Application Report

SLLA375–September 2017

Signal Integrity vs. Transmission Rate and Cable Length for RS-485 Transceivers

Cristian Soltero

ABSTRACT

This application note contains lab data on the signal integrity of the THVD1550 RS-485 transceiver device at various cable lengths and data rates. Jitter measurements were gathered with the results tabulated and plotted.

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Trademarks

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1 Introduction

The THVD15xx family of transceivers is designed to operate at a single supply voltage of 5 V and ensure robust system operation in noisy environments. This family contains multiple devices that vary in signaling rate and pin-out as well as duplex type, node capacity, and options to enable. For this document, the focus will be on one particular version, the THVD1550.

Applications in which the transceivers are used involve factory automation, building automation, and many other areas where robust serial communications over a multipoint network are crucial. These THVD1550 RS-485 transceivers provide a balanced interface for multipoint, bi-directional communication with large differential signal and common-mode range and data rates reaching up to 50 Mbps. The TIA and EIA “Recommended Standard” specifies several features including the signal amplitude, input sensitivity, and input impedance; however, cabling (type and link distance), connectors, data rate protocol, and bus topology are not defined, which requires users to choose these appropriately to support the needs of their applications. This application note runs through the cabling aspect by analyzing signal integrity data gathered at various cable lengths and data rates.

2 Jitter

For many, it is commonly misconceived that driver strength (i.e., output resistance) leads to better transmission of data over longer lengths of cable. In fact, driver behavior is one of the lesser factors when trying to transmit data over long distances of cable. Receiver performance is also less of a factor in comparison to the performance of the cable. When running through long distances of cable, the low pass effect of the cabling causes the rising and falling edges to deviate in time. This leads to what is called jitter and tends to be the limiting factor of signal integrity as cable length and data rate increase. Many factors affect the amount of jitter and the overall quality of a signal including termination schemes, amount of crosstalk, and of course, cable length. Jitter can be inherently random as well. Eye diagrams provide a quick and accurate way to visually analyze and evaluate the quality of a transmitted signal. Typically, an eye diagram appears as shown in Figure 1. A healthy eye diagram on the bus of an RS-485 interface circuit is shown in Figure 2. The minor roll off seen on the edges is due to the capacitance present when a node is tied to the bus

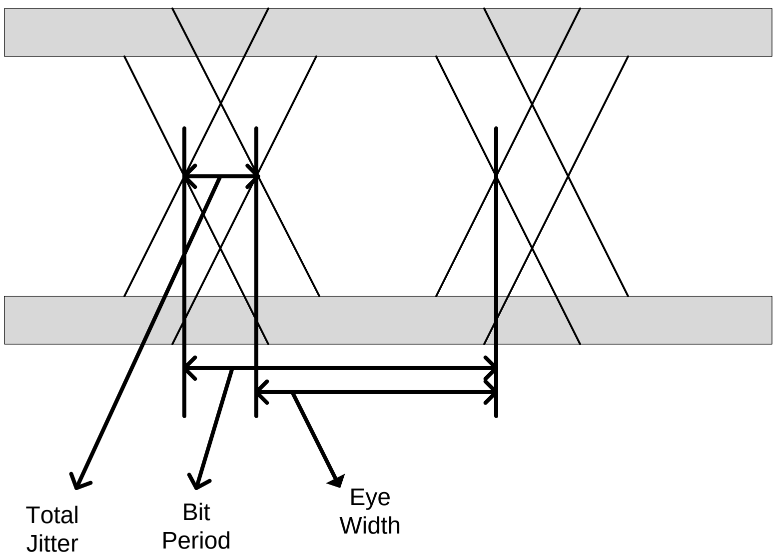


Figure 1. Typical Eye Diagram

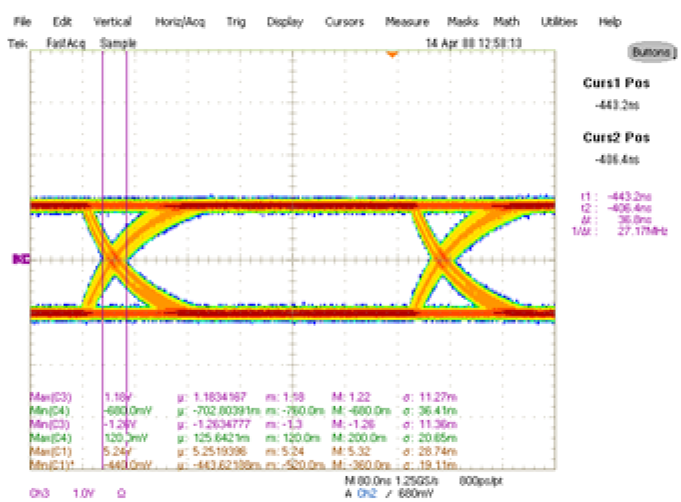


Figure 2. Actual Differential Receiver Input A-B after 1000 ft at 3 Mbps

The look of an eye diagram at the receiver output will be different, too, with the rise and fall of the signal taking on a fairly vertical shape. This is inherent to the design of the receiver as it takes in a differential signal from the bus, attenuates the voltages, interprets that differential signal as a binary logic level, and outputs the signal as a high (near V_{CC}) or low (near ground) state. Figure 3 shows a typical eye diagram at the receiver output.

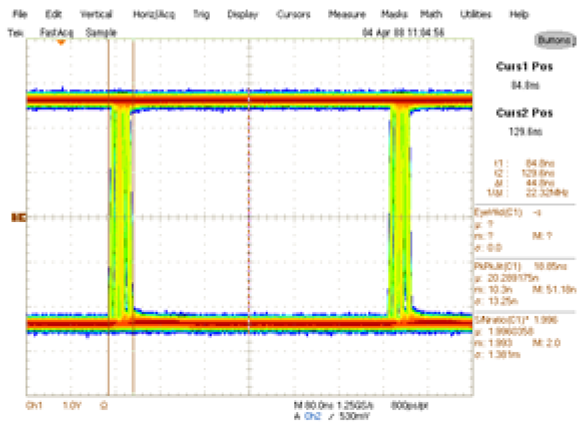


Figure 3. Actual Receiver Output after 1000 ft at 3 Mbps

When comparing the waveforms at the differential A-B receiver input and the receiver output, it should also be noted that the jitter is larger at the receiver output. This is due to the fact that the receiver itself implements failsafe biasing by intentionally offsetting the input thresholds from the 0-V crossing, so the rising and falling edges are instead received at a wider gap (about 50-100 mV).

3 Measurement Setup

Two THVD1550 devices were soldered on to two Texas Instruments RS-485 EVMs; one transmitting, one receiving. Using a data generator, PRBS-7 data was generated and used as the driver input to one device. In connecting the bus of the driving device to the receiving device, Unshielded Twisted Pair Ethernet Category 5 cable (low cost, generic cable commonly found in industry) was used with 120-Ω termination on either side of the cable. Cable lengths of 1000 ft., 2000 ft., 3000 ft., 4000 ft., and 5000 ft. were used during testing. A differential probe was placed on the receiving bus to gather A-B eye diagrams, while a single-ended probe was placed at the receiver output. Those probes were then connected to an oscilloscope. Rather than triggering off the PRBS-7 data itself, a trigger output from the data generator synchronized with the PRBS-7 data was supplied and input into the oscilloscope for synchronization. Figure 4 provides a flow chart of this setup.

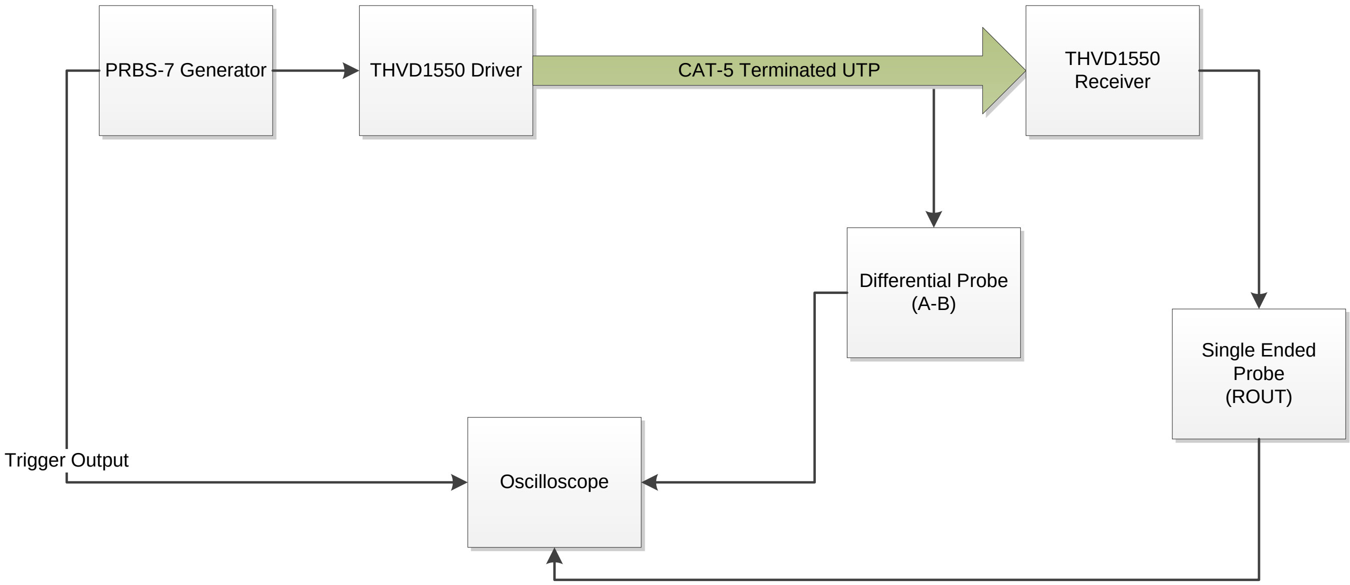


Figure 4. Lab Setup

4 Lab Results

For each different cable length, various data rates were transmitted ranging from 200 kbps up to 10 Mbps at certain lengths. Total jitter was recorded for each data point. Eye width was calculated by subtracting the total jitter from the bit duration (the period), and jitter percentage was obtained by dividing the total jitter by the bit duration and multiplying by 100. Due to the measurement limitations of the oscilloscope, jitter was measured by hand using the cursors.

Table 1 shows the differential receiver input A-B data collected at 5 different cable lengths with varying data rates, and Table 2 shows the data for the receiver output.

Table 1. Total Jitter of Differential Receiver Input A-B Eye Diagram

Distance	Data Rate (Mbps)	Bit Duration (ns)	Eye Width (ns)	Jitter (ns)	Jitter Percentage
1000 ft.	0.20	5000	4976	24	0.48
	0.40	2500	2472	28	1.12
	0.50	2000	1968	32	1.60
	0.60	1666.67	1626.67	40	2.40
	0.80	1250	1214	36	2.88
	1	1000	964	36	3.60
	2	500	463.20	36.80	7.36
	4	250	196.40	53.60	21.44
	5	200	144.80	55.20	27.60
	7	142.86	82.06	60.80	42.56
	8	125	65	60	48
	10	100	34	66	66
2000 ft.	0.20	5000	4880	120	2.40
	0.40	2500	2380	120	4.80
	0.50	2000	1880	120	6
	0.60	1666.67	1554.67	112	6.72
	0.80	1250	1134	116	9.28
	1	1000	892	108	10.80
	2	500	338.40	161.60	32.32
	3	333.33	134.93	198.40	59.52
	4	250	13.20	236.80	94.72

Table 1. Total Jitter of Differential Receiver Input A-B Eye Diagram (continued)

Distance	Data Rate (Mbps)	Bit Duration (ns)	Eye Width (ns)	Jitter (ns)	Jitter Percentage
3000 ft.	0.20	5000	4820	180	3.60
	0.40	2500	2316	184	7.36
	0.50	2000	1824	176	8.80
	0.60	1666.67	1482.67	184	11.04
	0.80	1250	1054	196	15.68
	0.90	1111.11	899.11	212	19.08
	1	1000	772	228	22.80
	2	500	133.60	366.40	73.28
	2.50	400	0	400	100
4000 ft.	0.20	5000	4760	240	4.80
	0.25	4000	3740	260	6.50
	0.40	2500	2228	272	10.88
	0.50	2000	1744	256	12.80
	0.60	1666.67	1378.67	288	17.28
	0.65	1538.46	1226.46	312	20.28
	0.75	1333.33	997.33	336	25.20
	0.80	1250	890	360	28.80
	1	1000	572	428	42.80
	1.50	666.67	38.67	628	94.20
5000 ft.	0.20	5000	4680	320	6.40
	0.30	3333.33	2973.33	360	10.80
	0.35	2857.14	2457.14	400	14
	0.40	2500	2084	416	16.64
	0.45	2222.22	1774.22	448	20.16
	0.50	2000	1552	448	22.40
	0.60	1666.67	1170.67	496	29.76
	0.80	1250	662	588	47.04
	1	1000	312	688	68.80
	1.50	666.67	0	666.67	100

Table 2. Total Jitter of Receiver Output

Distance	Data Rate (Mbps)	Bit Duration (ns)	Eye Width (ns)	Jitter (ns)	Jitter Percentage
1000 ft.	0.20	5000	4940	60	1.20
	0.40	2500	2460	40	1.60
	0.50	2000	1952	48	2.40
	0.60	1666.67	1618.67	48	2.88
	0.80	1250	1210	40	3.20
	1	1000	960	40	4
	2	500	455.20	44.80	8.96
	4	250	190	60	24
	5	200	132.80	67.20	33.60
	7	142.86	72.86	70	49
	8	125	53	72	57.60
	10	100	21.20	78.80	78.80

Table 2. Total Jitter of Receiver Output (continued)

Distance	Data Rate (Mbps)	Bit Duration (ns)	Eye Width (ns)	Jitter (ns)	Jitter Percentage
2000 ft.	0.20	5000	4900	100	2
	0.40	2500	2380	120	4.80
	0.50	2000	1880	120	6
	0.60	1666.67	1546.67	120	7.20
	0.80	1250	1126	124	9.92
	1	1000	880	120	12
	2	500	319.20	180.80	36.16
	3	333.33	120.53	212.80	63.84
3000 ft.	0.20	5000	4800	200	4
	0.40	2500	2308	192	7.68
	0.50	2000	1784	216	10.80
	0.60	1666.67	1442.67	224	13.44
	0.80	1250	1050	200	16
	0.90	1111.11	895.11	216	19.44
	1	1000	764	236	23.60
	2	500	90.40	409.60	81.92
4000 ft.	0.20	5000	4740	260	5.20
	0.25	4000	3740	260	6.50
	0.40	2500	2220	280	11.20
	0.50	2000	1736	264	13.20
	0.60	1666.67	1386.67	280	16.80
	0.65	1538.46	1226.46	312	20.28
	0.75	1333.33	997.33	336	25.20
	0.80	1250	886	364	29.12
	1	1000	564	436	43.60
	1.50	666.67	68.27	598.40	89.76
5000 ft.	0.20	5000	4640	360	7.20
	0.30	3333.33	2973.33	360	10.80
	0.35	2857.14	2465.14	392	13.72
	0.40	2500	2116	384	15.36
	0.45	2222.22	1822.22	400	18
	0.50	2000	1560	440	22
	0.60	1666.67	1138.67	528	31.68
	0.80	1250	634	616	49.28
	1	1000	288	712	71.20

Figure 5, Figure 6, and Figure 7 plot the eye width, total jitter, and jitter percentage versus the data rate for A-B and the receiver plots are found in Figure 8, Figure 9, and Figure 10.

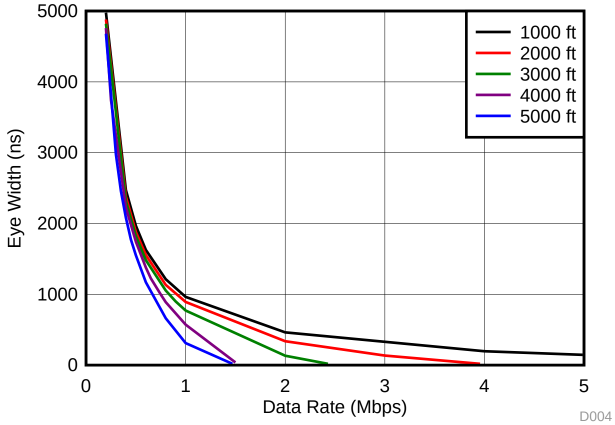


Figure 5. A-B Bus Eye Width vs Data Rate

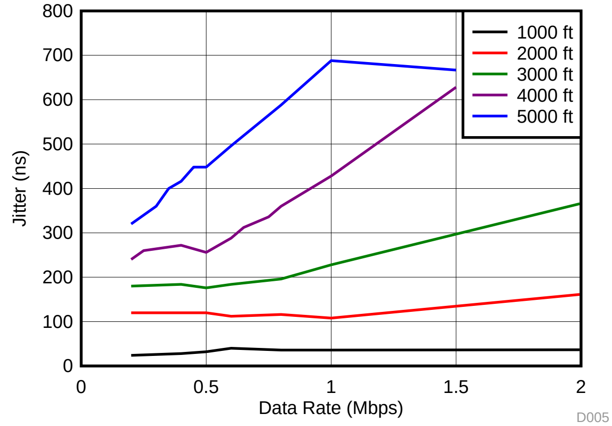


Figure 6. A-B Bus Jitter vs Data Rate

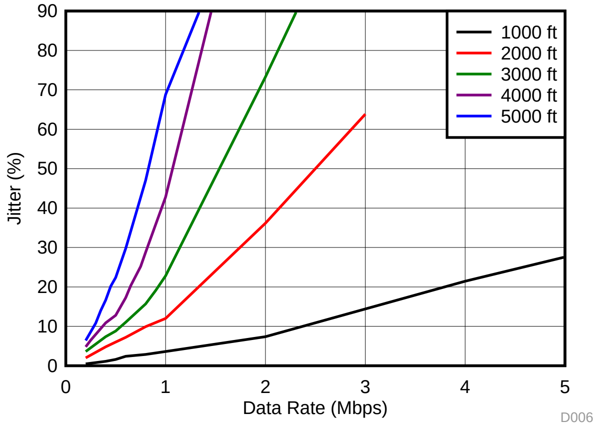


Figure 7. A-B Bus Jitter % vs Data Rate

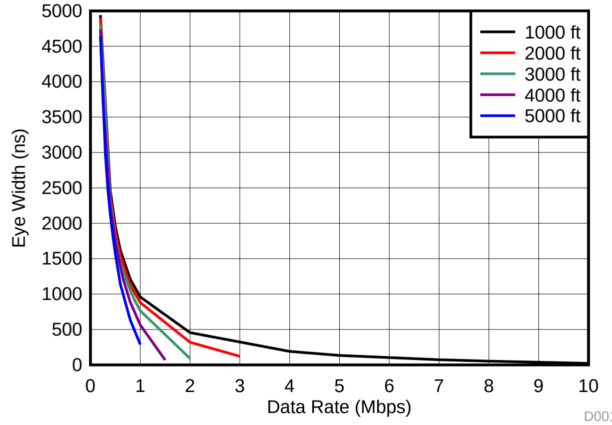


Figure 8. Receiver Eye Width vs Data Rate

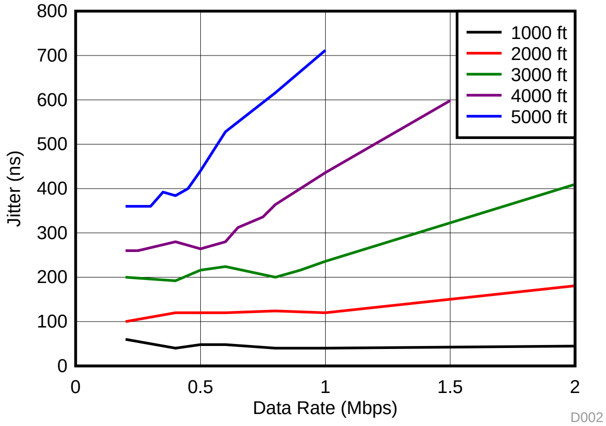


Figure 9. Receiver Jitter vs Data Rate

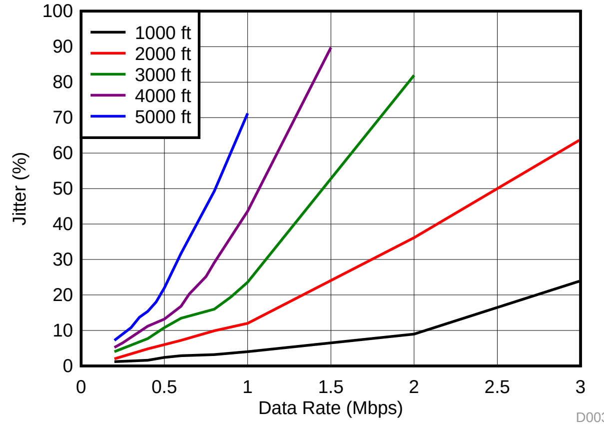


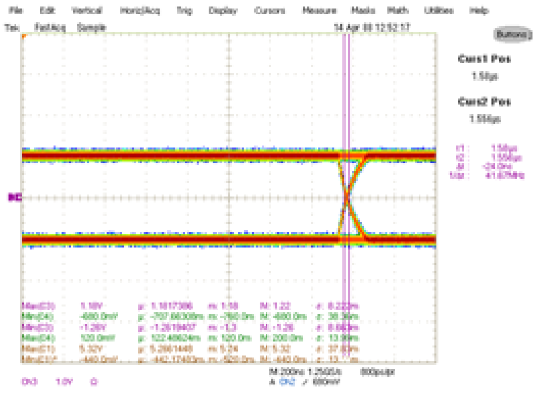
Figure 10. Receiver Jitter % vs Data Rate

A few observations can immediately be made from these graphs. The rate of decrease in eye width is about the same for all cable lengths as the data rate approaches 1 Mbps. From that point forward, the slopes begin to change to a slower rate, moreso for shorter cable lengths. For the total jitter graphs, the jitter amounts stay fairly stable until a point is reached where they begin to increase. The slopes are larger for greater cable lengths. The point where jitter begins to increase can be anywhere between 10% and 20% jitter, based on the provided jitter percentage graphs. The jitter percentage graphs show a similar trend in that for higher cable lengths, the slopes are larger.

Note how the slopes do not add linearly for increasing cable lengths (the slope at 2000 ft. is not twice the slope at 1000 ft.). This can be attributed to the fact that as data rate is increased, the driving signal amplitudes on the bus do not necessarily reach their desired maximum and minimum steady-state values. This occurrence is also dependent on the data pattern as well. Shorter consecutive bit runs will have a shorter settling time for maximum/minimum values than longer consecutive bit runs. This alone is not detrimental to the overall receiver output because the receiver threshold is narrowly set around 0 V, but more jitter may be observed due to the edge transitions varying in rising or falling times since smaller peak values will cross the receiver threshold earlier than larger peak values.

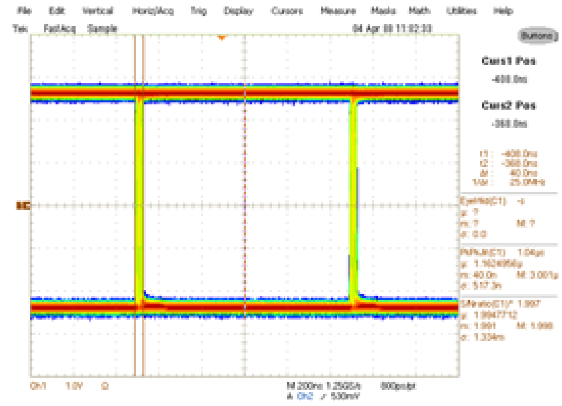
For many applications where RS-485 transceivers are used, the desired percentage of jitter to ensure signal reliability is usually no greater than 20%. Some systems may be able to allow up to 30% or even 40% jitter, but there will always be the risk of having bit errors. To get an idea of how a signal looks at different rates, cable lengths, and jitter percentages, The following eye diagrams are provided to illustrate signal quality.

4.1 Eye Diagrams, 1000 Feet



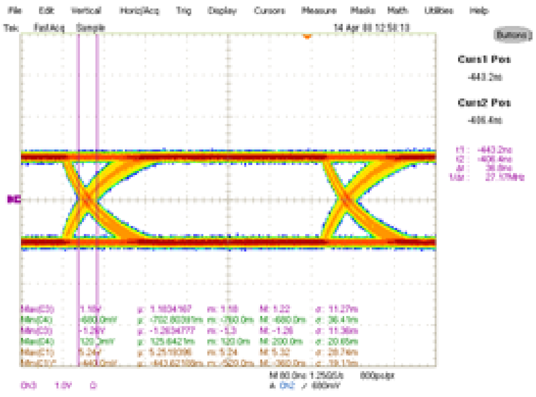
5% 2 Mbps

Figure 11. Differential Receiver Input (A-B)



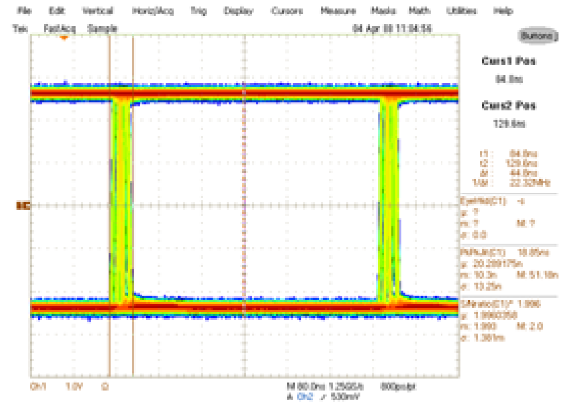
5% 2 Mbps

Figure 12. Receiver Output



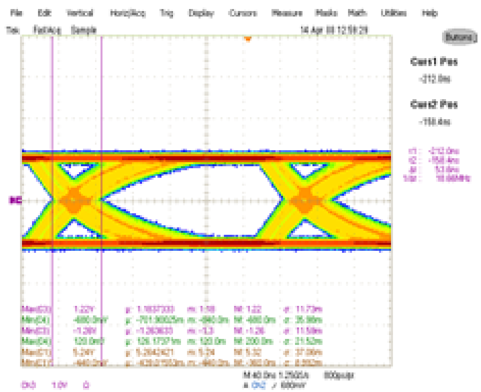
10% 3 Mbps

Figure 13. Differential Receiver Input (A-B)



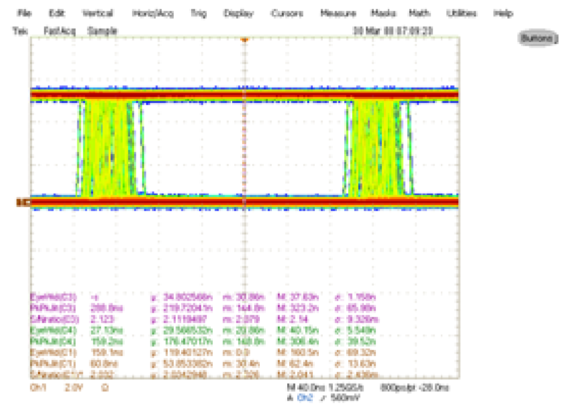
10% 3 Mbps

Figure 14. Receiver Output



20% 4 Mbps

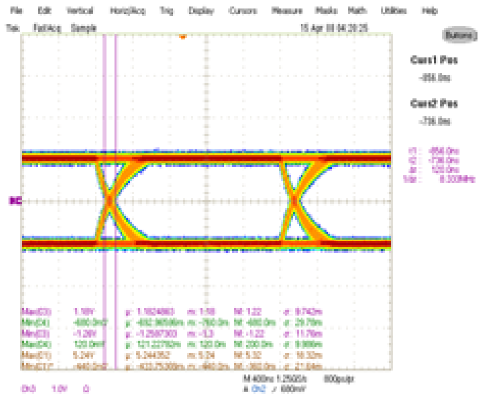
Figure 15. Differential Receiver Input (A-B)



20% 4 Mbps

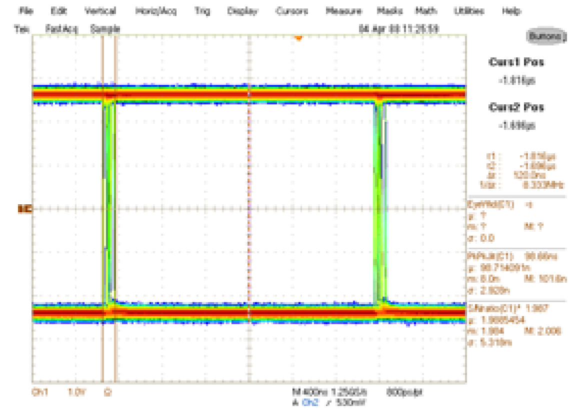
Figure 16. Receiver Output

4.2 Eye Diagrams, 2000 Feet



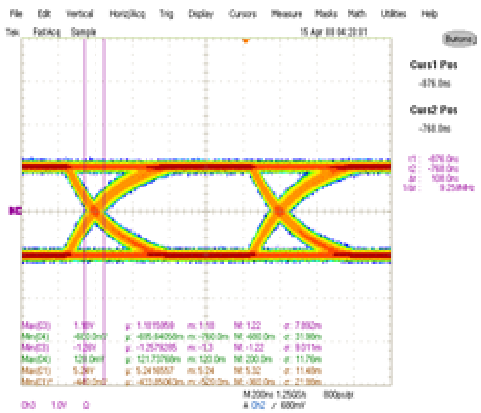
5% 2 Mbps

Figure 17. Differential Receiver Input (A-B)



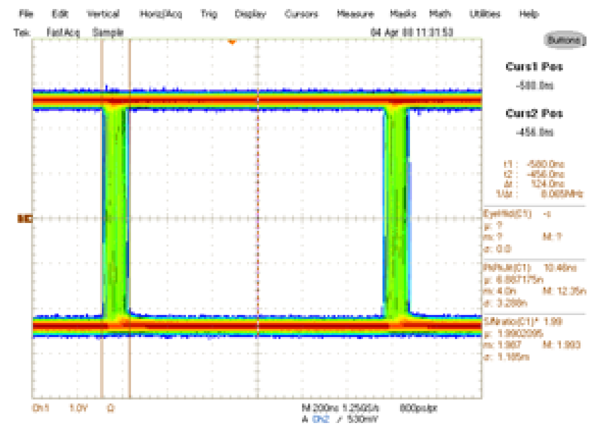
5% 2 Mbps

Figure 18. Receiver Output



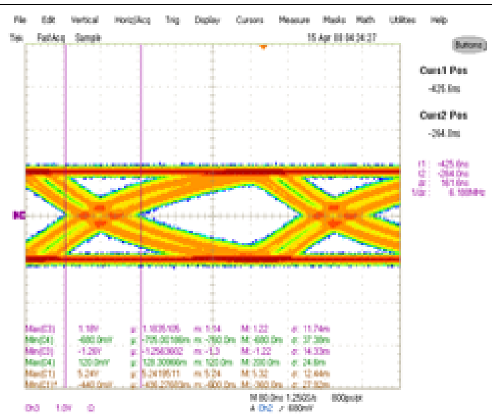
10% 3 Mbps

Figure 19. Differential Receiver Input (A-B)



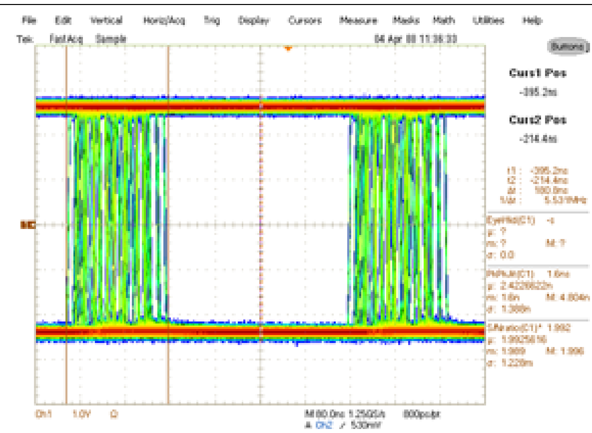
10% 3 Mbps

Figure 20. Receiver Output



20% 4 Mbps

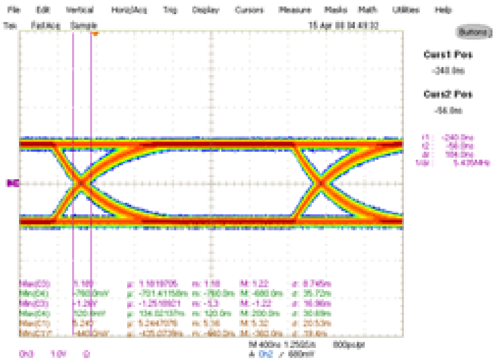
Figure 21. Differential Receiver Input (A-B)



20% 4 Mbps

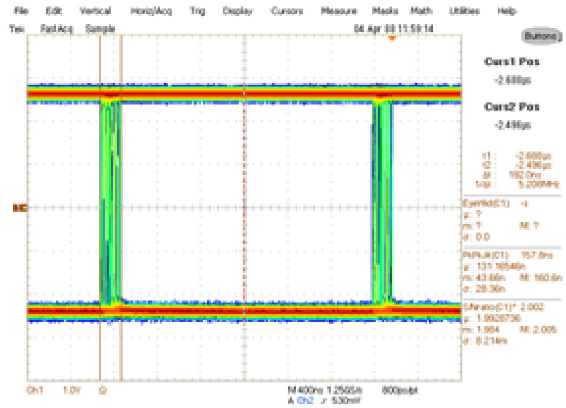
Figure 22. Receiver Output

4.3 Eye Diagrams, 3000 Feet



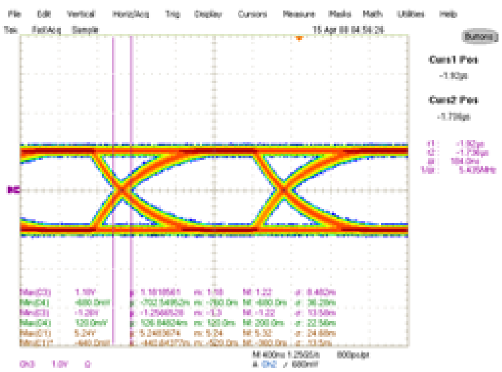
5% 2 Mbps

Figure 23. Differential Receiver Input (A-B)



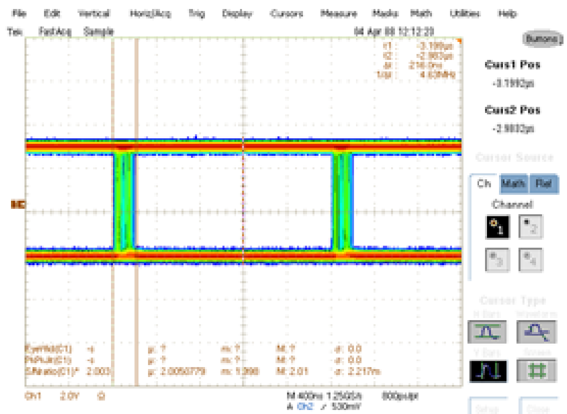
5% 2 Mbps

Figure 24. Receiver Output



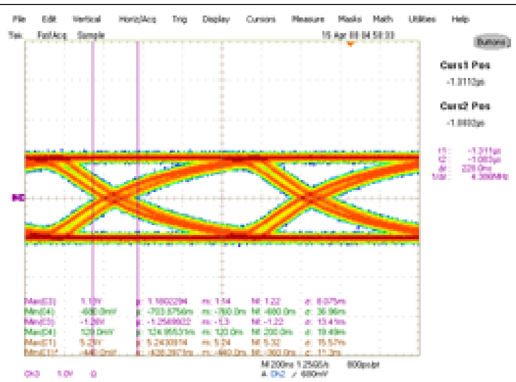
10% 3 Mbps

Figure 25. Differential Receiver Input (A-B)



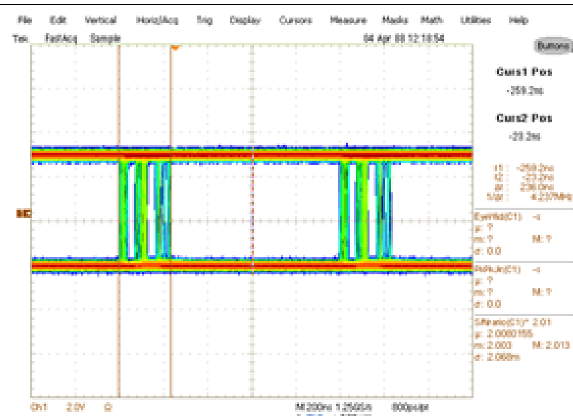
10% 3 Mbps

Figure 26. Receiver Output



20% 4 Mbps

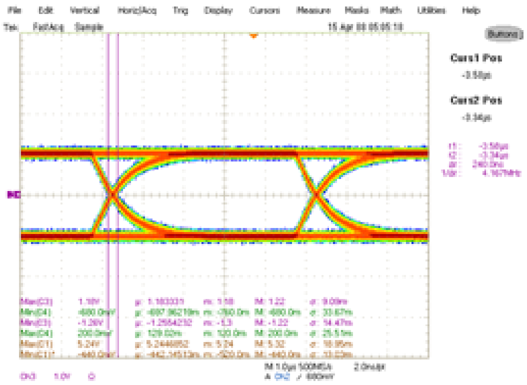
Figure 27. Differential Receiver Input (A-B)



20% 4 Mbps

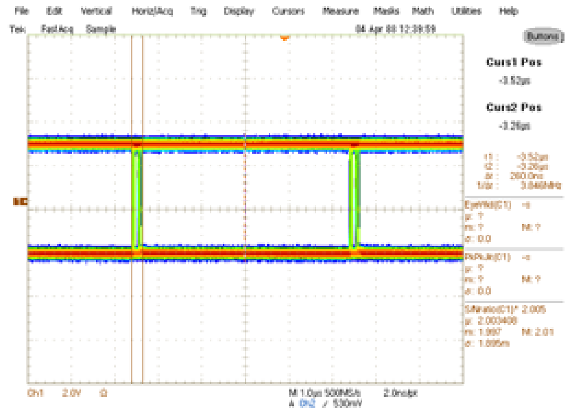
Figure 28. Receiver Output

4.4 Eye Diagrams, 4000 Feet



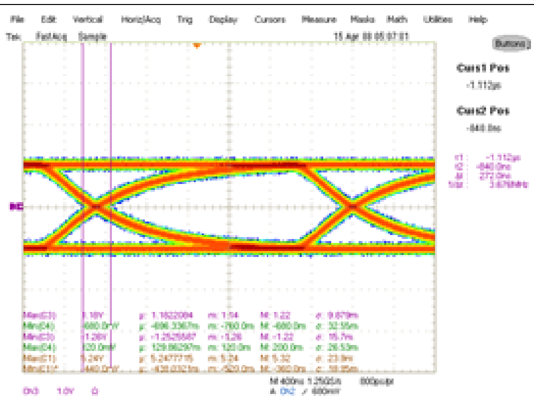
5% 2 Mbps

Figure 29. Differential Receiver Input (A-B)



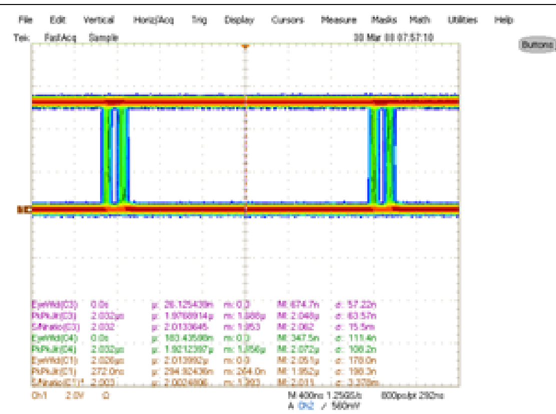
5% 2 Mbps

Figure 30. Receiver Output



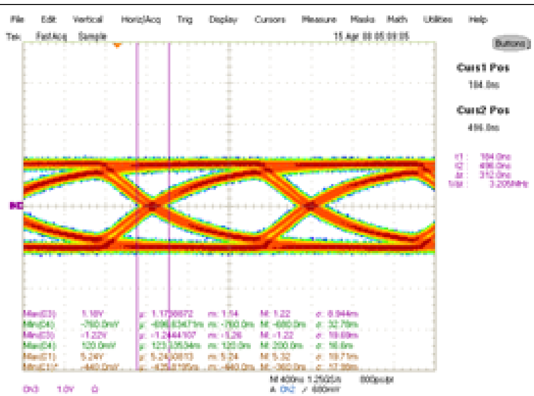
10% 3 Mbps

Figure 31. Differential Receiver Input (A-B)



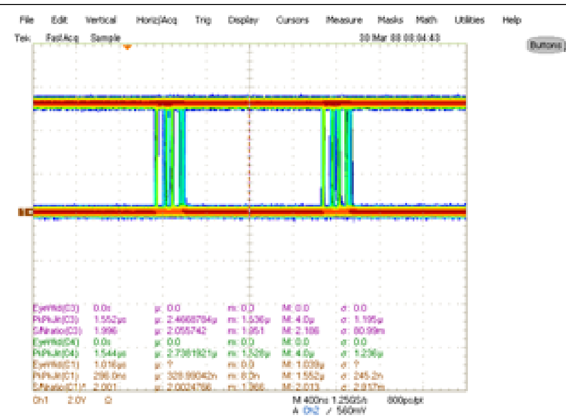
10% 3 Mbps

Figure 32. Receiver Output



20% 4 Mbps

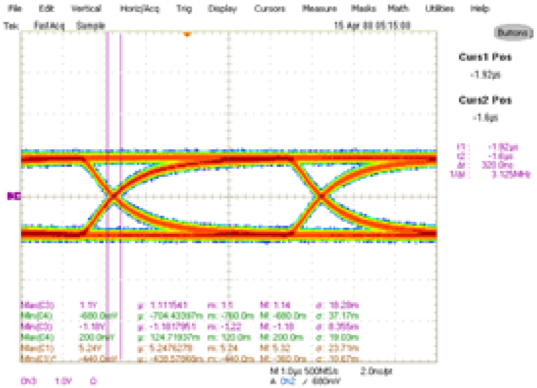
Figure 33. Differential Receiver Input (A-B)



20% 4 Mbps

Figure 34. Receiver Output

4.5 Eye Diagrams, 5000 Feet

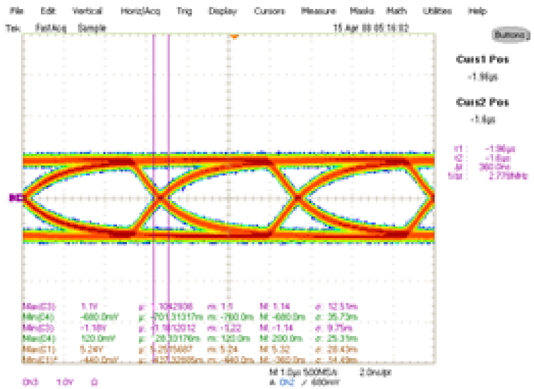


5% 2 Mbps

Figure 35. Differential Receiver Input (A-B)

5% 2 Mbps

Figure 36. Receiver Output

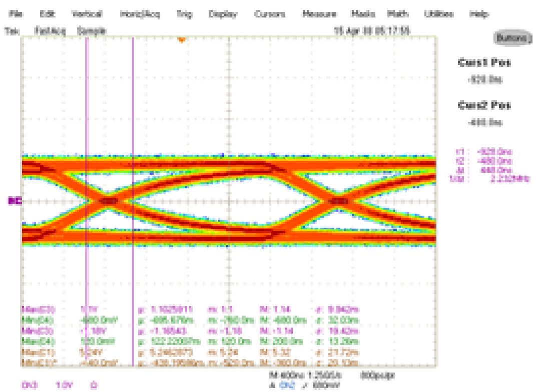


10% 3 Mbps

Figure 37. Differential Receiver Input (A-B)

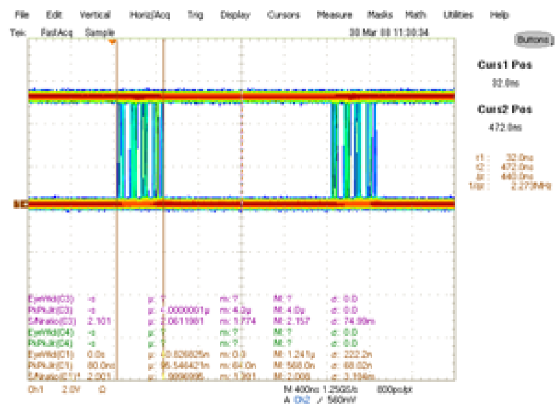
10% 3 Mbps

Figure 38. Receiver Output



20% 4 Mbps

Figure 39. Differential Receiver Input (A-B)



20% 4 Mbps

Figure 40. Receiver Output

5 Summary

Jitter serves to be a direct indicator of signal quality largely determined by the characteristics of the cable used. The data presented in this report demonstrates that the THVD1550 device provides fairly long-reach data communication over low cost, common cabling. It also gives the user an idea of which data rates and cable lengths provide certain jitter percentages for their designs.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265