AN1579

USB 3.0 Internal Cable and Connector Evaluation

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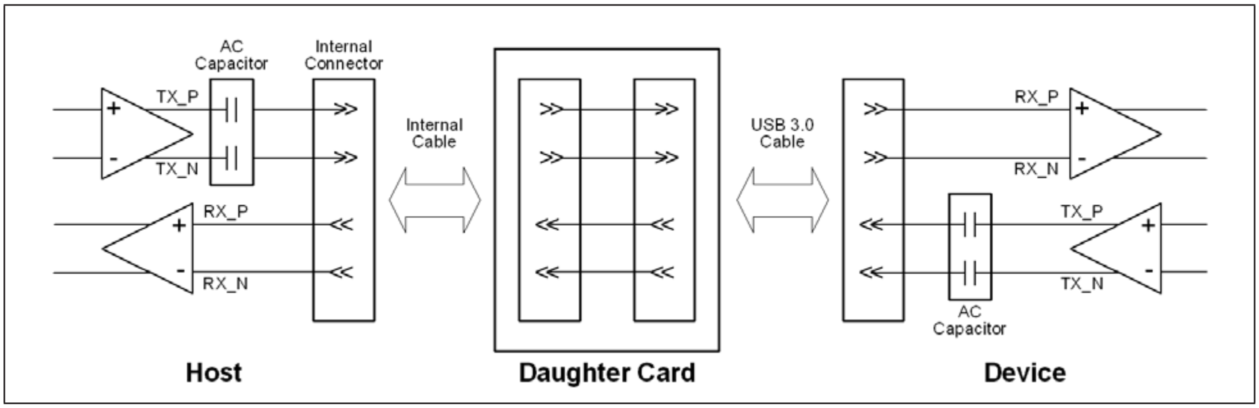
INTRODUCTION

In USB applications, internal cable assemblies may be used to connect external USB ports on the front panel of the motherboard or to connect the main board of a monitor to a daughter card. An example of this can be seen in Figure 1.

FIGURE 1: CABLE ASSEMBLY BLOCK DIAGRAM



Proper selection of a motherboard mating connector for front panel USB support is important to ensure signal quality is not adversely affected due to a poor connector/cable interface. When the wrong types of connectors are used, or other forms of inductive discontinuities are added to the transmission path, jitter will increase and the eye opening will decrease. As the frequency and rise times of signals increase, jitter can become a significant issue. Additionally, when signals become increasingly stressed (i.e., random), jitter becomes more pronounced.

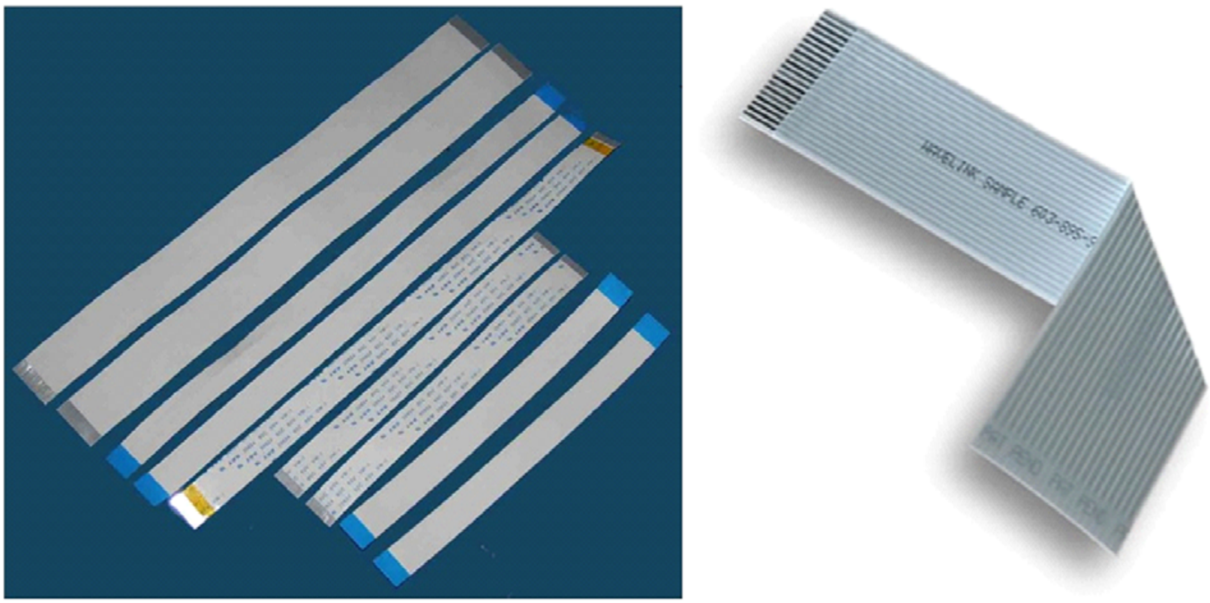
The cable and PCB mating connector must also pass the TDR requirements listed in the USB 3.0 Specification. Intel's "USB 3.0 Internal Connector & Cable Specifications" (Rev 1.0 Aug. 20 2010)" provides details on internal connector and cable assemblies. For 5Gbps transmission, it is increasingly difficult for copper interconnections to remain competitive with the price, performance, and size/weight requirements. A typical Amphenol internal USB 3.0 cable assembly is shown in Figure 2. This type of cable is higher cost compared to traditional internal cables such as ribbon type, twisted pair type, flexible flat cable (FFC) type, etc. Moreover, this type of cable cannot be used in products which require a flexible cable. The purpose of this document is to describe alternatives to this traditional USB internal cable type.

FIGURE 2: INTERNAL CABLE ASSEMBLY

FLEXIBLE FLAT CABLE (FFC)

Since 1970, Flexible Flat Cable assemblies (FFC) have been used as a standard interface between PCBs (Printed Circuit Boards). FFC typically consists of a flat and flexible plastic film base, with multiple metallic conductors bonded to one surface, as shown in Figure 3.

FIGURE 3: TYPICAL FLEXIBLE FLAT CABLES



There are three way to terminate FFCs:

1. Direct Solder: Permanent connection for low cost applications
2. Crimped Contacts: Separable connection for high end plug ability
3. Connectors: Low Insertion Force (LIF) or Zero Insertion Force (ZIF) connectors

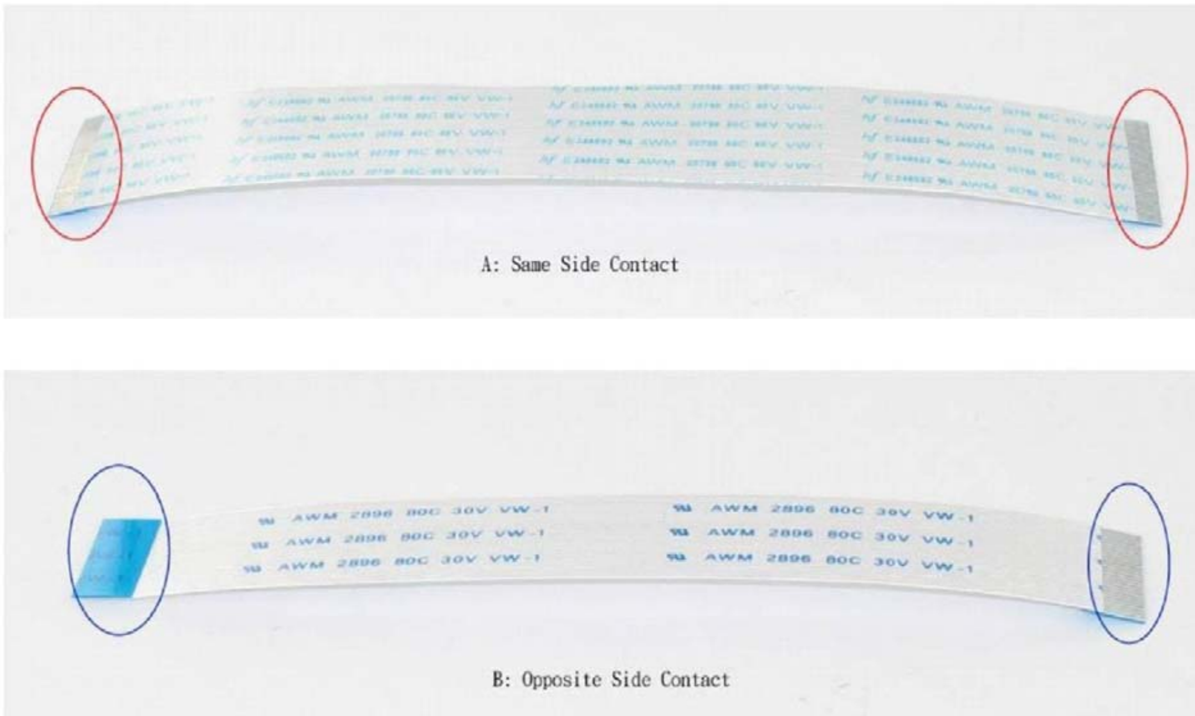
In general, shielded FFCs perform better than unshielded FFCs and are available in two types:

1. Shielded with aluminum tape
2. Shielded with conductive silver paint and protective varnish

Additionally, there are two types of FFC contacts (see Figure 4):

1. Type A: Same side contact
2. Type B: Opposite side contact

FIGURE 4: TYPE A AND B FLEXIBLE FLAT CABLE CONTACTS



To evaluate the FFCs internal connections, two sets of tests were performed:

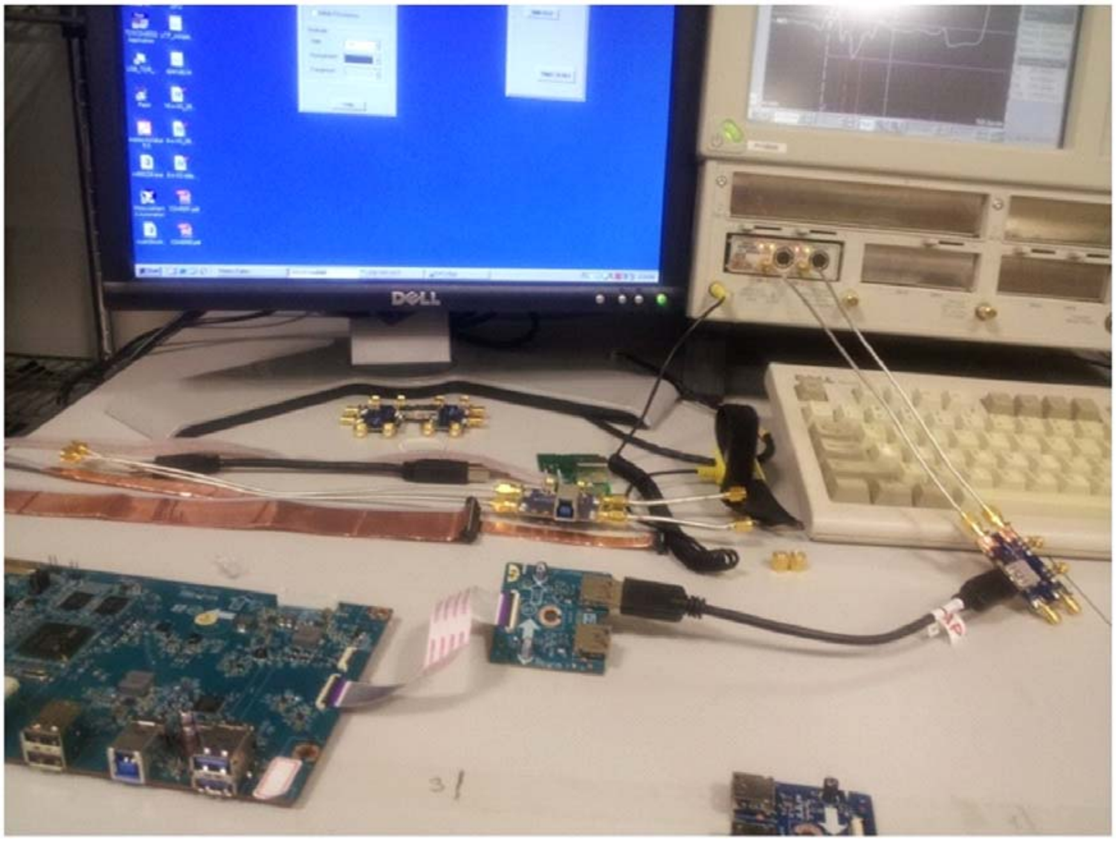
- Time Domain Reflectometry (TDR) Testing
- USB 3.0 Transmitter Compliance Testing

Time Domain Reflectometry (TDR) Testing

Time Domain Reflectometry (TDR) is a way to observe discontinuities on a transmission path. The time domain reflectometer sends a short duration pulse with a very fast rise time through the transmission line. Reflections occur when the pulse of energy reaches either the end of the transmission path or a discontinuity within the transmission path. From these reflections, the engineer can determine the characteristics of the line, such as the impedances and propagation delays along the signal path. This measurement can give a good indication of any discontinuities within the line that would occur with an open, short, or any other impedance mismatch. The nature of the line, i.e. resistive, inductive or capacitive, can be observed on the oscilloscope's display. For a capacitive load, a dip in the TDR plot will be seen, while for an inductive load a surge in the TDR plot will be seen.

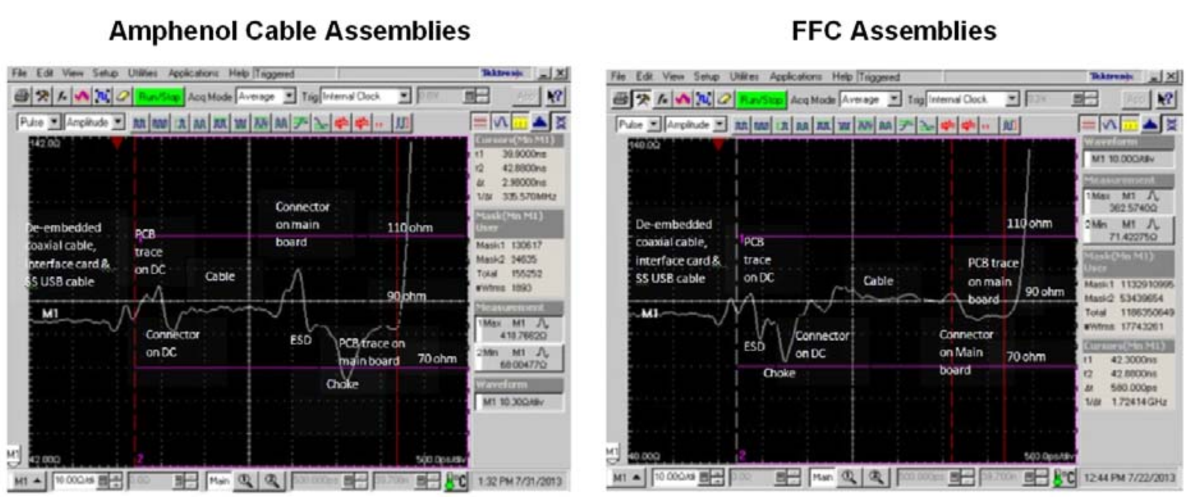
Figure 5 shows the test setup used by Microchip. A Tektronix TDS-8000 Digital Sampling Oscilloscope equipped with a dual-channel Sampling Module model 80E04 was used to measure differential impedance.

FIGURE 5: TDR TEST SETUP



The plots shown in x detail the TDR measurements on Amphenol and FFC cable assemblies.

FIGURE 6: TDR TEST SETUP



The TDR test results show the Amphenol cable superior to the FFC. However, the ZIF connector and assembly of the FFC provide improved impedance mismatch versus the through-hole connectors of the Amphenol cable assembly.

USB 3.0 Transmitter Compliance Testing

The USB 3.0 transmitter compliance test is a comprehensive toolset for validation and characterization of the serial data link and others to verify the eye diagram, jitter, and other performance measurements. The USB 3.0 transmitter test requires the use of reference channels and Continuous Time Linear Equalization (CTLE). LeCroy's automated test engine QualiPHY, equipped with an SDA 8Zi-A oscilloscope and QPHY-ISB3-TX-RX application, was used to perform the transmitter compliance test.

Table 1 details the performance comparison between the Amphenol and FFC cable assemblies. As shown in the table, the FFC with ZIF connector performed comparatively well. Though eye height is shorter (180mV versus 195mV), the jitter measurements are impressive.

TABLE 1: USB 3.0 TRANSMITTER COMPLIANCE TEST RESULTS

Measurement	Amphenol	FFC	Test Criteria
Polling.LFPS Minimum Burst Width	998 ns	998 ns	600 ns <= x <= 1.4 us
Polling.LFPS Mean Burst Width	1.001 us	1.001 us	600 ns <= x <= 1.4 us
Polling.LFPS Maximum Burst Width	1.003 us	1.003 us	600 ns <= x <= 1.4 us
Polling.LFPS Minimum Burst Repeat Time	10.01 us	10.01 us	600 ns <= x <= 1.4 us
Polling.LFPS Mean Burst Repeat Time	10.02 us	10.02 us	600 ns <= x <= 1.4 us
Polling.LFPS Maximum Burst Repeat Time	10.04 us	10.04 us	600 ns <= x <= 1.4 us
LFPS Period	39 ns	35 ns	20 ns <- x <= 100 ns
LFPS Rise Time	243 ps	262 ps	x <= 4.0 ns
LFPS Fall Time	244 ps	264 ps	x <= 4.0 ns
LFPS Duty Cycle	51.0%	48.2%	40.0% <= x <= 60.0%
LFPS Differential Voltage Peak-Peak	988 mV	933 mV	800 mV <= x <= 1.200 V
LFPS AC Common Mode Voltage Peak/Peak	82.159 mV	45.378 mV	x <= 100.000 mV
SSC Deviation Min	92.7 PPM	115.9 PPM	-300.0 PPM <= x <= 300.0 PPM
SSC Deviation Max	-4.6700 kPPM	-4.6977 kPPM	-5.3000 kPPM <= x <= -3.7000 kPPM
SSC Modulate Rate	30.792 kHz	30.794 kHz	30.000 kHz <= x <= 33.000 kHz
Tj CP1	29.55 ps	26.09 ps	x <= 132.00 ps
Rj (rms) CP1	1.105 ps	1.025 ps	x <= 3.270 ps
Phase Jitter Slew Rate Max	3.039 ms/s	3.171 ms/s	x = 0 us/s +/- 10.000 ms/s
Phase Jitter Slew Rate Min	-3.062 ms/s	-3.150 ms/s	x = 0 us/s +/- 10.000 ms/s
Tj CP1 SigTest	28.42 ps	25.87 ps	x <= 132.00 ps
Rj (rms) CP1 SigTest	1.273 ps	1.153 ps	x <= 3.270 ps
Tj CP0	67.15 ps	50.07 ps	x <=132.00 ps
Rj (rms) CP0	1.120 ps	1.039 ps	x <= 3.270 ps
Dj CP0	51.18 ps	35.25 ps	x <= 86.00 ps
Eye Diagram Mask Hits	0 hits	0 hits	x = 0 hits
Eye Height	195 mV	180 mV	100 mV <= x <= 1.200 V
Tj CP0 SigTest	69.60 ps	51.02 ps	x <= 132.00 ps
Rj (rms) CP0 SigTest	1.273 ps	1.153 ps	x <= 3.270 ps
Dj DD CP0 SigTest	51.70 ps	34.81 ps	x <= 86.00 ps

RIBBON CABLE

Ribbon cable (also called multi-wire planar cable and suitcase connector) is designed to be used with multi-contact IDC connectors in such a way that many IDC connections can be made at once, saving time in applications where many connections are needed. These connectors are not designed to be reusable, but can often be re-used if care is taken when removing the cable. An insulation-displacement connector (IDC), insulation-displacement technology/termination (IDT), or insulation-piercing connector is an electrical connector designed to be connected to the conductor(s) of an insulated wire or cable by a connection process which forces a selectively sharpened blade or blades through the insulation, bypassing the need to strip the wire of insulation before connecting. When properly made, the connector blade cold-welds to the wire, making a highly reliable gas-tight connection. Ribbon cables are available in shielded and unshielded varieties. There are many different types of ribbon cables, which include high flex life, high density insulated, color coded, and high temperature non-burning. The most popular ribbon cables (i.e., 26AWG wire, 0.050” spacing and common PVC insulation) provide 120 ohms impedance for any two adjacent wires. However, with copper tape on one side, 90 ohms impedance is achievable. The configuration shown in Figure 7 is ideal for controlling impedance.

FIGURE 7: RIBBON CABLE PINOUT

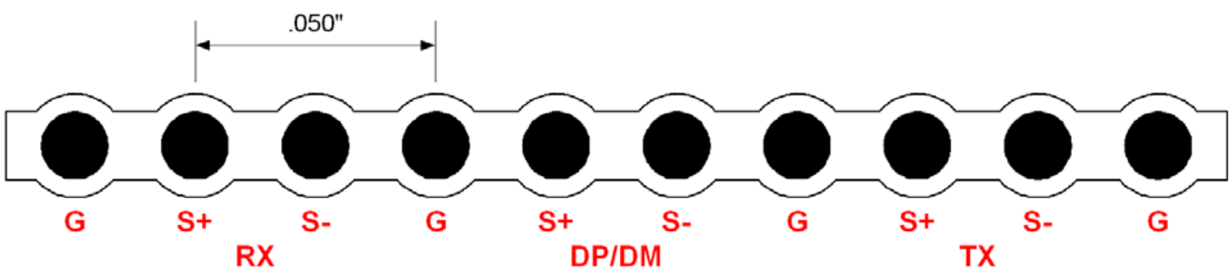


Figure 8 shows the ribbon cable test setup used by Microchip. Figure 9 a selection of the various ribbon cable lengths between 40 mm to 440 mm that were tested.

FIGURE 8: RIBBON CABLE TEST SETUP

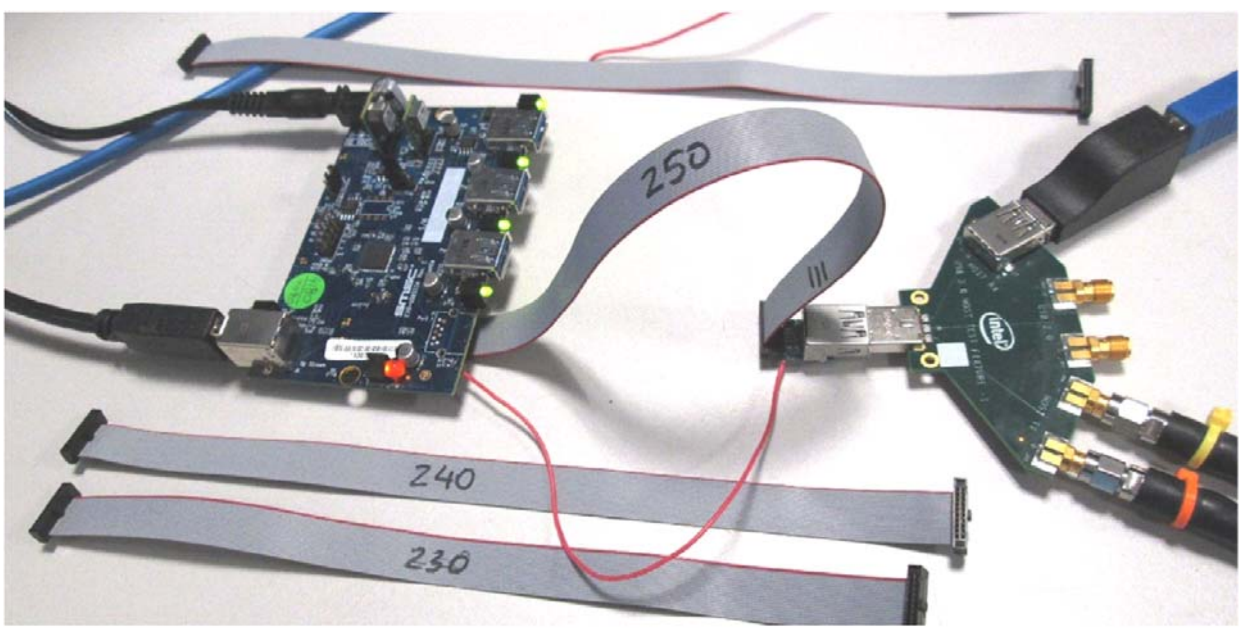


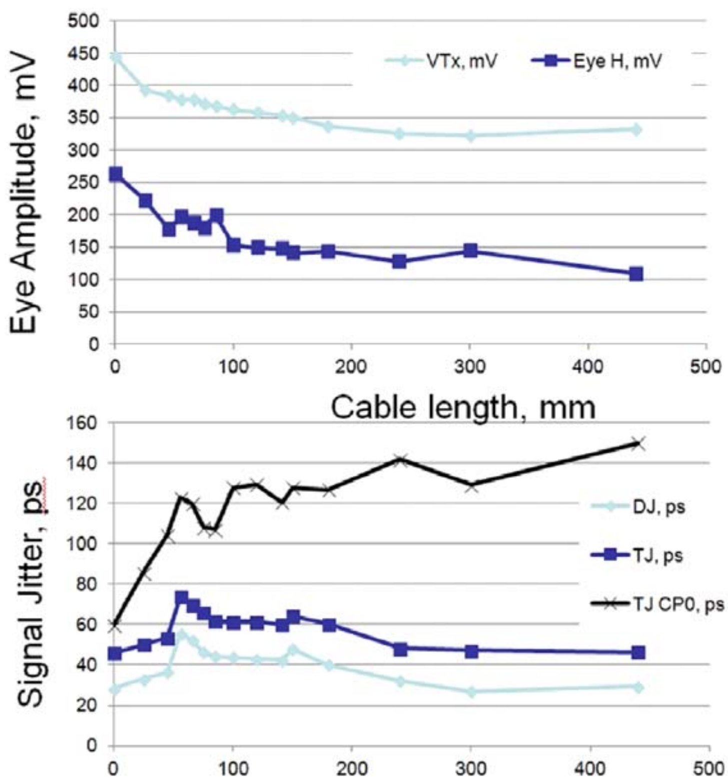
FIGURE 9: RIBBON CABLE TEST LENGTHS

Using TekExpress from Tektronix, the cables were tested to USB 3.0 TX parameter specifications. All cable lengths up to 300mm passed the USB 3.0 TX tests, as shown in Table 2 and Figure 10.

TABLE 2: RIBBON CABLE TEST RESULTS

Test Name	Low Limit	Measured Value	High Limit	Margin	Test Result
Dj-TX Deterministic Jitter - Dual Dirac	NA	11.752 s	86.000ps	74.248ps, NA	Pass
Eye Height - Transmitter Eye Mask	100.000mV	158.897mV	1.200 V	1.041V, 58.897mV	Pass
Mask Hits	NA	0	NA	NA, NA	Pass
Rj-TX Random Jitter - Dal Dirac	NA	1.527ps	3.290ps	1.763ps, NA	Pass
TCDR Slew Max Slew Rate	NA	4.894ms/s	10.000ms/s	5.106ms/s, NA	Pass
Tj-TX Total Jitter - Dual Dirac @ 10E-12 BER	NA	33.227ps	132.000ps	98.773ps, NA	Pass
TSSC - Mod Rate - SSC Modulation Rate	30.000kHz	30.781kHz	33.000kHz	2.219kHz, 780.769Hz	Pass
TSSC - USB Profile	NA	200.448ps	NA	NA, NA	Pass
UI - Unit Interval	199.940ps	200.452ps	201.060ps	607.897fs, 512.103fs	Pass
VTX Diff PP Differential PP TX Voltage Swing	100.000mV	489.681mV	1.200V	710.319mV, 389.681mV	Pass
Width @ BER	68.000ps	78.881 ps	NA	NA, 10.881ps	Pass

FIGURE 10: RIBBON CABLE TEST RESULT CHARTS

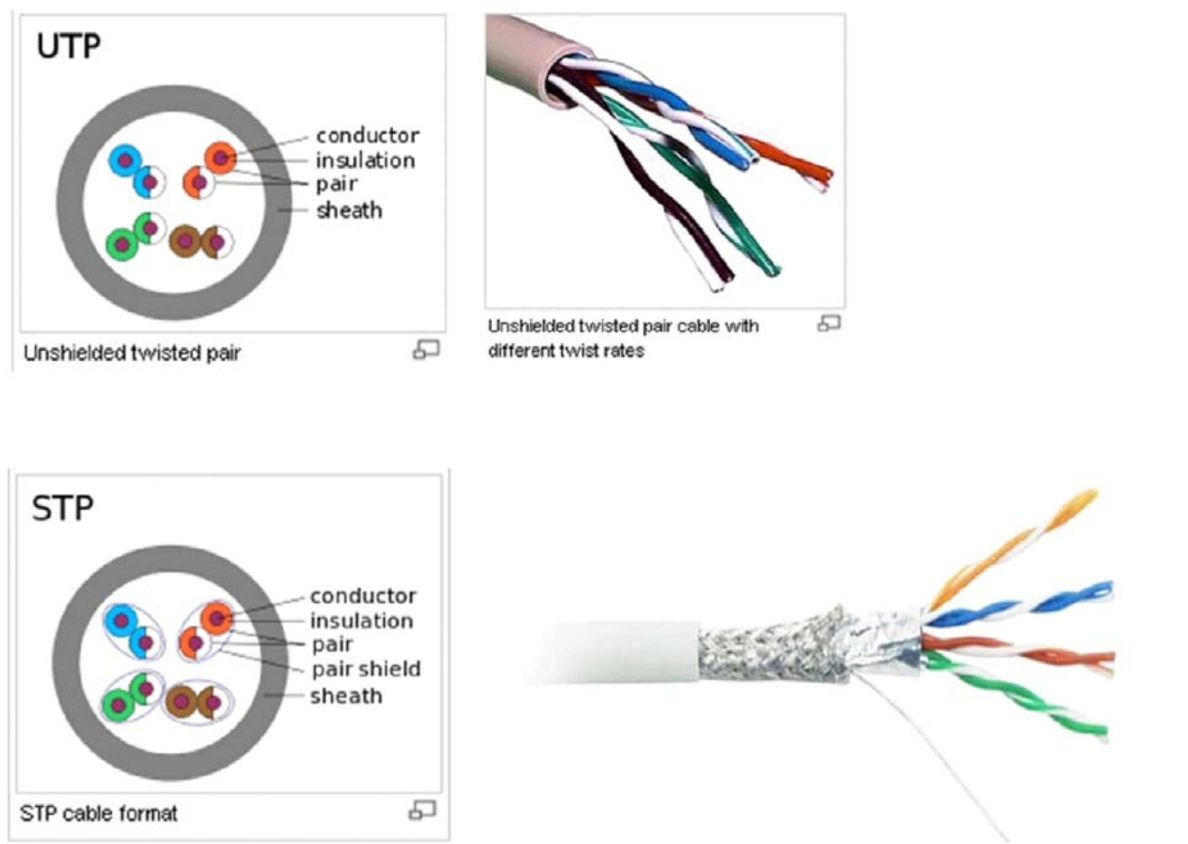


TWISTED PAIR CABLE

Twisted pair cabling is a type of wiring in which two conductors of a single circuit are twisted together. The pairs are twisted to provide protection against crosstalk (the noise generated by adjacent pairs). When electrical current flows through a wire, it creates a small, circular magnetic field around the wire. When two wires in an electrical circuit are placed close together, their magnetic fields are the exact opposite of each other. Thus, the two magnetic fields cancel each other out. They also cancel out any outside magnetic fields.

As shown in Figure 11, two basic types of twisted-pair cable exist: unshielded twisted pair (UTP) and shielded twisted pair (STP).

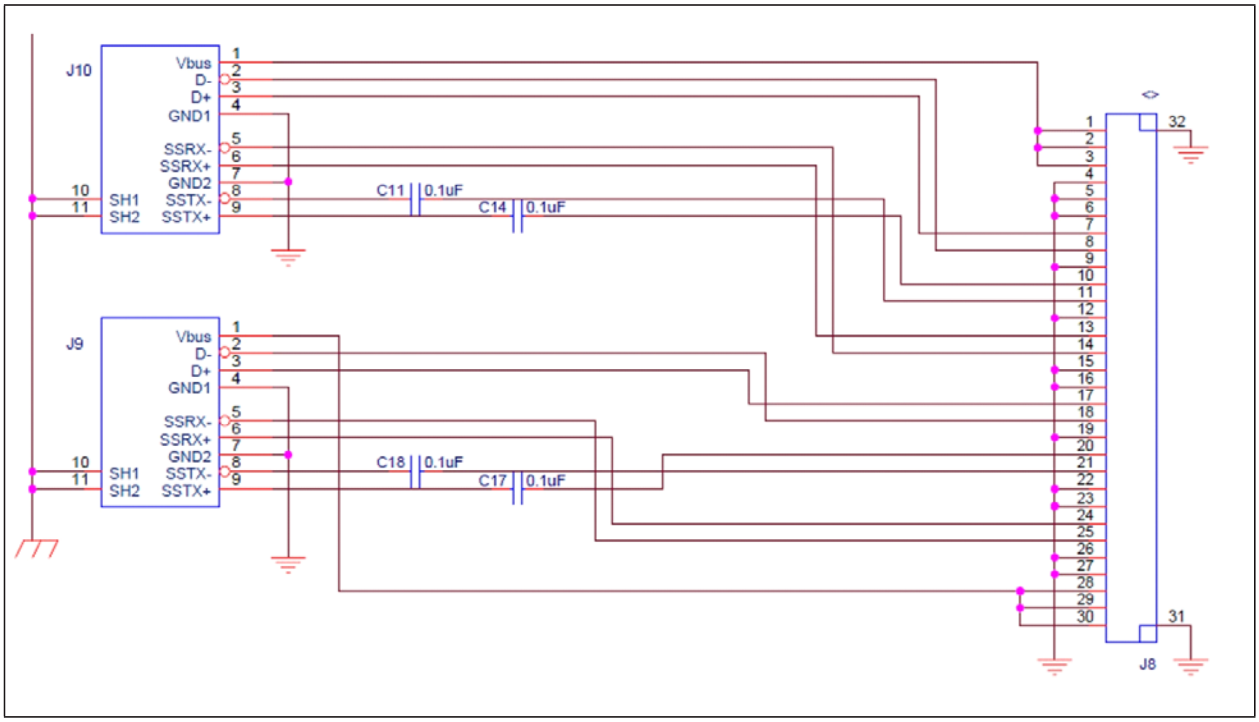
FIGURE 11: TWISTED PAIR CABLE TYPES



CONNECTORS

For USB 3.0 applications, selecting connectors requires careful considerations of EMI (due to series inductance), cross-talk (due to mutual inductance), and signal propagation (due to parasitic capacitance). With data transfer rates of 5Gbps, connectors play a critical role of maintaining signal integrity. However, due to cost, complexity and size, low-loss connector designs are increasingly difficult. However, selecting a connector with the shortest pin length possible, carefully assigning a pin pattern (adjacent power & ground pins, signal pin coupled to a return pin), and utilizing a surface mount type connector can help minimize signal integrity issues. A sample 30-pin FFC/ZIF connector schematic with signal/ground paired pins can be seen in Figure 12.

FIGURE 12: 30-PIN FFC ZIF CONNECTOR SCHEMATIC



Surface mount connectors have been proven to are perform better than through-hole connectors. Table 3 details a JTOL comparison between Standard B and Micro B connector from LeCroy's PeRT3 Eagle System, equipped with SDA 8Zi-A oscilloscope and QPHY-ISB3-TX-RX application.

TABLE 3: STANDARD B VS. MICRO B JTOL COMPARISON

	Micro B			Standard B		
	50MHz	33MHz	20MHz	50MHz	33MHz	20MHz
Board 1	44.80	48.60	60.00	41.00	46.60	58.20
Board 2	46.60	50.00	58.20	37.00	41.20	50.20
Board 3	46.00	48.00	59.00	41.00	45.40	55.80
Board 4	42.60	45.40	55.20	41.40	46.20	58.60
Board 5	44.20	50.80	60.40	41.20	46.20	58.20
Average	44.84	48.56	58.56	40.32	45.12	56.20

Note: The measurements in Table 3 are not absolute compliance measurements. They are only intended to show the relative difference between the connector types.

The constructions of standard B connectors varies, as can be seen in Figure 13. Table 4 details the performance differences between Standard B connectors from different manufacturers. Test were performed with LeCroy's PeRT3 Eagle System, equipped with an SDA 8Zi-A oscilloscope and the QPHY-ISB3-TX-RX application. TDR plots of the connectors can be seen in Figure 14.

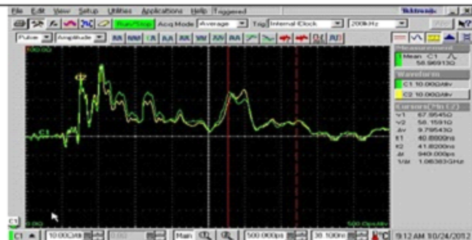
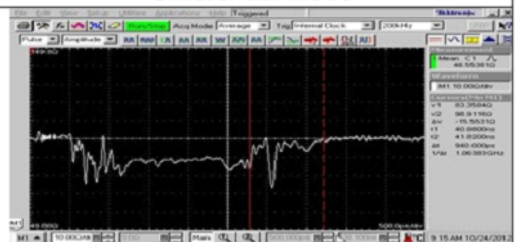
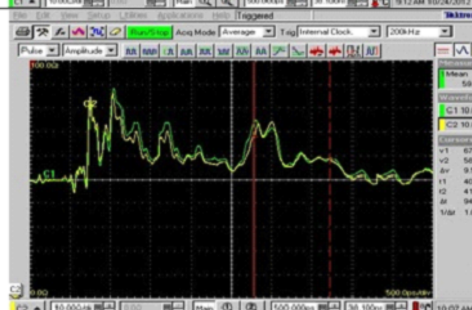
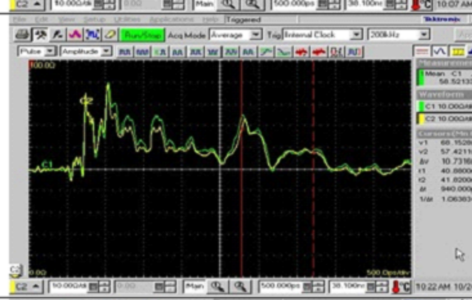
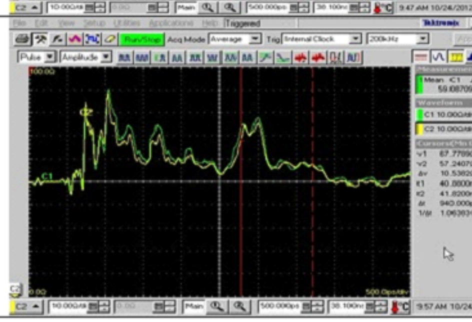
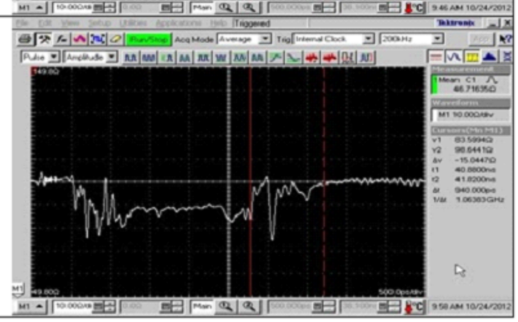
FIGURE 13: VARIOUS STANDARD B TYPE CONNECTORS

TABLE 4: STANDARD TYPE B CONNECTOR TEST RESULTS

	Smith Connector	Samtec U SB3-B-S-S-TH	CNC 1003-003-02000	Assmann AU-Y1007-3-R	Wurth 692221030100	Main Super 00004011x-00001	TE Connectivity 1932259-1
Board 1	39.00	N/A	44.40	46.60	49.00	47.00	49.60
Board 2	43.60	N/A	43.80	48.90	48.40	49.40	51.60
Board 3	36.72	46.80	40.50	47.60	44.40	44.20	50.00
Board 4	37.20	46.80	41.50	46.40	47.60	47.20	44.00
Board 5	38.60	46.20	38.60	45.80	46.80	44.20	49.00
Board 6	37.50	46.80	38.80	46.50	46.40	45.60	47.00

Note: The measurements in Table 4 are not absolute compliance measurements. They are only intended to show the relative difference between the connector types.

FIGURE 14: CONNECTOR TDR PLOTS

Manufacturer	Common Mode	Differential Mode
Amphanol P/N GSB3211311WEU		
Samtec P/N USB3-B-S-S-TH		
CNC P/N 1003-003-02000		
Main Super P/N 00004011x-00001		
TE Connectivity P/N 1932259-1		

SUMMARY

Connectors and cable assemblies are critical to enhance performance in USB 3.0 applications. A carefully designed PCB with a shielded Flexible Flat Cable or Ribbon Cable with ZIF/LIF type connectors provides excellent USB 3.0 performance. High performance internal USB 3.0 connections can be achieved with alternatives to expensive cable assemblies.

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APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision Level & Date	Section/Figure/Entry	Correction
A (09-19-13)	All	Initial Release

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