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.

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 1: CABLE ASSEMBLY BLOCK DIAGRAM

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

FIGURE 5: TDR TEST SETUP

FIGURE 6: TDR TEST SETUP

Amphenol Cable Assemblies

FFC Assemblies
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**

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

![Ribbon Cable Pinout Diagram]

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**

![Ribbon Cable Test Setup Image]
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**

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

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

<table>
<thead>
<tr>
<th></th>
<th>Micro B</th>
<th></th>
<th>Standard B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50MHz</td>
<td>33MHz</td>
<td>20MHz</td>
</tr>
<tr>
<td>Board 1</td>
<td>44.80</td>
<td>48.60</td>
<td>60.00</td>
</tr>
<tr>
<td>Board 2</td>
<td>46.60</td>
<td>50.00</td>
<td>58.20</td>
</tr>
<tr>
<td>Board 3</td>
<td>46.00</td>
<td>48.00</td>
<td>59.00</td>
</tr>
<tr>
<td>Board 4</td>
<td>42.60</td>
<td>45.40</td>
<td>55.20</td>
</tr>
<tr>
<td>Board 5</td>
<td>44.20</td>
<td>50.80</td>
<td>60.40</td>
</tr>
<tr>
<td>Average</td>
<td>44.84</td>
<td>48.56</td>
<td>58.56</td>
</tr>
</tbody>
</table>

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 vary, 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

<table>
<thead>
<tr>
<th></th>
<th>Smith Connector</th>
<th>Samtec U SB3-B-6-5-TH</th>
<th>CNC P/N 1003-003-02000</th>
<th>Assmann P/N AU-Y1007-3-R</th>
<th>Wurth P/N 692221030100</th>
<th>Main Super P/N 00004011x-000001</th>
<th>TE Connectivity P/N 1532259-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board 1</td>
<td>39.00</td>
<td>N/A</td>
<td>44.40</td>
<td>46.60</td>
<td>49.00</td>
<td>47.00</td>
<td>49.60</td>
</tr>
<tr>
<td>Board 2</td>
<td>43.60</td>
<td>N/A</td>
<td>43.80</td>
<td>48.90</td>
<td>48.40</td>
<td>49.40</td>
<td>51.60</td>
</tr>
<tr>
<td>Board 3</td>
<td>36.72</td>
<td>46.80</td>
<td>40.50</td>
<td>47.60</td>
<td>44.40</td>
<td>44.20</td>
<td>50.00</td>
</tr>
<tr>
<td>Board 4</td>
<td>37.20</td>
<td>46.80</td>
<td>41.50</td>
<td>46.40</td>
<td>47.60</td>
<td>47.20</td>
<td>44.00</td>
</tr>
<tr>
<td>Board 5</td>
<td>38.60</td>
<td>46.20</td>
<td>38.60</td>
<td>45.80</td>
<td>46.80</td>
<td>44.20</td>
<td>49.00</td>
</tr>
<tr>
<td>Board 6</td>
<td>37.50</td>
<td>46.80</td>
<td>38.80</td>
<td>46.50</td>
<td>46.40</td>
<td>45.60</td>
<td>47.00</td>
</tr>
</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Common Mode</th>
<th>Differential Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphenol P/N GS83211181W1U</td>
<td><img src="image" alt="Amphenol TDR Plot" /></td>
<td><img src="image" alt="Amphenol Differential Plot" /></td>
</tr>
<tr>
<td>Samtec P/N US83-B-5-5-TH</td>
<td><img src="image" alt="Samtec TDR Plot" /></td>
<td><img src="image" alt="Samtec Differential Plot" /></td>
</tr>
<tr>
<td>CINC P/N 1903-003-92000</td>
<td><img src="image" alt="CINC TDR Plot" /></td>
<td><img src="image" alt="CINC Differential Plot" /></td>
</tr>
<tr>
<td>Main SUPER P/N 90004011x-00001</td>
<td><img src="image" alt="Main SUPER TDR Plot" /></td>
<td><img src="image" alt="Main SUPER Differential Plot" /></td>
</tr>
<tr>
<td>TE Connectivity P/N 1932259-1</td>
<td><img src="image" alt="TE Connectivity TDR Plot" /></td>
<td><img src="image" alt="TE Connectivity Differential Plot" /></td>
</tr>
</tbody>
</table>
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.

REFERENCES

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3. History of FFC/FPC", Elco/AVX
4. Guidelines for Designing High-Speed FPGA PCBs', Altera
5. usb3-internal-connector-cable-specification", Intel Corporation
6. USB_3_0_e-Compliance_methodology_0p5_whitepaper", USB-IF
7. Wikipedia.org
APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

<table>
<thead>
<tr>
<th>Revision Level &amp; Date</th>
<th>Section/Figure/Entry</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (09-19-13)</td>
<td>All</td>
<td>Initial Release</td>
</tr>
</tbody>
</table>

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