Digital Design Best Practices - Signal Integrity

This article concentrates on signal integrity, one of the three core components in digital system architecture. The other two, equally important components are content protection and resolution management. Signal integrity relates to maintaining the signal waveforms and sync timing throughout the signal path so that the receiving circuit can read each data bit correctly. In order for this to happen, a digital signal needs to be free of bit errors. Bit errors occur when the receiving circuit fails to properly identify whether the data bit received is high or low. The subject of bit errors can be explored much deeper, but for the purpose of these best practices, it's important to know that, according to the High-Definition Multimedia Interface Specification Version 1.3, the required pixel error rate is 10^{-9} or one pixel error per billion. This translates to a required bit error rate of less than $3.3x10^{-11}$. Such an extremely low error rate may sound like a challenging goal for any digital system design, but with proper planning and adherence to the best practices in this article, it is well within reach. Before we dive into the best practices, let's talk a little about diagnosing signal loss.

Diagnosing Digital Signal Loss

Unlike its analog cousin, digital signal loss is more abrupt and much harder to diagnose. A digital communications analyzer can be used to provide a visual representation of digital signal errors by sampling a series of bits and producing an "eye diagram" from the signals' waveform traces. Signal errors cause the eye diagram to distort and collapse, introducing bit errors. See Figure 1 and Figure 2. Observing an eye diagram can be helpful in visualizing the waveform's integrity, but the eye diagram does not provide measurable clues as to the cause of the signal degradation or disclose how well your receiver can tolerate signal errors. Digital diagnostic equipment, such as a digital communications analyzer, is very expensive and inconclusive. This is often reason enough to take extra time planning a digital system and to employ the best practices described in this article.

Best Practices for Ensuring Signal Integrity. Start at the Source.

There is a wide variance in the quality of the hardware within any signal path, and under the same conditions, one brand of Blu-ray player may perform fine, while another may not. The same goes for displays. Testing source components or displays during initial system conceptual design can save time and money when determining why you're seeing poor

What do bit errors look like?

Bit errors typically appear as video "noise" and escalate rapidly toward transmission failure. If you're seeing symptoms such as distortion, missing lines in the frame or line header, or sparkles or streaking within the video, then your signal is at the verge of collapse. Jitter is another sign of bit loss, and is characterized on your display as data edges appearing to dance back and forth randomly.

Digital images should reflect pristine, bit-for-bit representations of source material. Sparkling, as seen in this screen capture, is a certain sign of bit error and indicates that the image may soon fail entirely.

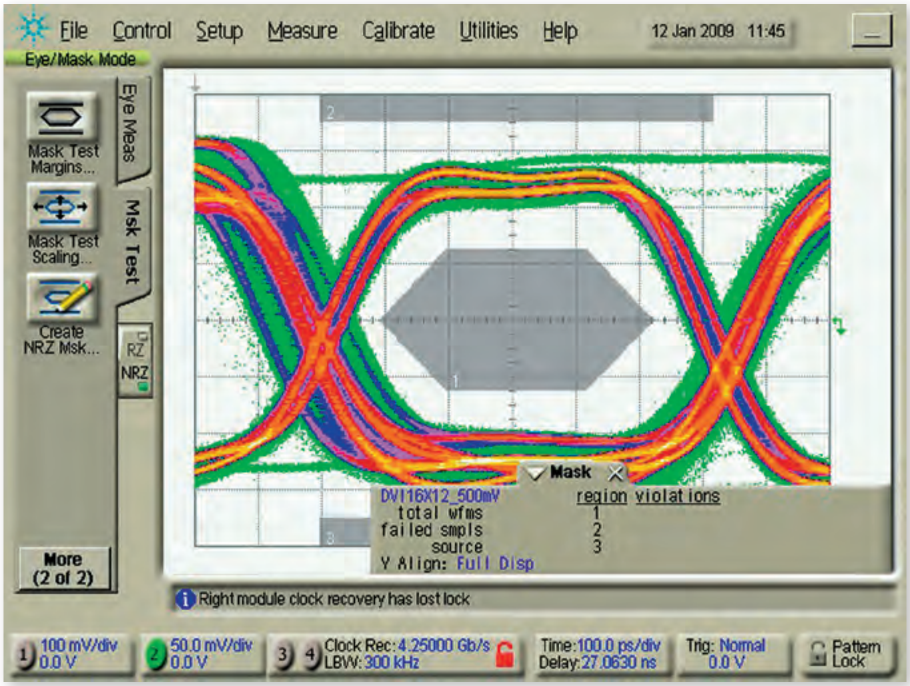

Figure 1: A typical eye diagram showing an acceptable digital signal. The inner portion, or eye mask, indicates the boundary area where signal degradation will lead to image errors. This signal has good clearance from the eye mask boundary.

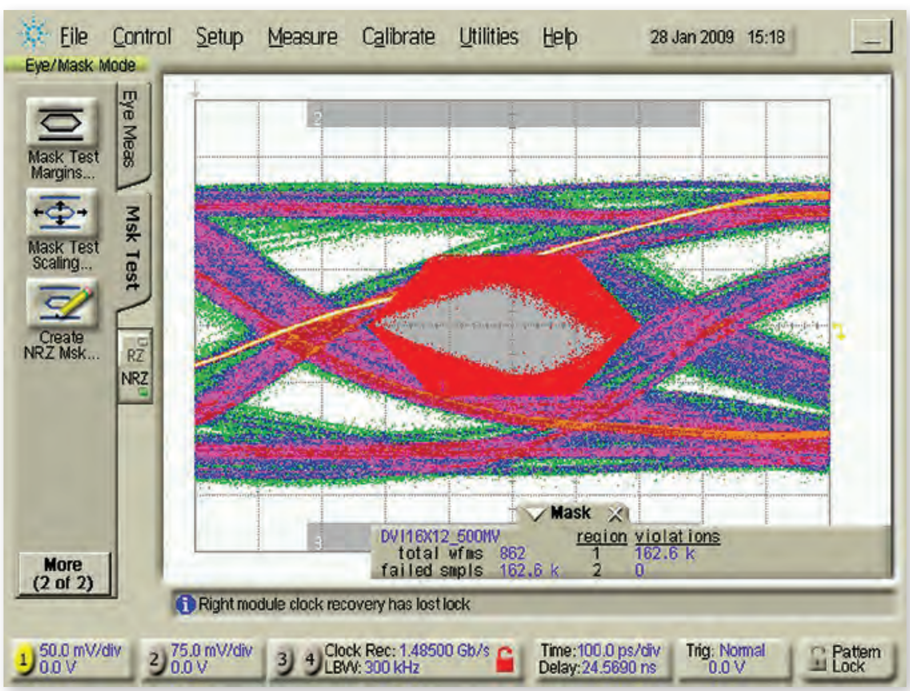

Figure 2: This eye mask has collapsed and indicates digital signal degredation. In this case, the signal was degraded by simply inserting a DVI gender changer. The signal encroaches the eye mask to the point where severe bit errors will be evident or the image will not be displayed at all.

image quality or a blank screen. However, before you swap out the components, check the source and the display first by connecting them with a short length of pre-tested cable to make sure they are operational under ideal conditions.

Keep it Simple

While analog A/V systems typically have high tolerance for several devices between the source and the display, digital A/V systems work best when the "less is more" rule is applied. High resolution digital signals are designed for short, point-to point connection between a source and a display, and are inherently finicky about the number of connections in the signal path. More connections, meaning adapters, wallplates, cables, and component I/Os from cascading A/V devices, may result in signal attenuation and timing errors, or jitter, which will negatively impact signal integrity and the displayed image.

Use Single Cable Connections Between Devices

Avoid using gender changers to "extend" cables, but when signal processing or distribution devices are necessary, try to employ them as sparingly as possible and try to choose devices that have signal equalization built in. Signal conditioning should include input signal equalization and output signal regeneration or reclocking, two advanced features that help compensate for signal degradation.

Keep Cables as Short as Possible

In the analog realm, signal loss is gradual as cable length increases. Losses may be visible on-screen, but are not likely to be distracting unless the losses are substantial. Due to digital signals' high data rates, there is much more demand placed on choosing quality components and cables within the signal path to accommodate the required data rates over longer distances. Also, when data bit loss occurs, effects on the image display are abrupt and far more noticeable than with analog signals.

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Select Good Quality Cables Constructed for the Distance Required

Quality cables are available for lengths up to 200 feet (60 meters), but longer distances are possible with specially designed cables and different cable types, such as twisted pair and fiber optic cables. Manufacturers typically employ their own cable engineering to improve performance, so use their guidelines as a starting point. Regardless of manufacturer claims, however, select cables that are just long enough for each signal path.

Use a Cable Equalizer for Long Cable Runs

Cable equalizers attach to the ends of cables near the display or projector and optimize image quality by reshaping and restoring digital signals sent over long cable runs. Remember that, generally speaking, higher resolution signals travel shorter distances than lower resolution signals. This means that under similar conditions, cables carrying high resolution signals will require the use of a cable equalizer before the same length of cable carrying low-resolution signals will require one. Whenever possible use a short cable from the equalizer to the display.

HDMI 201 - Twisted Pair Extender pair

Choose the Appropriate Type of Cable for Application and Distance

In addition to standard DVI and HDMI cables, digital video signals can be sent over twisted pair and fiber optic cables. Each cable type has its advantages, so here are some best practices and some tips for choosing the right type.

Standard DVI and HDMI Cables

Use standard cables for short, device-to-device connections within a system. Use equalizers for long standard cable runs, up to about 200 feet. The basic off-the-shelf DVI or HDMI dedicated cable was designed to satisfy a limited-distance interface. Equalizers can be incorporated to compensate for signal loss and allow for much longer cable runs.

Since it is neither easy nor recommended to terminate standard cables in the field, it is crucial to choose the right length of cables. If you have a cable that is too short, buy a longer, high performance cable to replace it instead of using a gender changer to attach an additional length of cable. Although two short cables connected by a gender changer is a cheaper solution than one long, high-performance cable, the signal attenuation and reflection through a gender changer would cause undesirable image quality or loss of image, entirely.

Twisted Pair Extenders

Consider using twisted pair extenders instead of non-equalized standard cables when runs exceed 50 feet (15 meters). Twisted pair can transmit low and medium resolution signals up to 200 feet and high resolution signals up to 150 feet. When compared to standard DVI and HDMI cables, twisted pair is more cost-effective, offers increased protection from interference, can be pulled through conduit and other small spaces, and is easy to field-terminate. Consider using shielded twisted pair cables instead of unshielded for increased protection from interference and better overall performance.

Fiber Optic Extenders

Use fiber optic extenders in very long distance applications and in environments where electrical sensitivity or confidentiality are concerns, such as medical, military, and government applications. Fiber optic cables can transmit digital signals from hundreds of feet to kilometers or miles. These cables are virtually immune to electromagnetic and radio frequency interference and their resistance to eavesdropping makes them very secure. If security is a concern, consider using fiber optic cable even if your installation has short to moderate length cable runs.

Initial Testing

Whenever possible, perform the initial test of the system inside your shop instead of at the job site. Troubleshooting is more time-efficient and easier in a familiar environment.

For Further Reference

The Extron Digital Design Guide is an excellent reference for integrating digital technologies into new and legacy presentation systems. It provides a comprehensive resource for A/V system designers seeking to understand these emerging technologies and the many options available to them. You can find our Digital Design Guide on our Web site here: extron.com/ddg.

For details on any of the best practices mentioned in this article, or for questions on how to maintain signal integrity within your specific system design, please contact an Extron Customer Support Representative.

HDMI 101 - HDMI Cable Equalizer