Physical Layer Testing of 3G-SDI and HD-SDI Serial Digital Signals

Application Note

The transition to high definition (HD) and 3 Gb/s SDI (Serial Digital Interface) can be executed smoothly if careful engineering practices are followed in the initial stages of planning the facility. Selection of the correct type of cable appropriate for the high data rates of HD and 3 Gb/s signals is critical to ensuring a quality installation. Careful installation, avoiding incorrect crimping, twists, bends or stress to the cable, will ensure the high speed SDI signal will be transmitted easily and successfully. During installation, simple test and measurement procedures should be carried out to ensure the performance of each link and ensure that each piece of equipment performs to its specification. A waveform monitor with Eye and Jitter measurement capability is an invaluable tool in investigating physical layer problems with the SDI signal.

Tektronix®

Cable Type	3 Gb/s-SDI		HD-SDI		SD-SDI	
	Feet	Meters	Feet	Meters	Feet	Meters
Belden 8281			260	79	1000	305
Belden 1694A	250	76	364	111	1339	408
Belden1855A	154	47	209	64	732	223
Belden 1505A	215	66	308	94	1111	339
Image 1000					1325	404
Canare L-5CFB					1210 (max)	368

Table 1. Common Cable types and recommended cable lengths.

The Cable

Different cable types have varying physical properties which allow the digital signal to be propagated over a certain length of cable. The manufacturer of the cable can provide specifications for the maximum recommended distance that should be used to transport the 3 Gb/s, HD and SD-SDI signals. Table 1 shows some of the common cable types used and the recommended transmission distance of the cable for SD (270Mb/s), HD (1.5 Gb/s) and 3 Gb/s data rates.

There are several other factors that can affect the decision of which type of cable to use and how to ensure the cable is installed correctly.

- The temperature rating of the cable needs to be suitable for the environment in which it will be used.

- The physical dimensions of the cable will affect the choice of BNC connector type.

- The thickness of the cable will affect the bend/flex radius and the pulling tension allowable during installation.

- The weight of the cable, when multiple bundles of the cable are used, needs to be taken into consideration, as this may stress the cables once installed.

- The mechanical fixtures used to support the cables need to have adequate strength.

During the installation of the cable it is important to handle it with respect to maintain the health of the system. 3 Gb/s and HD-SDI are less forgiving than an SD-SDI signal. Stress to the cable can be introduced during the installation process that cannot be physically seen, but will affect the signal quality margin of the system. If a person steps on a cable or runs an equipment cart over it this can distort the shape. Although there maybe no visible damage, it will affect the propagation properties of the cable. When the cable is uncoiled from the drum it is important to ensure that there are no kinks in the cable. Kinks may create reflections as the signal is transmitted.

Installing the cable often means pulling the cable through various ducts and runs. Pulling of the cable should be done in a slow and steady fashion. Jerking on the cable or exceeding the maximum pull tension will stretch and cause distortion. Again, even though no visible damage may be apparent, the physical properties may be changed and result in a lower performance level. With multiple cables being pulled through various runs, an anti-friction lubricant (that is compatible with the cable jacketing material) should be used.

Often the cables will need to be bent around certain objects in order to change the path of the cable. Each type of cable has a minimum bend radius of typically 10 times the diameter of the cable. Exceeding this bend radius will put pressure on the cable and may cause stress and physical changes to the properties. Note a 90° turn of the cable is equivalent to adding an additional 30 feet of cable to the physical path of the signal.

Many of the cables are bundled together into racks or carried on cable support trays. A large bundle of cables can be very heavy and each cable pressing against each other can cause distortion. No more than 8 inches of cable sag should be allowed within the installation, as this can also lead to distortion. System integrators often use "J" hooks or cable ties to group the cables together. A good rule of thumb is if you cannot move any cable inside a tied bundle then the cable tie is too tight. Spacing of the cable tie or "J" hook is also important. For symmetry and neatness most people place the cable tie or "J" hooks at identical distances apart. Doing so can lead to a deformation at a given wavelength which can cause an accumulated reduction in return loss within the system[1]. Therefore cable ties should be placed at random distances apart and allow for movement of cables within the bundle.

[1] Reference High-Definition Cabling and Return Loss By Stephen H. Lampen, Martin J. Van Der Burgt, and Carl W. Dole of Belden.
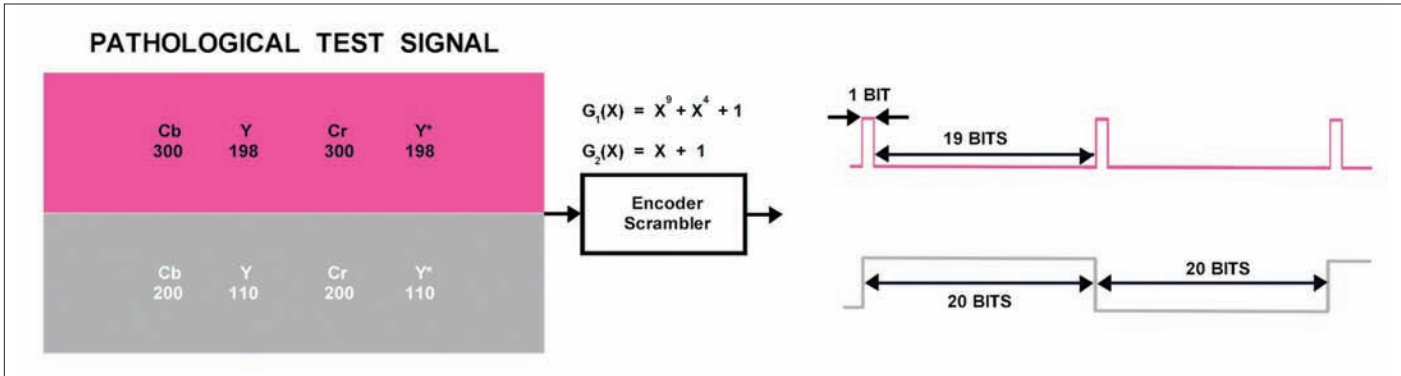
Figure 1. SDI check field "Pathological Test Signal."

When connecting the cable to the equipment it is important to remember that groups of cables (and bending of the cable to reach a specific input) may also lead to stress of both the cable and connector. Over time, this may lead to improper contact between conductors and connectors. Care should be taken when the cable is connected to equipment. System integrators should ensure that bend radius and weight of other cables do not put stress on the cable or connection. All of these measures will help to keep the original physical shape of the cable and maintain the properties to ensure optimal performance.

Stress Testing

Unlike analog systems that tend to degrade gracefully, digital systems tend to work without fault until they crash. To date, there are no in-service tests that will measure the headroom of the SDI signal. Out-of-service stress tests are required to evaluate system operation. Stress testing consists of changing one or more parameters of the digital signal until failure occurs. The amount of change required to produce a failure is a measure of the headroom of the system.

Starting with the specifications in the relevant serial digital video standard (SMPTE 259M, SMPTE 292M or SMPTE 424M), the most intuitive way to stress the system is to add cable until the onset of errors. Remember that although the video is encoded as a digital data stream, the SDI signal itself is still analog in nature and suffers from the same types of analog distortions such as attenuation and phase shifts.

To compensate for these distortions, an adaptive cable equalizer is used within a piece of receiving equipment. This device compensates for signal loss and phase shifts due to the attenuation and frequency response performance loss down the cable. By adding additional length of cable to the system, the receiver characteristics can be evaluated, specifically the automatic equalizer range and noise performance.
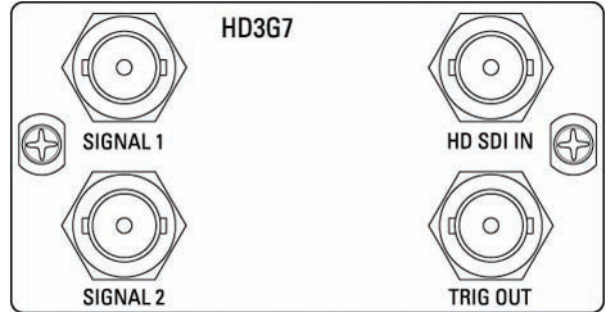
SDI Check Field

The SDI Check Field (also known as a "pathological signal") is a full-field test signal and therefore must be done out-of-service. It's a difficult signal for the serial digital system to handle and is a very important test. The SDI Check Field is designed to create a worst-case data pattern for low-frequency energy, after scrambling, in two separate parts of the field. Statistically, these intervals will occur about once per frame.

One component of the SDI Check Field tests equalizer operation by generating a scrambled NRZI (Non-Return to Zero Inverted) sequence of 19 zeros followed by a 1 (or 19 ones followed by 1 zero). This occurs throughout a single line about once per field as the scrambler attains the required starting condition; and when this occurs it will persist for the full line and terminate with the EAV (End of Active Video) packet. This sequence produces a high DC component that stresses the analog capabilities of the equipment and transmission system handling the signal. This part of the test signal may appear at the top of the picture display as a shade of magenta, with the value of luma set to 198h, and both chroma channels set to 300h as shown in Figure 1.

Figure 2. (a) TG700 Sync Pulse and Test Signal Generator.

(b) HD3G7 3Gb/s SDI Generator module for TG700.

The other part of the SDI Check Field signal is designed to check phase-locked loop performance with an occasional line consisting of scrambled NRZI of 20 zeros followed by 20 ones. This provides a minimum number of zero crossings for clock extraction. This part of the test signal may appear at the bottom of the picture display as a shade of gray, with luma set to 110h and both chroma channels set to 200h.

Some test signal generators may use a different digital value order, with the picture display in shades of green instead of magenta. Receiving devices should handle the SDI Check Field test signal without errors. The SDI Check Field is a fully legal signal for component digital but not for the composite domain. The SDI Check Field is defined in SMPTE Recommended Practice RP178 for SD and by RP198 for HD.

There is currently no standard for 3 Gb/s SDI Check Field, although the same data patterns may been used within generators such as the TG700 and HD3G7 3 Gb/s generators module as shown in Figure 2. Within the 3 Gb/s standard there are two levels; Level A provides a mapping structure for the various format which was specifically developed for the 3 Gb/s format, and Level B allows for Dual Link signals standardized in SMPTE 372M and dual SDI signals to be multiplexed into a 3 Gb/s data stream. Therefore the data patterns for the SDI Check Field needs to be mapped in specific ways for the Level A and Level B mapping structures to produce a pathological signal.

CRC Error Testing

A Cyclic Redundancy Check (CRC) can be used to provide information to the operator or even sound an external alarm if the data does not arrive intact. A unique CRC pair is present in each video line with a separate value for chroma and luma components in high-definition or 3 Gb/s formats, and may be optionally inserted into each field in standard definition formats. A CRC is calculated and inserted into the data signal for comparison with a newly calculated CRC at the receiving end.

For standard definition formats, the CRC value is inserted into the vertical interval, after the switch point. SMPTE RP165 defines the optional method for the detection and handling of data errors in standard definition video formats. Full Field and Active Picture data are separately checked and a 16-bit CRC word generated once per field. The Full Field check covers all data transmitted except in lines reserved for vertical interval switching (lines 9-11 in 525 or lines 5-7 in 625 line standards). The Active Picture check covers only the active video data words, between but not including, SAV and EAV. Half-lines of active video are not included in the Active Picture check. Digital monitors may provide both a display of CRC values and an alarm on any CRC errors.

Figure 3. Status display showing CRC errors of an HD SDI signal.

Figure 4. WFM8300 Waveform monitor showing eye and jitter displays.

The CRC for high-definition formats is defined in SMPTE 292M and for 3 Gb/s formats is defined in SMPTE 425. The CRC value is inserted following the EAV and line number words, so CRC checking is performed on a line-by-line basis. Waveform monitors such as the Tektronix WVR series or the WFM series presents this data within the Video Session status display as shown in Figure 3 and report the number of errors on a field by field basis. The user can then monitor the number of errors they have received along the transmission path.

Ideally, the instrument will show zero errors indicating an "error-free" transmission path. If the errors increase to one every hour or minute, this indicates the system is approaching the digital cliff. The engineer should investigate the transmission path to isolate the cause of the error. Approaching the digital cliff makes it more difficult to troubleshoot the problem.

Visible errors may be noticed on the picture monitor initially as sparkle effects (black and white pixel drop-outs) as the receiver fails to recover the data correctly. If the signal degrades further, there will be complete or partial lines that
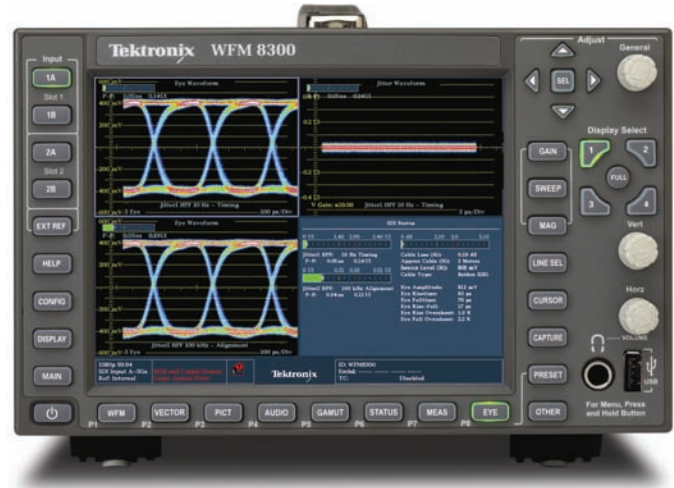
will begin to drop out from the picture display before the picture will freeze or go to black. This indicates the transmission has crossed the digital cliff. To prevent this situation the health of the physical layer needs to be monitored.

Monitoring Eye and Jitter

The WFM8300 (Figure 4) and WFM8200 waveform monitors are the latest Tektronix measurement instruments to provide the ability to monitor the physical layer of the SDI signal. The WFM8000 series platform allows for monitoring of the 3 Gb/s, HD and SD digital signals. The WFM8200 unit supports option EYE that can be added to the instruments that allows the user to view the eye display of the SDI signal. Engineers commonly use eye diagrams to analyze serial data signals and diagnose problems. Becoming familiar with the characteristics of the eye display can help determine problems within the path of the SDI signal.

The eye pattern is an oscilloscope view of the analog signal transporting the data. The signal highs and lows must be reliably detectable by the receiver to yield clock and real-time data without errors.
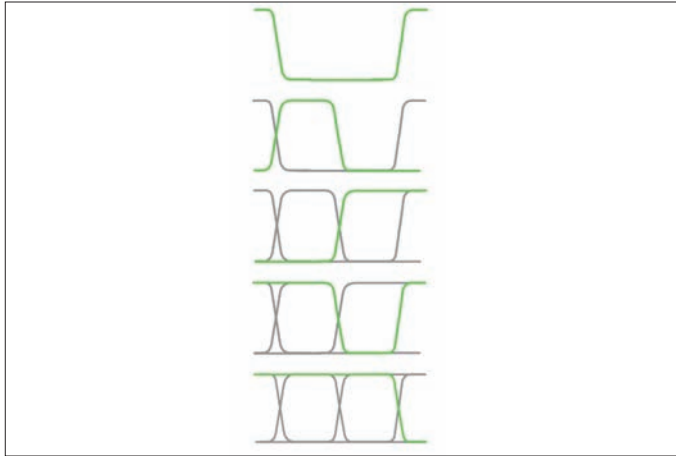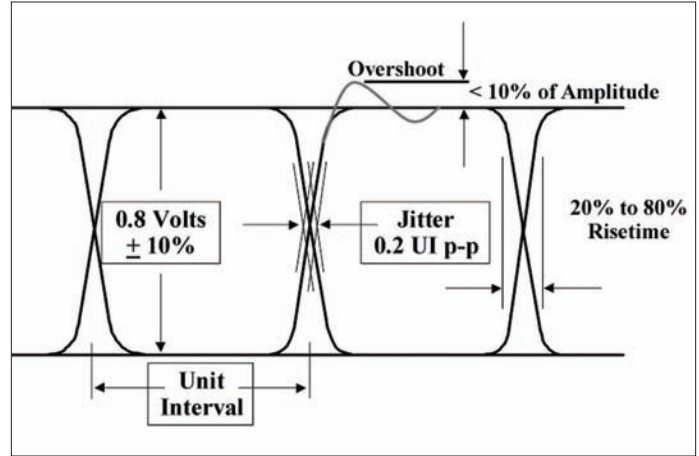
Figure 5. Development of the eye display.

Figure 6. Eye measurement specifications.

	SD	HD	3 Gb/s
Amplitude	800mv +/- 10%	800mv +/- 10%	800mv +/- 10%
Overshoot	10% of Amplitude	10% of Amplitude	10% or Amplitude
Rise/Fall time	Shall be no less than 0.4 ns, no greater than 1.50 ns, and shall not differ by more than 0.5 ns	Shall be no greater than 270 ps and shall not differ by more than 100 ps	Shall be no greater than 135 ps and shall not differ by more than 50 ps
Jitter Timing (10Hz)	0.2UI (740 ps)	1.0UI (673.4 ps @ 1.485 Gb/s) (674 ps @ 1.4835 Gb/s)	2.0UI (673.4 ps @ 2.97 Gb/s) (674 ps @ 2.967 Gb/s)
Jitter Alignment	0.2UI (740 ps) @ 1 kHz	0.2UI (135 ps) @ 100 kHz	0.3UI (101 ps) @ 100 kHz Maximum Preferred 0.2UI (67.3 ps) @ 100 kHz

Table 2. Eye specifications.

To make the eye diagram, the instrument aligns the equivalent time-sampled segments using a reference clock signal. This reference clock is extracted from the data signal within the waveform monitor. The measurement instrument equivalent time samples this data stream, taking segments of the samples to reconstruct the eye diagram. This is done by overlaying enough of these segments so the eye display is formed as shown in Figure 5.

The basic parameters measured using the eye pattern display are signal amplitude, overshoot, rise time and fall time. Jitter can also be measured with the eye pattern

display if the clock recovery bandwidth is specified. SMPTE standards (SMPTE 259 M, 292 M, 424 M and RP184) defined specifications for these parameters and the launch amplitude of a device. These specifications are summarized in Table 2 and Figure 6. It is recommended to use a short piece of high quality cable (typically one meter / three feet) between the device under test and the measurement instrument. In this case the effects of noise and frequency roll off will be negligible. The device should also generate a color bar test pattern which is a non-stressing test signal.
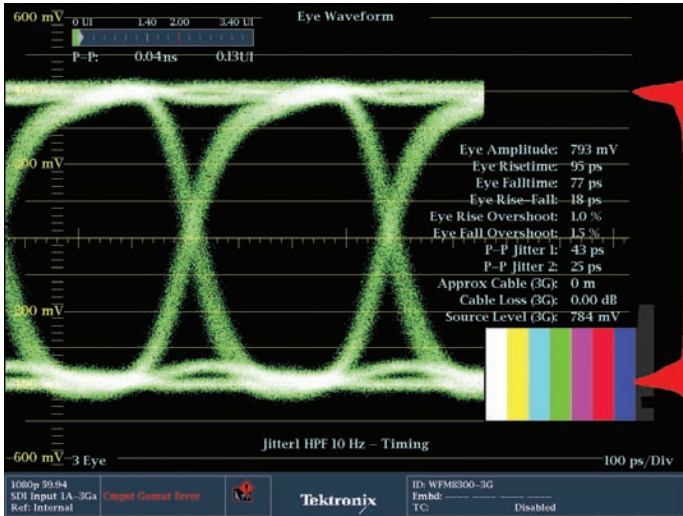
Figure 7. 3Gb/s Automated eye measurement.

Figure 8. Eye decision threshold.

The time interval between two adjacent transitions is referred to as a Unit Interval (UI) which is the reciprocal of the clock frequency. The unit intervals 3.7 ns for digital component 525/625 (SMPTE 259 M), 673.4 ps (1.485 Gb/s) or 674 ps (1.485 Gb/s) for digital High definition formats (SMPTE 292 M) and 336.7 ps (2.97 Gb/s) or 336.4 ps (2.967 Gb/s) per SMPTE 424 M for 3 Gb/s signals. When viewing the eye display on the waveform monitor, cursors can be used to make these measurements on the instrument. One difficulty is that measurements can be made at slightly different points; sampling process and noise within the signal can make it difficult to determine the actual measurement locations. For consistency, the waveform monitor can make these measurements automatically and provide precise, repeatable measurements. Option PHY on the WFM8300 provides this capability, as shown in Figure 7. Measurement of amplitude, rise time, fall time, overshoots and jitter are automatically made with option PHY. Additionally, an eye amplitude histogram is shown on the display when in full screen.

A serial receiver determines if the signal is a "high" or a "low" in the center of each eye at the decision threshold (Figure 8), thereby detecting the serial data bit transmitted. When using a short piece of cable to connect the transmitting device to the receiver, the a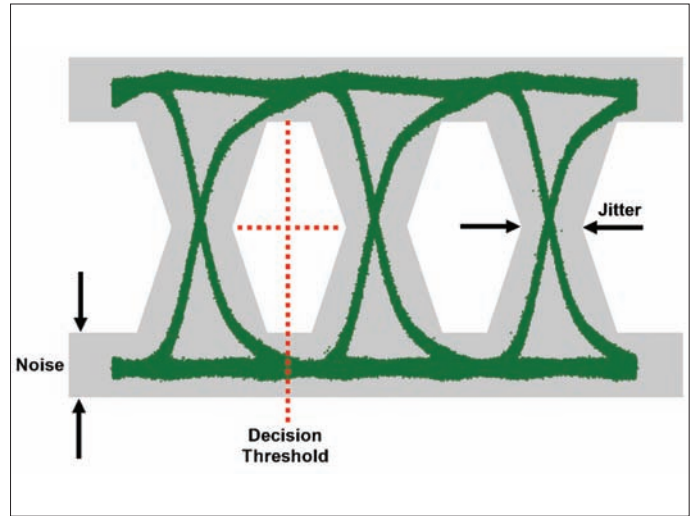daptive cable equalizer will have little effect on the system. The eye display will be termed "open" as there is a maximum distance between transitions at the cross-over point. As noise and jitter in the signal increase through the transmission channel, they will narrow the eye opening. Increased cable length, in which the SDI signal travels, will cause attenuation of the signal and frequency roll off, requiring the adaptive cable equalizer within the receiver to compensate for these losses.

Typically the receiver selects the best decision threshold in the center of the eye for recovery of the clock and data, although some receivers select a point at a fixed time after each transition point. Any effect which closes the eye may reduce the usefulness of the received signal. In a general communications system with forward error correction, accurate data recovery can be made with the eye nearly closed by use of both equalization and error-correction. However, without forward error correction and with the very low error rates required for correct transmission of serial digital video, a rather large and clean eye opening is required after receiver equalization. This is because the random natures of the processes that close the eye have statistical "tails" that would cause an occasional, but unacceptable, error. Also the SDI equalizer is tuned for coax cable loss only and does not equalize for linear distortions.

Jitter Measurements

Ideally, the time interval between transitions in an SDI signal should equal an integer multiple of the unit interval. In real systems, however, the transitions in an SDI signal can vary from their ideal locations in time. This variation is called Time Interval Error (TIE), commonly referred to as jitter. This timing variation can be induced by a variety of frequency, amplitude and phase-related effects. *(Note: More detailed information on jitter can be found in the Tektronix Video Primer "Understanding Jitter Measurements for Serial Digital Signal").*

Tektronix waveform monitors use the phase demodulation method to automatically measure peak-to-peak video jitter on the 3 Gb/s, HD and SD-SDI signals. The waveform monitor measures the jitter in an equalized SDI signal that corresponds closely to the signal that the SDI receivers decode. Since there is no separate clock provided with the video data, a sampling clock must be recovered by detecting data transitions. This is accomplished by directly recovering energy around the expected clock frequency to drive a high-bandwidth oscillator locked in real-time with the incoming signal. This oscillator then drives a heavily averaged, low-bandwidth phase locked oscillator. These oscillators are then compared in a phase demodulator. The phase detector within the instrument then generates a demodulated jitter signal in real-time and displays a jitter waveform. This waveform display is correlated to the line or field frequency of the video signal and the user can select bandwidths for the band-pass filtered demodulated display.

There are two defined types of jitter as specified in SMPTE RP184:

Timing Jitter

The variation in position of a signal's transitions occurring at a rate greater than a specified frequency, typically 10Hz or less. Variations occurring below this specified frequency are termed wander.

Alignment Jitter

The variation in position of a signal's transition relative to those of a clock extracted from that signal. The bandwidth of the clock extraction process determines the low-frequency limit for alignment jitter. For SD systems this frequency limit is 1 kHz and for HD systems the frequency limit is 100 kHz.

Allowed timing jitter is specified as 0.2UI for SD signals (740 ps for digital component 525 and 625) and 1.0UI (673.4 or 674 ps) for digital high definition formats. In the case of alignment jitter the specification allows 0.2UI down to a frequency of 1 kHz for SD systems and a frequency of 100 kHz for HD. For high speed 3 Gb/s signals the specification for timing jitter is 2.0UI and alignment jitter is defined to be 0.3UI at 100 kHz, but is preferred to be 0.2UI (Table 2 on page 6).

Digital video systems will work well beyond these specifications, but will fail at some point. Unfortunately, it is difficult to characterize when this failure point will occur and therefore it is vital to maintain the health of the digital SDI signal. Preventing conditions which would cause the system to fall off the edge of the cliff due to jitter need to be avoided.
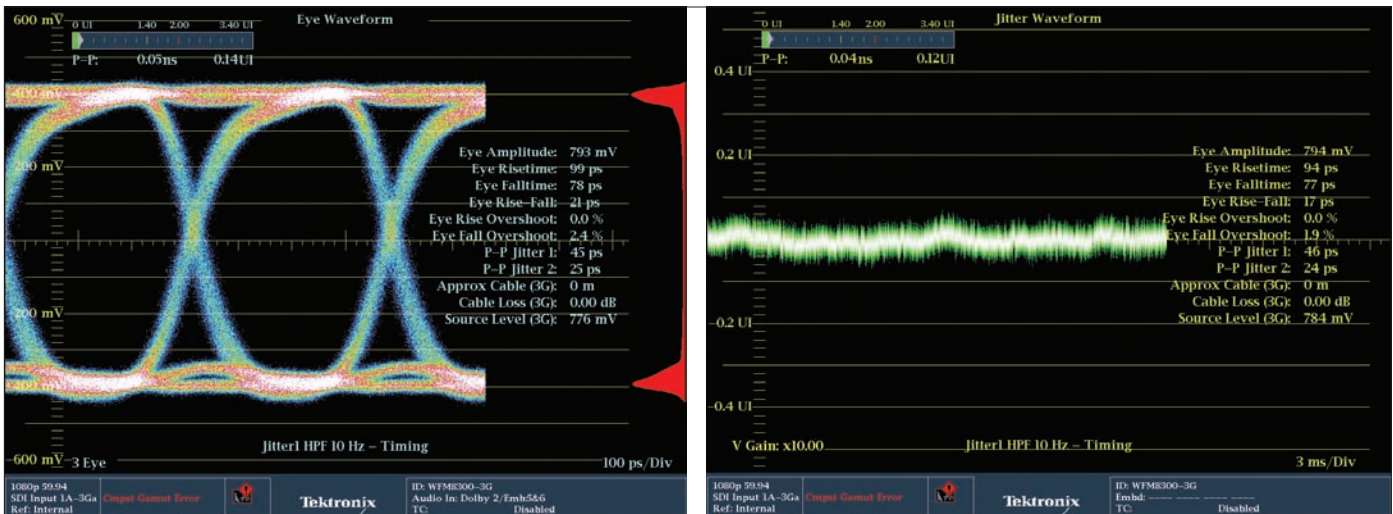
Figure 9. (a) HD SDI eye and (b) jitter waveform display, using short 1 meter length of cable.

Diagnosing SDI Physical Layer Problems

Signal amplitude is important because of its relation to noise, and because the receiver estimates the required high-frequency compensation (equalization) based on the half-clock-frequency energy remaining as the signal arrives. Incorrect amplitude at the sending end could result in an incorrect equalization being applied at the receiving end, causing signal distortions. Rise time measurements are made from the 20% to 80% points as appropriate for ECL logic devices. Incorrect rise time could cause signal distortions such as ringing and overshoot, or if too slow, could reduce the time available for sampling within the eye. Overshoot could be the result of incorrect rise time, but will more likely be caused by impedance discontinuities or poor return loss at the receiving or sending terminations.

By analyzing the eye and jitter displays of the waveform monitor, engineers can determine possible problems associated with the transmission of the SDI signal. Figure 9a shows an 3 Gb/s-SDI signal connected from a test signal generator on a short one meter length of cable. Voltage and time measurement cursors can be placed on the eye display to make the measurements manually. Alternatively automated measurements can be made by the instrument itself. In this case the eye display is "wide open" and the signal is within the launch amplitude specification of SMPTE 424. The jitter display is a horizontal line, and when magnified to its maximum allowable range shows random noise across the horizontal line display. This is basically the noise floor of the system as shown in Figure 9b.
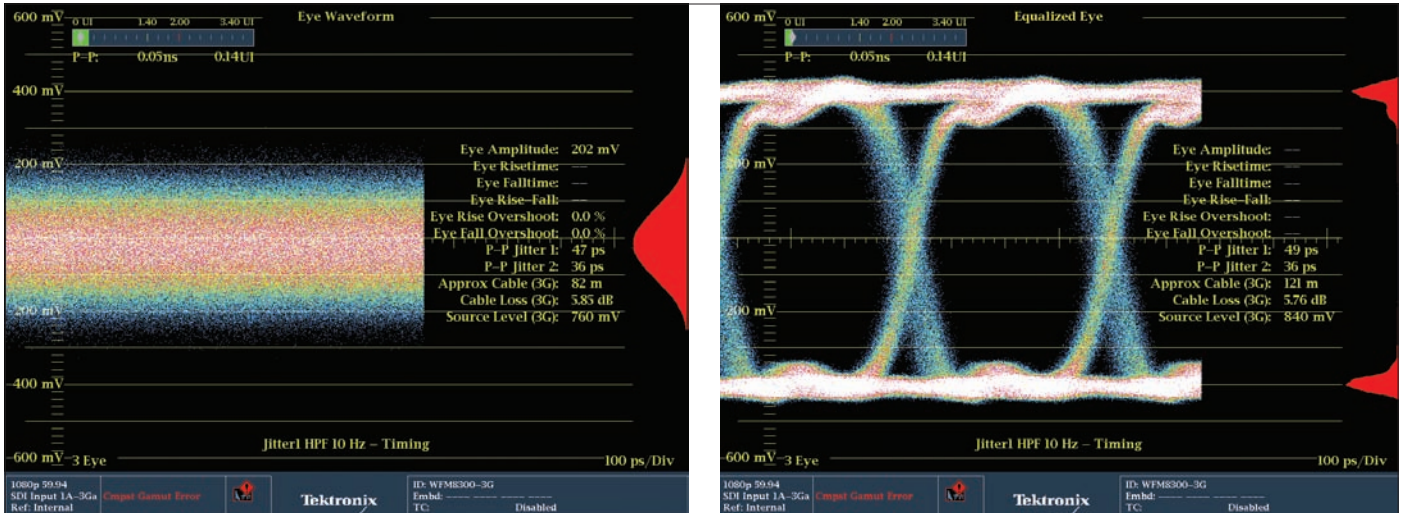
Figure 10. (a) Eye display with closed eye and (b) equalized eye display of same signal.
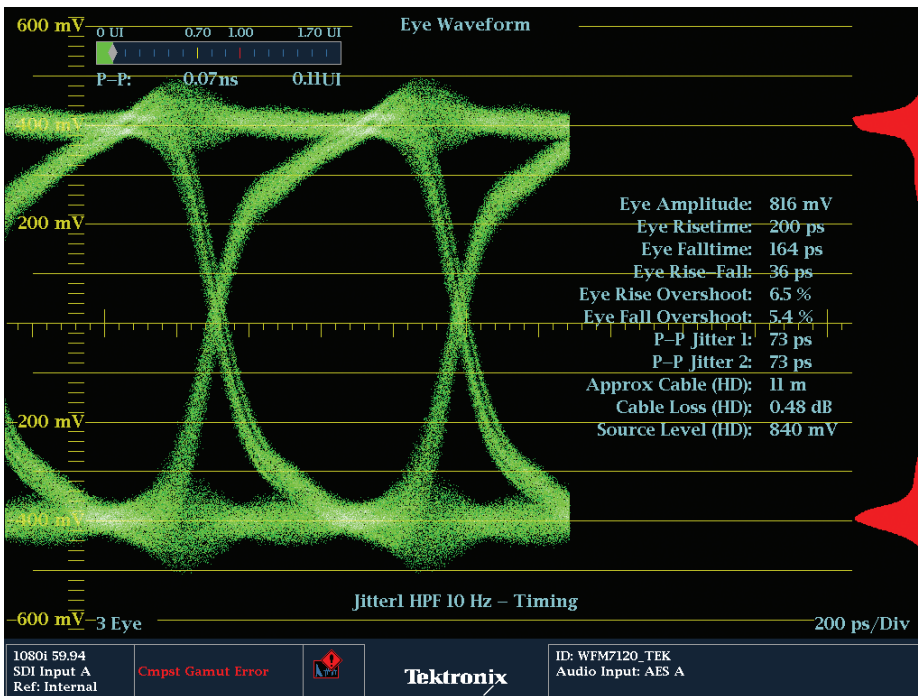

Figure 11. Eye display with incorrect termination.

Adding 50 meters of Belden 1694 cable between the generator and the instrument results in attenuation of the amplitude at high frequencies, producing a longer rise and fall time of the signal. The losses along the cable narrows the eye opening and it is no longer clearly visible within the eye display as shown in Figure 10a. However, this signal is still able to be decoded correctly. In this case the equalized eye mode on the WFM8200/8300 will allow the user to observe the eye opening as shown in Figure 10b. The Equalized Eye display shows the signal that receivers with adaptive cable equalizer will decode.

Proper termination within an 3 Gb/s or HD-SDI system is even more critical because of the high clock rate of the signal. Improper termination will mean that not all of the energy is absorbed by the receiving termination or device. This residual energy will be reflected back along the cable creating a distorted waveform. These reflections can produce ringing within the signal and the user will observe overshoot and undershoots on the eye display as shown in Figure 11.

In this case the SDI source device has two weakly isolated outputs. One, was left unterminated creating a reflection onto the other output signal being monitored, even though it is properly terminated. The anomaly can be corrected by properly terminating the unconnected output. Note that this termination error did not cause a problem to the signal being received. However this distortion will add to other distortions along the signal path, narrowing the eye opening more quickly and decreasing the receiver's ability to recover the clock and data from the signal.

So far we have shown typical defects that are seen due to cable and incorrect termination. These are problems you may encounter when qualifying an installation. Typically the distortion of the signal caused by the physical cable does not add significantly to the jitter of the system. More often active devices typically contribute jitter and other defects to the eye display within the system. There are two types of jitter:

Random Jitter is inherent with all systems to some degree, since this random jitter is introduced by thermal or shot noise of the device. This type of jitter is typically characterized by a largely unbounded Gaussian probability distribution. Therefore, the RMS (Root Mean Squared) value of the jitter is best used as a universal measure of the jitter amplitude. However, since it is the jitter peaks that cause the errors and even if they occur with low probability due to the nature of the Gaussian distribution, the peak or peak-to-peak jitter is still important and should be quantified.

Deterministic Jitter often has a periodic nature but is primarily characterized as being bounded with a maximum peak-to-peak jitter. Deterministic jitter is more easily characterized within the system than random jitter, since it generally is not dependent on the measurement time. Deterministic jitter can be introduced by an active device into the system by a number of conditions.

- Switching power supply which could introduce periodic deterministic jitter, related to switching frequencies of the supply or related to the mains frequency of 50/60Hz.

- Differences in rise and fall times of transitions from a device can introduce duty-cycle.

- A device during its processing of video signals may introduce periodic jitter related to the line and field rate. For instance a device which is genlocked to a video reference could cause the master clock to be varied. These components of jitter related to line and field frequencies could then be transferred to the SDI output.

- The parallel-to-serial conversion process within the device may introduce word correlated jitter to the SDI output.

- In some cases the frequency response of the cable could produce jitter dependent on the data transmitted along the cable.

Jitter within the SDI signal will change the time when a transition occurs and cause a widening of the overall transition point as shown in Figure 8 (page 7). This jitter can cause a narrowing or closing of the eye display and make the determination of the decision threshold more difficult. It is only possible to measure up to one unit interval of jitter within the eye display by the use of cursors manually, or by making automated measurement based on the eye display. It can also be difficult within the eye display to determine infrequently occurring jitter events, since the intensity of these events will be more difficult to observe, compared to the regular repeatable transitions within the SDI signal.
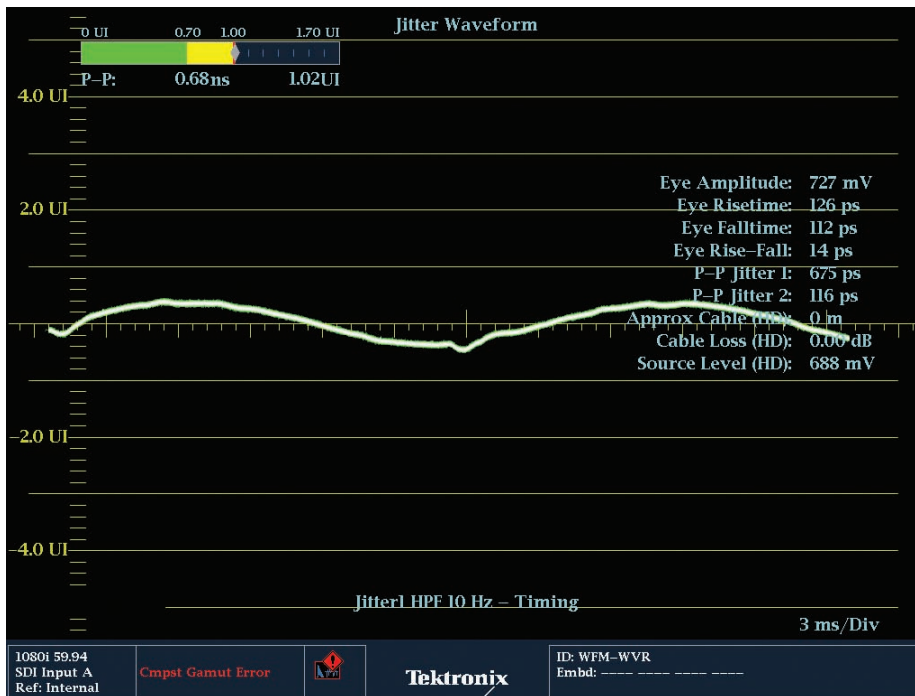
Figure 12. Eye decision threshold.

Figure 13. 60Hz mains frequency jitter.

In the WFM8200, WFM7120 and WFM6120 EYE option, a jitter readout is provided within the eye display. The readout provides a measurement in both unit intervals and equivalent time. For an operational environment, a jitter thermometer bar display provides simple warning of an SDI signal exceeding a jitter threshold. This threshold value is selectable by the user. The display is configured to show a range around the user-selectable threshold. The total bar display represents a 170% of the user selectable value and changes from a green bar display to yellow, and then red as the value of the jitter increases as shown in Figure 12. At a value of 70% of the threshold value the bar display will change from green to yellow. At 100% of the jitter measurement value the bar display will change from yellow to red. This allows users to easily visualize a potential problem within the SDI signal and quickly see any changes to the jitter performance of the system. The jitter readout is affected by the choice of jitter filter used and

can therefore provide measurement of timing and alignment jitter by selection of the appropriate filter.

To characterize different types of jitter, the jitter waveform display available with the PHY option on the WFM8300 and WFM7120, allows a superior method to investigate jitter problems within the signal than the eye display and jitter readout. The jitter waveform can be displayed in a one line, two line, one field or two field display related to the video rate. When investigating jitter within the system it is useful to select the two field display and increase the gain within the display. A small amount of jitter is present within all systems but the trace should be a horizontal line. Increasing the gain to ten times will show the inherent noise or noise floor within the measurement system as shown in Figure 9b (page 9). This should be random in nature and uncorrelated with the video signal. If not, there is likely to be a deterministic component of jitter present within the signal.

If mains hum is present within the signal then this will add a frequency deviation to the jitter trace at the mains frequency. This will produce a cyclic vertical disturbance to the jitter trace related to the mains frequency as shown in Figure 13. There are a variety of different band-pass filters within the instrument that can help to isolate jitter frequencies present within the signal. Selection of the 100 Hz filter within the instrument should reduce the effect of these mains frequency components within the jitter display without attenuating the horizontal line correlated and higher frequency components.

The readout provides a measurement in both unit intervals and time. A selectable threshold can also be set within the instrument, causing the jitter thermometer to turn red when this value is exceeded. This alarm condition can also be reported in the error log of the unit, so that these errors can be monitored over time to see their variation or help determine when an error occurred within the system.
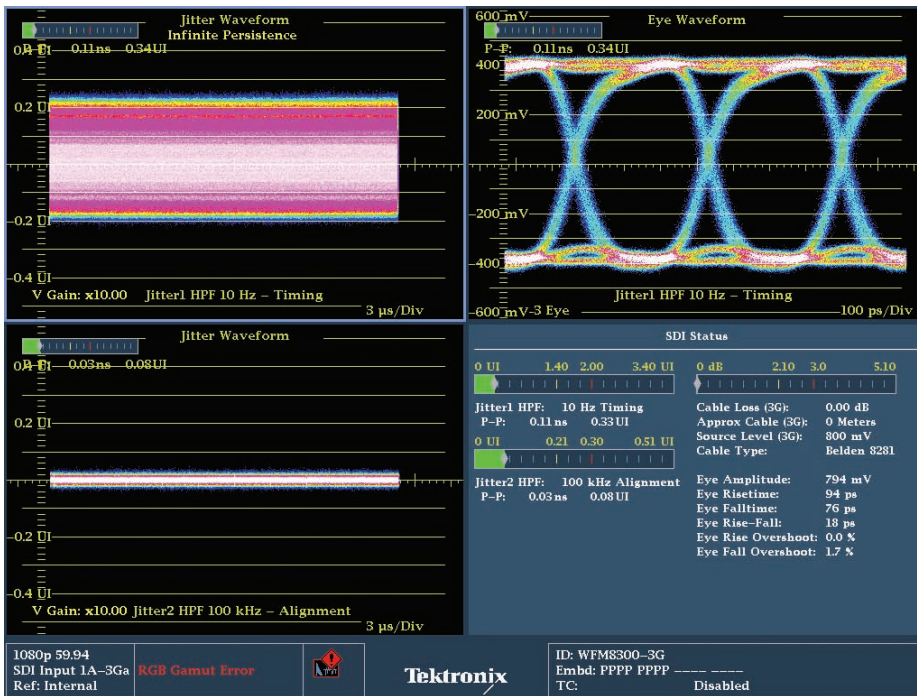
Figure 14. Simultaneous measurement of timing and alignment jitter.

Figure 15. Jitter display on WFM7120 with PHY option.

Within the WFM8300 and WFM7120 it is possible to simultaneously measure jitter with two different jitter settings. For instance, one filter could be selected to measure timing jitter and the other selected to measure alignment jitter. Note that within the instrument tiles 1 & 2 are associated with the Jitter 1 measurement, and tiles 3 & 4 are associated with Jitter 2 measurement (Figure 14). In this case the Timing (tiles 1 & 2) and Alignment filters (tile 3) have been selected allowing comparison of jitter between two jitter band-pass filter bandwidths.

The simplified case in Figure 13 shows just an individual component of jitter at 60 Hz. However, in many cases there may be multiple frequency components of jitter within the signal as in Figure 15. It can be difficult to isolate all the individual frequency components of jitter within the SDI signal. A simplified way to isolate these components is to use the band-pass filter available within the instrument.
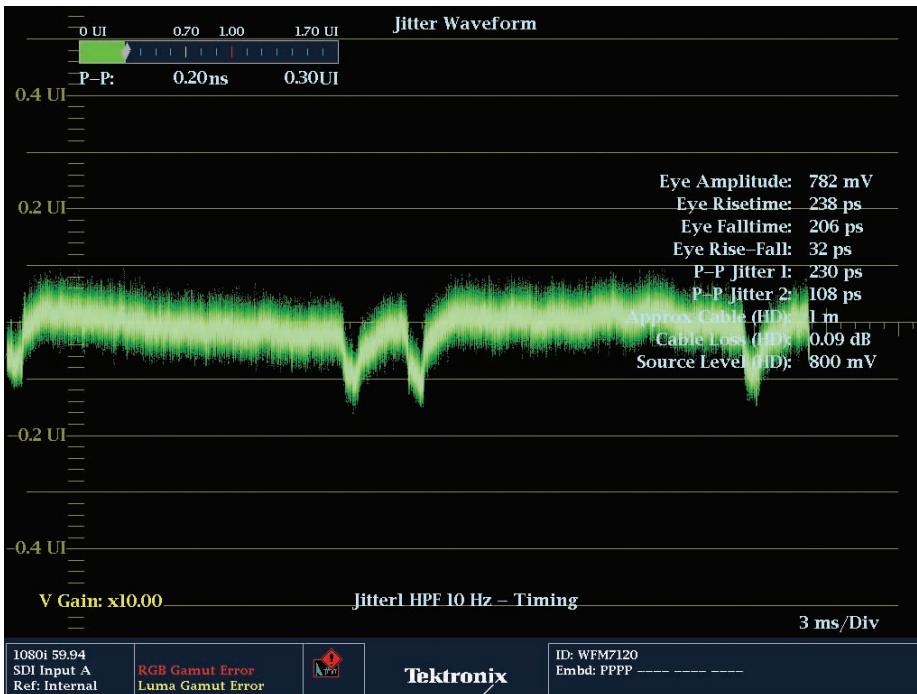
Take a closer look at the possible frequency components derived from the signal in Figure 15. At the low band-pass filter setting of 10 Hz (Timing Jitter) and looking at the jitter waveform in 2 field mode, a variety of frequency components, present within the signal. It can be difficult to isolate individual frequency components, but the use of the jitter band-pass filters can help to see where (Bandpass filter are 10 Hz-100 kHz) most of the components that are contributing to the peak-to-peak of the jitter reside.
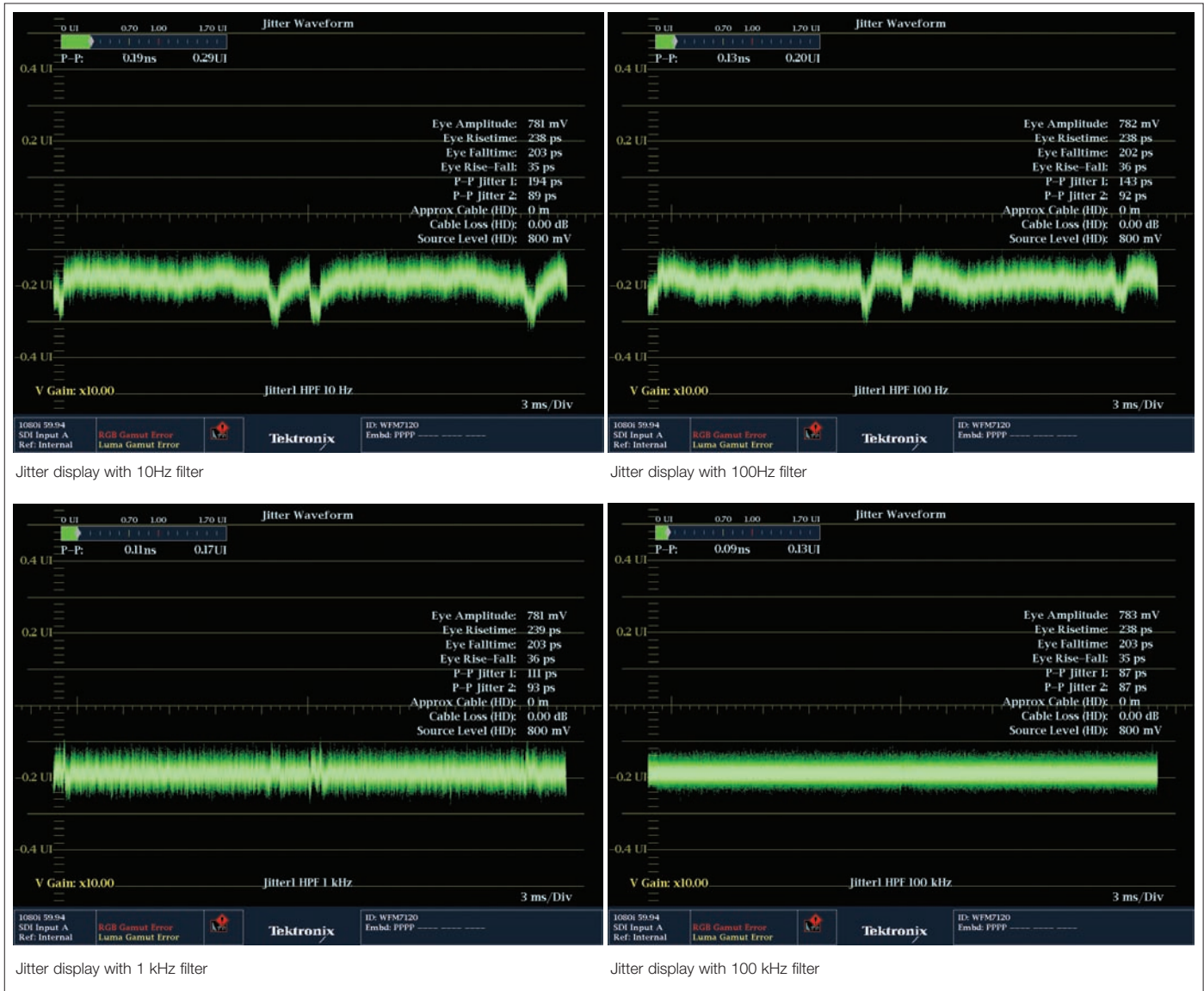
Jitter display with 10Hz filter

Jitter display with 100Hz filter

Jitter display with 1 kHz filter

Jitter display with 100 kHz filter

Figure 16. Jitter display with different filter selections.

From the instrument menu users can apply 10 Hz, 100 Hz, 1 kHz, 10 kHz and 100 kHz filters within the display. In this example as shown in Figure 16, different filters were used and the direct jitter readout and jitter waveform display are shown. With the filter set to 10 Hz the measurement of jitter is 0.29UI and there are disturbances to the trace at field rates. There is also some occasional vertical shifts in the trace when viewed on the waveform display (not shown from the snapshot of the image in Figure 15) this gives rise to the larger peak-to-peak measurement value than actually one would visually measure from the display itself. There may potentially be a wander component of jitter within the signal.

When a 100Hz filter is applied some of the components of jitter are reduced and the vertical jumping of the trace is not present. This creates a more stable display and the measurement now reads 0.20UI. The disturbances at field rate are still present however. Application of the 1 kHz reduces the additional components of jitter and the trace is more of a flat line. The presence of the disturbances at field rate can still be observed. The jitter readout did not drop significantly between the 100 Hz and 1 kHz filter selections (0.20UI to 0.17UI). With the 100 kHz filter applied the display now shows a flat trace and the jitter readout is significantly lower at 0.13UI. In this case the output of the device is within normal operating parameters for this unit and provides a suitable signal for decoding of the physical layer.

Normally as the band-pass get narrrower and the filter selection is increased you typically expect the jitter measurement to become smaller as in this case. But suppose that as the filter value is increased and the band-pass bandwidth narrowed that the jitter readout actually increased. What would this mean was occurring in the SDI signal? In this case, an explanation of these measurement results would be that a pulse of jitter was present within the signal and this pulse of jitter was within the band-pass edge of one of the filter selections. Instead of this component being removed by the filter selection it was actually differentiated, producing a ringing at the rising and falling transition of the pulse effectively producing a larger value of peak-to-peak jitter even though the RMS value of the pulse was reduced by the higher bandwidth filter.

This piece of equipment was used to illustrate how to determine jitter problems within a device or system. However there is some very low frequency jitter within the device that could cause problems on longer cable runs or conversion to composite analog. Very low frequency jitter within the signal, typically below 10Hz, is termed wander and is not generally considered part of a jitter measurement. Wander can cause its own set of unique problems within the system.

For instance, an ATM switched network which carries an SDI signal or an MPEG transport system can introduce wander components (momentary frequency shifts) into the system.

No effect within the SDI transport may be observed in the decoding of the signal. In the eye display itself you may observe a slight oscillation of the eye display back and forth. If this SDI signal is then applied to a composite encoder, the wander components can introduce minor frequency variations to the color burst of the composite signal. When this encoded composite signal is genlocked to a reference, you may observe a slight occasional movement in the burst position from its ideal position when viewed on a vectorscope. Some older composite recorders will often have trouble tracking the wander, recording a permanent color shift into the video signal.

In some cases you may observe a color flash on the picture monitor if the disturbance is significant and causes the color burst to unlock. In this case it will be necessary to work through the system to track down the specific piece of equipment producing this wander component.

In designing these SDI systems, it is possible to further characterize the individual jitter components by use of the phase demodulated output or clock output from the EYE or PHY option (WFM8300 or WFM7120). This output signal can then be applied to an oscilloscope with a FFT spectrum display or a spectrum analyzer for more detailed analysis of the jitter frequency components present.

The eye display typically has the cross point of the transitions in the middle of the eye display at the 50% point as shown in Figure 9a (page 9). If the rises time or fall time of the signals transitions are unequal, then the eye display will move away from the 50% point, depending on the degree of inequality between the transitions. AC-coupling within a device will shift the high signal level closer to the fixed decision threshold, reducing noise margin. Typically, SDI signals have symmetric rise and fall times, but asymmetric line drivers and optical signal sources (lasers) can introduce non-symmetric transitions as shown in Figure 17.
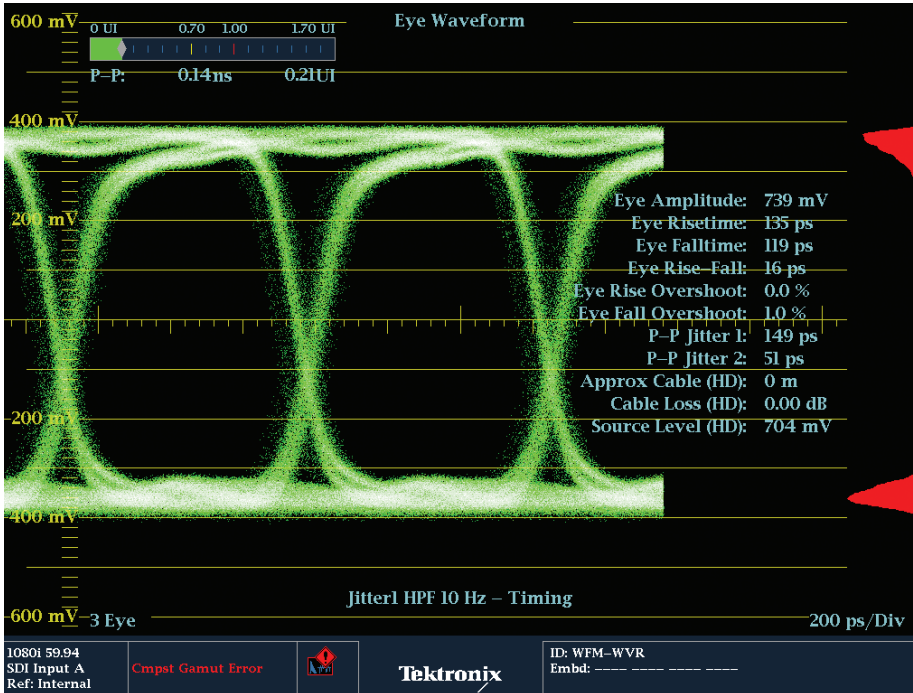
Figure 17. Eye display with different rise / fall times.

Figure 18. 20 eye display of HD signal.

While potentially significant, these source asymmetries do not have especially large impacts on signal rise and fall times. In particular, cable attenuation will generally have a much larger impact on signal transition times. Without appropriate compensation or other adjustments, asymmetries in SDI signals can reduce noise margins (with respect to the decision threshold) used in decoding and can lead to decoding errors.

So far we have shown the typical three-Eye display which is common in most instruments. This three-Eye display is uncorrelated to the data structure of the SDI signal. In the process of converting the SDI signal from a parallel data stream to a serial signal a number of processes occur. In SD the 10 bit data of the Cb, Y, Cr, Y* data stream are applied to the shift register and output as a serial Non-Return to Zero (NRZ) data format. Following serialization of the parallel information, the data stream is scrambled (divided) by the following mathematical function:

$$G_1(X) = X^9 + X^4 + 1$$

where the exponents represent clock delays and the plus sign represents modulo-two addition (exclusive-or). It is then encoded into NRZI (Non-Return to Zero Inverse) by a concatenation of the following function:
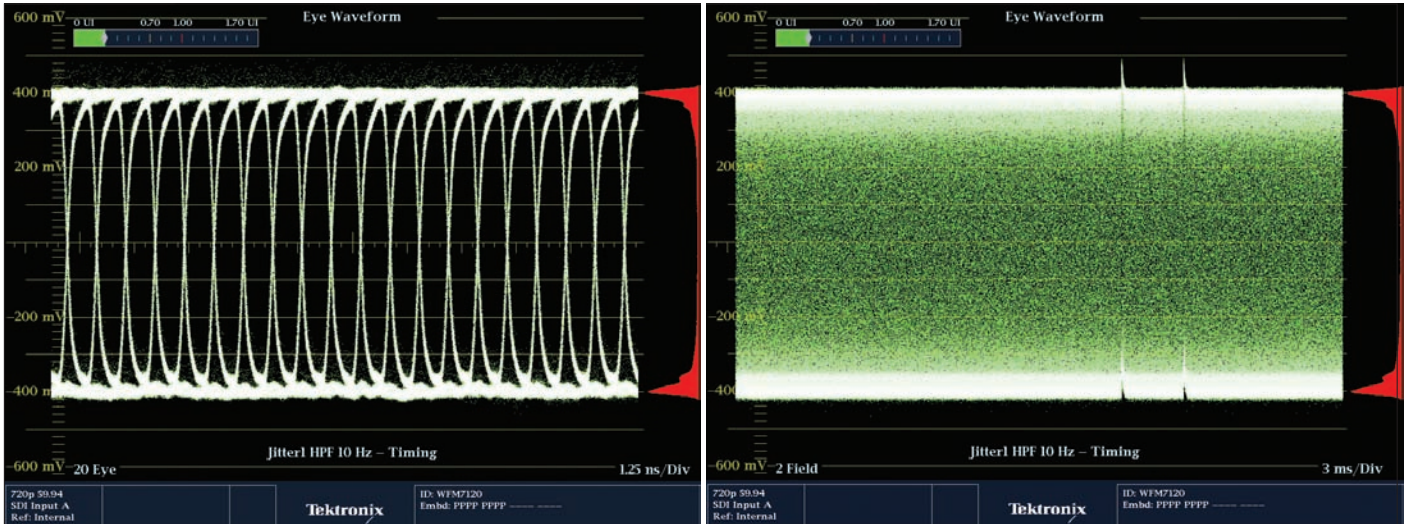
$$G_2(X) = X + 1$$

Figure 19. Pathological equalizer test signal for 20 eye and field display.

Scrambling the signal makes it statistically likely to have a low DC content for easier handling and have a greater number of transitions for easier clock recovery. NRZI formatting makes the signal polarity insensitive since a logic level one is conveyed by a change from the previous bit interval (either hi/lo or lo/hi) and a logic zero by no change. In the case of HD and 3 Gb/s-SDI, the parallel data stream is processed in 20 bit words rather than 10 bit time multiplexed as in SD. The rest of the serialization process is the same as SD. In the parallel-to-serial conversion process, variations in the clocking of the data, from the shift register or specific video data patterns, can lead to word correlated jitter at 1/10th or 1/20th the clock frequency.

To isolate word correlated jitter within the SDI output, the engineer can view the 10 Eye (for SD) or the 20 Eye (for HD and 3 Gb/s) word correlated display. This display is correlated to the data words of the SDI signal. It should produce identical eye openings for each of the data bits as shown in Figure 18 for this HD signal. Certain data structures of the video signal or incorrect conversion in the parallel-to-serial conversion can affect the structure of the 10/20 eye display.

In Figure 19 the Equalizer test signal was applied to the unit which creates a specific bit pattern every so often within the transmitted signal when the scrambler attains the necessary initial condition. This bit pattern can be observed as fuzziness on the top and bottom of the 20 Eye display. Additionally, by placing the eye display in field mode, one can see these glitches within the signal as shown in the right frame of Figure 19.

When qualifying a system, it is useful to know the length of cable along which the signal is being transmitted. The WFM8000 or WFM7000 series and the WVR series provide a cable length measurement dependent on the type of cable used within the SDI Status display. There are several of the most common cable types available within the instrument (Belden 8281, 1505, 1695A, 1855A, Image 1000 and Canare L5-CFB). The equivalent cable measurement is useful when measuring a specific cable length or when evaluating a problem. However if your facility is using a different cable type you may think you cannot use this measurement since your cable is not provided within the selection. This is not the case, most manufacturers specify the length of cable which their device will transmit the signal along, using one of these common cable types. In this case, select this cable type and evaluate the devices to ensure that it is not exceeding cable length specification.

Once the cable type has been selected the applied SDI signal to the instrument will provide measurements of Cable Loss, Cable Length and estimated Source Signal Level.

Cable Loss shows the signal loss in dB (deciBels) along the cable length. The value of 0 dB indicates a good 800mV signal, whereas a value of -3 dB would indicates a source with 0.707 of the expected amplitude.

Cable Length indicates the length of the cable between the source signal and the waveform monitor. The instrument calculates the cable length based on the signal spectral roll-off at the output and is independent of the source signal amplitude. The type of cable selected is used to compute the physical length of that cable type or equivalent length for that cable type selection, even if another cable type or concatenation of types is actually used.

Source Level shows the calculated launch amplitude of the signal source, assuming a continuous run of cable, based on the specified type selected.

These types of measurements can be particularly useful when qualifying a system and verifying its performance. By knowing the performance specification of the cable type used within the installation (supplied by the manufacturer), the systems integrator can verify each link within the system is within the manufacturer's recommended operational performance for the maximum cable length. For instance, Table 1 (page 2) shows the recommended maximum distance for Belden 1505A for an HD signal being 300 ft (91 meters). If the SDI status display indicates that for an HD signal, this

measurement is 89 meters, then the system integrator knows the system likely has only two meters of cable headroom within the system.

The systems engineer must then decide if this is suitable for the application. Remember this measurement assumes a continuous run of cable. In some cases this measurement may have been made with a number of active devices within the signal path. If this is the case, then each link should be measured separately, with a test signal source applied at one end of the cable and the measurement device at the other end. This will give a more reliable indication of the measurement of cable length within each part of the system and ensure the system has sufficient headroom between each signal path. If the transmitted signal distance exceeds the maximum length specified by the cable manufacturer, then additional active devices need to be inserted within the signal path. The engineer can choose from a variety of different digital distribution amplifiers.

Equalizing Distribution Amplifier (DA) This type of device has a built-in equalizer which compensates for signal loses due to cable length and will re-establish the signal amplitude, but it will not remove any inherent jitter or noise that maybe present within the signal. This type of equalizing DA should be used for short cable runs from a device where multiple outputs of the signal are required. However, it is not recommended to cascade multiples of this type of device within the signal path as the jitter present tends to accumulate over the total path.

Re-clocking Distribution Amplifier (DA) This type of device not only has a built-in equalizer, but will extract the clock embedded within the data stream. The data stream is then re-clocked with this stable extracted clock. This type of DA will reduce jitter outside of the Phase Locked Loop bandwidth of the clock extraction circuit. However, jitter within the loop bandwidth will be reproduced and may accumulate significantly with each generation. Therefore there is a finite limit to the number of these devices which can be cascaded together within the system. This will depend on the type of device used, the type of oscillator used, its loop bandwidth and the type of cable and connectors used within the system.

The correct selection of the type of DA to be used is important in ensuring error-free operation of the system. It is important to understand the difference between the variety of devices available and the specification of each manufacturer's device.

Commissioning of a HD-SDI Facility

During the installation and commissioning of the SDI facility, the variety of tools discussed so far can be used to qualify and troubleshoot the system, as each part of the facility is brought online. Initially, each link should be qualified by applying a known test signal source of both color bars and pathological test patterns, at one end of the link and monitoring the signal at the other end with a waveform monitor, such as the WFM8300 and WFM7120. The FlexVu™

display of these units allows several different displays of the signal to be viewed simultaneously. For instance Eye, SDI Status, Picture and Video Session can be displayed at the same time within the instrument. This allows the engineer to view at-a-glance the received eye display and obtain SDI measurements of jitter and cable length in the SDI Status display. The engineer can also view the picture display, providing a visual check of the signal, ensuring that no drop outs or picture disturbances are present. The video session screen display provides a check of the CRC values present with the decoded video signal and ensures error free operation.

Once a check of the cable system is complete the various pieces of video equipment can be brought online. Ideally this should be done in a gradual and methodical way, allowing for the testing of each piece of the system as it is brought online. The output of each piece of equipment should be tested to ensure it is operating normally and within its specifications. Many pieces of equipment have their own built-in test generator which may allow the devices output to be tested and verified rather than the pass-through of the SDI signal through the device. This also allows isolation of input and output devices and can help in troubleshooting of problems through the signal path of the system, should they occur. Again using a waveform monitor to view the physical layer characteristics can help verify and maintain the quality of the system at key points within the facility.
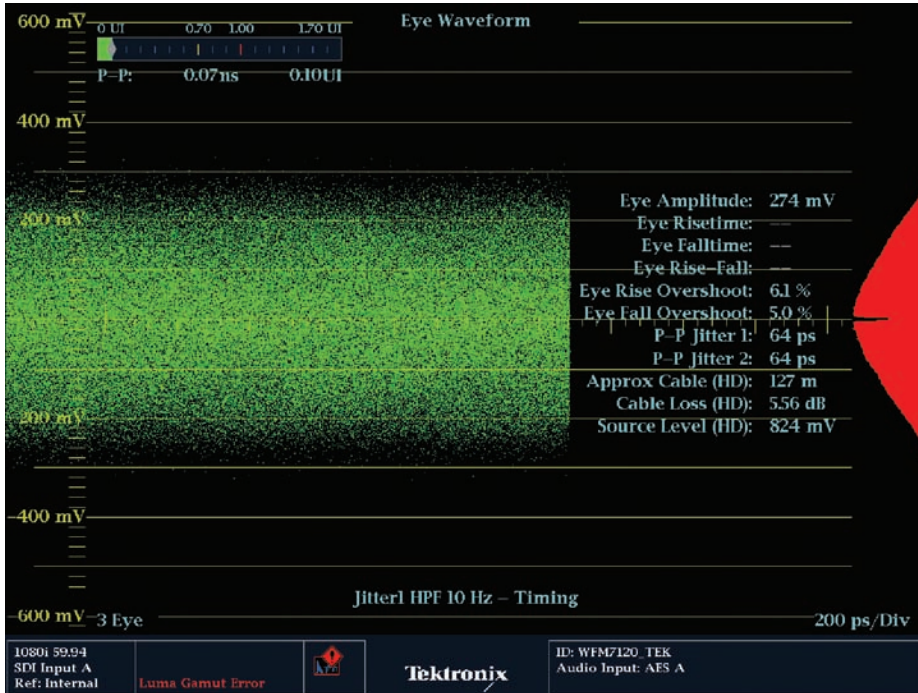
Figure 20. Closed eye of SDI signal.

Figure 21. Equalized eye display with limited eye opening.

If any problem occurs, during the commissioning of the facility, it is important to be able to isolate the cause of the problem. If sparkle effects, line drop outs or frozen images are observed, then the receiver at the end of the path is having problems extracting the clock and data from the SDI signal. Applying the signal to the waveform monitor and viewing the eye display will allow further investigation of the problem. If the eye is closed as shown in Figure 20 it is difficult to make any determination of what is happening to the signal and the engineer should select the Equalized eye display on the waveform monitor. If the equalizer within the instrument is able to recover data the equalized eye display should be like Figure 10b (page 10). The equalized eye display is similar to Figure 21, then the receiver will have to work hard to recover the clock and data, which may result in more potential data errors to occur in the receiver.
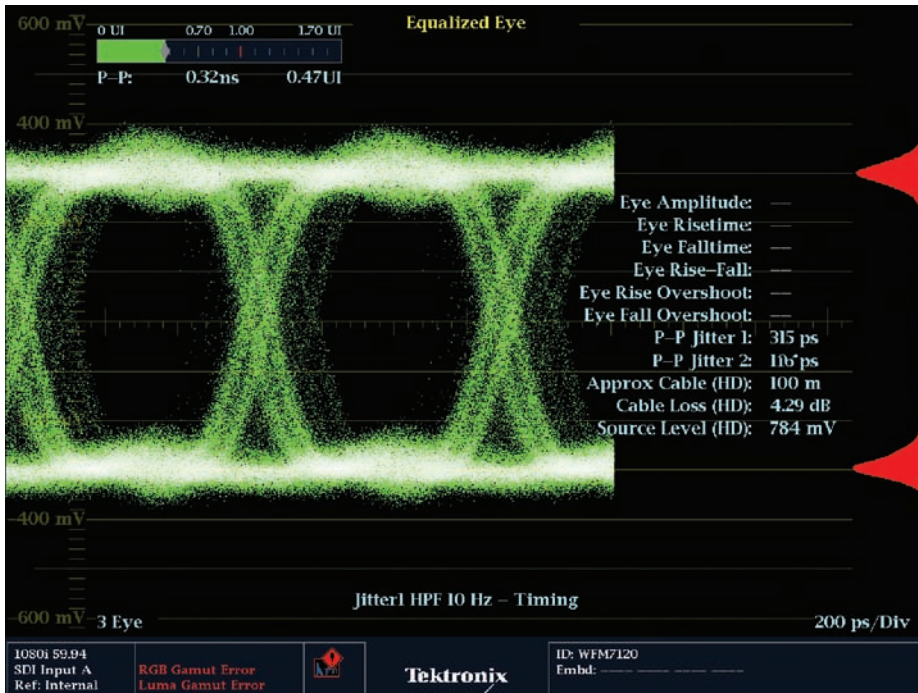
In this case the eye opening is less discernable, the cable length is too long or there is a problem in the transmitting device or cascading of devices. It is now a process of elimination to determine the problem. Use the instrument to confirm the cable length of the path and ensure that the correct cable type is selected to be used within the facility. In this case Figure 22 shows the calculation measurement to be 65 meters of cable between source and destination. Note that this assumes a continuous run of cable between source and destination and does not account for the cascading of devices. The maximum limit for Belden 8281 and an HD-SDI signal is 79 meters so the signal is not within the specification for the cable. Thus the problem is not directly related to the cable length of the system.
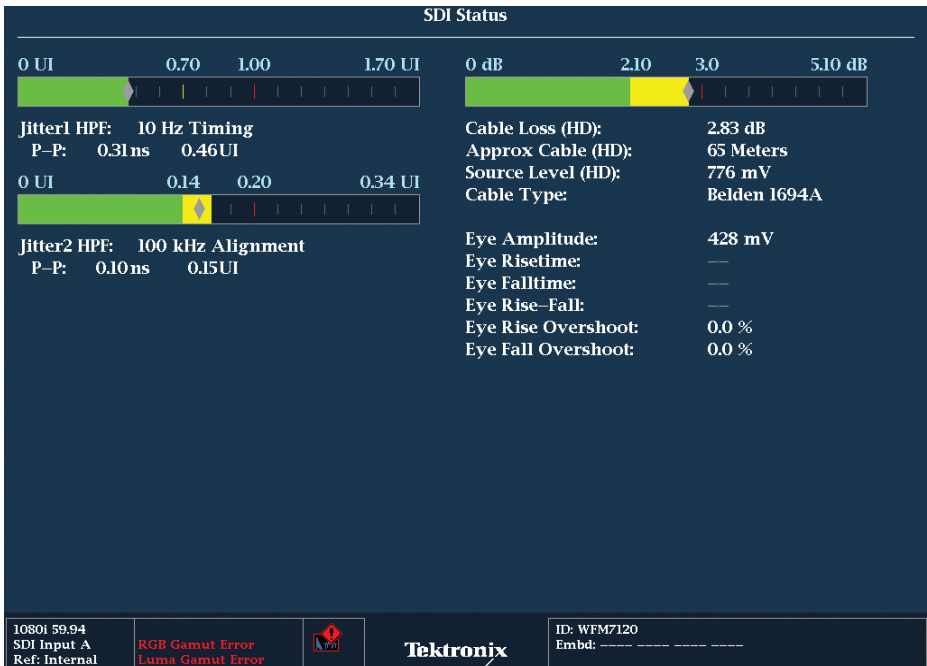
Figure 22. SDI status display showing cable length measurement.

In this example there are several active devices cascaded together, so it is necessary to trace the signal path back to the next active device within the system and verify its operation. If the problem still exists, it will be necessary to track further back through the path of the system until an error free signal is observed. Once the engineer has determined the point at which the SDI signal is performing error free, it is necessary to verify the equipment down stream of this point.

This should be done by applying a known SDI test signal source to verify the operation of the equipment and signal path. Since this did not appear to be a cable problem the eye and jitter display were used to isolate the problem further. In this case one of the devices showed significant jitter present at its output and it was necessary to take this device out-of-service and replace with another unit.

Using the jitter band pass filters, the engineer can help determine the individual jitter component present within the signal by placing the jitter display in the two field mode.

In this system, the engineer may wish to add a re-clocking distribution amplifier to the system or choose a device which is better able to reject the components of jitter which were causing the problem. Once the system is installed and commissioned, good engineering practices still dictates careful monitoring of the system. The fast pace of post production and broadcast facilities may mean short cuts are taken in order to achieve the final product. This can lead to contamination of the facility. Most facilities today operate in a hybrid operation with analog, SD digital, HD and 3 Gb/s signals being transported around the facility. With this variety and complexity within the system, a mix of different types of cable and terminators exist. For instance, we have already seen that using an incorrect termination can cause reflections along the SDI signal path. If a terminator is used without checking it is appropriate to use within a HD system, then the SDI signal could become contaminated by the incorrect terminator.

For instance, a passive loop through connection is available on the WVR7120 rasterizer. If the terminator used happens to be a termination normally used for an analog composite signal, then the HD-SDI signal may be compromised. It is therefore important to allow for operational monitoring of the system to ensure that these potential contaminations do not occur and may be quickly isolated within the system.
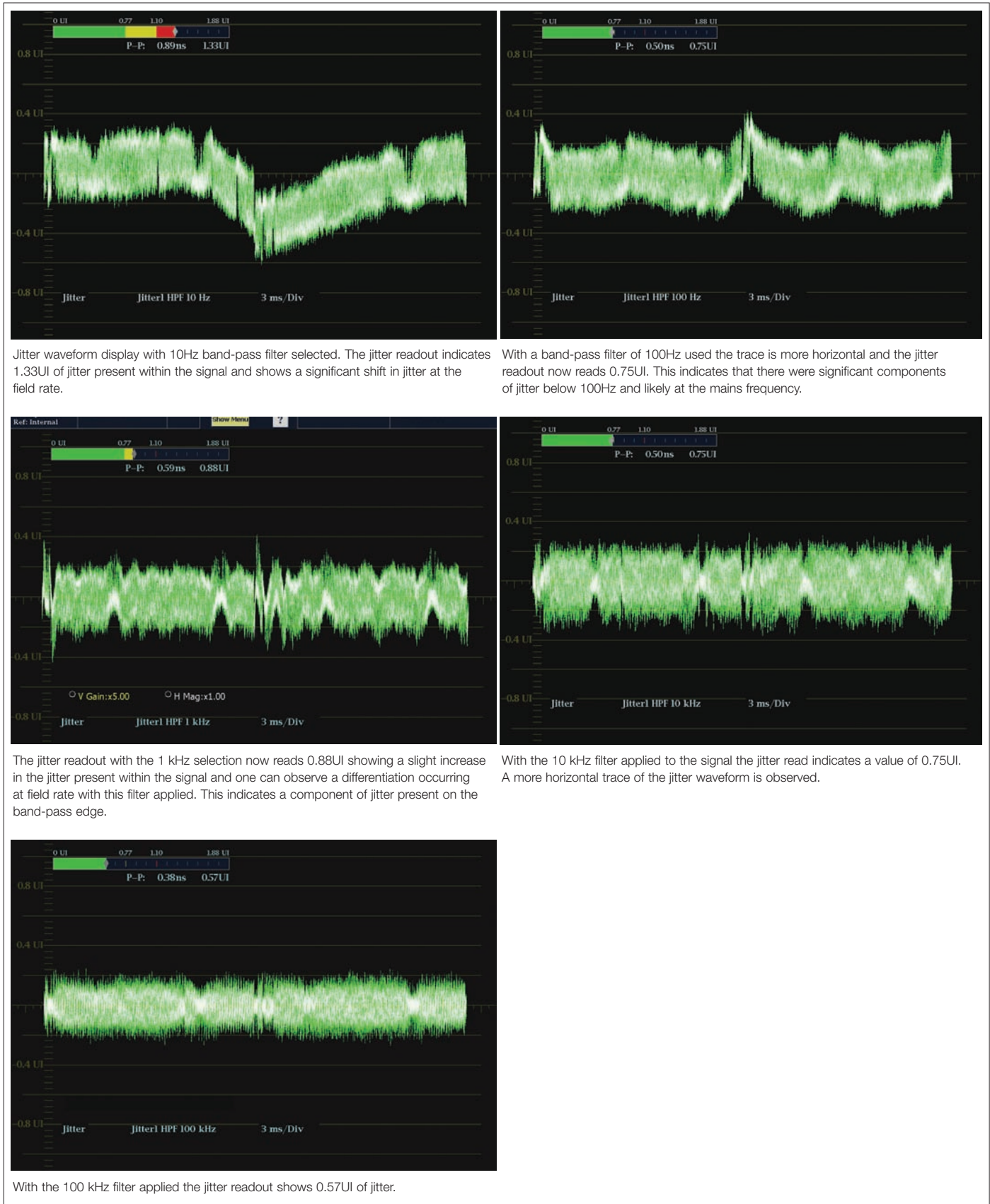
Jitter waveform display with 10Hz band-pass filter selected. The jitter readout indicates 1.33UI of jitter present within the signal and shows a significant shift in jitter at the field rate.

With a band-pass filter of 100Hz used the trace is more horizontal and the jitter readout now reads 0.75UI. This indicates that there were significant components of jitter below 100Hz and likely at the mains frequency.

The jitter readout with the 1 kHz selection now reads 0.88UI showing a slight increase in the jitter present within the signal and one can observe a differentiation occurring at field rate with this filter applied. This indicates a component of jitter present on the band-pass edge.

With the 10 kHz filter applied to the signal the jitter read indicates a value of 0.75UI. A more horizontal trace of the jitter waveform is observed.

With the 100 kHz filter applied the jitter readout shows 0.57UI of jitter.

Figure 23. Jitter display with various different band-pass filters selected.

Operational SDI Monitoring

The operator can be provided with several simple tools to allow continual monitoring of the SDI signal. Each line of the HD or 3 Gb/s SDI signal contains a CRC for both luma and chroma components. By using the Video Session display as shown in Figure 3 (page 5), this simple approach can be the first line of defense in detecting problems within the system. The measurement instrument can be setup to watch a signal path and provide alarms when this type of error occurs. If the instrument starts to report CRC errors occurring within the data used then this may be an indication the signal is getting closer to the digital cliff. The error log can provide a list of when these CRC errors occurred, and can be used to isolate possible signal path or device problems.

If the waveform monitor is equipped with an eye display, the engineer can set up limits for the allowed range for which the physical layer of the signal should be maintained. If the signal falls outside of these limits, the error log can provide a list of when these errors occurred related to the internal clock of the unit or to timecode. When these errors occur, the operator can then select the eye display and monitor the eye opening and the jitter bar display. If the jitter bar display is showing a red indication in the bar as shown in Figure 13 (page 12), then this can provide a warning of possible problems with the signal. The engineer can then further investigate the problem that may be causing contamination with the system.

For instance, suppose an additional length of cable is added to part of the system in order to add a device to allow continued editing of a program. This was done quickly in order to meet the fast paced requirements for broadcast of this material. However, the cable used was a piece of RG59 cable which is more appropriate for analog composite signal transmission. It is typically not recommended for this type of cable to be used for an HD or 3 Gb/s SDI installation and this type of contamination can cause the frequency response and the headroom of the system to be exceeded. By diligently monitoring the system, the eye alarms and CRC checking can provide information that the system has exceeded its normal limits and possible problems and changes are within the system. This allows the engineers to further investigate the problems and isolate the source of the error.

Conclusion

Following good engineering practices during installation and using suitable cable for transporting of the 3 Gb/s or HD-SDI signal is critical in ensuring an error-free transport of the physical layer of the SDI data stream. Measurement equipment, such as digital test signal generators and waveform monitors with eye and jitter measurements, can be used to verify the performance of the system during installation as well as providing continual performance monitoring of the facility. The eye display can provide a visual check of the health of the SDI physical layer and ensure a wide open eye suitable for the receiving devices to recover the clock and data. Additionally, the jitter waveform and automated eye measurements will allow further investigation of the physical layer and continually monitoring of the signal. These tools are invaluable in troubleshooting problems with SDI signals or equipment. The WFM8200/8300 (3 Gb/s, HD-SDI & SD-SDI) and WFM7120/WFM6120 (HD-SDI & SD-SDI) along with the WVR series, have options which allow eye and jitter measurements to be made on the physical layer.

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