

Video Signals and Slip Rings

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- Slip rings are often part of compact assemblies that require de-rotation of multiple power, signal, data, and video channels
- The problem of designing slip rings for video applications is addressed by combining broadband electrical interconnect solutions with optimized sliding contacts
- The bandwidth challenges of transmitting video signals through slip rings present issues similar to any interconnect problem -- control of the impedance, attenuation, and dispersion are all critical issues

Introduction

One of the most common questions asked of a slip ring supplier is “Will your slip rings handle video signals?” The short answer is “Yes, there is a slip ring solution for every rotating video problem.” The long answer gets to the purpose of this application note. What are the important parameters to understand when specifying a slip ring for video applications, and what slip ring features ensure specification compliance? Even more importantly, how should a slip ring to be used in a video application be specified?

Slip rings are required to “de-rotate” a signal coming from a rotating platform, such as a rotating gimbal of a scanning vision system. CCTV is one common application, but sophisticated multi-spectral surveillance vision systems also require slip rings to carry signals from infrared (IR), day, and night cameras from a rotating to a stationary platform. As these designs continue to transition from standard or analog video to high definition (HD) digital video, slip ring designs have kept up with the increased bandwidth requirements.

Slip Ring Configuration

Slip rings operate on the physical layer (PHY), so transmission line qualities are the parameters of interest. Ideally any device such as a connector or slip ring that is inserted into a transmission line should have the properties of the transmission media (for

example, 75^Ω coaxial cable). But perfect transmission line matching is difficult, so slip rings do not look exactly like a piece of wire. Transmission line qualities such as impedance matching and shielding effectiveness are the primary parameters of interest.

Slip rings are often part of compact assemblies that require de-rotation of multiple power, signal, data, and video channels. The size constraints that normally result from limited system space place challenges on circuit performance in terms of matching impedance and controlling crosstalk isolation. Slip rings use continuous rings and sliding electrical contacts, or brushes, to maintain electrical continuity during rotation. There are three basic slip ring configurations shown in Figure 1a-c. A decision on which of these design approaches to use is normally driven by mechanical considerations regarding available space or system design, but each of these designs comes with its own electrical advantages and disadvantages in regards to video transmission.



Figure 1a: Capsule assemblies



Figure 1b: Through-bore assemblies



Figure 1c: Platter style assemblies

Capsule Assemblies (Figure 1a)

Slip rings are often put on the center axis of rotation of an assembly, and this real estate near the centerline is usually valuable. Miniature capsule assemblies are used in these designs. Since space is very limited in these miniature assemblies, crosstalk isolation is usually the most critical design issue in the transmission of video.

Through-bore Assemblies (Figure 1b)

These slip rings are designed to provide a through-bore for a shaft, sub-assembly, or assembly clearance. The increased diameter changes the focus to impedance matching and jitter control as the most critical electrical parameters, especially with digital video. Moog's Application Note #228, High Speed Data and Commercial Slips (Dorsey, 2009) provides additional details on the diameter effect on slip rings.

Platter Style Assemblies (Figure 1c)

Moog's patented broadband platter design uses micro-strip design techniques with platter assemblies to provide a low profile, high bandwidth option for slip ring packaging. The improvements yielded by this micro-strip printed board design improve the bandwidth of slip rings requiring a through bore. The slip ring diameter effect on

bandwidth cannot be avoided however, so jitter control is the primary challenge with digital video.

It is important to understand the role and impact of the sliding electrical contacts (the ring-brush interface) in the quality of video signals transmitted through a slip ring assembly. These sliding contacts are typically the first area of concern when slip rings are included into a video transmission line. There is some variation in contact resistance produced at the slip ring contacts during rotation, and there is logical concern that this variation in resistance will produce video noise. In fact in properly designed slip rings, the sliding contacts themselves have minimal impact on the performance of video signals through slip rings.

Sliding Contact Integrity

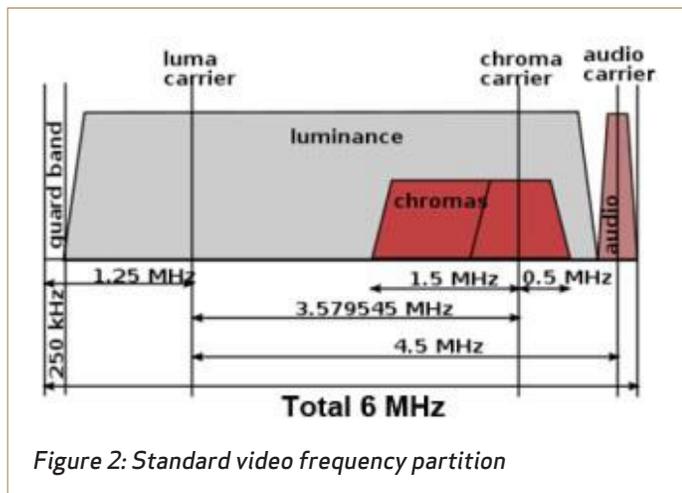
Slip rings used to transmit sensitive signals have evolved from designs used for very low level analog signals in the "pre-digital" age. The precious metal contact materials, the design parameters, and manufacturing techniques were all developed for negligible contact resistance, low resistance variation with rotation, and long life. These analog applications were very noise sensitive and often required noise levels measured in the μV range. In fact the contact noise requirements of these slip rings 50 years ago were much more stringent than required for video and digital applications. But it is not just these proven materials that make the difference. Recent work in the field of nano-tribology (the study of friction and wear on the nano scale) has provided new lubricants, materials, and design insight into improved sliding contact designs.

Recent research (Dorsey, Coleman et al. 2012) has shown that sliding contacts do not limit the bandwidth of signals transmitted through properly-designed precious metal contacts. This is to say that there is no critical frequency or bandwidth for which sliding contacts are not appropriate. Slip ring design for analog video, as well as digital video, revolves around inserting these optimized sliding contacts into a transmission line design that minimizes the effects of transmission line perturbations. So the problem of designing slip rings for video applications is addressed by combining broadband electrical interconnect solutions with optimized sliding contacts.

Standard Video

Standard or analog video is known as NTSC in North America, Western South America, and parts of Asia

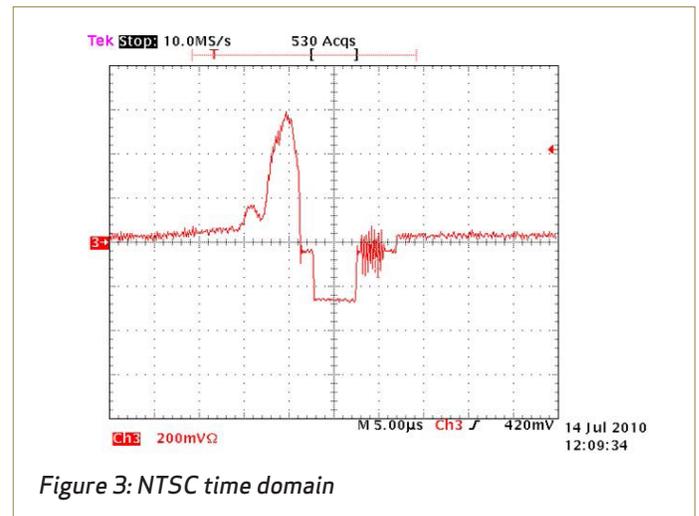
and PAL in Europe and the rest of the world. The corresponding component video formats are RS 170 (NTSC) and CCIR (PAL). The composite formats provide for video carrying luminance (Y) and chrominance (C) in a single signal with a bandwidth of 6 MHz (allocated as shown in Figure 2), while component video carries this information on separate lines. The precise bandwidth allocation for a complete color signal is complex, but it is safe to assume that good performance across a 6 MHz bandwidth is the critical PHY specification for specifying a slip ring to carry standard video. Figures 3 and 4 illustrate this 6 MHz bandwidth with time and frequency domain plots of NTSC video. It is important that a slip ring have sufficient bandwidth to transfer a DC-6 MHz signal and sufficient crosstalk isolation within this bandwidth to maintain the required signal-to-noise ratio. A crosstalk specification that ensures a noise floor of <10 mV is well under the NTSC signal to noise requirement. This is typically -40 dB for most potentially noisy data signals measured within the DC-6 MHz band. Signals with the greatest potential for a deleterious effect are high speed data channels including digital video channels.



It is important to stress that modern slip ring design techniques provide sufficient bandwidth and crosstalk isolation to provide good video performance with all three design configurations (i.e., capsule, through-bore, and broadband platter) with slip ring diameters up to 1 meter or more. The primary risk is appropriate crosstalk isolation. Crosstalk, the result of capacitive coupling from one channel to another, can occur in a slip ring from ring-to-ring coupling as well as coupling of the internal as well as external wiring. It is important to isolate video channels from “noisy” circuits (e.g., noisy power or digital data) both internal to the slip ring as well as any external wiring.

Standard composite video is carried on coaxial cable, and slip rings carry the coax cable through on multiple rings; typically one ring is dedicated to the center conductor of the coax and the shield is carried through on one ring or both of the rings on either side of the center conductor ring. In many cases, the coax conductor cannot be carried inside the slip ring due to space constraints, and terminations are made to the shield and center conductor outside the slip ring. This termination technique is usually acceptable when internal leads can be physically separated, but in the case of small slip rings where leads are closely packed, care must be exercised to minimize the length of unshielded conductors to avoid crosstalk issues.

It is in this transition from an unbalanced coaxial cable to a balanced ring configuration that determines successful slip ring performance in video transmission. Good slip ring design minimizes the effective electrical length of this transition, controls the differential impedance of the center conductor to ground as closely as possible to the nominal impedance of the channel, and controls the noise introduced on the circuit.



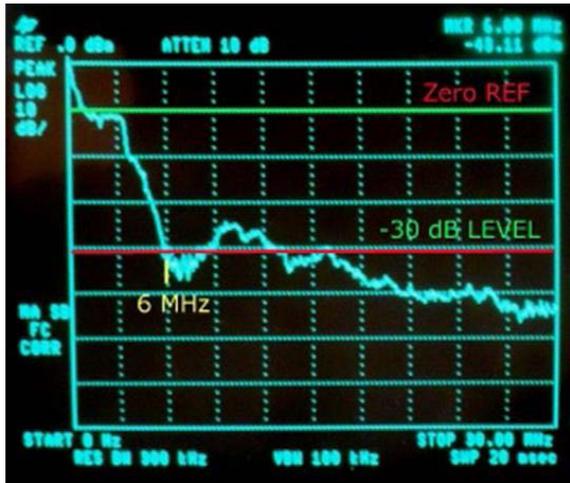


Figure 4: NTSC frequency domain

A phenomena known as “video ghosting” can occur whenever the unbalanced configuration (center conductor surrounded by a shield) of the transmission line is disturbed. Figure 5 illustrates this ghosting effect which is the result of signal reflections generated at impedance discontinuities of a coaxial transmission line. Typically these reflected signals, carried on the shield layer, are well down under the noise floor, but in some cases under the right combination of cable length and impedance discontinuity length, these reflected signals can cause visible ghosting.

One solution to the ghosting problem is to use a balun, a device that handles the BALanced to Unbalanced energy transfer. The simplest balun is an RF choke placed around the coax to increase the impedance of the outside surface of the coax. At this point, the energy that escapes from inside the coax and travels on the outside of the shield can be partly absorbed and partly reflected back toward the discontinuity, where it can rejoin the original signal with only a small displacement in time and negligible ghosting. The distance between the RF choke and the end of the open coax shield determines the temporal displacement of the signal those image. The energy that travels past the RF choke is strongly attenuated, as is the residual reflection. The RF choke has the added effect of ameliorating the effects of an impedance mismatch at the slip ring and the ensuing reflection. Simple ferrite beads placed around the coaxial cable are a common method of integrating an RF choke.

In the case of slip rings, the coaxial cable is terminated to discrete rings producing an unbalanced to balanced line transition. Proper slip ring design avoids this ghosting problem by minimizing the length of the impedance mismatch among other strategies. This ghosting is not a common problem, but is worth mentioning in case the problem must be corrected. Standard analog video is normally carried without problems on slip ring assemblies when properly wired. A slip ring that is supplied pre-wired with the proper impedance value coaxial cable is normally “good to go” with analog NTSC or PAL video. In cases where coaxial cable must be terminated outside the slip ring or when especially noisy signals must be transmitted through the slip along with the analog video, special precautions might be required to avoid image ghosting or noise coupling.

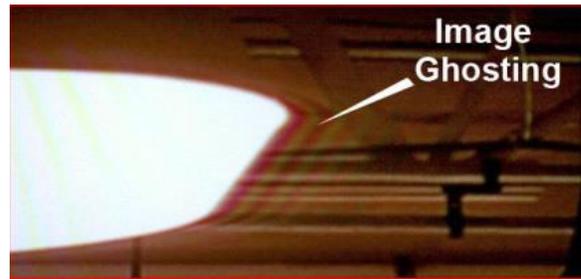


Figure 5: Video ghosting as the result of signal reflections from impedance mismatches

Digital Video - SMPTE Standards

The transition from analog to digital video is moving quickly in order to achieve an improvement in overall image quality by improving the signal-to-noise ratio with digital signal processing (DSP). There are a number of digital video formats that are being used to transmit digital data. Probably the most common are the series of serial digital interface (SDI) standards defined by the Society of Motion Picture and Television Engineers (SMPTE). Table 1 shows the controlling standards for SDI video along with their common names, serial bit rates, and the vertical spatial resolution. There are a number of other SMPTE standards that fall under each of these individual standards that control digitizing parameters for video and audio, encoding schemes, and ancillary data packets.

Standard	Main	Bitrates (Mbps)	Video Formats
SMPTE 259M	SD-SDI	143, 177, 270, 360	480i, 576i
SMPTE 344	SD-TI	540	480p, 576p
SMPTE 292	HD-SDI	1485, 1485/1001	720p, 1080i
SMPTE 372	Dual Link HD-SDI	2970 AND 2970/1001 in two parallel channels	1080p
SMPTE 424	3G-SDI	2970 and 2970/1001	1080p

Table 1: SMPTE serial digital interfaces (SDI) standards

The top-level SDI standards shown in Table 1 relate to digital signals carried on coaxial cable. In addition SMPTE 297 defines the fiber optic interface for the reception and transmission of SDI signals (SMPTE 259, 344, 292 and 424). Important system performance parameters of transceivers, transmitters, and the overall system such as the optical loss budget are provided in SMPTE 297. Figures 6 and 7 illustrate how SMPTE specifications work together to define SD and HD video data streams.

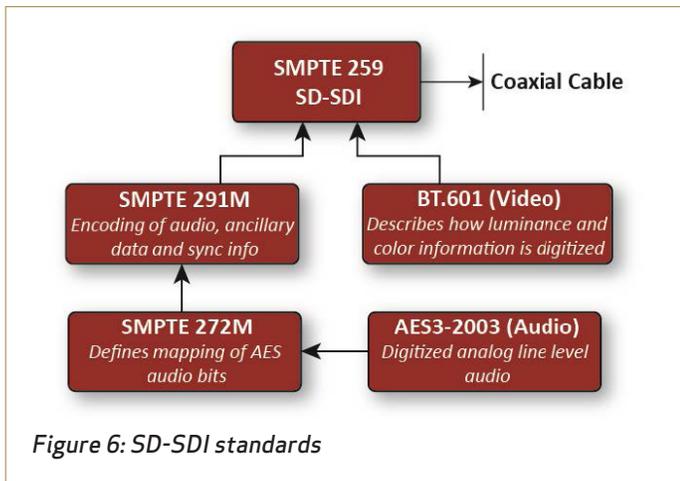


Figure 6: SD-SDI standards

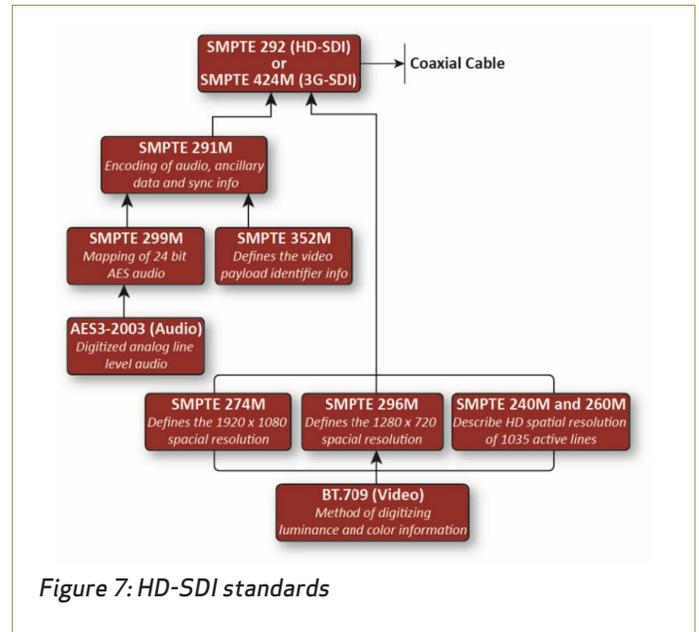


Figure 7: HD-SDI standards

As digital video has progressed from SDI to HD-SDI and 3G-SDI, the move has been towards greater spatial resolution as shown in Figure 8. This increased sampling rate has led to a resultant increase in digital bitrates necessitating increased attention to the quality of the transmission line that carries the signal and its bandwidth. It is at this point we ask the question, "What effect does the insertion of a slip ring in a digital video transmission line have on the quality of the video signal?" In terms of physical media considerations, these digital video signals, defined by a complex set of interrelated format standards, are simply 800 mV serial data streams. However there are some specifics of the video formats that require specific attention when specifying transmission line properties.

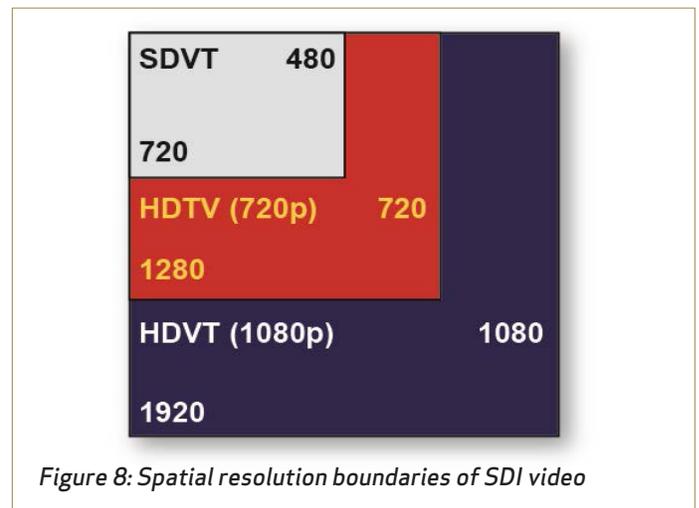


Figure 8: Spatial resolution boundaries of SDI video

To examine these special signal properties, SMPTE 292, HD-SDI will be used as an example. In the case of SMPTE 292, Section 8.1 defines the transmission line properties or signal level and specifications. Paragraphs 8.1.1 through 8.1.7 define the quality of the signal produced by the generator and paragraphs 8.1.9 through 8.1.11 the quality of the signal that the receiver can recover, (i.e., signal to noise ratio evaluation criteria). Although specific transmission line quality metrics are not given, they can be inferred from the difference between the receiver and generator signal quality metrics.

The SMPTE standards all define coaxial transmission lines (i.e. single-ended). Most other high speed digital data formats are differential in order to achieve good common-mode noise rejection. However, the advantage of installing digital video on existing coaxial cable infrastructure overrode this noise rejection consideration when defining the standard. This single-ended characteristic of SDI does pose the critical problem of ensuring adequate noise rejection. The earlier discussion about the criticality of control of the unbalanced to balanced transition at the slip ring interface is relevant in discussions of the signal to noise ratio of SDI signals, and the same parameters (electrical length of the transition, value of the impedance, and noise introduction) are important. However, the problem is exacerbated by the higher signal bandwidth. The primary issue, just as in analog video, is still the reflections caused on the line by the cabling transitions. The amplitude and phase characteristics of these reflections can be controlled (not eliminated) by good slip ring design practices. These reflections result in noise, or jitter, on the receiver end of the transmission line. As in the case of analog video, this deterministic jitter is a much more critical issue than the very non-deterministic jitter caused by contact noise.

Jitter is the most common metric used to define the quality of the digital transmission line. SMPTE standards RP 184 and 192 address the Specification of Jitter in Bit-Serial Digital Systems and the Jitter Measurement Procedures in Bit-Serial Digital Interfaces respectively. SMPTE 184 defines the input jitter allowed by the equipment as well as the intrinsic jitter at the equipment output in the absence of input jitter (i.e., the jitter from the transmission line and system electronics downstream from the input). This amplitude and phase jitter is defined in terms of Unit Interval (UI) which normalizes the jitter values to the period of one clock cycle (or the nominal minimum time between transitions of the serial signal).

SMPTE 292 provides a detailed breakdown of the jitter requirements of HD-SDI which is replicated in Table 2. Timing jitter is defined in RP 184 as the variation in position of a signal's transitions occurring at a rate greater than a specified frequency (typically 10 Hz, B1 of table 2). Variations occurring below this specified frequency are termed wander and are not addressed by this practice. Alignment jitter is the variation in position of the signal's transitions relative to those of a clock extracted from that signal and is typically the primary concern of the video performance.

B1	10 Hz	Timing jitter lower band edge
B2	100 kHz	Alignment jitter lower band edge
B3	>1/10 the clock rate	Upper band edge
A1	1 UI	Timing jitter (Note 1)
A2	0.2 UI	Alignment jitter (UI = Unit Interval)
Test Signal	Color bar test signal	(Note 2)
n	10 (preferred)	Serial clock divided (Note 3)

Notes:

1. Designers are cautioned that parallel signals could contain jitter up to 2 ns p-p. Direct conversion of such signals from parallel to serial could result in excessive serial signal jitter.
2. Color bars are chosen as a non-stressing test signal for jitter measurements. Use of a stressing signal with long runs of zero could give misleading results.
3. Use of serial clock divider value of 10 could mask word correlation jitter components.
4. See SMPTE RP 184 for definition of terms.

Table 2: From SMPTE ST 292-1: 2012

It is important to note that these jitter budgets are total acceptable values at the receiver, and the output jitter from the transmitter must be added to overall jitter from the transmission line. Since the output jitter from most SDI transmitters is around 0.1 UI, the total alignment jitter allocated to the transmission line by the standard can be assumed to be around 0.1 UI. Figure 8 shows the jitter of a fairly simple SMPTE 292 channel in a gimbaled video application with no slip ring. This jitter was part of a study to show the effect of adding a slip ring into the transmission line. As it can be observed, since the transmission line without the slip ring has alignment jitter of 0.16, the contribution of the slip ring to jitter must be less than 0.04 UI to maintain the 0.2 UI alignment jitter specification.

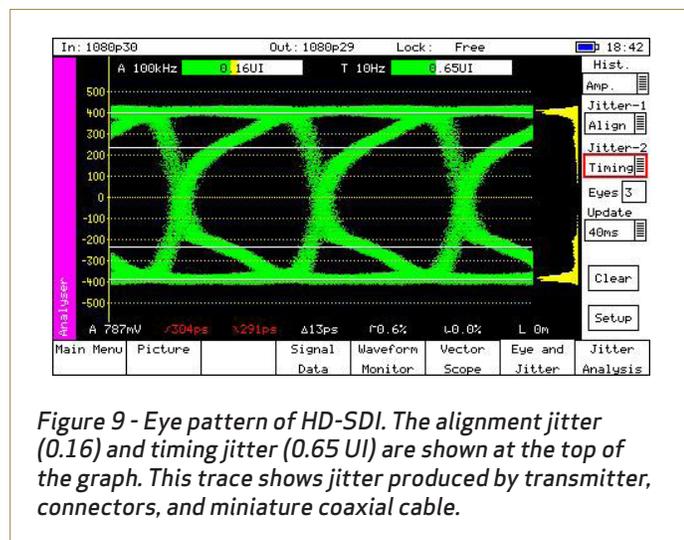


Figure 9 - Eye pattern of HD-SDI. The alignment jitter (0.16) and timing jitter (0.65 UI) are shown at the top of the graph. This trace shows jitter produced by transmitter, connectors, and miniature coaxial cable.

This 0.2 UI alignment jitter specification is a pretty tough requirement in many of the rotating systems that use slip rings. As can be seen from Figure 9, much of the jitter budget is “used up” by the transmitter, connectors, cables, etc. These components quickly erode the 0.2 UI alignment jitter especially in the case of digital data about 1 GHz (i.e., SMPTE 292 and 424). A significant part of the degradation of the signal waveform (alignment jitter) can be compensated for by the use of transmit pre-emphasis and receive equalization (Zhang and Wong 2002). In fact, many of the SDI receivers have built in equalization circuitry making them much more forgiving of alignment jitter than suggested by the specification. Figure 11 (from Zhang and Wong) shows the effect of this equalization on jitter caused by signal dispersion on a printed circuit board.

Rise time and fall time (20% and 80% of the amplitude points) are parameters that are addressed in paragraph 8.1.5. These values should be “no greater than 270 ps and shall not differ by more than 100ps.” Figure 10a shows rise and fall times that do not meet the standard’s requirement for rise and fall times (as seen by the red values—304 and 291 ps) due to the sharp knees in both rise and fall time curves.

Slip rings designed for SDI video are a subset of high speed data slip rings. The primary difference is the level of standardization imposed by the SMPTE standards compared to many other data formats. High speed data slip rings utilize design strategies to minimize the problems of impedance mismatching, crosstalk, and attenuation to expand the bandwidth. To enable proper recovery of serial data, a system from the transmitter to detector should have a frequency response that is nearly flat to at least 1/2 of the clock rate (fundamental frequency) and the roll-off should be reasonably gentle out to three times the clock rate (TECHNICAL 2011). In the case of SMPTE 292, this means that the transmission line, including the slip ring, should have a bandwidth of at least 2.25 GHz (i.e, 3 x 750 MHz).

The SMPTE standards were developed around a system that is composed of a signal generator, a length of coaxial cable, and a receiver. SMPTE 292 suggests that the maximum signal attenuation from cable can be in the range of 20 dB at 1/2 the clock frequency. This equates to around 100 m of coaxial cable (depending on the cable specification). The specification also allows for a wide variety of receiver re-clocking and signal recovery capabilities. Non-standard transmission line features such as slip rings, non-standard connectors, PC boards, and non-standard cable that are often used in custom video or vision systems are not adequately covered in the specification. Signal pre-emphasis and equalization, robust receiver technology, and short cable runs all serve to significantly improve the jitter margin of these systems and system tests are required to accurately assess the system capability. In the ideal situation, the slip ring should pass all the SMPTE requirements as demonstrated by the slip ring signal shown in Figure 10a. However, 100% compliance is not required for a slip ring to perform well in a transmission line. Figure 10b shows the waveform of a slip ring that fails to satisfy the rise time and fall time requirement of the SMPTE requirement. In systems with relatively low attenuation (less than the 100m of the cable allowed), this slip ring should perform adequately. Slip ring suppliers can provide data on video slip rings that can help the system architect determine if the end-

to-end transmission line has sufficient margin to reliably transmit video data, but in some cases engineering judgment and/or testing is required to make the final assessment.

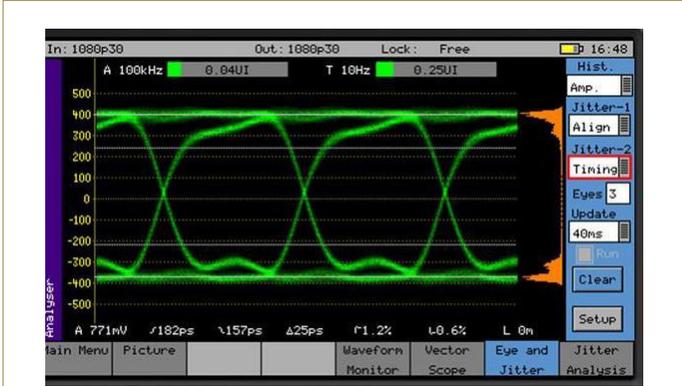


Figure 10a: Fully compliant SMPTE 292 waveform

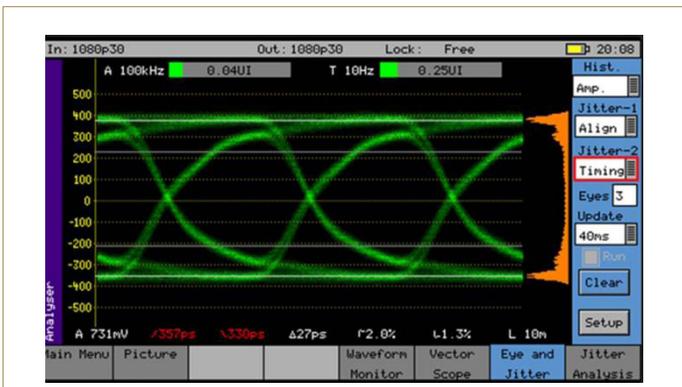


Figure 10b: SMPTE 292 waveform that fails to satisfy the rise time and fall time requirements

Digital Video - Other Standards

There are a number of other HD digital data formats that were developed to address some of the issues surrounding the SMPTE standards, most particularly related to single-ended high-speed data transmission.

Cameralink® was developed by an industry consortium of companies who produce cameras and frame grabbers with the goal of standardizing communications between cameras and frame grabbers. Image data is transmitted on four parallel LVDS (low-voltage differential signaling) per ANSI/TIA/EIA-644 and the LVDS clock is transmitted on a separate pair. The maximum data transmission rate

of the Channel Link chipset (the National Semiconductor building block of Camera Link) is up to 2.38 Gbps or 595 Mbps per twisted pair. The advantage is that the data rate for HD video is decreased per channel compared to HD-SDI, and the data is transmitted differentially for better noise rejection. The disadvantage is that a single coaxial connector is replaced with a 26 pin connector to accommodate the image and control signals. Not all pins are used on the base configuration, but the configuration is more complex than a single coaxial lead. In addition, cable length is limited to 10 meters without repeaters or fiber converters and a frame grabber is required.

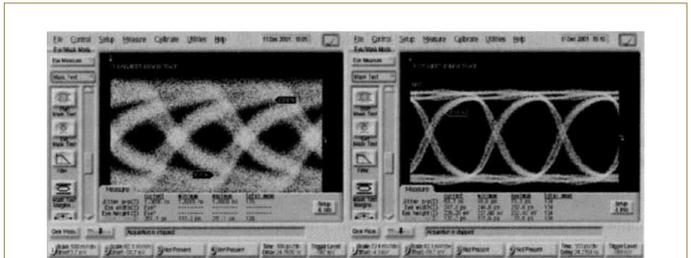


Figure 11: Effect of equalization at the receiver on 3.125 Gbps data (SMPTE 424). The data shows the effect of a 40 inch printed circuit board trace on the alignment jitter of high speed data. From (Zhang and Wong 2002)

GigE Vision® takes advantage of the popular and inexpensive Gigabit Ethernet PHY (physical layer) and internet protocol (IP) to transport image data with CAT 5 or CAT 6 cable. This is another standard introduced by a consortium of camera manufacturers and is maintained by AIA (Automated Imaging Association). The advantage of GigE Vision is that it takes advantage of the unique IEEE 802.3 encoding scheme to achieve a bi-directional aggregate data speed of up to 1.0 Gbps on four twisted pairs with a bit rate of only 125 Mbps on each twisted pair at up to 100 m of cable length. (Dorsey 2012) discusses the transmission of Ethernet signals through slip rings. An upgrade to 10 Gbps can be achieved by the use of CAT 6a cable. The additional networking capability is an added advantage.

DVI (Digital Visual Interface) is an HD display format used to send graphics data to HD monitors (HDMI adds audio). It is not a true video camera format, but the transmission line issues are the same. DVI uses a transition minimized differential signaling (T.M.D.S.) technique to transmit the pixel data on 3 twisted pair and a clock. A single-link DVI connection consists of four TMDS links; each link transmits data from the source

to the device over 1 twisted wire pair. Three of the links correspond to the RGB components of the video signal: red, green, blue (for a total of 24 bits per pixel.) The fourth link carries the pixel clock. Each TMDS link carries binary data at ten times the pixel clock reference frequency, for a maximum data rate of 1.65 Gb/s × 3 data pairs for single-link DVI. The maximum pixel clock speed is 165 Mbps for a maximum data rate per twisted pair of 1.65 Gbps. DVI is a very robust format as defined in Section Four of the DVI Standard. Slip rings that can handle SMPTE 292 can transmit DVI data if care is exercised to avoid channel to channel crosstalk. However, DVI does require a pin connector which uses up 24 slip ring circuits making it a fairly impractical method of transmitting HD video through slip rings.

Summary

The bandwidth challenges of transmitting video signals through slip rings present issues similar to any interconnect problem. Control of the impedance, attenuation, and dispersion are all critical issues, and the rotation of the slip ring does cause additional time variable parametric changes. These RF transmission line properties are more important than the sliding contacts themselves in good signal transmission; however, the contacts do need to provide good contact resistance over the total life of the ring. There are designs that provide solutions to all rotating video problems. It is important to understand the effect the slip ring has on the overall quality of the transmission line (PHY layer) but some judgment is required when applying video specifications to non-traditional applications to avoid unnecessary constraints on performance.

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