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Analyzing Signals Using the Eye Diagram

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The eye diagram provides visual information that can be useful in the evaluation and troubleshooting of digital transmission systems

The eye diagram is a useful tool for the qualitative analysis of signal used in digital transmission. It provides at-a-glance evaluation of system performance and can offer insight into the nature of channel imperfections. Careful analysis of this visual display can give the user a first-order approximation of signal-to-noise, clock timing jitter and skew.

The eye diagram is an oscilloscope display of a digital signal, repetitively sampled to get a good representation of its behavior. In a radio system, the point of measurement may be prior to the modulator in a transmitter, or following the demodulator in a receiver, depending on which portion of the system requires examination. The eye diagram can also be used to examine signal integrity in a purely digital system—such as fiber optic transmission, network cables or on a circuit board. Figure 1 shows a simple eye diagram that is undistorted, and another that includes noise and timing errors.

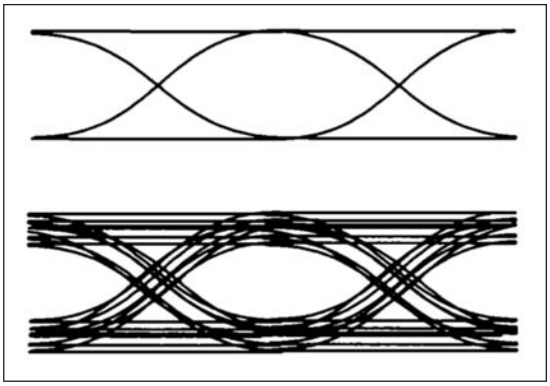


Figure 1 · At top is an undistorted eye diagram of a band-limited digital signal. The bottom eye pattern includes amplitude (noise) and phase (timing) errors. The various transition points can provide insight into the nature of the impairments.

Radio Communications

The transmission of digital signals by radio requires modulation of the RF signal by a train of digital pulses. At its simplest, the data will be a single sequence of logical zeros and ones that are either referenced to zero volts (RZ, or return-to-zero) or with no voltage reference (NRZ, or non-return-to-zero). NRZ data signals are most common, and are the basis for the illustrations in this tutorial.

The simplest 2-state modulation types are on-off keying (OOK), frequency-shift keying (FSK) and phase-shift keying (FSK). They all rely on a transition between two states to convey the binary digital data.

In our beginning communications theory courses, we learned that pulses contain considerable amounts of energy at multiples of the repetition rate (harmonics). The amount of energy in the harmonics, relative to the fundamental, is related to rise and fall time and pulse duration. Fast rise and fall times (“square” transitions) and narrow pulse durations create the most harmonic energy. This is unlike a purely digital system, where these “clean” transitions are highly desirable.

In order to reduce interference, radio transmission channels are not permitted to have unlimited bandwidth. Otherwise, the harmonic energy in the data signal would create corresponding modulation sidebands that

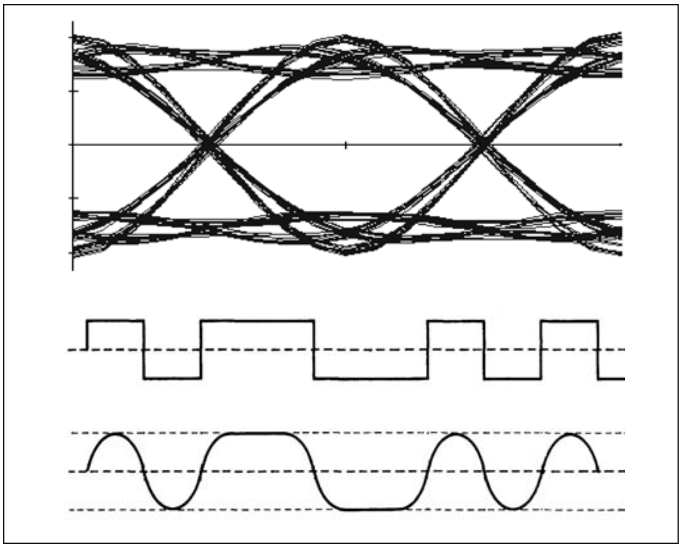


Figure 2 · At the top is the eye diagram of a raised cosine filtered signal ($\alpha = 0.6$) as it might be applied to a modulator. The two lower waveforms represent the square-wave bitstream before and after filtering (these are not aligned with the eye diagram display).

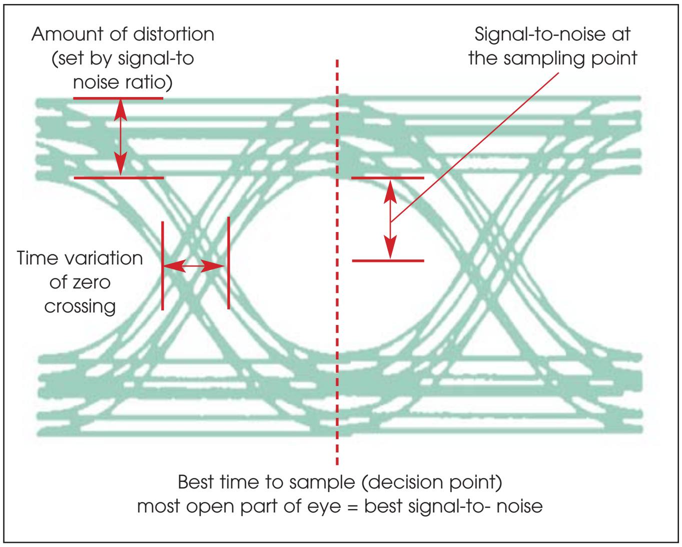


Figure 3 · Basic information contained in the eye diagram. The most important are size of the eye opening (signal-to-noise during sampling), plus the magnitude of the amplitude and timing errors.

extend well beyond the intended bandwidth of the allocated communications channel.

To reduce these unwanted sidebands, the data signal must be band-limited (filtered) in a manner that reduces the harmonic energy while maintaining the integrity of the transmitted data. The eye diagram can be used to look at the signal before transmission, to assure that the filter is behaving properly (Figure 2). A more obvious use of the eye diagram is to evaluate the received signal quality. The diagram in Figure 3 illustrates the type of information that can be determined from the eye diagram.

Impairments to the signal can occur in many places, from the pre-filtering in the transmitter, through the frequency conversion and amplifier chain, propagation path, receiver front-end, IF circuits, and baseband signal processing. Information from the eye diagram can help greatly with troubleshooting. Noise problems will most often be external to the equipment and timing issues can be isolated to the receiver or transmitter with tests on each. It is also important to record the eye diagram so it is available for comparison if new problems arise in the future.

Digital Signal Integrity

The eye diagram is also a common indicator of performance in digital transmission systems. Makers of digital communications hardware often include eye diagrams in their literature to demonstrate the signal integrity performance of their products.

When evaluating digital signals, the eye diagram will be nearly square, since filtering is not usually required for these contained systems. Figure 4 shows the idealized undistorted eye diagram of a digital signal. As expected, the eye opening is wide and high.

Some common impairments of a high-speed digital signal are illustrated in Figure 5. At (a) we see the effects of time errors. These may be due to clock jitter or poor synchronization of the phase-locking circuitry that extracts timing data from the received signal in a transmission system (wireline or optical). In (b) note that as bit rate increases, the absolute time error represents an increasing portion of the cycle, reducing the size of the eye opening, which increases the potential for data errors.

Figure 6 shows a digital signal with reflections from a poorly terminated signal line [1]. If these reflected waves are of significant amplitude, they can reduce the size of the eye opening and, therefore, increase the potential for errors. Additional errors not shown include amplitude distortion due to losses in the transmission system and problems such as crosstalk with other signal lines. Crosstalk can be elusive, since it may involve signals other than the desired one. The non-synchronized crosstalk effects may not be clearly visible on the display.

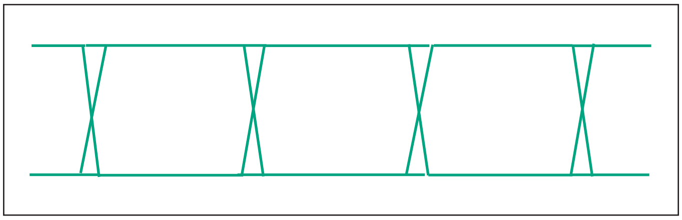


Figure 4 · Idealized digital signal eye diagram (with finite rise and fall times).

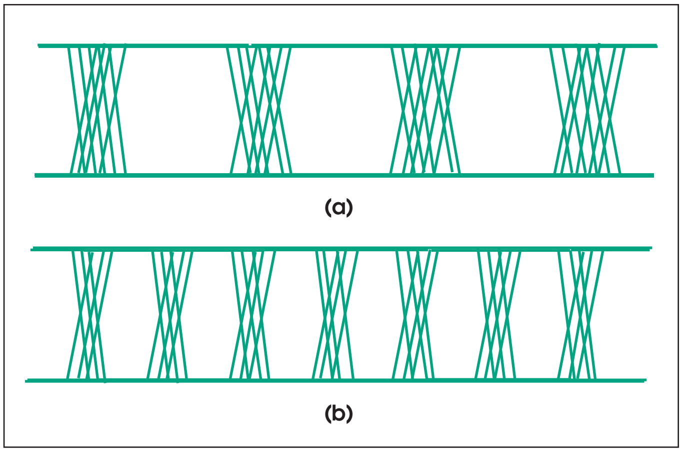
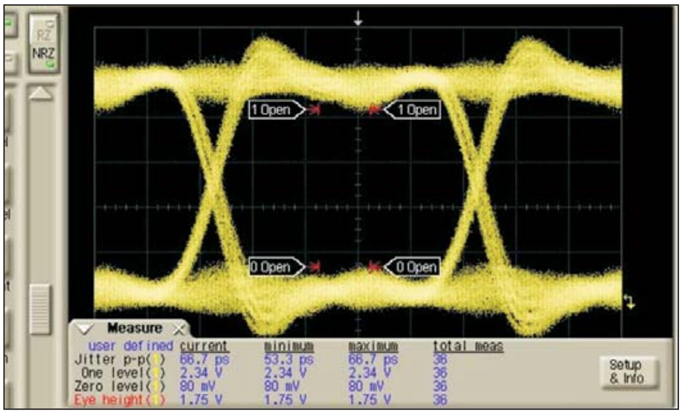


Figure 5 · Timing error: (a) Misalignment of rise and fall times (jitter). (b) With a higher data rate, this diagram has much less open eye area than (a) despite a smaller absolute time error.



user defined	current	minimum	maximum	total meas
Jitter p-p( )	66.7 ps	53.3 ps	66.7 ps	36
One level( )	2.34 V	2.34 V	2.34 V	36
Zero level( )	80 mV	80 mV	80 mV	36
Eye height( )	1.75 V	1.75 V	1.75 V	36

Figure 5 · Oscilloscope display of a digital signal with reflection due to imperfect termination (1).

A final note that applies primarily to high-speed digital signal analysis is the quality of the oscilloscope used to observe the eye diagram. The bandwidth of the instrument must be sufficient to accurately display the waveform. This usually means that the bandwidth must include the third, and preferably the fifth, harmonic of the bit rate frequency.

In summary, the eye diagram is a simple and useful tool for evaluating digital transmission circuitry and systems. It provides instant visual data to verify quality or demonstrate problems. Used in conjunction with other signal integrity measurements, it can help predict performance and identify the source of system impairments.

Reference

1. Jerry Seams, “A Comparison of Resistive Terminators for High Speed Digital Data Transmission,” *High Frequency Electronics*, October 2005.