APPLICATION NOTE

# Overcoming Crosstalk Challenges in Today's Digital and Wireless Designs


KEYSIGHT
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One of the greatest challenges design engineers face today is the effects of crosstalk in their designs. Crosstalk is more prominent in today's devices due to the increase in data communications speeds and higher circuit density in smaller devices where multiple high-speed signals are designed extremely close to each other. With crosstalk issues becoming more prominent, engineers need better tools and methods to analyze and debug crosstalk issues. With more detailed crosstalk information, engineers can make important decisions such as which crosstalk reductions will improve their designs and increase robustness.

# Crosstalk Defined

Crosstalk is a type of distortion that comes from amplitude interference uncorrelated with data patterns. A clean signal, "victim", can be affected by crosstalk from an "aggressor" signal due to a coupling effect. The aggressor distorts the shape of the victim signal and closes the eye diagram of the victim signal. Engineers want a clean signal with little or no crosstalk to obtain a wide open eye diagram and provide error free data transmission. When crosstalk is present in the victim signal, the interference causes the eye diagram to close, which can result in small design margins or even measurement failures (Figure 1). Crosstalk also decreases the vertical and jitter performance of the victim signal which increases interoperability issues in a communication link.

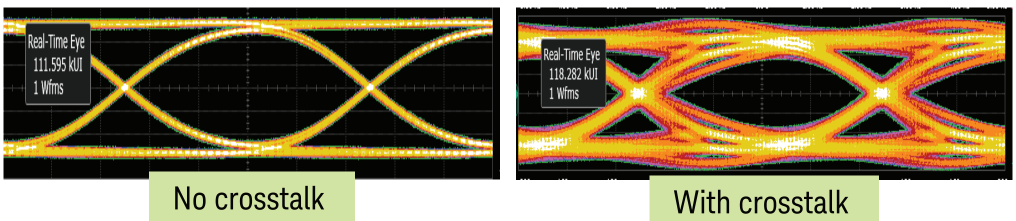


Figure 1. Eye diagram of the victim signal with and without crosstalk. Crosstalk causes the eye to close, reducing design margins and potentially violation to the specifications.

## Crosstalk sources

Being familiar with possible aggressor crosstalk sources is very important for engineers as they work to develop or improve their device designs. Two of the most common crosstalk sources are the transmission line and power supply (Figure 2).

The transmission line can affect both the serial data line and power supply in a device design causing different types of eye closure. Power supply interference on the transmitted serial data line can result in both noise and jitter.

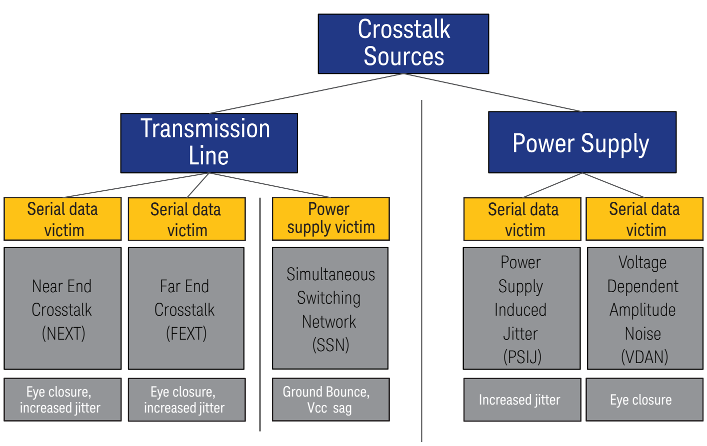


Figure 2. Sources of crosstalk, and their impact to the serial data and power supply victims.

## Effect of transmission line crosstalk on victim

Faster data rates and more lanes packed into a smaller circuit area are seen in design examples like the 100G standards with 4 parallel 25 Gb/s lines, and ASICs with 100s of SerDes, have led to the increase of crosstalk in designs.

Electromagnetic interference between circuit components that are in close proximity can cause transmission line crosstalk. Transmission lines that run parallel to each other are likely causes of crosstalk due to their combined inductance and capacitance which couples the energy from one signal into the other. Capacitive coupling voltage results in a current that travels in both directions, compared to inductive coupling which results in current that travels only in the reverse direction. When combined, the two currents reinforce the reverse direction current. The reverse current travels back to affect the transmitter and is called “near-end” crosstalk (NEXT). Residual forward traveling current affects the receiver and is called “far-end” crosstalk (FEXT). The magnitude and shape of these waveforms are very different from each other (Figure 3).

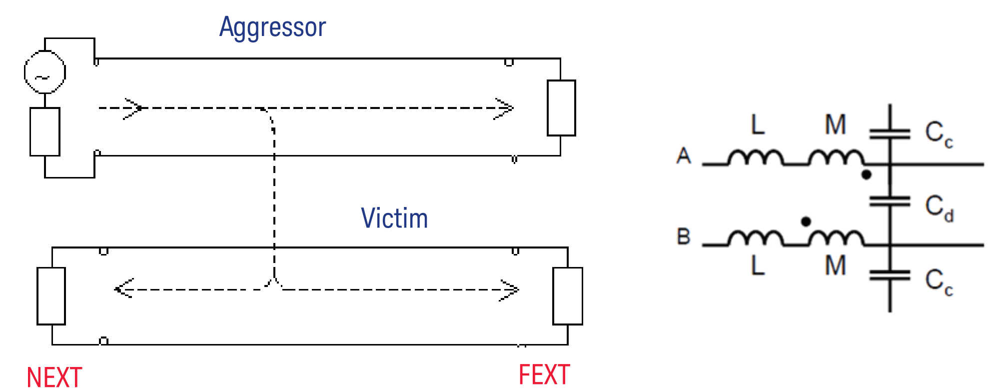


Figure 3. The (Right image) Circuit model of crosstalk between transmission lines. (Left image) NEXT and FEXT effects on the victim from a data aggressor.

A near-end crosstalk aggressor travels in the opposite direction of the victim signal and can cause a “smeared” distortion of the victims’ eye diagram (Figure 4). This is due to the addition of the aggressor’s edge which is at a different bit position than the victims.

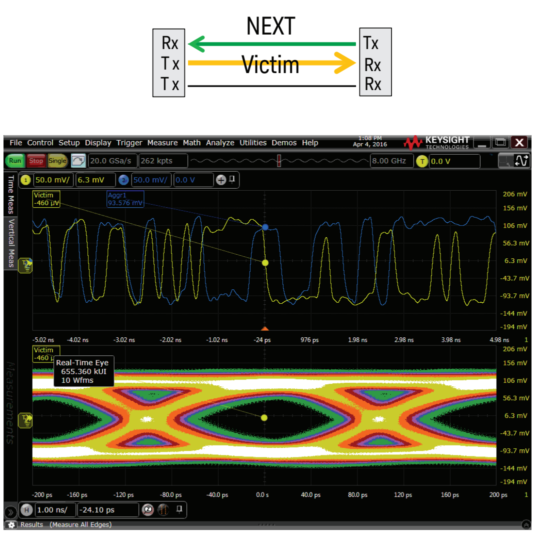


Figure 4. A NEXT serial aggressor signal travels in the opposite direction as the victim signal. The aggressors’ data rate and pattern are offset from the victim signal causing eye diagram to appear smeared.

Far-end crosstalk travels in the same direction as the victim signal. The aggressors' data rate and pattern can be the same as the victim signal. In this situation, the victims' eye diagram will show bulging (see Figure 5 below) due to the aggressor affecting the same edge or position in the victims bits


Figure 5. A FEXT serial aggressor signal travels in the same direction as the victim signal. When the aggressors' data rate and pattern are the same as the victim signal, the victims' eye diagram will show bulging.

The transmission line can also affect the power supply due to the switching network, which may include simultaneous switching noise (SSN) and can cause ground bounce and Vcc sag in a device. Inductance is caused by lag of the current that travels between the device and board ground. This happens when a serial data line switches state and current flows through the inductances and produces a voltage drop. The more lines that simultaneously switch, the larger the voltage drop. This effect causes the transmission line to transfer noise directly to the device ground resulting in ground bounce. Ground bounce can travel to other circuits within the device causing jitter and eye closure. Refer to Figure 6.

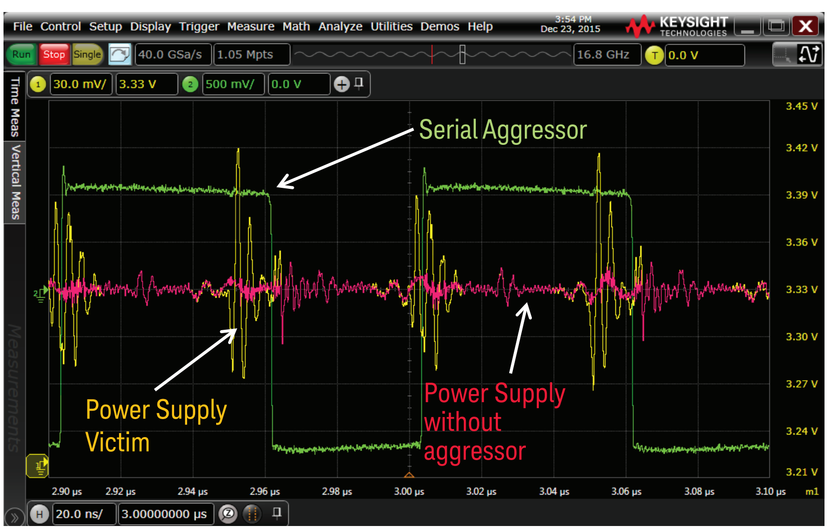


Figure 6. Serial aggressor causes ground bounce that appears as spikes on the power supply victim signal (yellow signal). When the serial aggressor is removed, the spikes disappear (red signal).

## Effect of power supply crosstalk on victim

Power supply induced jitter (PSIJ) is caused by a power supply that creates high frequency noise in addition to a low frequency ripple. As the power travels through the phased locked loop, the noise translates into jitter causing horizontal closure of the eye of the serial data victim (Figure 7).

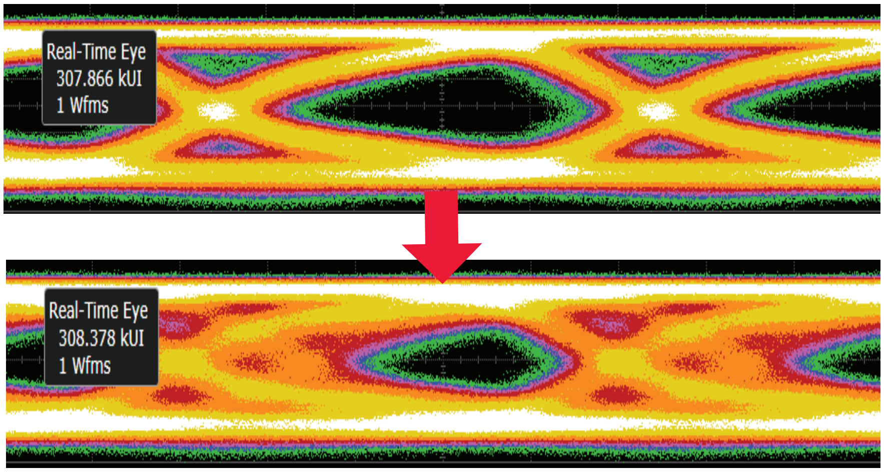


Figure 7. Horizontal eye closure due to power supply noise.

Voltage dependent amplitude noise (VDAN) affects the serial data victim as well, by adding noise from the voltage references. Logic zero is typically tied to ground, while logic one is connected to Vcc, so any noise present on ground or Vcc will affect the logic one or logic zero. The example below shows a ramp of the logic high and Vcc aggressor signals as well as the logic low signal. The logic high and Vcc aggressor signals have similar amplitude ramps making it possible for crosstalk to occur and affect the serial data. In this case, the logic low is not affected like the logic high resulting in an eye diagram with a thicker high level, and both vertical and horizontal eye closure is seen (Figure 8 on right, below).


Figure 8. (Left image) Similar amplitude ramps of logic high and Vcc aggressor signals. (Right image) Thick high level of eye diagram caused by Vcc aggressor signal on logic high victim signal.

## Crosstalk analysis solutions and challenges

Depending on the device design, different methods have been used to identify sources of crosstalk and reduce or eliminate their effects.

- Isolating circuits - Engineers have measured crosstalk in digital communication systems for many years by selectively disabling some channels while enabling others and comparing the eye diagram results. Engineers must measure the crosstalk effects in the system while operating in special test modes. This method is not ideal because it does not reflect the true world operation of the design while it is only partially operational and, often times, designs are not capable of operating in this unusual mode. If a design is demonstrating a closed eye, engineers may not be able to determine which circuit is the cause of the crosstalk and remove it. Additionally, if a closed eye is the result of crosstalk from multiple serial aggressors, many engineering hours can be invested trying to determine the different sources and crosstalk magnitude for each (Figure 9).

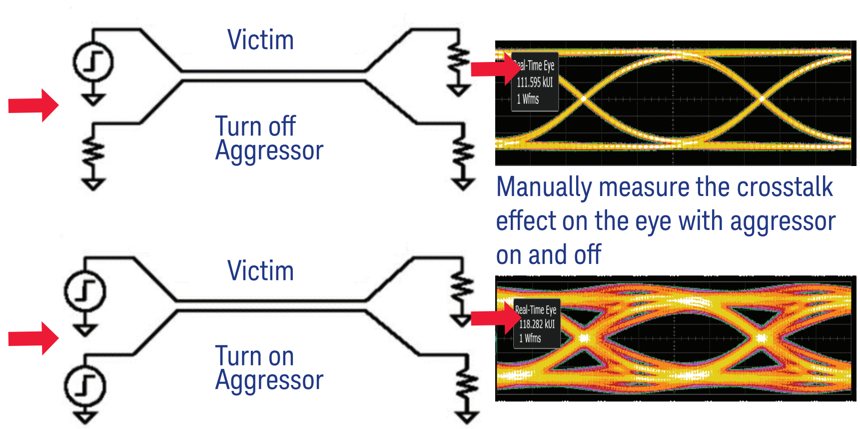


Figure 9. Turning an aggressor signal on and off to determine the effects on the victim signal

- Serial data line simulation - A vector network analyzer (VNA) can be used to characterize crosstalk between serial data lines, or S parameter models. Then, an oscilloscope with software tools and the acquired S parameter models is used to simulate the waveform distortion through the victim signal. If, for example, measurements are made on three signals, the first, is the victim signal and the second and third signals are aggressors (Figure 10). The S parameters can be applied to determine how much of the content of the second and third signals is crosstalk components affecting the first victim signal. All three signals can be combined to simulate the eye opening on the first victim signal. This method can only be used during simulation and requires a known source or sources of crosstalk which is not helpful when trying to identify a real source of crosstalk for a design, or remove the crosstalk to determine margin improvement.

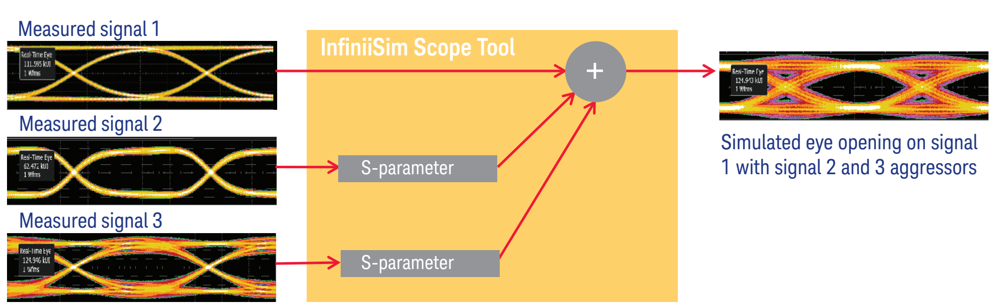


Figure 10. Turning an aggressor signal on and off to determine the effects on the victim signal.

- Power supply simulation - Characterization of the power supply using simulation is not as straight forward as simulation for the serial data lines. This is due to the nonlinear distortion of the victim signal caused by the power supply noise. A VNA cannot be used to characterize power supply crosstalk because it is a nonlinear transfer function to the victim.
- Inaccessible aggressor signals – There are situations when the crosstalk generated in a design is not accessible for probing, simulation or even to determine the true source. One example is when crosstalk occurs within an integrated circuit and the high speed serial data output is the only accessibly signal. Another example is high-density backplane connectors and switches which can be very susceptible to crosstalk. Pinpointing or isolating the source of crosstalk in these areas is difficult because it is nearly impossible to probe individual signals.
- Correlating measurements - Synchronizing measurements of victim and aggressor signals is necessary to analyze the effect of crosstalk on the victim. An oscilloscope is used to simultaneously capture the signals. Engineers must be careful not to cause undesirable time skews between the signals which can be introduced by crosstalk propagation delay, signal access points and differences in probing cables.
- Ideal access points (or probing points) should be used to minimize effects of test instrument contact on the signals. The recommended access points vary depending on whether the serial data signal, power supply aggressor or power supply victim signal are being analyzed. Below are the recommended probe locations for the best signal representation:
  - Serial data crosstalk
    - Victim: probe close to the receiver to view the signal as it receives it
    - Aggressor: probe close to the suspected crosstalk transmitter to see the most prominent aggressor signal
    - Multiple victims & aggressors: probe close to the receiver
  - Power supply aggressor
    - Victim: probe close to the receiver
    - Aggressor: probe anywhere along the same voltage node as the suspected aggressor power supply pin
  - Power supply victim
    - Victim: probe anywhere along the same voltage node where crosstalk distortion is observed
    - Aggressor: probe close to suspected transmitter to see the most prominent aggressor signal

Taking into consideration the crosstalk analysis capabilities engineers have today, and what they really need, an ideal solution for crosstalk analysis of a design would begin with an easier way to identify crosstalk sources and determine which signals are coupling with the victim(s). Then, have the ability to quantify the amount of error induced by each aggressor and simulate the signal without the added effects of the aggressor to determine the possible improved margin and ability to pass. These key crosstalk analysis abilities would help engineers to determine where to invest time to reduce or remove specific aggressors to successfully improve the resulting device design.

## Keysight crosstalk analysis solution

Keysight provides the ideal solution, solving crosstalk analysis challenges with the combined N8833A/B crosstalk analysis application and Keysight Infiniium V-Series, Z-Series, or 90000 Series oscilloscopes. Signals demonstrating aperiodic bounded uncorrelated jitter (ABUJ) may be due to crosstalk from adjacent signals or a power supply. Performing crosstalk analysis on the victim and aggressor signals will help to determine the crosstalk source. The crosstalk analysis application looks at the input signals, removes inter-symbol interference (ISI), finds the crosstalk effects, and displays the victim signal with the crosstalk removed enabling engineers to make measurements or perform real-time eye analysis on the signal with crosstalk removed to see how crosstalk if affecting the signal margins. The application detects and quantifies the presence of crosstalk and also determines which aggressors are the primary contributors. This enables engineers to determine how much affect an aggressor signal has on a victim. The N8833A/B can remove the crosstalk from the victim to offer a visual comparison of the original waveform with a clean waveform.  Measurements can be made on the resulting clean waveform which helps to determine the margins that can be recovered. This can be used to determine if crosstalk removal for a specific failing signal will enable that signal to pass specifications (Figure 11).

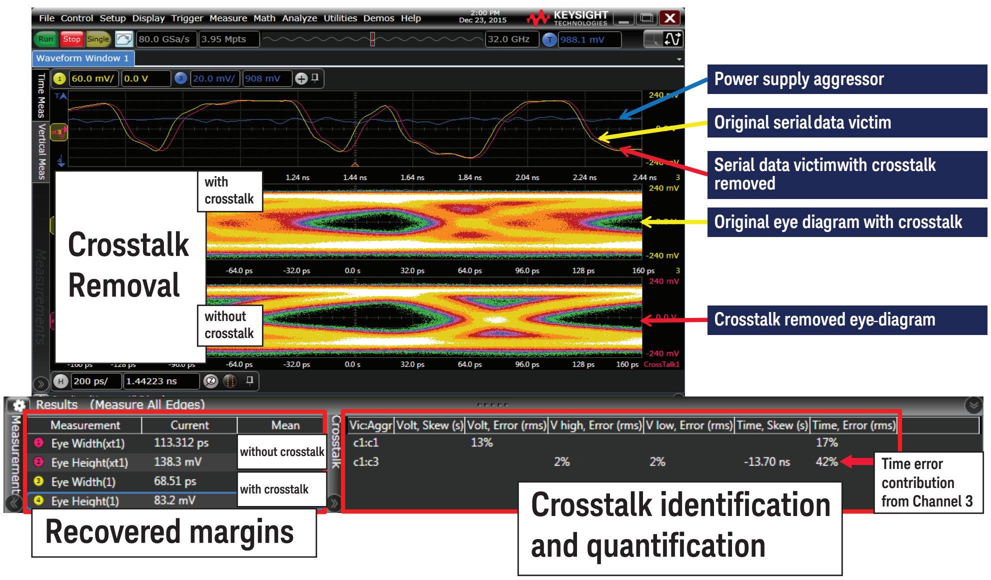


Figure 11. View victim signal with aggressor signal removed to determine margin improvements.

The N8833A/B crosstalk application goes beyond just identifying crosstalk, it also helps engineers to make decisions on which sources of crosstalk are most beneficial to fix in the design. The application enables engineers to quickly make decisions on where to concentrate efforts (time and cost) to improve the signal, saving them weeks of crosstalk debugging time and effort.

No simulation models or inputs are required. Connect a probe to the signal point and select the type of victim signal, whether it is a power supply, zero data or other. Next, select the number of aggressors, up to 3 signals, and the aggressor types. With these inputs, the application performs the analysis and reports the amount of crosstalk for each aggressor and returns a waveform with the crosstalk removed for additional analysis.

Figure 12 below shows an example, using the N8833A/B crosstalk application, of an eye diagram of victim (yellow waveform) with a near-end serial data aggressor (green waveform). You can see (bottom left of Figure 12) the resulting eye width (119.81 ps) and height (123.8 mv) of the victim signal with crosstalk.


Figure 12. View eye width and height of victim signal with crosstalk.

Within the N8833A/B crosstalk application, simply select Analyze -> CrossTalk , and check Enable and in 15 seconds you are able to compare the victim eye diagram (yellow waveform) with an eye diagram where the aggressor is removed (red waveform). Also displayed is the improved eye width (116.88 ps) and height (130.9 mv), Figure 13.


Figure 13. View eye width and height of victim signal with crosstalk and compare to signal without crosstalk.

A resulting waveform, with the crosstalk removed, can be combined with any other analysis available from the oscilloscope, for example the eye diagram, jitter decomposition, de-embed-ding and embedding, equalization, and mask test. The waveform can also be saved and used in a simulation environment.

## Summary

The Keysight N8833A/B crosstalk application helps engineers overcome today's crosstalk analysis challenges by identifying, quantifying and removing crosstalk within device designs. This tool enables engineers to troubleshoot their crosstalk issues more quickly and accurately than ever. In a short time, they are able to determine how much margin can be recovered from signals with the crosstalk removed and in turn, make important design decisions before making design changes, saving time and cost.

For more information on the N8833A/B crosstalk application see www.keysight.com/find/N8833A and www.keysight.com/find/N8833B

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