Application Note

Compensate for Channel Loss with Equalizer Settings on High-Speed USB Isolators

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ABSTRACT

ISOUSB211DP repeater has embedded equalizers on its receiver and transmitter. These equalizers play a significant role in improving signal integrity in reducing inter-symbol interference (ISI) caused by the characteristic of PCB traces losses that are frequency dependent. This application note provides an overview of the effect of PCB trace loss, transmitter pre-emphasis, receiver equalization, and how to use ISOUSB211 pre-emphasis and equalizer to compensate for board trace and cable losses.

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1 PCB Trace Insertion Loss and Inter-Symbol Interference

A redriver and an isolated repeater are devices that enhance the signal integrity by equalizing and amplifying the signals. The main difference is the redriver behaves as an analog buffer which its output waveform is linearly proportional to the input waveform without equalization applied, but the isolated repeater consists of a digital isolator that generates a fresh copy of the signal across the isolation barrier based on the logic of the input signal. The input jitter that has not been compensated by the equalizer of the redriver and isolated repeater will be reflected at the transmitter output. Since the isolated repeater has an additional On-Off Keying circuitry, the total output jitter of an isolated repeater is the root sum squared of the jitter generated by the isolation circuitry and the uncompensated input jitter.

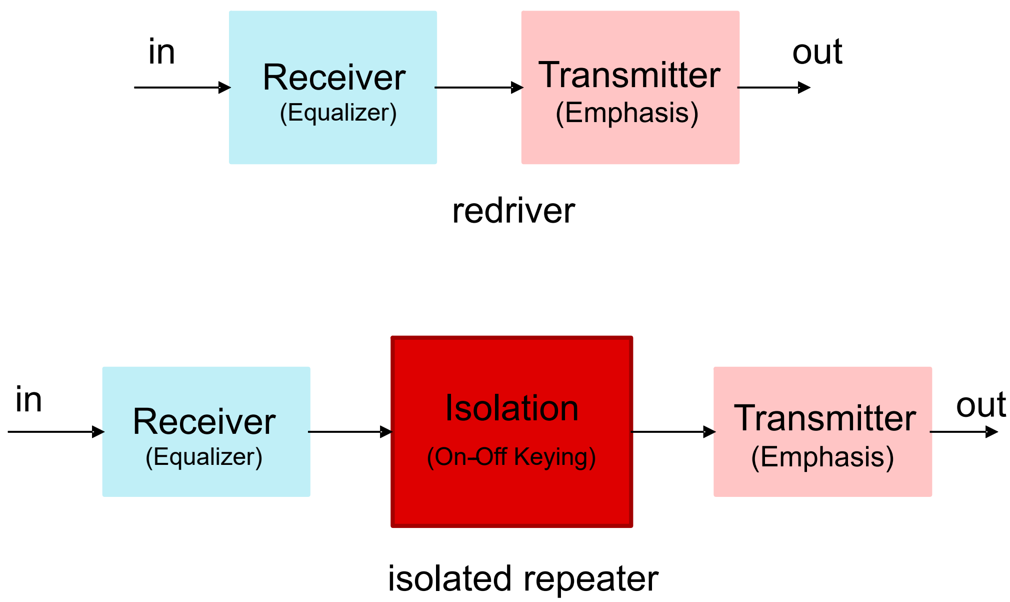

Figure 1-1. Isolated Repeater vs. Redriver

Figure 1-2 shows a printed circuit board (PCB) that consists of five pairs of differential traces. The USB 2.0 type-A to type-B receptacles placed at the two ends of these traces connect these traces to the ISOUSB211DPEVM through USB cables. The differential impedance (ZDiff) of these differential traces was designed to be 90-ohm achieved by setting the track-width to be 50mil, track-spacing to be 9 mil, track-height to be 0.4 mil, isolation height to be 59.2 mil, and the dielectric constant to be 4.9. Figure 1-3 shows the USB receptacles have been replaced by SubMiniature version A (SMA) connectors to properly connect to a vector network analyzer (VNA) for measuring the insertion loss of these differential traces.

Figure 1-2. FR4 board with USB 2.0 Receptacles

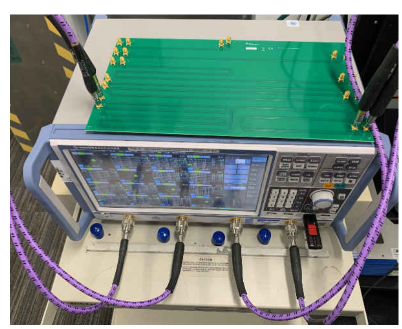

Figure 1-3. FR4 board with SMA connectors

Figure 1-4 shows the measured differential insertion losses for the five differential traces ranging from 6 inches to 4 feet. The first observation is a longer trace length results in a higher DC loss. The second observation is the insertion loss of a PCB trace increases proportionally to the transmission frequency. The third observation is the ringing on the curves caused by the impedance discontinuity along the traces. In general, the DC loss causes signal amplitude reduction similar to the effect of a resistor. The insertion loss at high frequency (operating frequency) and the reflection cause inter-symbol interference (ISI), thereby greatly reducing the receiver's drive length and increasing bit-error rate (BER).

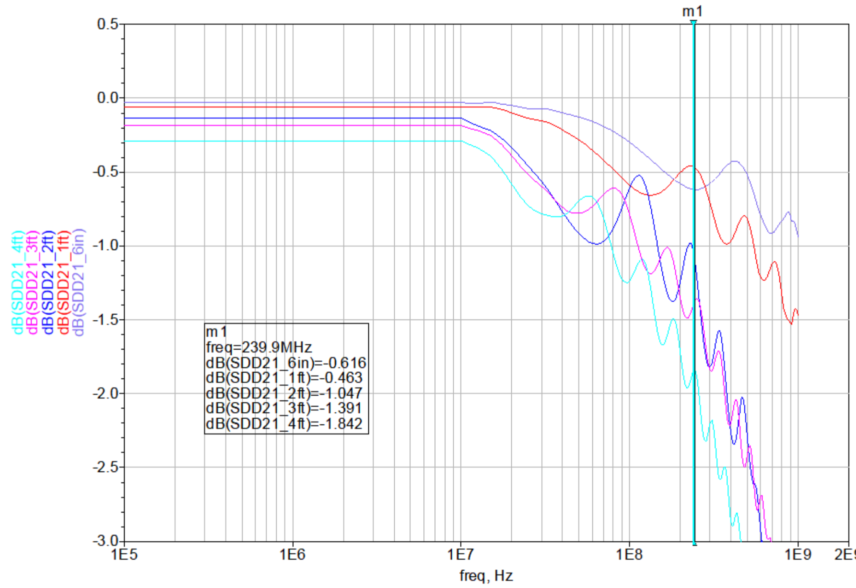

Figure 1-4. Insertion Losses for Differential Traces

A signal traveling through an ideal transmission medium such as a superconductor completes the transition within a symbol interval as shown in Figure 1-5. However, when the signal travels through the aforementioned lossy backplane, the transition expands to adjacent intervals. The resulting effect is the signal compels to make a transition to the opposite rail even before completing its transition when transmitting a high activity factor data such as a clock pattern and this behavior is called an ISI. Figure 1-6 shows the worst-case happens when there is a long run-length of zeros followed by a single one or vice versa in which the signal has sufficient time to reach one of the rails, but this causes the next opposite transition to have lowest peak voltage and directly reduces the eye-height. Figure 1-7 shows the impact of the ISI in eye diagrams for FR4 traces from 6inch, 1-feet, 2-feet, 3-feet, to 4-feet. The eye height and eye width shrink proportionally to the insertion loss of the lossy FR-4 traces.

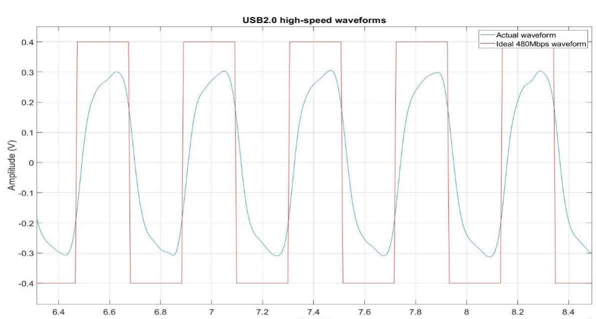

Figure 1-5. Ideal and Actual USB 2.0 Waveforms

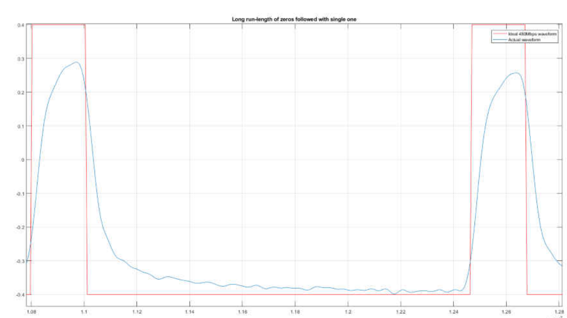

Figure 1-6. Ideal and Actual USB 2.0 Waveforms with Long Run-length

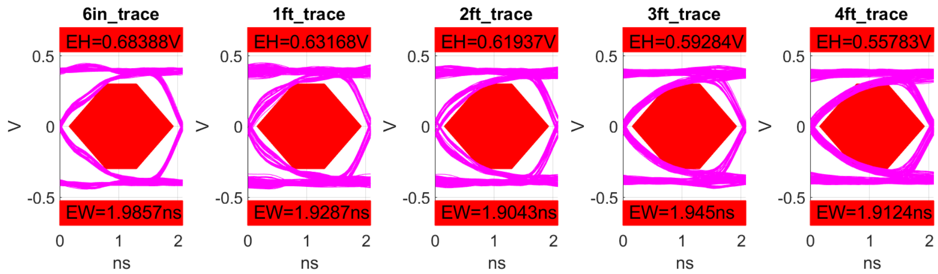

Figure 1-7. Eye-diagrams for 6 inch to 4 feet Traces

2 Transmitter Pre-Emphasis and Receiver Equalizer

ISOUSB211 transmitter consists of nine programmable pre-emphasis settings, and the receiver consists of nine programmable equalizer settings implemented with continuous-time linear equalizer (CTLE) architecture. We can estimate these nine pre-emphasis/equalizer characteristics using a 1-zero and 2-pole system that peaks at 240 MHz from 0.25 dB to 4 dB to the first-order approximation. The CTLE amplifies the high-frequency signal around 240 MHz while keeping the low-frequency signal unchanged. The pre-emphasis/equalizer boosts the high-frequency signal, and this has the effect of reducing the rise and fall times and thus allows the signal to get closer to the power rail and complete a transition within a symbol interval as shown in Figure 2-1 and Figure 2-2.

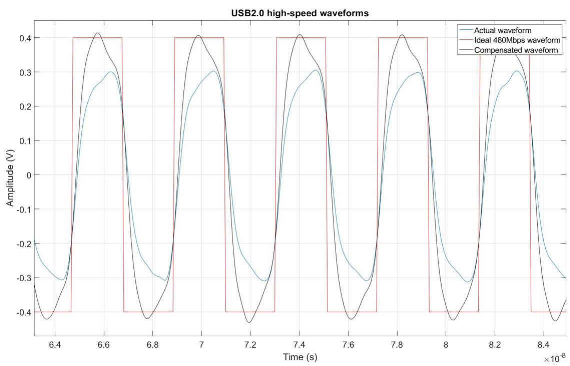

Figure 2-1. Compensated, Actual, and Ideal Waveforms

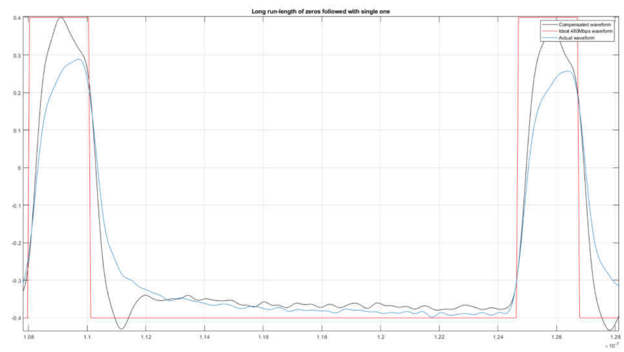

Figure 2-2. Compensated, Actual, and Ideal Waveforms with Long-Run Length

Figure 2-3 shows the time-domain waveforms of the nine ISOUSB211 transmitter pre-emphasis with a data pattern of long run-length of ones and zeros. The emphasized signal has a fixed width of a single bit (1/480 Mbps), and its strength is scaled proportionally from 00 to 11. With this variety of pre-emphasis settings, we are empowered to pick the optimal pre-emphasis setting to compensate for trace and cable losses.

Figure 2-3. ISOUSB211 Transmitter Pre-emphasis Measurements

3 Selecting an Optimal Pre-emphasis for Your System

Eye-height (EH) and eye-width (EW) of an eye diagram are the two metrics used to quantify the signal integrity in an interface system. The USB 2.0 standard requires a USB device to comply with the near-end and far-end eye-masks. Hence, selecting an optimal pre-emphasis to compensate for your system trace loss will improve the eye width and eye height to meet the USB 2.0 eye-mask requirements. Figure 3-1 and Figure 3-2 show two ISOUSB211 placements for reducing the ISI caused by the insertion losses of the FR4 differential traces as shown in Figure 1-2 to comply with the USB 2.0 near-end eye-mask. These insertion losses can either be compensated using the transmitter pre-emphasis by placing the trace at the upstream of the ISOUSB211 as shown in Figure 3-1 or the receiver equalizer by placing the trace at the downstream of the ISOUSB211 as shown in Figure 3-2.

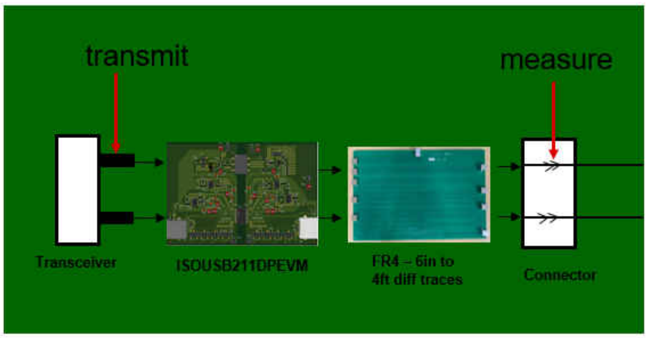

Figure 3-1. NE Setup 1

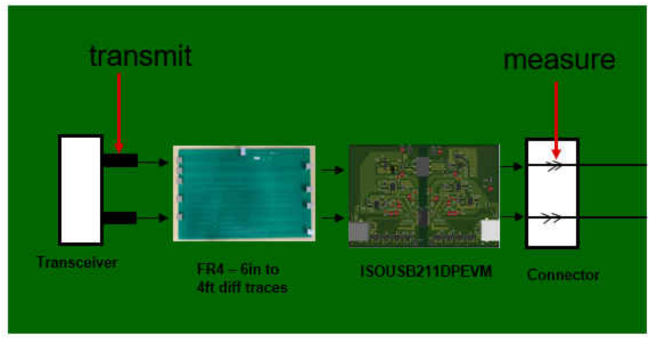

Figure 3-2. NE Setup 2

4 Eye-Diagrams for 6 inch to 4 feet Traces with all Nine Pre-Emphasis Settings for USB 2.0 Near-end Eye-mask

Figure 4-1 through Figure 4-6 show the eye-diagram measurements with Figure 3-1 setup that uses the transmitter pre-emphasis to compensate for the trace loss. The receiver equalizer is set to 00 throughout the measurements since the loss between the transceiver and ISOUSB211DPEVM is ignorable. The first subplots of each figures show the measured eye-diagrams of FR-4 traces without including the ISOUSB211DPEVM. It is obvious that the system fails the near-end eye-mask even with a 6-inch trace length. We use the EH multiplied with EW as the metric to justify transmitter pre-emphasis performance as shown in Figure 4-6.

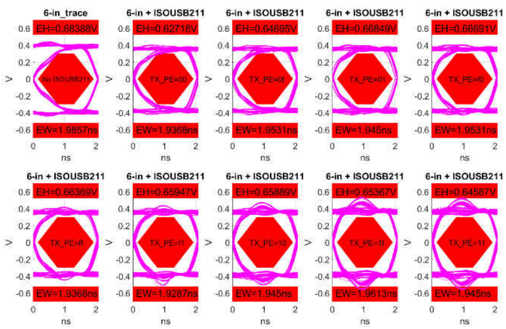

Figure 4-1. NE TX_PE 6-inch Trace

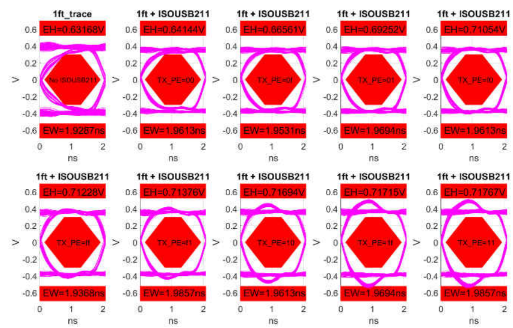

Figure 4-2. NE TX_PE 1-feet Trace

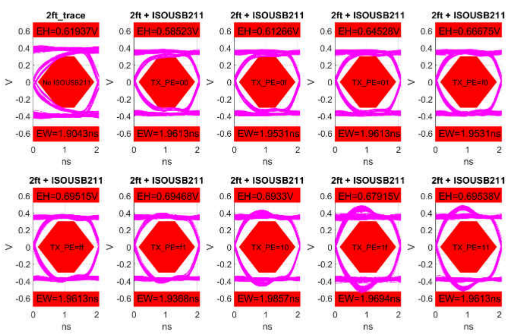

Figure 4-3. NE TX_PE 2-feet Trace

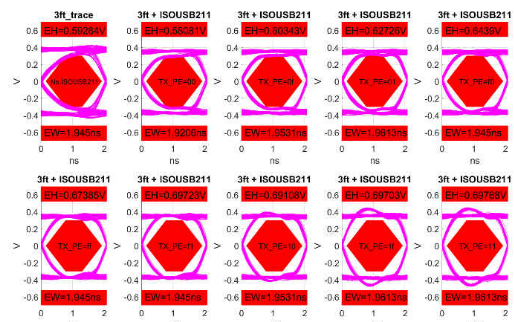

Figure 4-4. NE TX_PR 3-feet Trace

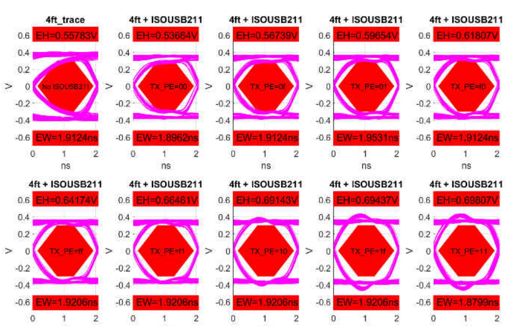

Figure 4-5. NE TX_PE 4-feet Trace

	00	0f	01	f0	ff	f1	10	1f	11
6inch	1.2148	1.2636	1.3002	1.3026	1.2855	1.2719	1.2815	1.282	1.2562
1ft	1.258	1.3	1.3639	1.3936	1.9368	1.9857	1.9613	1.9694	1.9857
2ft	1.1478	1.1966	1.2656	1.3022	1.3634	1.3455	1.3767	1.3375	1.3638
3ft	1.1155	1.1786	1.2302	1.2524	1.3106	1.3561	1.3498	1.3671	1.3683
4ft	1.0176	1.0851	1.1651	1.182	1.2325	1.2764	1.3279	1.3336	1.3123

fail marginal pass optimal

fail = EH and/or EW violate eye-mask
marginal= EH < 5mV or EW < 0.05UI from eye-mask
pass = meet eye-mask
optimal = best performance setting

Figure 4-6. Summary of EH*EW Metric for NE TX_PE 6-inch to 4-feet Traces

Figure 4-7 through Figure 4-12 show the eye-diagram measurements with Figure 3-2 setup that uses the receiver equalizer to compensate for the trace loss. The transmitter pre-emphasis is set to 00 throughout the measurements. As mentioned, due to the fact that the On-Off Keying circuitry in the isolator of the ISOUSB211 generates a fresh copy of the signal based on the logic of input signal, this cannot justify the receiver equalizer performance by gauging the eye-height (EH). The output jitter of the ISOUSB211 is additive from the uncompensated input jitter and the jitter generated by the On-Off Keying circuitry. We can pinpoint the optimal receiver equalizer settings for each trace length by judging the eye-diagram that has the wider eye-width (EW) or lowest jitter as shown in Figure 4-12.

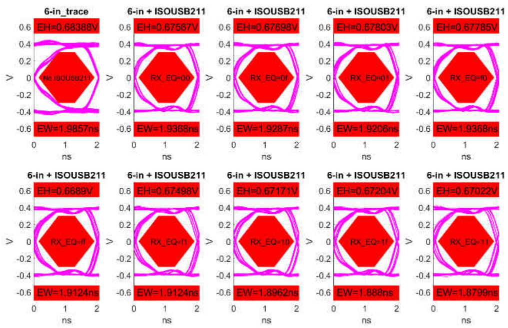

Figure 4-7. NE RX_EQ 6-inch Trace

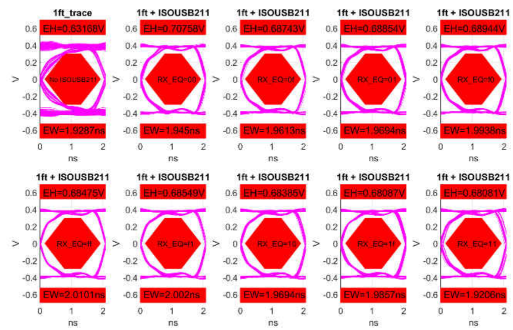

Figure 4-8. NE RX_EQ 1-feet Trace

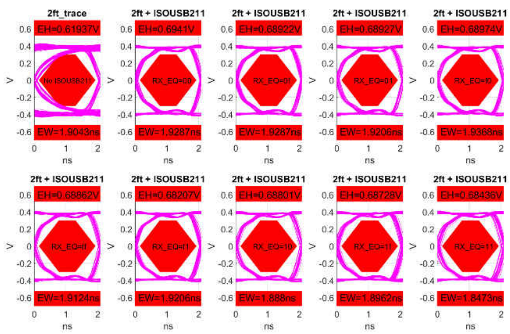

Figure 4-9. NE RX_EQ 2-feet Trace

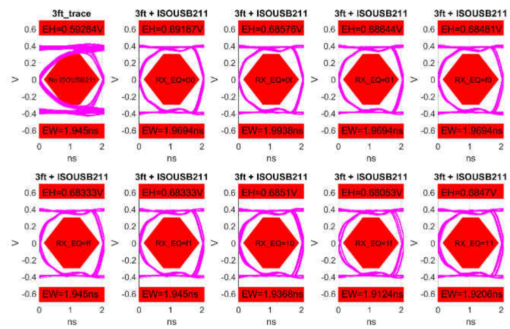

Figure 4-10. NE RX_EQ 3-feet Trace

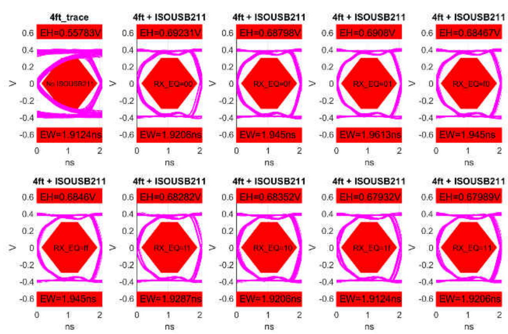

Figure 4-11. NE RX 4-feet Trace

	00	0f	01	f0	ff	f1	10	1f	11
6inch	1.9368	1.9287	1.9206	1.9368	1.9124	1.9124	1.8962	1.888	1.8799
1ft	1.945	1.9613	1.9694	1.9938	2.0101	2.002	1.9694	1.9857	1.9206
2ft	1.9287	1.9287	1.9206	1.9368	1.9124	1.9206	1.888	1.8962	1.8476
3ft	1.9694	1.9938	1.9694	1.9694	1.945	1.945	1.9368	1.9124	1.9206
4ft	1.9206	1.945	1.9613	1.945	1.945	1.9287	1.9206	1.9124	1.9206

fail　marginal　pass　optimal

fail = EH and/or EW violate eye-mask
marginal= EH < 5mV or EW < 0.05UI from eye-mask
pass = meets eye-mask
optimal = best performance setting

Figure 4-12. Summary of EW metric for NE RX_EQ 6-inch to 4-feet Traces

5 Eye-Diagrams for 6 inch to 4 feet Traces and 5m Cable with all Nine Pre-emphasis Settings for USB 2.0 Far-end Eye-mask

Figure 5-1 shows the setup for measuring the far-end eye-mask as specified by the USB 2.0 standard. The ISOUSB211 is placed next to the transmitter, and a USB receptacle connects the FR4 trace to a 5-m USB cable. We used a 5-m cable to account for the worst-case cable loss that is specified by the USB 2.0 standard. The signal is measured at the other end of the 5-m cable for its far-end eye performance.

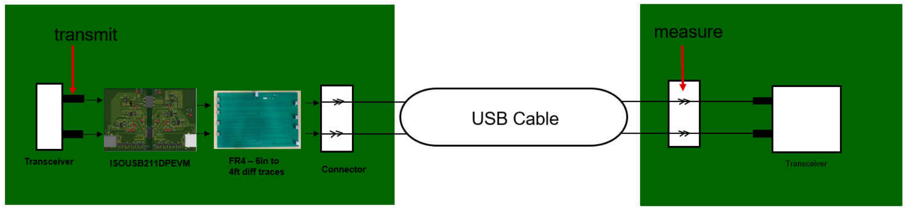

Figure 5-1. Far-end Eye Measurement Setup

Figure 5-2 through Figure 5-7 show the eye-diagram measurements with Figure 5-1 setup that uses the transmitter pre-emphasis to compensate for the trace and cable losses. The receiver equalizer is set to 00 throughout the measurements. The transmitter pre-emphasis performances are evaluated by multiplying the EW with EH as shown in Figure 5-7.

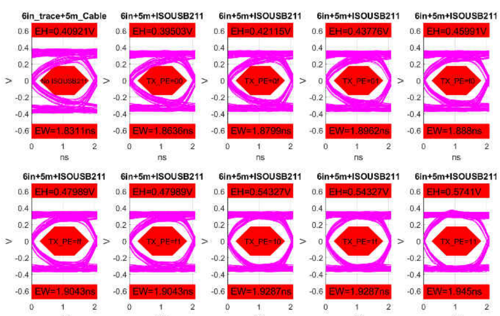

Figure 5-2. FE TX_PE 6-inch + 5 m

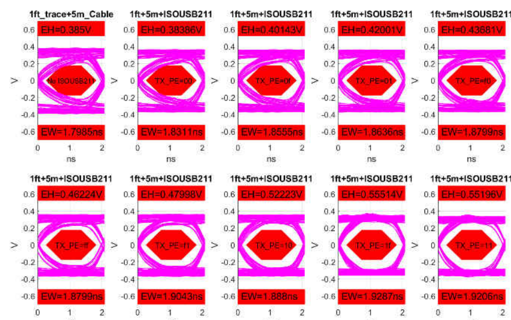

Figure 5-3. FE TX_PE 1-feet + 5 m

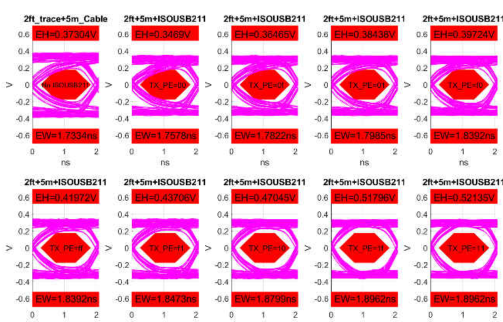

Figure 5-4. FE TX_PE 2-feet + 5 m

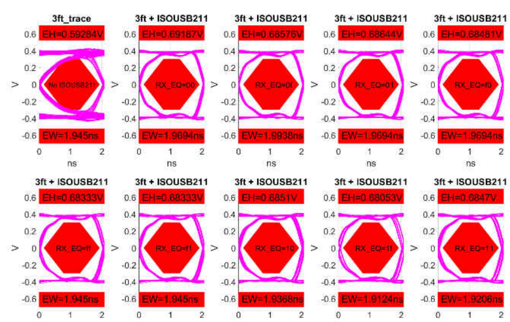

Figure 5-5. FE TX_PE 3-feet + 5 m

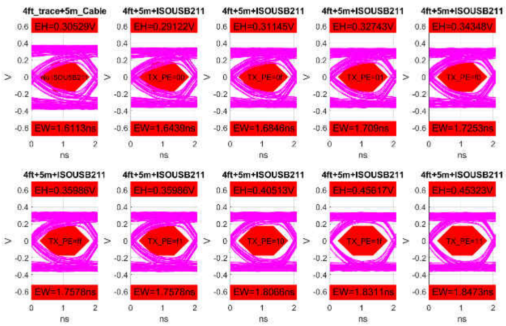

Figure 5-6. FE TX_PE 4-feet + 5 m

	00	0f	01	f0	ff	f1	10	1f	11
6inch	0.7361	0.7917	0.83006	0.8686	0.91386	0.91386	1.0478	1.0478	1.1166
1ft	0.70288	0.74485	0.7827	0.82115	0.8689	0.914	0.9859	1.0707	1.0832
2ft	0.6097	0.6498	0.6913	0.7306	0.7719	0.8074	0.8843	0.9821	0.9885
3ft	0.577	0.618	0.6334	0.6802	0.7102	0.738	0.8188	0.929	0.9411
4ft	0.4787	0.5246	0.5595	0.59259	0.6325	0.63256	0.73192	0.8352	0.8372

fail marginal pass optimal

fail = EH and/or EW violate eye-mask
marginal= EH < 5mV or EW < 0.05UI from eye-mask
pass = meet eye-mask
optimal = best performance setting

Figure 5-7. Summary of EH*EW metric for FE TX_PE 6-inch to 4-feet Traces

6 Using Receiver Equalizer and Transmitter Pre-emphasis for Channel Loss Compensation Simultaneously

In the previous sections, the trace is either located upstream or downstream of the ISOUSB211 isolated repeater. Hence, we use either receiver equalizer or transmitter pre-emphasis to compensate for the trace loss. For a system that has a trace differential loss greater than 2 dB, it is recommended to distribute the loss to the upstream and the downstream of the ISOUSB211 and use the receiver equalizer and the transmitter pre-emphasis to compensate for the trace loss simultaneously. Figure 6-1 shows ISOUSB211EVM located between the FR-4 traces. In this setup, the receiver equalizer and the transmitter pre-emphasis work together to compensate for the total trace loss; the receiver equalizer compensates for the upstream trace loss, and the transmitter pre-emphasis compensates for the downstream trace loss.

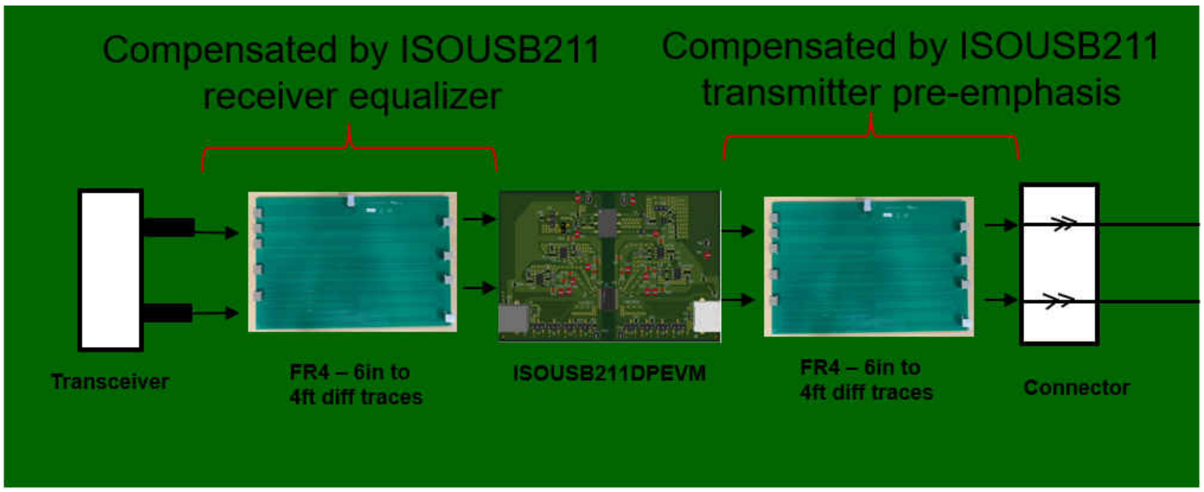

Figure 6-1. Using RXEQ and RX PE for Trace Loss Compensation

7 Summary

The ISOUSB211DP consists of nine transmitter pre-emphasis settings and nine equalizer settings to compensate for different trace and cable losses to enhance the system signal integrity. An USB 2.0 system with a need for isolation that struggles with ISI can benefit from using ISOUSB211DP equalizer and pre-emphasis to improve the EH and EW to meet the USB 2.0 near-end eye-mask and far-end eye-mask requirements. We have seen that the ISOUSB211 transmitter pre-emphasis and receiver equalizer manage to compensate FR4 differential trace up to 4 feet length, or less than 2dB differential loss respectively. For a system that has higher loss, you can distribute the loss on both transmitter and receiver sides and rely on the transmitter pre-emphasis and receiver equalizer to compensate for the higher loss.