

Average Rating: (0) [Rate this:](#)

## De-embedding improves measurement accuracy

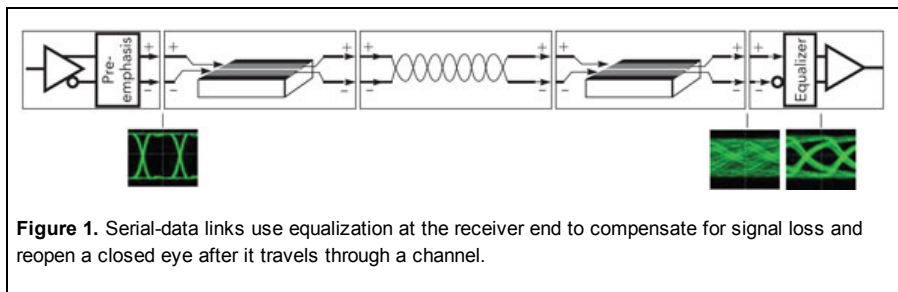
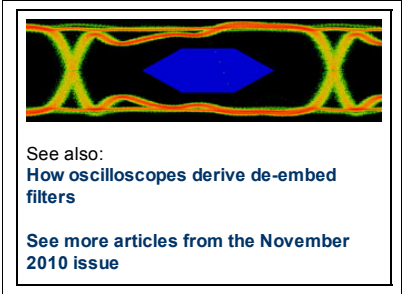
### Engineers can compensate for signal loss in cables, connectors, and test fixtures.

By Randy White, Tektronix -- Test & Measurement World, 11/1/2010 12:00:00 AM

The relentless increase in serial-data rates forces engineers to understand the effects that test fixtures and transmission channels have on eye-diagram measurements. As data rates increase, losses in fixtures and transmission channels can produce an inaccurate eye diagram. Removing, or de-embedding, the fixture and channel effects from a measurement lets you view an eye diagram that is closer to the true signal.

As a high-speed signal travels, it loses fidelity, especially if the transmission channel medium is inexpensive FR-4 PCB (printed-circuit board) material. Cables, connectors, and test fixtures also contribute to signal degradation. The result: a closed (or nonexistent) eye diagram at the far end of a transmission channel.

Making characterization measurements is a fundamental part of producing a robust design. When you can't connect an oscilloscope directly to a device's pins and you need to measure the transmitter through a fixture, you'll find that the fixture impacts the measurements. If you're accustomed to making signal-integrity measurements without concern about fixture or channel effects, then you may not realize how much signal loss occurs at data rates of 5 Gbps and higher. At those speeds, you can no longer assume that if the transmitter output meets the eye-diagram mask limit, the system will work flawlessly. In most cases, you must consider the complete link when making a signal measurement.



Transmitters and receivers can compensate for channel loss in communications systems. Pre-emphasis in the transmitter reduces eye closure caused by loss and dispersion, particularly at speeds of 2.5 Gbps and above. A receiver equipped with equalization is capable of decoding signals even when an eye diagram is completely closed. The receiver's equalizer opens the eye to a point where the receiver can interpret the stream's data. **Figure 1** shows how a transmission channel can degrade a serial data stream. An open eye at the transmitter closes as the signal travels through the channel, but then the receiver's equalizer reopens the eye enough to make the system reliable.

The interaction between a transmitted signal's true shape and the channel parameters is complex and difficult to predict. You can observe the performance of the whole serial link when you connect the transmitter's output to the channel and observe how the signal degrades along the path.

You can also emulate a channel in software based on the channel's network parameters. Thus, the channel doesn't have to be physically present for you to understand how it degrades a signal. You can emulate the channel using S-parameters in the frequency domain or with a network description using time-domain techniques. You can measure the signal at the end of the emulated channel with or without pre-emphasis or de-emphasis.

Often, you can't probe a receiver directly at its pins. Board layouts may force you to measure signals with several inches of trace between your preferred measurement point and your actual test point. This results in lower-quality measurements and loss of transmitter margin. Therefore, you must characterize the transmission channel and the path from the desired measurement point to the oscilloscope. With that, you can de-embed test fixture and cabling effects, especially for data streams over 5 Gbps.

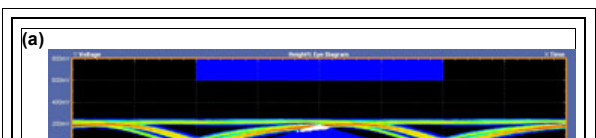
#### How does de-embedding work?

De-embedding lets you remove fixturing and instrumentation effects from signal-integrity measurements. By removing the degrading effects of a signal path, you essentially make measurements at the desired point. You've moved the reference plane of a measurement closer to the DUT (device under test).

Measuring S-parameters requires you to use a standard calibration procedure that has well-controlled physical properties. Physical properties include known impedances such as a short, open, load (reference impedance, usually 50 Ω) and a thru or transmission standard. This is referred to as a SOLT (short–open–load–thru) calibration.

Once you have a calibrated instrument, you can measure a serial-data fixture using either time-domain reflectometry or frequency-domain measurements, then develop a multiport Z-parameter or S-parameter interconnect model. With this model, you can measure the DUT signal and de-embed the impact of the fixture measurement from it.

Knowing the fixture's characteristics lets you remove the fixture's effects from the acquired signal—packaging effects, PCB trace loss, and test-fixture effects—when performing high-speed measurements such as jitter or eye height. This approach lets you "probe" virtual test points such as those underneath packages or several inches from an edge connector.



Most oscilloscope software tools can import S-parameter files and so use a channel's frequency response data. Software can then de-convolve, or de-embed, the interconnect effects over the frequency range of interest. An IFFT (inverse fast Fourier transform) is the basis for the process. (See "[How oscilloscopes derive de-embed filters](#)".)

**Figures 2a** and **2b** show how de-embedding can open an eye diagram so it doesn't appear to have failed an eye-mask test. By removing signal degradations caused by fixtures, you'll minimize the failures, which are highlighted in white in Figure 2a; the failures don't appear in Figure 2b because the eye clears the mask.

De-embedding a fixture's effects will remove some of the fixture-caused ISI (intersymbol interference) degradation, but it will also amplify noise. To minimize the noise amplification and optimize SNR (signal-to-noise ratio), you also need to apply a low-pass filter. You can apply a fixed-loss-level or threshold (in decibels) filter to a data stream to reduce noise. For example, if you need to measure a 5-Gbps data signal across a cable that produces a -6-dB loss at 7.5 GHz, you'll find that after applying a 7.5-GHz low-pass filter, the de-embedded response has about 3 dB of loss at 7.5 GHz (-6 dB original + 6 dB from inversion - 3 dB filter).

You can also select the cutoff frequency based in the fifth harmonic of the signal's fundamental frequency. A 5-Gbps signal has a 2.5-GHz fundamental frequency whose fifth harmonic is at 12.5 GHz. In most systems, most of the signal energy is contained within the fundamental, third, and fifth harmonics.

The channel model is a critical factor in filter cutoff selection. You need well-behaved time-domain or S-parameter data. You should also consider whether the frequency spacing and time window of the channel model will allow transient events (such as reflections) to settle and whether DC is included in the data set. These conditions may not be factors for short fixture traces, but for longer structures, the conditions may well affect your measurements, depending on the distance between impedance mismatches.

Reflections can cause significant frequency nulls or dips that, after you apply an inverse function, could produce signals that exceed an oscilloscope's SNR. Assume that a cable has a large dip in its frequency-response plot at 9 GHz. If the de-embed filter consists of a low-pass filter with a cutoff frequency of 10 GHz, you can see a boost of about 60 dB, which is well above the noise floor of most oscilloscopes (**Figure 3**). A better approach that balances SNR and a high-frequency signal uses a filter with a 5-GHz cutoff frequency. The resulting spectrum (**Figure 4**) doesn't have the peaks that were visible in Figure 3.

### De-embedding guidelines

Here are a few guidelines that you can use when you need to de-embed a channel or fixture from your measurements.

- *Know the signal's spectrum.* To obtain accurate de-embedding, you need an accurate model of the channel's response all the way to your test point. The model must cover beyond the highest frequency of the spectrum that still carries significant energy. In practice, if you can estimate the spectrum bandwidth, you'll optimize the de-embedding effort.

Theoretically, the spectrum of an NRZ (non-return-to-zero) signal can have enough energy to impact an eye diagram even beyond the seventh harmonic. If you need to de-embed the impact of a fixture from a 5-Gbps (2.5-GHz) signal, your fixture measurements must be accurate beyond 12.5 GHz (the signal's fifth harmonic).

- *Know the de-embedding filter's dynamic range.* Assume the spectrum of the original signal multiplied by the channel loss must be within the oscilloscope's dynamic range. Real-time 8-bit oscilloscopes typically have 30 dB of dynamic range at their highest frequency. Sampling oscilloscopes can achieve 40-dB or 50-dB resolution at the high end of their frequency range.

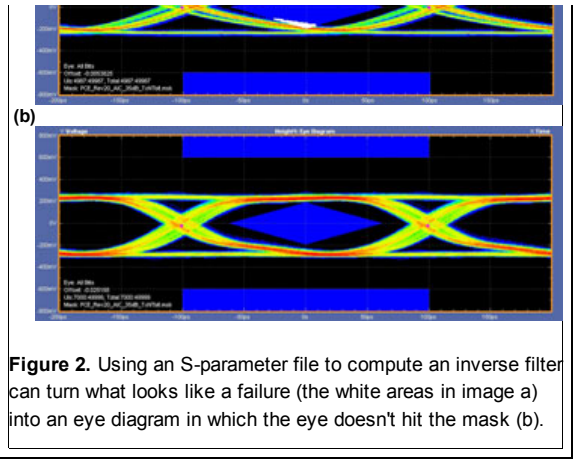
The following equation shows a filter's input signal,  $r(t)$ , and output signal,  $s(t)$ :

$$s(t) = \text{IFFT} \left[ H_{bw} \cdot H_{21}^{-1} \right] * r(t)$$

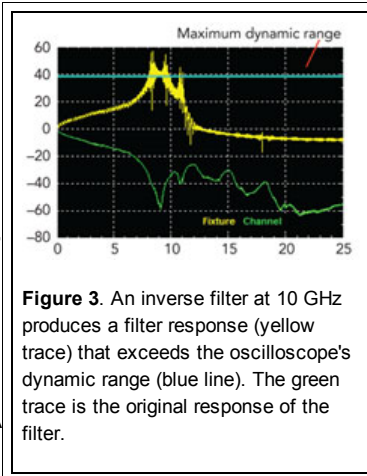
For the  $s(t)$  expression to be accurate to a certain frequency, the measurement of a channel's or fixture's response,  $H_{21}$ , and the input signal,  $r(t)$ , must be known to a sufficiently high frequency and dynamic range. At the maximum frequency, the spectra of the signal is 20 dB below the first harmonic, and you measure this signal through a fixture that has a 20-dB loss at this highest frequency. The highest frequency part of the signal's spectrum will be 40 dB below that of the first harmonic.

With an 8-bit digitizer, the high-frequency components of a signal will be indistinguishable from noise. Averaging can help increase the dynamic range of digitizers by increasing the effective number of bits and improving the SNR.

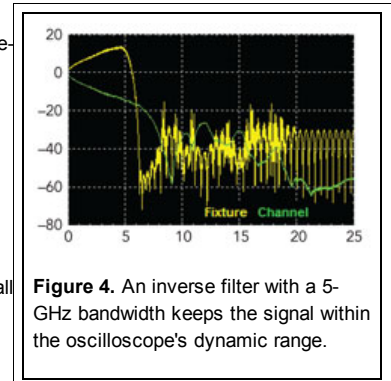
- *Get the right frequency range and timing resolution.* When developing a filter, you must calculate its time constant ( $t$ ), the time that represents the sum of the delay, and measure the fixture or channel's impulse response. If the captured waveform doesn't contain enough samples to account for the filter's transient delay, significant distortion will occur and the resulting filtered waveform data will be meaningless. A general rule of thumb is to set the oscilloscope's memory depth to



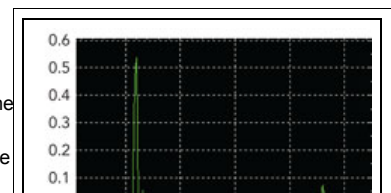
**Figure 2.** Using an S-parameter file to compute an inverse filter can turn what looks like a failure (the white areas in image a) into an eye diagram in which the eye doesn't hit the mask (b).



**Figure 3.** An inverse filter at 10 GHz produces a filter response (yellow trace) that exceeds the oscilloscope's dynamic range (blue line). The green trace is the original response of the filter.



**Figure 4.** An inverse filter with a 5-GHz bandwidth keeps the signal within the oscilloscope's dynamic range.



at least 10 times the filter length. For example, a filter length of 1000 coefficients would require at least 10,000 waveform samples.

Also, consider the signal's bandwidth of relevance ( $BW_{REL}$ ). This is the bandwidth at the measurement point where the spectral amplitude is about  $-20$  dB for real-time oscilloscopes and  $-40$  dB for sampling oscilloscopes relative to the instrument's dynamic range. The value of  $BW_{REL}$  lets you calculate the absolute minimum number of frequency domain points,  $P$ , that you must collect to represent the S-parameters over the range of DC to  $BW_{REL}$ :

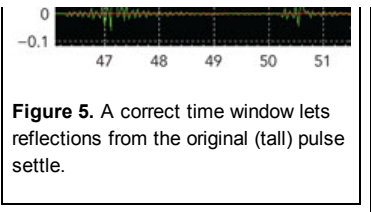
$$P = t \cdot BW_{REL}$$

$P$  is the number of points that you should measure on a vector network analyzer or on a time-domain reflectometer.

Additionally, you must ensure that the filter provides enough low-frequency resolution to capture the lowest expected frequencies. This often will dictate the frequency step between measurements. The frequency spacing,  $\Delta f$ , setting for the S-parameters will be:

$$\Delta f = \frac{1}{T}$$

Oscilloscopes have enough processing power to perform de-embedding once you provide them with sufficient data. Through de-embedding, you can get a clearer view of the signal that appears at an IC's pins when you can't probe the pins directly. De-embedding also lets you model a transmission channel so you can see how it can affect signal integrity before you have a physical sample to test.



**Figure 5.** A correct time window lets reflections from the original (tall) pulse settle.

**Randy White** is the serial applications technical marketing manager at Tektronix. He has given seminars on high-speed serial measurements and is actively involved in many working groups for high-speed serial standards. He holds a BSEE from Oregon State University.

Average Rating:

(0) [Rate this:](#)

[Share](#) [RSS](#) [Subscriptions](#) [Reprints/License](#) [Print](#) [Email](#)

#### TALKBACK

We would love your feedback!

[Post a comment](#)

[» VIEW ALL TALKBACK THREADS](#)

#### SIMILAR CONTENT FROM T&MW

[SIMILAR TOPICS](#) [MORE BY THIS AUTHOR](#) [TOP RATED](#)

No related content found.

#### SPONSORED LINKS



[Resource Center](#) [Browse Categories](#) [Browse Companies](#)

#### Featured Company

##### Camstar Systems, Inc.

Camstar is a leading innovator of software solutions that advance product quality in the manufacturing industry, enabling its customers to deliver the highest quality products on time, the first time, every time. The Camstar Enterprise Platform... [more](#)

#### Most Recent Resources

[Load, Pressure and Torque: Sensor Selection, Technology and...](#)

[Mass Flow Versus Volume Flow](#)

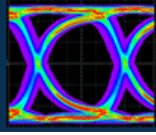
[Aries' New Fine Pitch Bump Adapters Adapt BGA Devices of Any Pitch...](#)

[New BGA Switch-A-Pitch Adapters from Aries Now Adapt 0.50 mm Devices...](#)

[The DataFlex-1000A Flight-Capable High-Speed, High-Capacity Data...](#)

ADVERTISEMENT

**NOVEMBER 3**  
**1 PM ET**  
**JOIN US**  
**CLICK HERE**



**EDN**  
**LeCroy**  
*Test &*  
**MEASUREMENT**

**WEBCAST**

# Fast S-parameter Measurement For Signal Integrity Engineers