resistors as shown in Figure 10. If the network bias consists of two resistors installed at one node, it would take two 620 ohm resistors to force a -200 mv condition to V_{ab} . This calculation uses the assumption that only two 120 ohm terminating resistors are used, with 32 nodes each with a nominal input impedance of 12 k ohms. It is important to note that the two 620 ohm bias resistors can only be installed on one node in the network. If these two resistors are installed at every node, it would effectively add a 39 ohm load across the network.

Multinode Bias Resistors

Many of B & B Electronics' converters use 4.7K ohm bias resistors as shown in Figure 11. When these resistors are installed only at one node, the line will not be forced to the idle state. It will take at least 8 nodes to get this condition, in a 32-node network.



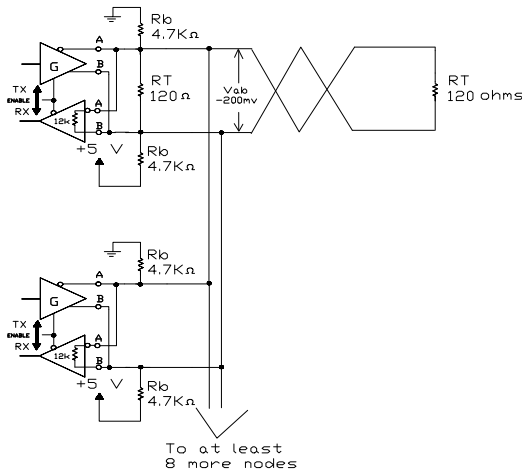
Note: If Rb were installed at every node on a 32 node network it would add a 39 ohm load to the transmission line. This is not desirable.

Bias Resistors can be used to force the line to an idle state when all drivers are off. If bias resistors are installed on one node it is easy to pick the value of bias resistors. In the above network, two 620 ohm resistors are used to force -200 mv for Vab to generate a line idle condition.

SINGLE NODE BIAS - NORMAL TERMINATION

FILENAME: B10.DAT

Figure 10



When 4.7K bias resistors are used, the bias resistors must be installed on 8 nodes to force the line to the idle state.

MULTI NODE BIAS - NORMAL TERMINATION

FILENAME: B11.DAT

Figure 11

AC Coupled Termination and Network Bias Resistors

Another lower power method of terminating a network is to AC couple the termination resistor to the line. This will reduce the amount of DC power required to bias the line in the idle condition. An example of this type of termination is in Figure 12. In a 32 node network the bias resistors can be increased to 4500 ohms and installed only at one node.

Increasing the Number of Nodes to More Than Thirty-Two

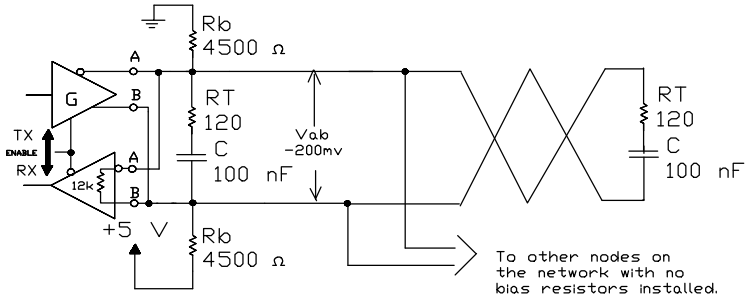
The line drivers in an RS-485 network are designed to drive thirty-two nodes. If this is a limitation for your system, you can increase the number of nodes by coupling part of your network to the system through an RS-485 repeater. The RS-485 repeater is a two-wire input and output device that listens to the network on both ports. When data occurs on either side of the device it is transmitted to the other side. Since the device transmits the signal at full voltage levels, another 32 (actually 31) nodes can be connected to your network. The device works like two RS-485 converters that use send data control (SD) to enable the output driver.

In addition to using an RS-485 repeater to increase the number of nodes in the system, it can be used to solve transmission line layout problems. One example of this, is when the system layout is a star configuration. Figure 13 illustrates this type of system. An RS-485 repeater solves this problem.

Transient Suppression

An effective way to reduce the susceptibility of damage to an RS-485 or RS-422 network is to install bipolar transient suppressors. A typical device will have a peak power rating of 500 watts for 1 ms. They have a typical surge current rating of 70 amps for 1/120 sec. The response time of these devices is almost instantaneous (1×10^{-12} sec.).

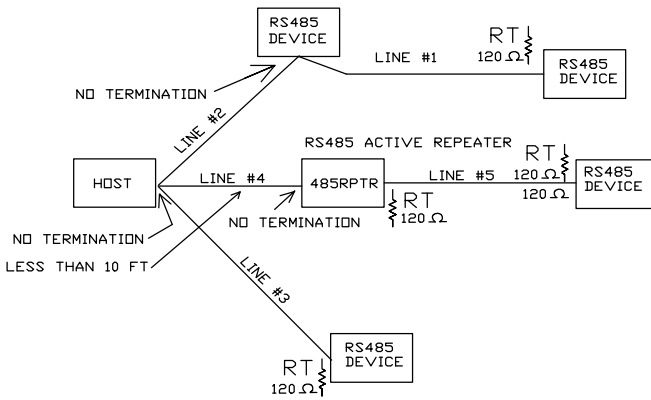
Figure 14 is a typical example of how to use these units. It is very important that the connection to the green wire ground (GWG) of the power system be verified when installing these devices.



When AC coupled termination is used, much larger bias resistors can be used.

SINGLE NODE BIAS AC COUPLED TERMINATION

Figure 12

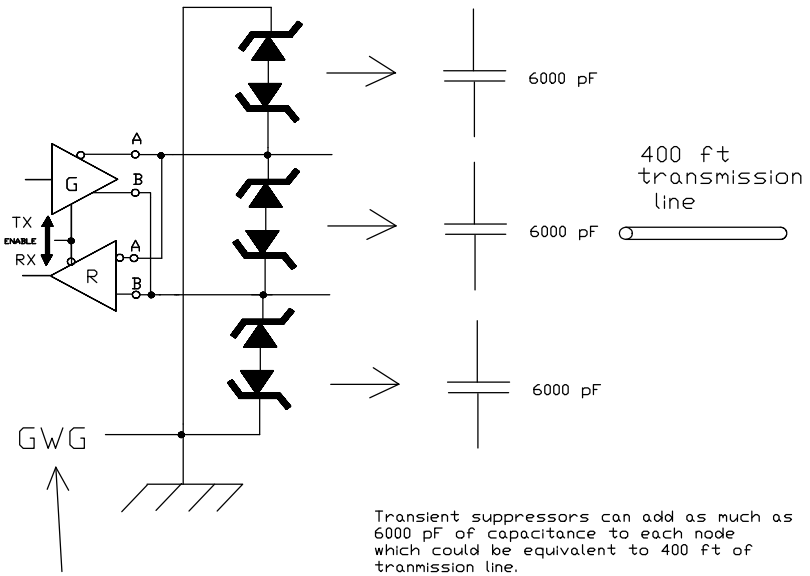


LINES 1, 2, AND 3 MUST NOT
TOTAL MORE THAN 4000FT.
LINE 5 CAN BE UP TO 4000FT.

STAR NETWORK USING A RS-485 REPEATER

Figure 13

TYPICAL RATING
 500 WATTS PEAK PULSE POWER
 FOR 1 MS



The connection to Green Wire Ground of the power system is very important.

TRANSIENTS SUPPRESSORS

Filename: TZSIP

Figure 14

A disadvantage of installing transient suppressors on all nodes in a network is the capacitive loading that these devices add to the transmission line. These devices can have capacitances of 6000 pF. that can be equivalent to as much as 400 ft. of transmission line. If you use these devices, you may not be able to use a 4000 ft. line.

SELECTION OF TRANSMISSION LINE FOR RS-422 AND RS-485

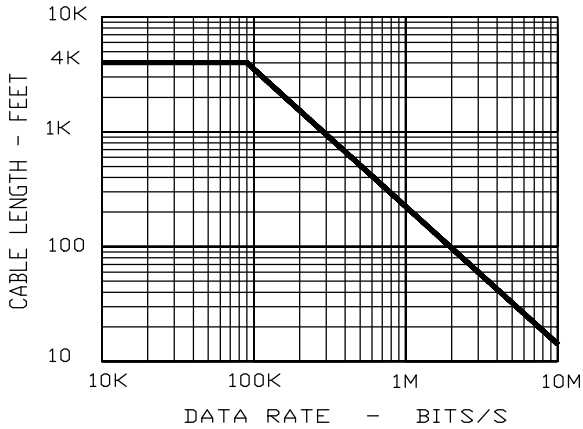
When choosing a transmission line for RS-422 or RS-485, it is necessary to examine the required distance of the cable and the data rate of the system. The Appendix to EIA RS-422-A Standard presents an empirical curve that relates Cable Length to Data Rate for 24 AWG twisted-pair telephone cable that has a shunt capacitance of 16 pF/ft. and is terminated in 100 ohms (see Figure 15). This curve is based on signal quality requirements of:

- a). Signal rise and fall time equal to, or less than, one-half unit interval at the applicable modulation rate.
- b). The maximum voltage loss between driver and load of 6 dB.

Losses in a transmission line are a combination of AC losses (skin effect), DC conductor loss, leakage, and AC losses in the dielectric. In high quality cable, the conductor losses and the dielectric losses are on the same order of magnitude. Figure 16 is included in this application note to point out the significant difference in performance of different cables. This chart shows Attenuation versus Frequency for three different Belden cables. Note that the polyethylene cables offer much lower attenuation than PVC cables.

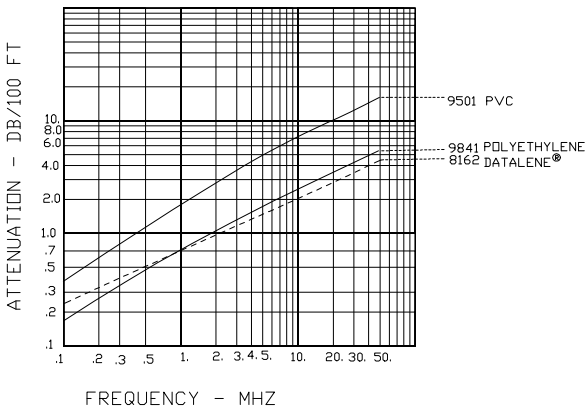
Another approach to choosing transmission line is the "E-GRADE Program," which has been established by Anixter Bros. Inc. Anixter is a worldwide distributor of wiring system products. Under this program, Anixter divides data interface cables into four categories as follows:

E-GRADE 1	LIMITED DISTANCE
E-GRADE 2	STANDARD DISTANCE
E-GRADE 3	EXTENDED DISTANCE
E-GRADE 4	MAXIMUM DISTANCE



DATA SIGNALLING RATE VERSUS CABLE LENGTH FOR BALANCED INTERFACE USING 24 AWG TWISTED PAIR CABLE

Figure 15



ATTENUATION VERSUS FREQUENCY FOR SEVERAL DATA CABLES

Note: 1) Above attenuation data is supplied courtesy Belden Wire and Cable Company
 2) Datalene is a registered trademark of Belden Wire and Cable Company. Datalene is a type of foamed cellular polyethylene insulation.

File name: 485CABLE

Figure 16

Simple charts are used to help the user select the proper cable without any technical understanding of the cable parameters. This program divides the usage categories into EIA-232-D, EIA-422-A, and EIA-423-A. When using this literature, use the EIA-422-A charts for choosing RS-485 cable.

EIA STANDARD RS-423 DATA TRANSMISSION

RS-423 data transmission uses an unbalanced line driver that connects to a RS-422 type balanced line receiver as shown in Figure 17. The RS-423 line driver is unique to this system. It produces voltage similar to RS-232 but has a slew rate control input that is used to limit rise times and cross talk on the data lines. Typical adjustments on the slew rate control is from 1 to 100 us. This is done by the proper selection of one resistor on the wave shape control input.

OBTAINING EIA DATA INTERFACE STANDARDS

EIA Standards and Publications can be purchased from:

GLOBAL ENGINEERING DOCUMENTS

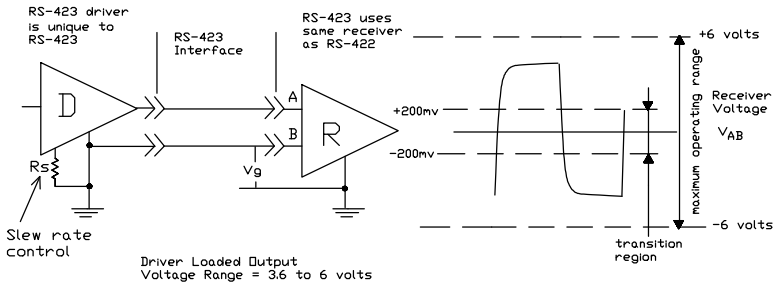
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FAX: (202) 331-0960



RS-423 INTERFACE CIRCUIT

FILENAME:423CKT

Figure 17

A few of the important data interface standards are:

- a) EIA-232-D Interface between data terminal equipment and data circuit-terminating equipment employing serial binary data interchange (ANSI/EIA-232-D)
- b) EIA-422-A Electrical characteristics of balanced voltage digital interface circuits
- c) EIA-423-A Electrical characteristics of unbalanced voltage digital interface circuits
- d) EIA-485 Standard for electrical characteristics of generators and receivers for use in balanced digital multipoint systems
- e) EIA-449 General purpose 37-position and 9-position interface for data terminal equipment and data circuit-terminating equipment employing
- f) EIA-530 High speed 25-position interface for data terminal equipment and data circuit-terminating equipment
- g) EIA/TIA-562 Electrical characteristics for an unbalanced digital interface

TABLE 1 EIA RS-232 SPECIFICATION SUMMARY				
Parameter	Conditions	Min	Max	Units
Driver Output Voltage Open Circuit			25	V
Driver Output Voltage Range	$3\text{ k}\Omega \leq R_L \leq 7\text{ k}\Omega$	5	15	V
Driver Output Resistance Power Off	$-2\text{V} \leq V_0 \leq 2\text{V}$		300	Ω
Driver Output Short-Circuit Current			500	MA
Driver Output Slew Rate All Interchange Circuits Control Circuits Rate and Timing Circuits	$\% \text{ of Unit Interval}$	6 6 4	30	V/ μ s V/ms V/ms %
Receiver Input Resistance	$3\text{V} \leq V_{IN} \leq 25\text{V}$	3000	7000	Ω
Receiver Input Threshold OUTPUT = MARK OUTPUT = SPACE		-3	3	V V

TABLE 2 EIA RS-423 SPECIFICATION SUMMARY				
Parameter	Conditions	Min	Max	Units
Driver Output Voltage Unloaded		4 -4	6 -6	V V
Driver Output Voltage Loaded	$R_L = 450\ \Omega$	3.6	6	V
Driver Output Resistance	$-2\text{V} \leq V_0 \leq 2\text{V}$		50	Ω
Driver Output Short-Circuit Current			± 150	MA
Driver Output Rise and Fall Time	Baud Rate $\leq 1\text{K Baud}$ Baud Rate $\geq 1\text{K Baud}$		300 30	μ s % Unit Interval
Receiver Sensitivity	$V_{cm} \leq \pm 7\text{v}$		± 200	mv
Receiver Common-Mode Voltage Range			± 10	V V
Receiver Input Resistance		4000		Ω

TABLE 3 EIA RS-422 SPECIFICATION SUMMARY				
Parameter	Conditions	Min	Max	Units
Driver Output Voltage Unloaded		4 -4	6 -6	V V
Driver Output Voltage Loaded	$R_T = 100 \Omega$	2 -2		V V
Driver Output Resistance	Per Output		50	Ω
Driver Output Short-Circuit Current			± 150	MA
Driver Output Rise Time			10	% Unit Interval
Receiver Sensitivity	$V_{cm} \leq \pm 7v$		± 200	mv
Receiver Common-Mode Voltage Range		-12	+12	V
Receiver Input Resistance		4000		Ω

TABLE 4 EIA RS-485 SPECIFICATION SUMMARY				
Parameter	Conditions	Min	Max	Units
Driver Output Voltage Loaded	$R_T = 100 \Omega$ RS-422	2 -2		V V
Driver Output Voltage Loaded	$R_L = 54 \Omega$ RS-485 $C_L = 50 \text{ pF}$	1.5 -1.5		V V
Driver Output Short-Circuit Current			± 250	MA
Driver Common Mode Voltage			3	V
Difference in Common Mode Offset			0.2	V
Receiver Sensitivity	$-7 \leq V_{cm} \leq +12$		± 200	mv
Receiver Common-Mode Voltage Range		-7	+12	V
Receiver Input Resistance		12K		Ω