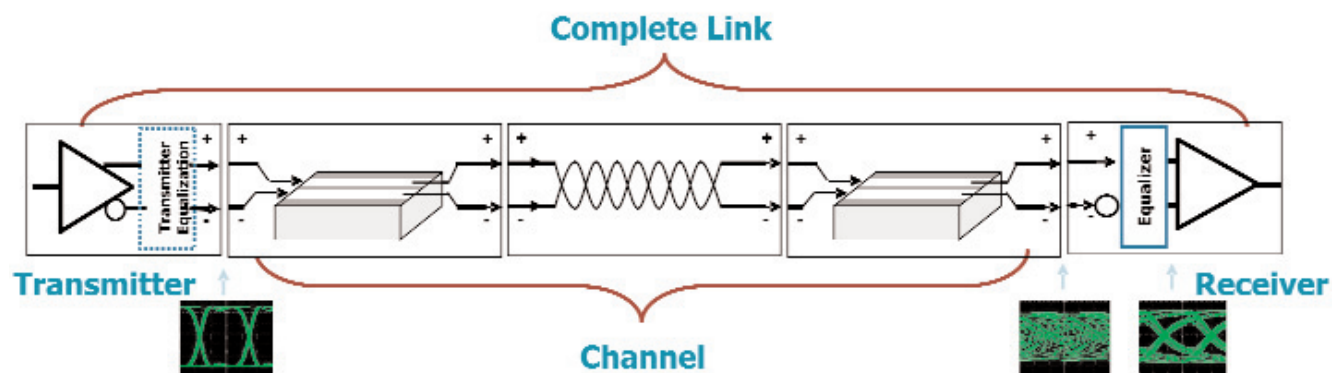


# Equalization and Serial Data Link Analysis Methods (SDLA) with 80SJNB Advanced



"This application note describes test and measurement methodology used by serial data standards running on lossy/dispersive channels which close the eye diagram at the receiver, and where equalization (FFE/DFE) is used to open the eye. Comparison of measurement at the receiver and the recommended measurement at the Transmitter is demonstrated, as well as other SDLA concepts of interest to serial data designers and test engineers. The software used in this application note runs on the DSA8200 and other 8000 Series sampling oscilloscopes."

## Closed Eye Diagrams, Equalizing Receivers and Transmitters

Currently a number of designs and standards for serial data links entered an era where their high speed signaling becomes severely channel (interconnect) limited, closing the eye diagram at the receiver end. Equalization methods are used to open the eye and operate the link.

There are several challenges when measuring or debugging a serial data link operating on a severely limiting channel: the channel and the transmitter interact in a complex way, the eye diagram at the receiver is nearly or completely closed, the receiver doesn't discriminate the signal directly but after equalization, and so on. This application note goes through an example of considering an Infiniband cable - four-lane full-duplex cable designed for operation at

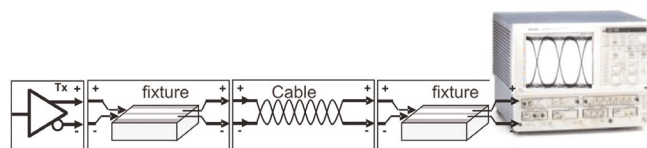
2.5 Gb/s - for signaling rate as fast as 8.5 Gb/s by the use of receiver equalization. Such example could be an extension of a "PCI-Express-over-cable"; the important point is that the system is running at a signaling bit-rate at which the cable severely degrades the transmitted NRZ (no-return to zero) pulses.

## Measurement Setup – End of a Physical Channel

Since we are testing transmitter + channel combination our complete link comprises of transmitter IC, the transmitter card (PCB and connector on the transmitter side), cable with its connectors, and receiver card (again with its connector and PCB). The receiver is represented by an equalizer emulator in the oscilloscope. Since we are at an exploratory stage the transmitter is represented by a laboratory signal source (AWG or a BERT).

# Equalization and Serial Data Link Analysis Methods with 80SJNB Advanced

## ► Application Note



► **Figure 1.** Serial Data link experiment setup.

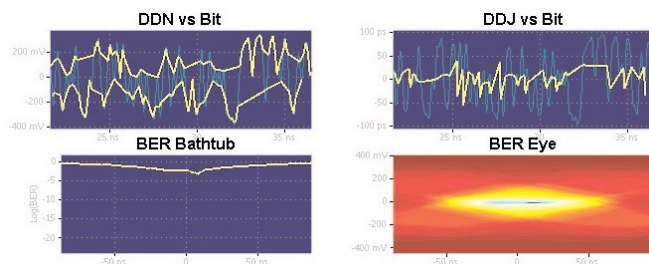
## First Measurement – End of the Channel

The whole system is first tested at our bit-rate of interest, with the setup shown in Figure 1. Note that measuring at the end of the channel introduces several problems; we'll look into them below.

Looking at the numeric results, we find that the eye opening at BER-12 is 0 V (Figure 2, Eye Opening @ 1E-12; obviously this channel can not be used without equalization. The 80SJNB package offers jitter, noise and BER plots; Figure 3 shows several of them. A review of the plots quickly gives more insight of the problems our receiver (the oscilloscope with 80SJNB in this case) encountered. First note the final result: the BER Eye plot, Figure 3. This is a view of the eye diagram in which the bit error rate result is shown as the receiver scans across the vertical threshold – voltage – and across horizontal decision point, i.e. over the unit interval (UI) left to right. At every point on this 2-dimensional space the resulting BER is scaled as color; deep blue means few or no errors, light blue some errors, yellow many, and red means very high rate of errors. Clearly the error rate in our plot is very high – we can see hardly any dark colored area (equivalent to a deep bathtub). Since the BER eye plot is a surface in 3D (time on X axis, threshold voltage on the vertical, and BER on the Z axis) it is difficult to represent it in a document beyond what's done with the color mapping; if you are in front of your running 80SJNB you can double-click the plot and select a rotate-able 3D view to get better understanding of the BER surface. Here we've used another graph to show a slice of the BER surface – the BER bathtub; see bottom left graph in Figure 3. The bathtub is a horizontal cut across the complete 3D surface at a given decision threshold;

Data Source: MATH1: C5-C6	Data Rate: 8.5 Gbps	Filter: None
SSC: Off	Pattern: 127 bits	Channel: None
Phase Reference: None	Sample Count: 52.70 k	Equalizer: None
<b>Jitter (Decision Threshold: -7.68 mV )</b>		
<b>Random Jitter</b>		
RJ (RMS)	= 829.36 fs	
RJ(h) (RMS)	= 600.00 fs	
RJ(v) (RMS)	= 572.57 fs	
<b>Deterministic Jitter</b>		
DJ	= 97.78 ps	
DDJ	= 90.50 ps	
DCD	= 5.36 ps	
PJ	= 2.50 ps	
PJ(h)	= 1.07 ps	
PJ(v)	= 2.26 ps	
<b>Total Jitter @ BER</b>		
TJ (1E-12)	= 107.52 ps	
Eye Opening (1E-12)	= 10.13 ps	
<b>Dual Dirac</b>		
RJ(d-d)	= 997.83 fs	
DJ(d-d)	= 93.44 ps	
<b>Noise (Sampling Phase: 0 UI )</b>		
<b>Random Noise</b>		
RN (RMS)	= 943.24 uV	
RN(v) (RMS)	= 942.24 uV	
RN(h) (RMS)	= 43.44 uV	
<b>Deterministic Noise</b>		
DN	= 328.97 mV	
DDN	= 326.79 mV	
DDN(level 1)	= 346.08 mV	
DDN(level 0)	= 345.29 mV	
PN	= 3.72 mV	
PN(v)	= 3.72 mV	
PN(h)	= 77.79 uV	
<b>Total Noise @ BER</b>		
TN (1E-12)	= 329.83 mV	
Eye Opening (1E-12)	= 0 V	
Eye Amplitude	= 329.83 mV	
<b>SSC Modulation</b>		
Magnitude	= 0 ppm	
Frequency	= 0 Hz	

► **Figure 2.** End of the physical cable: numerical results.



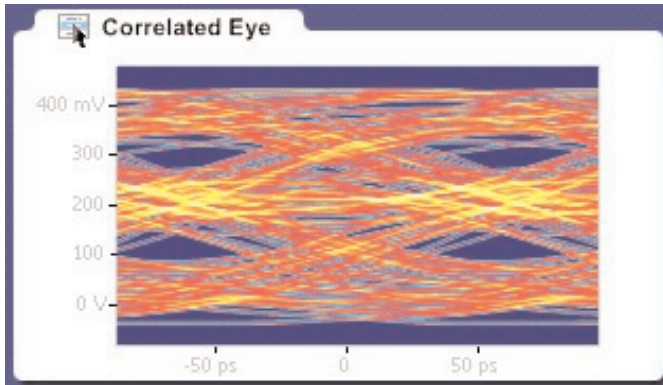
► **Figure 3.** End of the physical cable: selected important plots at the end of the cable.



see the menu Setup-> Analysis, (see above menu button) for setting of the voltage threshold, decision time, and other BER eye analysis settings.

Next step in the analysis of the plots is to find out what component (or components) of jitter or noise are causing this high error rate. Reviewing the “DDJ vs. Bit” plot (data dependent jitter vs. bit), or just the DDJ number we see that jitter is not the most limiting problem.

On the other hand the “DDN vs. Bit” (data dependent noise vs. bit) plot reveals the culprit: it's evident from this plot that that the lowest level of the High logic level approaches or crosses the highest level of the Low logic level; that is, the data dependent noise caused by ISI is the problem. This is verified with another view, the Correlated Eye plot in Figure 4.

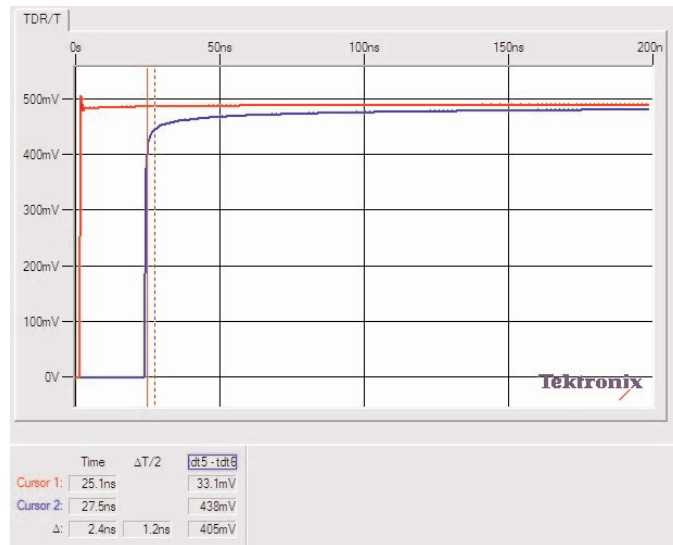


► **Figure 4.** End of the physical cable: numerical results: Correlated Eye diagram.

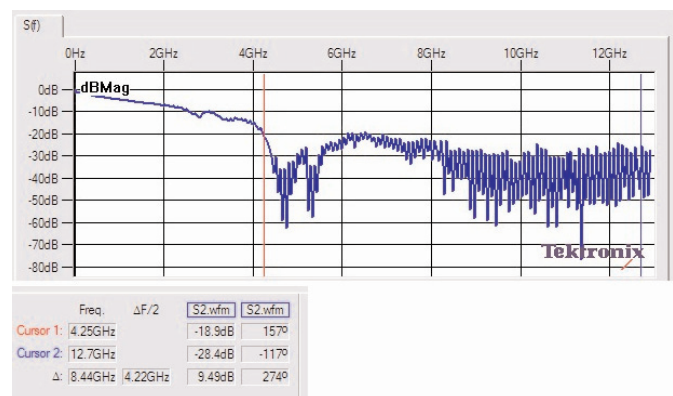
Interestingly, the standard eye shows reasonable amount of opening above and below the eye crossing. At those points half of the data – a steady high and a steady low – could be resolved. Unfortunately the other half of the data – all transitioning bits – is going through the crossing. Attempting to discriminate this data into High vs. Low at this timing will therefore be more difficult than any other timing in the whole eye; we can not use the four little opened eyes in the corners.

Note: the Correlated Eye plot is similar to normal eye but to one from which random and periodic noise and jitter were removed; in that is, to one with no uncorrelated effects. In other words, only ISI-caused effect, such as DDJ and DDN, are visible – and visible the clearer for not being obscured by the uncorrelated impairments.

Results above show the impact of the channel on our 8.5 Gb/s signal to be very significant. What does the channel's impedance analysis report? We'll analyze the channel with TDR/TDT\*1 and S-parameters plots for both time-domain and frequency domain view. First, the TDT result, Figure 5: the red trace is the reference step (bypassing the DUT). The blue channel is the step pulse at the output of the DUT. The response is smooth, without large reflections, but from the cursors it is obvious that the rise time is very long – on the order of one nanosecond – for a 8.5 Gb/s signaling, with its 117 ps UI interval. Of course the rise-time is measured at 10% to 90% and the signaling swings do not have to reach such high settling level, but clearly there will be significant ISI.



► **Figure 5.** Time-domain view of the channel's step response.

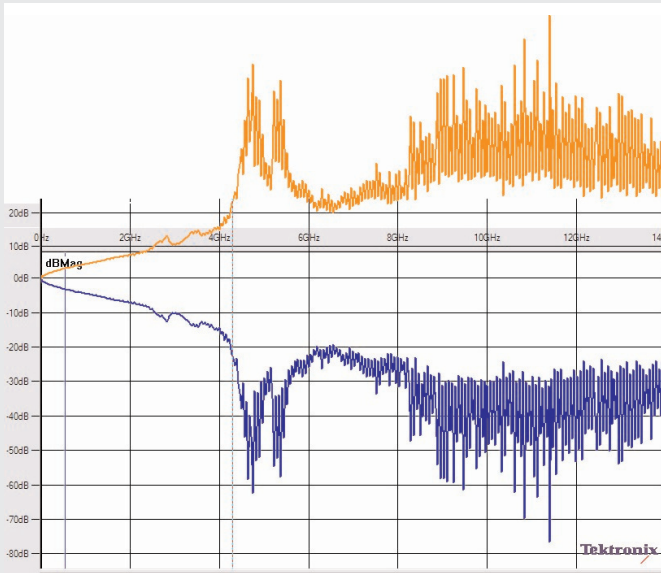


► **Figure 6.** Frequency domain view of the channel's loss.

Now consider the frequency domain picture: from readout for cursor 1 the loss is 19 dB at 4.25 GHz, the 1st harmonic of the signal; at 3rd harmonic the loss is 28 dB, and in area between 4 and 5 GHz are several spurs of very large loss of about 60 dB. Clearly this channel is not suitable for 8.5 Gb/s NRZ transmission without large degree of correction; this matched the observation of the closed eye diagram above.

– To recapitulate on what we did in this first part of the analysis of our design: measuring at the end of the channel (Infiniband cable) we verified that the cable completely closes the eye diagram, and is therefore unusable with a standard, non-equalizing receiver at the bit-rate given. This was confirmed in a time-domain and frequency-domain analysis of the channel.

\*1 TDR: Time Domain Reflectometry; TDT Time Domain Transmission. Typically used together. TDT is plotted here.



► **Figure 7.** Gain/Loss of the channel under investigation vs. frequency, with inverse curve.

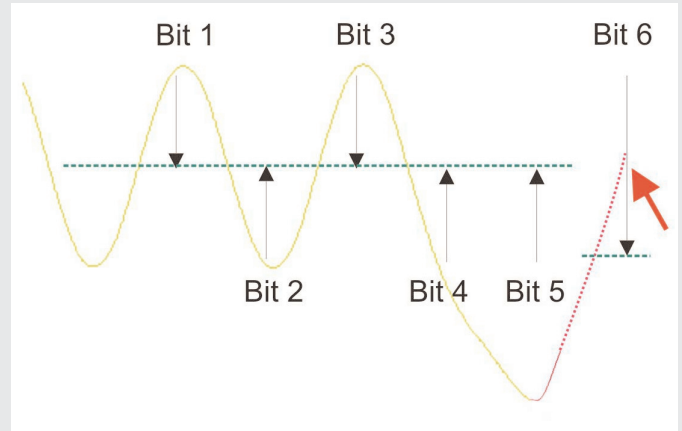
## Equalization: The Concept

In order to open the eye diagram – currently closed at the receiver – we will use equalization. Here's a brief explanation of this idea; please review the literature – two representative sources out of many are [1], [2] for more detailed information.

### – FFE equalization (Feed-Forward equalization)

Basic idea for FFE equalization is hinted at from the frequency plot of the loss of the channel: since the channel exhibits a frequency-dependent loss (see the blue trace in Figure 7), if we run the signal through a filter – equalizer – with an opposite magnitude of loss we should get a flat response again; this opposite magnitude is shown very simply as just a graphical inversion as the orange trace in Figure 7.

While this form of equalization works in principle, it is apparent that the inversion curve amplifies greatly the high frequency components of the signal – and therefore the noise as well. This is a weakness of FFE equalization.



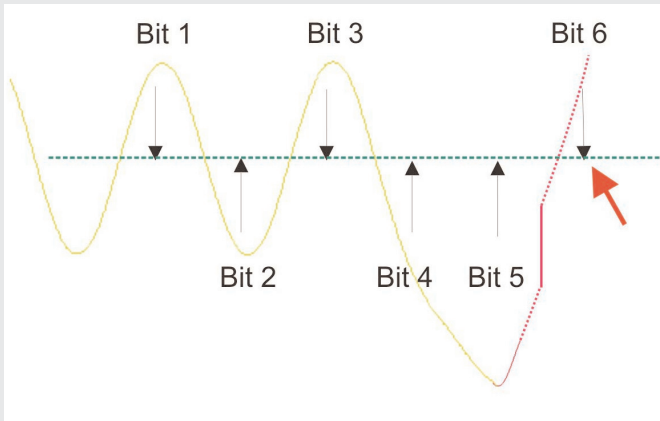
► **Figure 8.** DFE equalization concept.

### – DFE equalization (Decision Feedback Equalization)

Decision feedback equalization is based on the following observation: if we know that certain sequence of bits is moving the ideal threshold level used for distinguishing high from low (shown in green dashed line in Figure 8), then if such sequence of bits occurs in the already recognized signal the receiver should change the decision threshold accordingly to an appropriate new threshold. Figure 8 shows a graphical example.

The yellow trace is a sequence of NRZ bits; Bit 1 is logic “1”, Bit 2 is logic “0”, etc. The arrows below and above the bits show the threshold and timing point for decision of each bit. In the 1010 sequence the ideal threshold (green dashed line) for recognizing the next bit is in the mean of the 1010 pattern. The same threshold level recognizes bit 5, as a “0”. So far the bit sequence reads 10100 . Now if Bit 6 is logic “1” then the high-going waveform follows the red trajectory. If the same threshold as for the previous bits is used, shown by the (red arrow) – the waveform would be just crossing the threshold at the decision timing, and the bit would likely not be recognized as logic “1”. Since the receiver is aware that a 10100 sequence preceded Bit 6, under DFE the receiver adjusts its threshold for Bit 6 down (black arrow labeled Bit 6), and Bit 6 is now safely recognized as “1”.





► **Figure 9.** DFE equalization – typical implementation.

Before looking at a typical block diagram of a DFE equalizer, it is worth pointing out that instead of moving the threshold (as shown above), often the design moves the input waveform instead. So instead of moving the threshold for Bit 6 downward, threshold is kept constant, and a positive voltage is summed up to the waveform, so moving the waveform up – see Figure 9.

– Block diagram of a DFE equalizer is in Figure 10

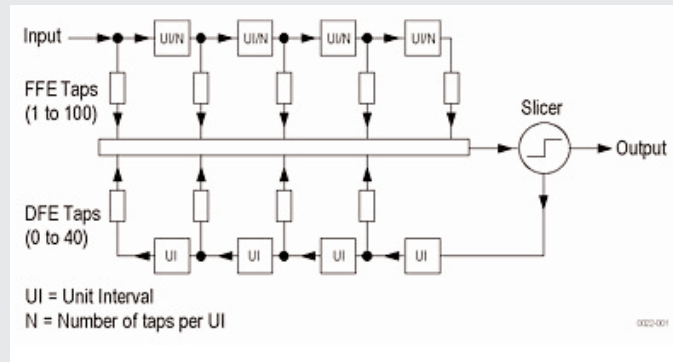
DFE equalizer has a FFE and a DFE parts. Note that the simpler FFE-only equalizer would simply not have the lower part (labeled “DFE Taps”). In the picture the vertical rectangles are tap weights –adjustable gain or loss blocks. The output block labeled “Slicer” is a combination of a comparator and a latch.

The FFE part of the equalizer is a FIR filter; input data is shifted and weighted into an adder. This realizes the frequency-response shaping function mentioned in the FFE discussion.

The DFE part again uses shift-weight-sum circuitry, but the input signal for this circuitry is fed back from the so-far recognized digital pattern. This pattern then influences the effective threshold for the decision of next bit via the shift-weight-sum blocks.

– Setting tap weights

The block diagram above ignores an important question: how to set the equalizer tap weights, or “taps” for short. 80SJNB Advanced uses an LMS (Least Mean Square) adaptive algorithm which searches for minimum vertical eye closure (i.e., minimum DDN) at the middle of the eye.



► **Figure 10.** Block diagram of a DFE equalizer.

– Transmitter equalization

Transmitter equalization is a concept very similar to the FFE – the signal is filtered in the transmitter so a boost is given to frequency bands most attenuated in the receiver. A FIR filter is an example of possible implementation. In the transmitter both previous and (several) future bits can be known (simply by delaying the current bit), and they can all be used to impact the precise output signal shape. Transmitter equalization is not the ultimate solution because strong emphasis of parts of the spectra leads to increased crosstalk and EMI problems.

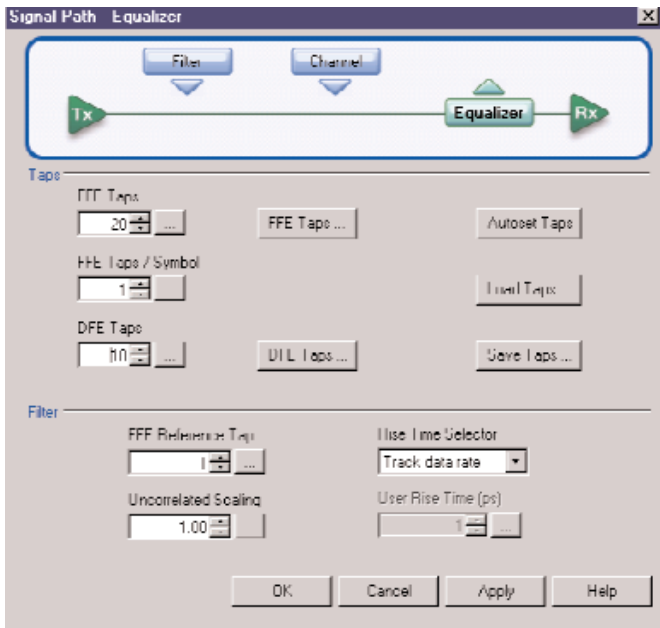
– Transmitter Pre-emphasis and De-emphasis

These two terms are used for the simplest version of Transmitter Equalization, in which only one bit type – the transition bit – is modulated relative to the rest of the bit sequence. In case of Pre-emphasis the transition bit is emphasized, the rest are at nominal amplitude; in De-emphasis the transition bit is at nominal amplitude and the rest is de-emphasized. So from the point of the signal waveform the two are the same, the difference is which one decides to call the nominal amplitude.

We will be using receiver DFE equalization in our design; transmitter equalization and its sub-types, such as transmitter pre-emphasis or de-emphasis, can be emulated in 80SJNB Advanced but is not the focus of this paper. If needed, Pre-emphasis and De-emphasis filters for 80SJNB Advanced can be downloaded from [www.tektronix.com](http://www.tektronix.com).

## Equalization and Serial Data Link Analysis Methods with 80SJNB Advanced

### ► Application Note



Data Source: MATH1: C5-C6	Data Rate: 8.5 Gbps	Filter: None
SSC: Off	Pattern: 127 bits	Channel: None
Phase Reference: None	Sample Count: 52.70 k	Equalizer: DFE (20/10)
<b>Jitter (Decision Threshold: 7.09 mV)</b>		
<b>Random Jitter</b>		
RJ (RMS)	= 606.29 fs	
RJ(h) (RMS)	= 600.00 fs	
RJ(v) (RMS)	= 87.08 fs	
<b>Deterministic Jitter</b>		
DJ	= 57.90 ps	
DDJ	= 55.04 ps	
DJCD	= 396.95 fs	
PJ	= 1.13 ps	
PJ(h)	= 1.07 ps	
PJ(v)	= 343.75 fs	
<b>Total Jitter @ BER</b>		
TJ (1E-12)	= 63.97 ps	
Eye Opening (1E-12)	= 53.68 ps	
<b>Dual Dirac</b>		
RJ(d-d)	= 698.84 fs	
DJ(d-d)	= 54.11 ps	
<b>Noise (Sampling Phase: 0 UI)</b>		
<b>Random Noise</b>		
RN (RMS)	= 942.28 uV	
RN(v) (RMS)	= 942.24 uV	
RN(h) (RMS)	= 8.80 uV	
<b>Deterministic Noise</b>		
CN	= 240.48 mV	
DDN	= 237.67 mV	
DDN(level 1)	= 259.05 mV	
DDN(level 0)	= 248.20 mV	
PN	= 3.72 mV	
PN(v)	= 3.72 mV	
PN(h)	= 15.76 uV	
<b>Total Noise @ BER</b>		
TN (1E-12)	= 270.18 mV	
Eye Opening (1E-12)	= 450.47 mV	
Eye Amplitude	= 720.65 mV	
<b>SSC Modulation</b>		
Magnitude	= 0 ppm	
Frequency	= 0 Hz	

► **Figure 11.** End of the physical channel, DFE equalization enabled: Numerical results.

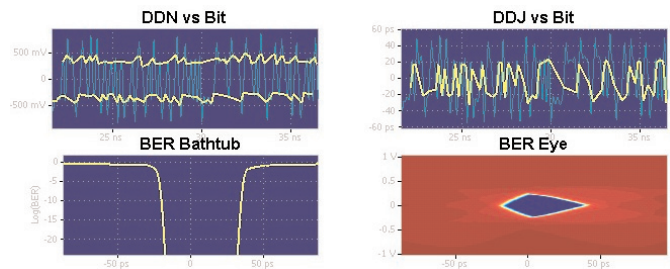
### Equalization Experiment at the Receiver End

Returning to results of measurements at the receiver end (Figure 2, Figure 3, and Figure 4), is obvious that our link transmits data at an unacceptably high bit error rate (BER) of about  $10^{-3}$ . In order to use the equalization algorithm built into the 80SJNB Advanced the UI is set as follows (since we now are just probing the space a somewhat theoretical 20/10-tap is used here).

The Autoset Taps function is then activated and found equalization applied for following results.

Equalization improves the results greatly: reading Figure 11 the eye opening at BER-12 is 451 mV and 54 ps – large enough for a realistic receiver. Looking at the Noise waveform (top-left plot in Figure 12), and comparing it to the result before equalization it's obvious that the most of the DDN is greatly improved.

<sup>\*2</sup> We are using the term "emulated" for simulation in the oscilloscope.



► **Figure 12.** End of the physical channel, DFE equalization enabled: Graphical Results.

Since we've found good equalization parameters (tap weights), it's a good idea to save them into a file, together with the images and numerical results table printouts.

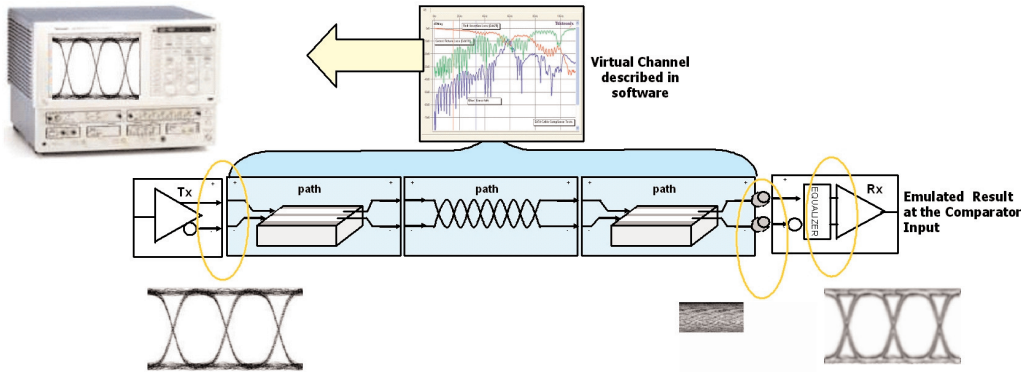
### Methodology: Measure at the Receiver, or Measure at the Transmitter and Emulate the Channel

Measuring at the Receiver, as done so far in this paper, gives a good answer to what are the signal impairments and what is the equalization design space. However there are several reasons why measuring at the receiver end is not preferred.

- Signal is (often) not easily accessible,
- Signal might be quite small and both the oscilloscope noise and the environmental electromagnetic interference decrease the signal fidelity.
- Also, sampling oscilloscopes require a clock recovery (CR) system; using one at the receiver end stresses the CR, in severe cases the clock recovery might not lock. Note: Using a real-time oscilloscope removes this concern; however the noise floor of a real-time oscilloscope is typically quite higher, so this is not a perfect solution to acquiring at the receiver end either.

Finally, a very important issue for compliance impacts the concept of measurement at the receiver: if a transmitter is to be measured against a "reference" channel then the procurement of a precise "reference" channel is a problem. Using an emulated channel, as described below, removes this problem.

For these reasons the emulated channel methodology is becoming the methodology of choice. This is how it is typically implemented: the transmitter waveform is captured at the transmitter. The channel is emulated<sup>\*2</sup> using S-parameters or time domain waveforms, (here we will again use the 80SJNB Advanced software). The output of the channel emulator can also be equalized just as shown above (the example at the physical Receiver end).



► Figure 13. Channel emulation methodology.

Data Source: MATH1: C5-C6	Data Rate: 8.5 Gbps	Filter: None
SSC: Off	Pattern: 127 bits	Channel: tdt5 - tdt6.wfm
Phase Reference: None	Sample Count: 52.70 k	Equalizer: None
<b>Jitter (Decision Threshold: -10.87 mV)</b>		
<b>Random Jitter</b>		
RJ (RMS)	= 824.09 fs	
RJ(h) (RMS)	= 600.00 fs	
RJ(v) (RMS)	= 564.90 fs	
<b>Deterministic Jitter</b>		
DJ	= 80.48 ps	
DDJ	= 73.33 ps	
DCD	= 4.43 ps	
PJ	= 2.32 ps	
PJ(h)	= 313.97 fs	
PJ(v)	= 2.30 ps	
<b>Total Jitter @ BER</b>		
TJ (1E-12)	= 89.44 ps	
Eye Opening (1E-12)	= 28.21 ps	
<b>Dual Dirac</b>		
RJ(d-d)	= 958.20 fs	
DJ(d-d)	= 75.93 ps	
<b>Noise (Sampling Phase: 0 UI)</b>		
<b>Random Noise</b>		
RN (RMS)	= 1.01 mV	
RN(v) (RMS)	= 1.01 mV	
RN(h) (RMS)	= 2.84 uV	
<b>Deterministic Noise</b>		
DN	= 318.12 mV	
DDN	= 314.62 mV	
DDN(level 1)	= 348.47 mV	
DDN(level 0)	= 340.62 mV	
PN	= 4.11 mV	
PN(v)	= 4.11 mV	
PN(h)	= 1.49 uV	
<b>Total Noise @ BER</b>		
TN (1E-12)	= 323.27 mV	
Eye Opening (1E-12)	= 0 V	
Eye Amplitude	= 323.27 mV	
<b>SSC Modulation</b>		
Magnitude	= 0 ppm	
Frequency	= 0 Hz	

► Figure 14. End of the emulated channel: Numerical results.

## Emulating the Channel

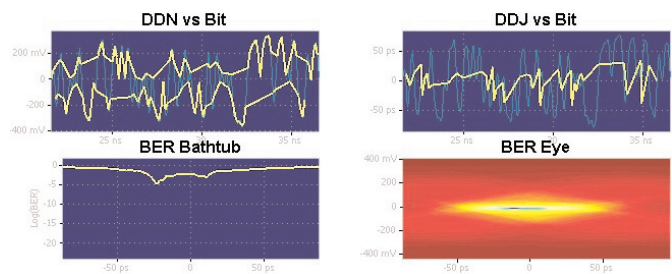
Figure above illustrates a typical setup.

### – Channel description

The interconnect channel can be described with TDR/TDT parameters, or with S parameters Touchstone matrix. Refer to Tektronix IConnect or VNA documentation for more information on S-parameters Touchstone matrix. For TDR/TDT the following measurement should be performed:

Capture TDT response (input to output) of your channel DUT with TDR step connected to the input and an acquisition channel connected to the output. Then remove your channel DUT and capture again; this is the reference. Save both traces. 80SJNB Advanced will require both of them.

If a fixture was used to connect the DUT to the TDR/TDT system, and you would like to remove the effect of the fixture from the measurement of the



► Figure 15. End of the emulated channel: Graphical results.

channel, then when capturing the reference above do not capture simple through-loop from the TDR to the acquisition channel, but insert the fixture reference traces instead. See “8 Consideration for the fixture removal”.

For both waveforms it is important that the far-end of the trace is settled; if not, reacquire with a longer time window. In case of very long DUT several TDR/TDT records might need be concatenated; Tektronix IConnect package supports an automated version of such acquisition.

In our experiment we used time domain description of the channel. Because the whole measured system is a differential system, we've measured the channel with a differential TDR. Fixture was not removed in this measurement as the cable dominates the impairments. The emulated channel followed by the equalizer match the block diagram of TWDP (Transmitter Waveform Dispersion Penalty) used by IEEE 802.3aq. Similar methodology is becoming prevalent in new standards in 2007. We are using a broader term SDLA (Serial Data Link Analysis) for this methodology.

## Equalization and Serial Data Link Analysis Methods with 80SJNB Advanced

### ► Application Note

Data Source: MATH1: CS-C6		Data Rate: 8.5 Gbps		Filter: None	
SSC: Off		Pattern: 127 bits		Channel: tdt5 - tdt6.wfm	
Phase Reference: None		Sample Count: 52.70 k		Equalizer: DFE (20/10)	
Jitter (Decision Threshold: 4.83 mV)					
Random Jitter					
RJ (RMS)	=	607.89 fs	Random Noise		
RJ(h) (RMS)	=	600.00 fs	RN (RMS)	=	1.01 mV
RJ(v) (RMS)	=	97.64 fs	RN(h) (RMS)	=	1.01 mV
Deterministic Jitter					
DJ	=	58.46 ps	DN	=	257.75 mV
DDJ	=	55.58 ps	DDN	=	253.95 mV
DCD	=	648.11 fs	DDN(level 1)	=	275.87 mV
PJ	=	506.39 fs	DDN(level 0)	=	223.68 mV
PJ(h)	=	313.97 fs	PN	=	4.11 mV
PJ(v)	=	397.31 fs	PN(v)	=	4.11 mV
			PN(h)	=	14.21 uV
Total Jitter @ BER					
TJ (1E-12)	=	64.29 ps	TN (1E-12)	=	280.55 mV
Eye Opening (1E-12)	=	53.36 ps	Eye Opening (1E-12)	=	416.06 mV
			Eye Amplitude	=	696.61 mV
Dual Dirac					
RJ(d-d)	=	684.14 fs	SSC Modulation		
DJ(d-d)	=	54.64 ps	Magnitude	=	0 ppm
			Frequency	=	0 Hz

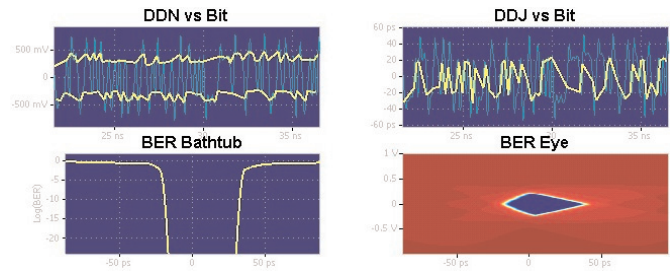
► **Figure 16.** End of the emulated channel, DFE equalization enabled: Numerical results.

Comparing the results of real physical channel measurement to that of the emulated (virtual) channel measurement, we notice that while there is a good match in the Noise waveforms, Jitter trend, etc. the results are not exactly the same –e.g. the jitter bathtub has a small change in shape. It's important to realize that this will always be the case; emulation and physical measurement are not going to match perfectly, and some margin has to be allocated for this. Some sources of these differences are typical simulation vs. measurement issues, and should be typically very small, e.g. numerical errors. One source of difference deserves a more detailed description:

80SJNB Advanced uses the through network parameter, that is the TDT waveform, or Sdd21<sup>\*3</sup>. This means that reflections from a physical channel that the transmitter would see are not captured, and the reflections between the physical transmitter and the physical oscilloscope will be present instead. If you are concerned about this difference, then consider the following to understand the impact of this error:

- size the error by observing the impact of reflection when measuring at the receiver end for two physical channels at the extremes of mismatch allowed;

or



► **Figure 17.** End of the emulated channel, DFE equalization enabled: Graphical results.

- split the signal at the transmitter and insert a physical mismatch or its physical model (while still acquiring at the transmitter end - the preferred methodology). Use TDR to verify that the physical mismatch and the artificial mismatch created with the splitter correspond to each other.

Both of these suggestions will address transmitter's (possibly) non-linear response to reflections, and will give an understanding of the size of the error caused by emulating just with the "through" network parameter..

### Equalization Experiment at the Transmitter End with an Emulated Channel

In Figure 16 see the results of equalization on the emulated channel. We are using the same number of taps and same tap-weights as before on the physical channel.

Just like with the physical channel, equalization helps a great deal and opens the eye BER eye nicely. Comparison of the emulated results with the results of the physical channel experiment ("4. Equalization Experiment at the Receiver end") shows a good –while again not perfect- match.

The discussion so far focused on the over-all methodology for designs working with deeply closed eyes. There are several side issues which will touch upon now.

<sup>\*3</sup> The 80SJNB Advanced accepts simple through, two-port, and four-port channel network description, and it extracts the through-gain from those.



## “Filter” and Considerations for Fixture Removal (Fixture De-embedding)

Our design space has two cases in which fixtures might be used, so it’s important to keep these separated.

- Fixture used to measure the channel (to gain network description data, e.g. TDR/TDT traces, or Touchstone S-parameters matrix).

This has been already commented upon above. If you would like to remove the effect of the fixture from the measurement of the channel, then when capturing the reference waveform do not capture simple through-loop from the TDR to the acquisition channel, but insert the fixture reference traces instead. If the fixture doesn’t have fixture reference traces then this becomes a more difficult problem beyond the scope of this paper.

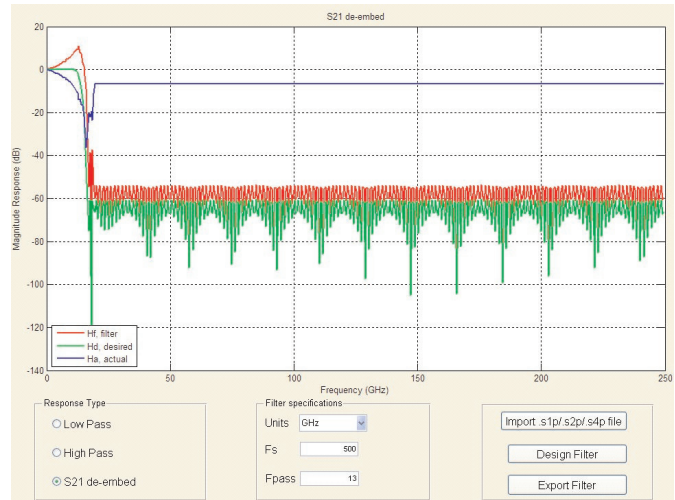
- Fixture used to measure the transmitter

If this fixture needs to be removed then it, or its fixture reference trace, has to be measured with a TDR/TDT or with a VNA. The result then can be passed on to the 80SJNB Advanced, but only after some pre-processing. In effect the network description has to be “inverted”. This is done with a tool called “fir” – a free utility you can get from your Tektronix support person and at some point at [www.tek.com](http://www.tek.com). (Note that of fall 2007 the tool only accepts S-parameters as network description; if you have TDR/TDT data, which is preferable because such data preserves the DC content – you’ll need to convert the data into S-parameters. We recommend Tektronix’ IConnect package for this conversion).

The de-embedding tool is shown in action in Figure 18; the fixture measured data is in blue (note the extension of measured data with a flat line), and the de-embedding network’s frequency response is in red. The green trace shows the aggregate of the two.

- General comment of the frequency range to which the fixture measurements has to be valid

Fixtures are often difficult to measure precisely into high frequencies. If the result of the fixture measurement is never going to be used without a



► **Figure 18.** Fixture de-embedding tool: blue trace: fixture; green trace: de-embedding network.

lossy channel, then the fixture description data doesn’t need to be very precise at the frequencies at which the loss of the lossy channel dominates the over-all loss.

## Consideration for Equalization Tap Values Autoset

The tap autoset function will compute a set of tap values that optimize the eye opening for the data pattern applied to the input of the equalizer. If the DFE tap number is 0, the algorithm will optimize set of FFE taps, while if the equalizer is specified as a DFE by a positive DFE tap number, the Autoset Taps algorithm will jointly optimize the forward and feedback loop tap coefficients. The optimization algorithm is the least-mean-square error (LMS). If you do not feel that found values of equalization taps are the best, then experiment with the equalizer settings to find a result more closely matching your expectations. In some cases the information about desired tap weights is available from other sources, e.g. from the channel network analysis results. Finally, the 80SJNB Advanced supports waveform export; the signal can be exported to a file and processed by an external software, and found tap weights can then be loaded back into to 80SJNB Advanced.

### Limitations of Current Solution

Things to keep in mind when using 80SJNB Advanced:

– Channel loss and impairments

Maximum channel impairments: if the channel collapses the eye to the point that there's a significant overlap between the low-level's highest peaks and high-levels' lowest peaks then several algorithms start running into problems. Typically first the Taps Autoset algorithm might not converge; saved tap values will still work. The Autoset might be helped with a bit of pre-emphasis (in the transmitter, or in the Filter block).

As an estimate the channel presented here (see "Figure 5 Time-domain view of the channel's step response" and "Figure 6 Frequency domain view of the channel's loss") is close to the limits of what can 80SJNB Advanced find taps for and equalize.

As the eye closes more and more, another, more difficult problem develops: determining the UI boundaries becomes complicated. When the 80SJNB can not find UI boundaries it will inform you of that, and it will fail the analysis. Equalization is then also not possible. There is no workaround, short of changing your signal; e.g. running at a lower bit-rate might give an insight into whether the analysis and equalization request is realistic at all; using pre-emphasis at the transmitter is again an option.

– VNA-caused limitation: Channel network description

Channel network description without DC information: when the data on which the channel emulation should be based is acquired on a VNA there is, typically, no result for the value of network parameters at DC. In other words, if your signaling is e.g. +ECL from the transmitter, and then you run through an emulated channel it's difficult for 80SJNB to sort out what should the DC level be – because the DC loss is not given in the AC-only Touchstone from the VNA. 80SJNB V2.0.0.0 extrapolates to DC value based on first few frequency points in the network description file (Touchstone). If these few points are not flat, 80SJNB will likely extrapolate erroneously, and the channel will become impenetrable to even a very slow bit rate; if the eye diagram is unexpectedly closed by an s-parameters described channel then verifying that the eye opens at low bit-rate will confirm or deny this problem with the data. Re-measuring to the lowest possible frequency might help.

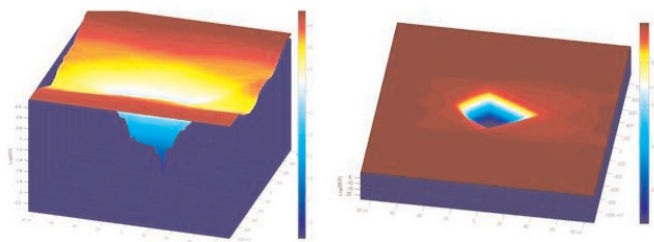
TDR/TDT data doesn't exhibit this problem because the DC value is included; Tektronix IConnect package also preserves the DC value; so e.g., IConnect calculated s-parameters will include DC if the s-parameters were calculated from TDR/TDT waveforms.

### Additional Resources

- [1] The help system of the 80SJNB Advanced is available at  
C:\Program Files\TekApplications\80SJNB\Documents  
on your oscilloscope.
- [2] Network parameters (some time-domain, some touchstone S-parameters) of several example devices are at  
C:\Program Files\TekApplications\80SJNB\Examples
- [3] The website [www.tektronix.com](http://www.tektronix.com) has a number of application notes and papers on network measurements, and specifically [www.tek.com/jitter](http://www.tek.com/jitter) has information about jitter and equalization and serial data link analysis (SDLA).
- [4] IConnect help files and tutorials are available e.g. on  
C:\Program Files\TekApplications\IConnect  
or C:\Program Files\TekApplications\IConnect Evaluation  
on your oscilloscope.

### Bibliography

- [1] "Digital Baseband Transmission and Recording",  
Jan W.M. Bergmans
- [2] Help system for Matlab's Signal Processing pack



► BER eye of an unequalized and of equalized channel discussed in this note.

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