Core Insights

From the experts at The Broadcast Bridge.

Advances in 12G-SDI

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Introduction by Tony Orme - Editor at The Broadcast Bridge.

Consumers are continually driving broadcasters to deliver improved video formats to further enhance their viewing experiences. It didn't seem long ago that HD was lauded as the best format out there and one that might halt the quest for new standards. Not only have we since quadrupled the number of pixels and frame rates with 4K, but with 8K and HDR/WCG we have more closely matched the requirements of the human visual system with high dynamic range and wide color gamut.

The increased bitrates these innovations require, however, have created an unprecedented obligation on the broadcast industry to find new methods of reliably distributing and processing 4K and 8K video, audio, and metadata within broadcast infrastructures.

SDI has been the mainstay of broadcast infrastructures since its adoption in the early 1990's. It may look like engineers are defying the laws of physics, but with incredible design skills, they have been constantly improving SDI so it can now deliver quad-link 12G-SDI capable of transporting 8Kp video with extremely low latency.

Data rate bandwidth is breathtaking. I still remember working on my first 270Mbit/s SD video installation and wondering how it could possibly work. 1.5G-SDI to support 720p and 1080i HD, 3G-SDI and 6G-SDI followed, and now we have 12G-SDI.

Understanding the right time and places to apply 12G-SDI is crucial when looking to build or enhance a broadcast infrastructure. For a deeper dive into the benefits that 12G-SDI may offer your facility, check out the following articles:

1. **Developing 12G-SDI**
An overview of SDI, where it came from and where we are now, including relevant standards and key advantages of using 12G-SDI.

2. **12G-SDI Technology**
Discussion of where 12G-SDI will excel in the overall broadcast infrastructure including HDR and WCG.

3. **Applications for 12G-SDI**
Description of some of the specific applications of 12G-SDI and the reasoning behind them, with backwards compatibility and future proofing highlighted.

Part 1 - Developing 12G-SDI

Since SMPTE formally standardized SDI in 1989, it has become the dominant video, audio and metadata transport mechanism for virtually all broadcast facilities throughout the world. Technology advances have not only made SDI incredibly reliable, but the specification has continued to progress, embracing ever increasing data-rates and video formats.

In this series of three articles we take a closer look at SDI to understand its origins, current state, and why it's here to stay for a long while yet.

The first version of SDI released by SMPTE in 1989 was SMPTE 259M, which supported four data-rates; 143, 177, 270 and 360 Mbits/s. Video was encoded with YCrCb and subsampled at 4:2:2.

At the time SDI debuted, video was generally distributed using PAL or NTSC. One of the major challenges with these formats was that the color was encoded using a form of quadrature amplitude modulated carrier. Although this system worked well, the color needed to be decoded to its component form (YUV or RGB) before processing.

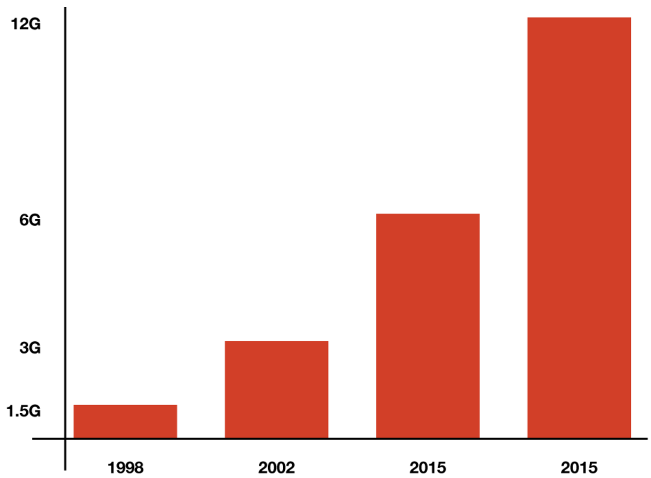


Figure 1 – each release of a new version of SDI has doubled the data rate of the transport stream.

RGB Limitations

Decoding video from PAL, NTSC or SECAM to its component parts would quickly result in artefacts appearing on the image due to the suboptimal modulation of the color components. To alleviate this, many facilities at the time would distribute video as RGB or YUV to maintain high video quality and reduce the possibility of these artefacts. A significant disadvantage of this system was the increase in cable and complexity. Even with the video syncs encoded on the green signal, the amount of cabling needed increased three-fold as each of the R, G and B signals needed their own cable.

Problems were further compounded as each of these cables had to be identical in length to prevent signal timing issues. Even a difference in cable length of a few meters would result in visible picture or color shifts potentially manifesting themselves as registration errors between the R, G, and B colors.

Although PAL and NTSC encoding solved the multiple cable requirement, this solution was at the expense of a degradation in quality, and other issues such as the 8-field PAL sequence manifested themselves and further led to compromises for editing.

Audio has historically been treated separately in broadcast stations. It is possible to modulate audio onto a PAL or NTSC carrier and this is how television is broadcast, but it's rarely done within a broadcast infrastructure. Consequently, audio signals were distributed independently of the video. As framestores started to appear, lip-sync and audio-video timing issues soon became apparent.

Furthermore, as PAL and NTSC video were analog, they would continually suffer degradation due to noise and distortion by virtue of the fact that they were analog and the mediums upon which they were recorded suffered from material degradation and generational fall off.

SDI Solutions

SDI solved many of these problems in one go. Only one cable was needed, the signals were digitally multiplexed as Y, Cr and Cb thus removing any crosstalk between the luma and chroma, and audio could be encoded into the “spare” data in the horizontal and vertical blanking. It’s true that the color bandwidth of YCrCb over SDI is half that of RGB but the benefits far outweigh the challenges.

Vertical (frame/field) and horizontal (line) syncs are technically no longer needed and could easily be replaced with a much more efficient method of system synchronization . However, they have been kept in the specifications to maintain backwards compatibility, especially as we transitioned from traditional Cathode Ray Tube televisions to flat screen TVs. Unique embedded codes within the SDI stream identify the start and end of active picture so the sync pulses are no longer needed. The space taken by these sync pulses can therefore be used for other information such as audio and metadata.

The next major advance for SDI was the move to SMPTE 292 to accommodate 1080i HD television. The bit rate increased to 1.485Gbits/s for PAL countries and 1.485/1.001Gbits/s for NTSC countries. Commonly referred to as 1.5G, SMPTE 292 also accommodated the change in aspect ratio from 4:3 to 16:9. SMPTE 296 further added support for 720p HD.

Moving to progressive 1080p formats meant a doubling of the bit rate from 1.485Gbits/s to 2.97Gbit/s. However, the chipsets and cable specifications weren’t available at the time to achieve reliable distribution over a single link. To address this, SMPTE 372 was released to specify distribution of a 1080p59/60 video signal over two 1.5G SDI links.

Reducing Cables

By 2006 the chipsets and cable tolerances had improved so a single SDI link could reliably deliver a 2.97Gbit/s signal. SMPTE 424M provided the specification for 3G-SDI to facilitate formats such as 1080p50/59.

Formats continued to develop and SMPTE released their ST-2081 suite of specifications to facilitate the move to higher 1080p frame rates and the progression to 2160p with the data rate of a single link being 5.940Gbits/sec and 5.940/1.001Gbits/sec.

6G became available in three versions; single link, dual link, and quad link. Each version of the link doubled the data capacity of its predecessor. Single link (5.940Gbit/sec) supports distribution of 2160-line (4K) up to 30fps and 1080-line up to 60fps. Dual link (11.88 Gbit/ sec) can distribute 4Kp60 (4:2:2). Quad link (23.76Gbits/sec) provides 4Kp60 (4:4:4), 4Kp120 (4:2:2), and 8Kp30 (4:2:2).

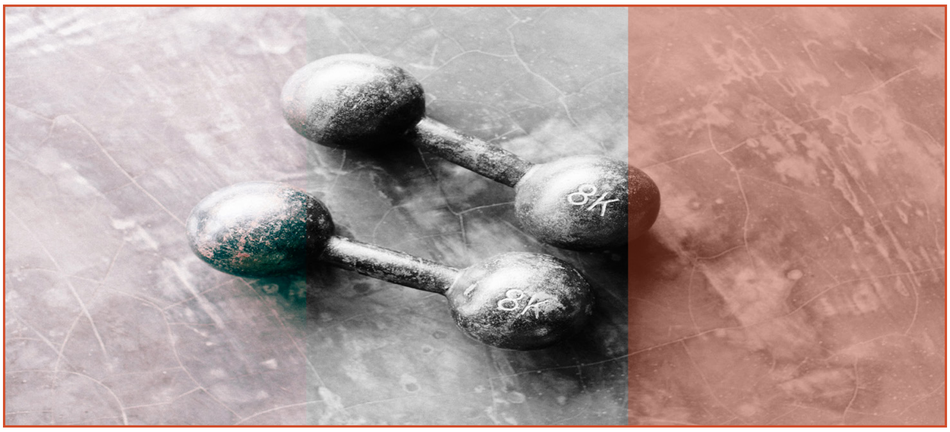
Within these limits the specifications allow for color subsampling to be traded at the expense of frame rate. For example, ST-2081-11 allows for a video frame of 4096 x 2160, but you can either have 30fps with 4:4:4 color subsampling or 60fps with 4:2:2.

Automated Multi-Link Construction

Although the dual and quad links needed require either two or four coaxial cable connections, they do not suffer from the same picture shift issues as their analog RGB predecessors. The cable lengths must be of similar lengths and type, but the specification and chipsets in the send and receive devices will automatically correct for small cable length discrepancies.

SMPTE released ST-2082 in 2015 to provide a data rate of 11.88Gbits/s and 11.88/1.001Gbits/sec. Now known as 12G-SDI, three versions are available; single- , dual- and quad-link.

The single link can provide 4K 4:4:4 at 30fps or 4:2:2 at 60fps. Dual link (23.76Gbits/sec) provides 8K (4:2:2) at 30fps and as we move to quad link (47.52GBits/sec) 8K (4:2:2) at 60fps becomes available along with 4K at 120fps.



Due to the large number of video formats supported within ST- 2082, a simplified method of determining the type of video that the signal it is carrying is needed. This is achieved using modes and each link-version has its own definition of modes.

For a single-12G link there are two modes of operation, ST2082-10 (single link) supports Mode 1 (4K/UHD up to 60fps) and Mode 2 (1080p 4:4:4 10 and 12-bit up to 120fps).

The dual-12G link provides three modes; mode 1, mode 2, and mode 3. Mode 1 describes 8K formats, mode 2 describes 4K 4:4:4 formats. And mode 3 describes 4K 4:2:2 formats with higher (extended) frame rates.

The quad-12G link only provides two modes; mode 1 and mode 2. Mode 1 describes 8K formats and mode 2 identifies 4K formats.

VPIDs Deliver Reliability

To help identify the format and mode type used, each link has an embedded label called a VPID (Video Payload Identifiers) to help the receiver identify the signal so it can correctly decode it. The VPIDs are sent in the ancillary data area so any receiving equipment can easily identify the type of signal it should be decoding.

The VPID's are defined in SMPTE 352 as well as the relevant SDI standard and carry information essential for the receiver allowing it to quickly and efficiently identify the signal being sent to it.

Although it may seem intuitively correct to use wide color gamut with high dynamic range as part of a 4K system, there are several variations of this and ST-2082 allows parameters to be specified to identify a particular format, for example HLG or PQ, or Rec.709 or Rec.2020.

Again, these parameters are transmitted in the VPIDs allowing any receiver to quickly set up and establish the format of the signal and display it accordingly.

SDI is continuing to flex its muscles and is showing no sign of standing aside. This isn't surprising as it is a thirty-year old technology and vendors, chip designers, and cable providers have had a long time to iron out any anomalies. The data rates have certainly increased, almost exponentially, from the 270Mbits of 1989 to the aggregated 47.52GBits/sec now available on quad-link 12G. SDI is as stable and easy to use as ever.

Part 2 - 12G-SDI Technology

In the last article in this series we looked at how SDI has developed over the years to reach an incredible 47.52Gbits/sec for quad-link 12G. In this article, we dig deeper and uncover the technology enabling SDI and its advantages.

Broadcast video and audio, distributed within a television station, must be low latency and very stable. To facilitate low latency there can be no resend of lost video or audio and therefore, we cannot afford corruption within a transport stream. Video and audio must be sent reliably with virtually no data loss.

Well-defined stable specifications are enormously important for the broadcast industry, especially as we move to the data rates ST-2082 is delivering. This is mainly due to the fact that a distribution system such as SDI must be hardware based. SDI is synchronous and embeds the bit clock into the transport stream to provide a highly synchronized system that is stable and delivers very low latency.

Hardware SDI

Although much processing of video and audio occurs outside of the SDI domain, it is virtually impossible to build an SDI interface in software. The synchronous and continuous data streams do not lend themselves well to asynchronous event-driven software architectures and solutions must be found in hardware.

This leads to a further challenge; hardware takes a long time to develop, especially when dealing with the speeds that 12G offers. To put these speeds into context, the radio frequency band for satellites stretches from approximately 3GHz to 30GHz, and the Ku-band has a spectrum of 12GHz to 18GHz. The fundamental frequency of the bit rate of a 12G-SDI signal is just short of the 12GHz Ku radio frequency band used for satellite communications. Working at these frequencies makes hardware design incredibly challenging resulting in long development cycles to deliver reliable products.

For a vendor to invest the time needed to design and then manufacture with the high yield rates required is very risky. The smallest design anomaly on a critical part of the circuit board could render a prototype useless requiring a costly redesign. Consequently, a manufacturer will not start a new hardware design until they are sure the specification is nailed down.

This is why SMPTE have been so successful. They spend a great deal of time designing specifications that they know are robust and reliable, as well as well-documented and readily available. We can be sure that if two ST-2082 compliant devices are connected together, then they will readily exchange video and audio between them. This is even more important now that we have descriptive data embedded within the ancillary data streams such as the VPID (Video Payload Identifier) as specified in SMPTE 352.

Frame Accuracy

SDI allows us to make use of the ancillary data available in the stream to embed audio or send frame accurate data. As we progress into areas such as HDR (High Dynamic Range), the need to provide frame accurate metadata and control data is beginning to become apparent.

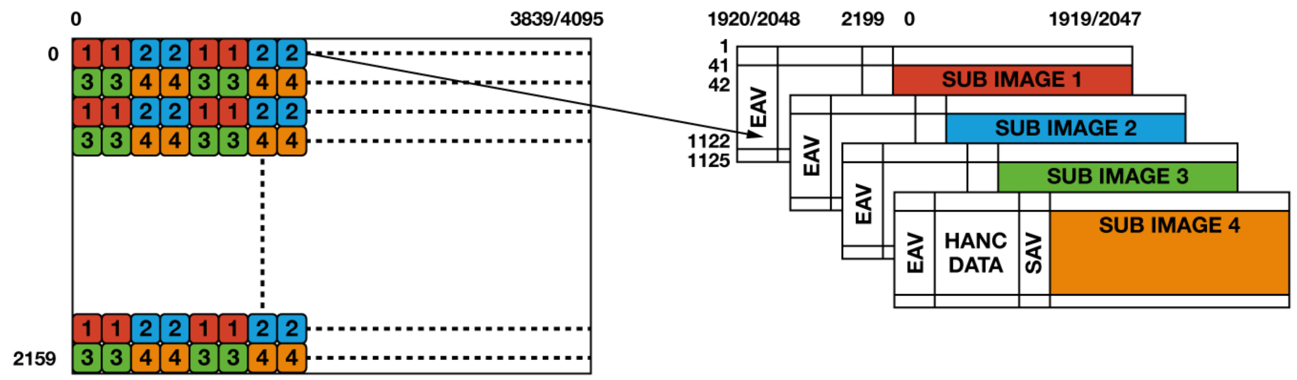


Figure 1 – to send a 4Kp signal over a quad-link 3G-SDI, the image is divided into four HD (1920 x 1080) sub images. Each sub image requires a 3G-SDI link allowing them to be sent over four coaxial cables. The receiver circuit reconstructs the four images to form a single 4Kp stream.

Key to the longevity of SDI is its inherent backwards compatibility. If you already have a 3G installation and then upgrade a part to be 12G, then any 3G signals routed through the 12G infrastructure should work reliably. There is a caveat here in that the vendor supplying the kit needs to make sure that they have provided multi-standard operation, but if they are using high-quality components then they have probably done this by default.

4K signals that may have been distributed as multi-link 3G or 6G can be more easily distributed over a single 12G link. For example, if a broadcast facility was using UHD 4:2:2 at 59.94fps over a 6G dual-link, then as the facility upgrades to 12G, only one cable link will need to be used as it will replace the 12G dual-link.

SDR and HDR Conversion

As we move to 4K while still embracing HD as a de facto mainstream format, new formats such as WCG (wide color gamut) and HDR (High Dynamic Range) are starting to appear. ST-2082 connectivity, whether through coax or fiber LC, implies that we should be thinking more about backwards compatibility. Converting between HDR/WCG and SDR is not always as simple as it may first appear. The different approaches to HDR, such as PQ or HLG, add complexity and the conversions require deep insight to this process.

Simply changing levels or using software to convert between color spaces is fraught with potential complications. Broadcast television is incredibly sensitive to gamut errors and even the smallest anomaly could have serious consequences for downstream compression systems.

Any HDR infrastructure must have an adequate number of HDR/WCG to SDR (and SDR to HDR/WCG) converters to truly integrate 4K into an existing broadcast infrastructure. Even connecting to the outside world will require some sort of conversion. Changing between 4K and HD is a lot more involved than just scaling and filtering an image.

LUTs (Look Up Tables) help provide the correct color conversions and standard reference models are available. However, these are complex to implement and require matrix programming and high precision mathematical solutions to get the best possible conversion.

Quality LUTs

A LUT is essentially a mathematical operation that takes the current RGB pixel value and applies a transform to it to provide a new value. These transforms are often non-linear and use resource hungry processing. The 3D-LUT can be thought of as a cube where the original pixel value and the new transformed value both reside.

3D-LUTs can be massive and complex. For a 10-bit system, there are over a billion possible values the new pixel can be mapped to for each pixel displayed on the screen. To reduce the number of calculations, 3D-LUT cubes are

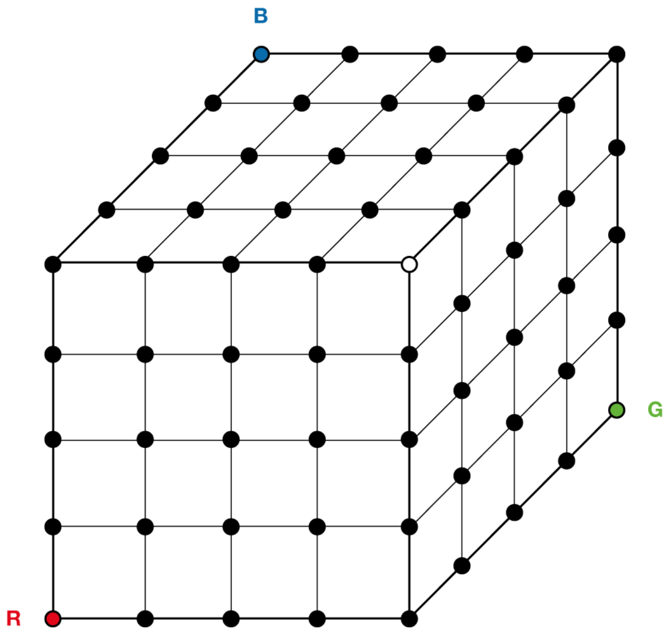


Figure 2 – a 3D-LUT can be visualized as a cube. There are potentially billions of possible points within the cube where the input pixel can be mapped to the output pixel. To optimize the number of calculations needed, the number of input and output points are reduced and any input or output falling between these nodes is averaged between the nearest neighbor. This can be a source of video banding. Therefore, the more complex and dense the 3D-LUT, the better the resulting image.

condensed into fewer nodes so that not all the pixel values are represented. These nodes represent averages between adjacent values and account for length variance in 3D-LUT files.

The 3D-LUT file size has a direct impact on the quality of the converted image. If too small, there are not enough nodes, and the software or hardware must make a lot of compromises resulting in the potential for visible banding and other artefacts on the screen.

Pixel Neighborhoods

This is one reason great care must be taken when choosing any framestore or HDR/WCG to SDR converter. If the 3D-LUT tables are not accurate enough then the converted image will deteriorate quickly. Much greater processing power is needed to provide the conversion using high quality 3D-LUTs containing many more nodes.

Quality of the conversion is not just about transforming the static pixel as they cannot be treated in isolation. Images containing specular highlights for example, greatly affect the neighboring pixels, and so the image must be considered as a whole to obtain the highest possible quality of conversion.

High Frame Rates

Greater fluidity of motion delivered through higher frame rates further improves the viewer experience. Greater creative freedom is also offered program makers and slo-motion can be much more effective.

The high frame rates that HDR and 4K have to offer must also be addressed. Standard HD frame synchronizers cannot cope with the 4K's high frame rates and careful planning is needed to make sure any connectivity to existing HD systems is adequately thought through.

SDI is providing broadcasters with many opportunities. With a thirty-year heritage and ease of use, it's held its position as a strong contender for signal distribution in broadcast facilities. The introduction of 12G-SDI makes the format even more appealing, especially as it has been integrated into many interface and conversion products. 12G-SDI Is empowering broadcasters to integrate 4K much more easily than ever imagined.

Part 3 - Applications for 12G-SDI

In the last article in our three-part series, we explored the advantages of SDI and how 12G-SDI is applied in broadcast facilities. In this article, we investigate applications where SDI excels.

Broadcasters looking to move to 4K have up until recently relied on quad-link 3G-SDI, as the bit rate for 4Kp60 is just under 12Gb/s. The bulk and weight of these cables, however, make them difficult to install into broadcast facilities and outside broadcast vehicles.

Moving to 12G-SDI reduces the cabling to a single point to point connection and with fiber solutions, the connectivity becomes even easier. However, few broadcasters have the opportunity to work on brand new green field installations, so many facilities develop them piecemeal to meet ongoing program maker requirements.

As formats are advancing so quickly, reliable and safe integration is becoming more of a necessity. Expensive kit procured only a few years ago still has a long service life and broadcasters simply cannot afford to throw away perfectly good cameras and vision switchers because a new version of SDI has appeared.

Optimized Infrastructures

There is, however, a compelling reason to switch to 12G-SDI for many broadcasters, especially those working with outside broadcast vehicles. The saving in weight of going from four coaxial cables to one for each link is considerable. Furthermore, infrastructure components such as routers and DA's reduce as only one connection is required. Reducing the cable and equipment soon adds up and freeing up axle weight on a truck will allow broadcasters to either install more facilities or move to a smaller truck.

SMPTE, when designing 3G-, 6G-, and 12G-SDI have future proofed the specification and hence the design of many facilities. This upgrade path and backwards compatibility has allowed vendors to provide converter boxes that can interface quad-link 3G-SDI to a single 12G-SDI. This makes the upgrade path much easier and more cost effective.

Low Latency Demands

Live events demand low latency as fast action-packed sports rely on sharing the emotion of the game with the audience as well as showing what is going on. With SDI, delay is kept to an absolute minimum as SDI is a synchronous distribution system meaning signals have the least delay possible when sent from the camera

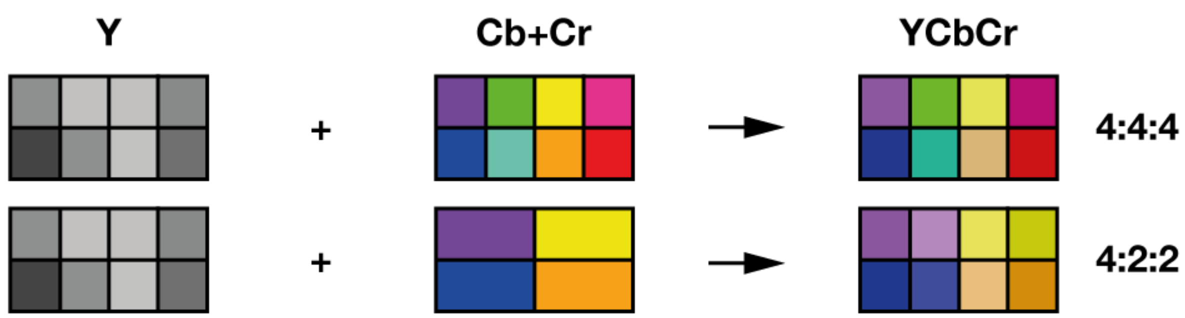


Figure 1 – ST-2082 provides the option of 4:4:4 color subsampling. Although the human visual system will tolerate the chroma bandwidth to be half that of the luma bandwidth, 4:4:4 processing is essential for post-production to keep the quality as high as possible.

to the vision switcher. Large buffers are simply not required as there is no packetized data to re-order or re-time.

Furthermore, the inherent near instantaneous plug-and-play ability of SDI makes rigging live events much easier and safer. As the SDI system has had over thirty-years to mature, cable designs and equipment reliability is probably as high as it's ever been. This further reduces complexity making multi-million dollar productions very reliable.

The learning curve for SDI is relatively low. Many engineers and technologists have grown up with SDI and understand it completely. The measurement and diagnosis tools are familiar, and the constraints of SDI are well known and documented. Essentially, the risk is very low.

Live sports events are well known for driving technology to its limits. Ever demanding audiences not only want the best pictures and sound possible, but they want more commentary and interviews. In today's high energy sports events there is no down time.

Co-timed Video and Audio

Keeping video and audio in-sync is more challenging now than ever. There's a miniature camera for nearly every imaginable application, all designed to help bring the ambiance and emotion of a live event home to the viewer. Unobtrusive, these devices can deliver stunning pictures. However, they generally don't have broadcast connectivity and need to run through a frame-synchronizer to provide an SDI interface and relevant timing.

Although video delay by a few frames is expected, the audio delay must match it or accumulative errors could manifest. One of the advantages of 12G-SDI, and SDI in general, is that the latency is low, but more importantly, it is predictable. The transmission time through an SDI interface is fixed due to the synchronous nature of the system.

As well as being able to embed the audio into an SDI stream, the predictability of the transmission path makes it much easier for a sound engineer to select the correct audio delay to match the video synchronizer and transmission paths. This is even more important when the program output and isolated feeds are transmitted back to the studio or playout facility. Having the video and audio arrive at the compression system co-timed helps remove potential timing anomalies.

HDR is gaining greater prominence in live sports events to meet the needs of the ever-demanding viewing audiences. Combined with WCG (Wide Color Gamut) and much more detail in the shadows and highlights, HDR is the obvious choice for stadium events. Shaders have many more options when trying to balance the bright sunlight on the playing field against the harsh shadows cast by the stadium.

Maintaining SDR

However, the vast number of viewers are still using SDR televisions, and although the future for HDR looks very promising, broadcasters must be realistic and still provide the SDR feed for these viewers. This usually implies a dual transmission path at some point where the SDR feed must be derived from the HDR feed (or the other way around if that is what the system designers have built).

Key to building reliable HDR systems is understanding the workflow requirements and keeping latency low. Again, simplicity and minimal delay are absolute necessities, especially for live events. Real-time processing is required with the smallest delay possible and the synchronous nature of SDI lends itself well to these applications.

As more demands are placed on HDR infrastructures, it's inevitable that frame accurate signaling and switching is going to be required for localization and sponsor opt-outs. Embedded data in the auxiliary SDI stream will further support this requirement.

Although broadcasters are familiar with using 10-bit SDI systems, 12G-SDI is providing future proofing through the provision for 12-bit samples. As well as being backwards compatible and maintaining 10-bit samples, ST-2082 makes provision for 12-bit samples. This will further enhance HDR images especially as we move beyond 4K to 8K. As screens improve and become physically bigger, banding and aliasing not seen on smaller screens will become more obvious, moving to 12-bits will help alleviate this.

HDR 12-Bit Video Future Proofing

Through quad-link 12G-SDI, bit rates of up to 47.52Gbits/sec are available. This allows 8K signals to be transferred for 10-bit 8Kp60 and 12-bit 8Kp30. Again, SDI and specifically 12G-SDI provides an upgrade path should a broadcaster want to provide an 8K service. 12G-SDI gives a broadcaster upgrade options as they can build an 8K facility using quad-link 12G-SDI.

Higher color spaces are also available through the provision of 4:4:4 color subsampling. This gives much higher color accuracy than the familiar 4:2:2 color subsampled system so colors can be better represented and rendered, especially in post-production.

Our human visual system may only need the bandwidth of the chroma to be half that of the luma, but processing in full chroma bandwidth using 4:4:4 will help reduce potential artifacts and concatenation errors. Again, these will be more obvious on large screens so we should do everything possible to keep the quality and accuracy as high as possible within the image.

SDI has stood the test of time and has gone through many iterations to reach the current 12G-SDI SMPTE ST-2082 standard. It's well understood, is already plug-n-play, and delivers simplicity.

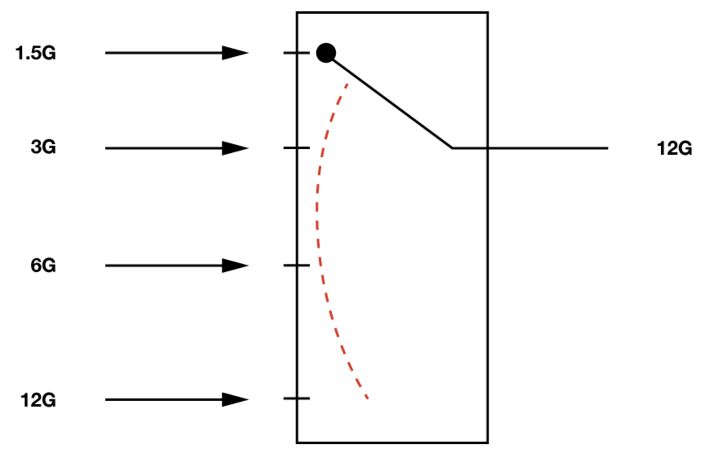


Figure 2 – 12G-SDI infrastructure cabling is backwards compatible with earlier versions of SDI to facilitate better integration.

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