By Steve Somers, Vice President of Engineering

HD-SDI, HDMI, and Tempus Fugit

HD-SDI (high definition serial digital interface) and HDMI (high definition multimedia interface) version 1.3 are receiving considerable attention these days. "These days" really moved ahead rapidly now that I recall writing in this column on HD-SDI just one year ago. And, exactly two years ago the topic was DVI and HDMI. To be predictably trite, it seems like just yesterday. As with all things digital, there is much change and much to talk about.

HD-SDI Redux

The HD-SDI is the 1.5 Gbps backbone of uncompressed high definition video conveyance within the professional HD production environment. It's been around since about 1996 and is quite literally the savior of high definition interfacing and delivery at modest cost over medium-haul distances using RG-6 style video coax. Defined in SMPTE (Society of Motion Picture and Television Engineers) 292M, this standard just underwent an update in late 2006. The technical data is essentially the same, but the standard's relationship to other SMPTE standards is now clarified via a roadmap within the new release.

And so it goes, but the real reason to discuss HD-SDI today is to introduce you to some of its variations. Why? The variations are taking on new meaning as the industry encounters the need for higher color depth and expanded transmission bandwidth. The digital cinema industry is well aware of the new flavors of HD-SDI and, in some applications, uses its variants to feed the voracious data appetite of the digital cinema projector.

SMPTE 292M describes the basic 1.485 Gbps serial digital interface capable of supporting high definition 10-bit, 1024 levels, component video in the 4:2:2 sampling format. This is digital component with the luminance channel having full bandwidth sampling at 74.250 MHz, the '4' in 4:2:2, while the two chroma difference channels suffice with one-half the sample rate at 37.125 MHz, the '2s' in 4:2:2. This format is sufficient for high definition television. But, its robustness and simplicity is pressing it into the higher bandwidth demands of digital cinema and other uses like 12-bit, 4096 level signal formats, refresh rates above 30 frames per second, and larger picture formats.

More Bits is More Better

SMPTE addressed this demand with SMPTE 372M, which describes a dual-link application of HD-SDI capable of 4:4:4 delivery; i.e. two coax cables supporting separate, but coordinated, interfaces with each delivering 1.485 Gbps for a total bandwidth of 2.970 Gbps. This adaptation supports component and RGB sources of 10-bits and 12-bits as well as an "alpha" channel. The alpha channel provides support for chroma keying and background clipping mattes. When the alpha channel is present, the sampling structure is referred to as 4:4:4:4. SMPTE 372M spreads out the image information between the two channels to distribute the data payload. Odd-numbered lines map to link A and even-numbered lines map to link B. Table 1 indicates the organization of 4:2:2, 4:4:4, and 4:4:4:4 data with respect to the available frame rates.

Applications like digital cinema demand the uncompressed, 12-bit 4:4:4 structure; meaning that each channel is full bandwidth RGB or component format with 12-bit depth per color. According to Table 1, a wide variety of frame rates may be accommodated, but digital cinema typically utilizes the 24 frame progressive mode listed so as to preserve the film look. Since this standard is an extension of SMPTE 292M, the original HD-SDI format, its versatility is utilized for some digital cinema interfacing installations; although at this time, the digital cinema infrastructure is still under considerable development and change.

Signal format sampling structure/ pixel depth	Frame/Field Rates
4:2:2 ($Y'C'_BC'_R$) / 10-bit	60, 60/1.001 and 50 progressive
4:4:4 (R'G'B'), 4:4:4:4 (R'G'B'+ A) / 10-bit	30, 30/1.001, 25, 24, and 24/1.001 progressive, PsF 60, 60/1.001, and 50 fields interlaced
4:4:4 (R'G'B') / 12-bit	
4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($Y'C'_BC'_R$+ A) / 10-bit	
4:4:4 ($Y'C'_BC'_R$) / 12-bit	
4:2:2 ($Y'C'_BC'_R$) / 12-bit	

Table 1: Source signal formats from SMPTE 372M-2002

Mapping Structure	Reference SMPTE Standard	Image Format	Signal Format Sampling/Pixel Depth	Frame/Field Rates
1	274M	1920 x 1080	4:2:2 ($Y'C'_BC'_R$) / 10-bit	60, 60/1.001, 50 frame progressive
2	296M	1280 x 720	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B'+ A) / 10-bit	60, 60/1.001, 50 frames progressive
			4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($YC'_BC'_R$+A) / 10-bit	30, 30/1.001, 25, 24, & 24/1.001 frames progressive
	274M	1920 x 1080	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B'+ A) / 10-bit	60, 60/1.001, 50 frames interlaced
			4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($YC'_BC'_R$+A) / 10-bit	30, 30/1.001, 25, 24, & 24/1.001 frames progressive
3	274M	1920 x 1080	4:4:4 (R'G'B') / 12-bit	60, 60/1.001, 50 frames interlaced
			4:4:4 ($Y'C'_BC'_R$) / 12-bit	30, 30/1.001, 25, 24, & 24/1.001 frames progressive
4	274M	1920 x 1080	4:2:2 ($Y'C'_BC'_R$) / 12-bit	30, 30/1.001, 25, 24, & 24/1.001 frames progressive
				60, 60/1.001, 50 fields interlaced

Table 2: Source Image Format Relationships from SMPTE 425M

SMPTE Dynamic Duo: 424M and 425M

Dual-link HD-SDI is certainly a step forward, but it demands that the interfacing devices be capable of managing a certain amount of timing skew that can occur as the signal travels through two separate cable pathways. It is imperative that cable length be managed closely to guard against increased skew time. Signal timing difference at the source must not exceed 40 nanoseconds. Wouldn't it be nice if we could manage the two data streams on one cable?

SMPTE 424M and 425M do just that. Both standards describe attributes of the new 3 Gbps HD-SDI often referred to as "dual rate". SMPTE 424M describes the physical interface while SMPTE 425M details image format mapping. Just think of 424M being two regular 10-bit HD-SDI data streams alternating, or time-multiplexed, onto one cable. In order to transmit the same information as two separate HD-SDI streams, the clocking rate is simply doubled. This arrangement is called a "virtual interface" within 424M. The connectivity via 75 ohm RG-6 style coax with BNC connectors and loss budget is the same as with the original SMPTE 292M for the standard HD-SDI. The only difference is that our -20 dB calculation for cable loss at one half the clock rate moves from 743 MHz to 1.485 GHz. Essentially, the loss is about double for the same distance with the same cable; or, we can transmit the signal half as far.

In SMPTE 425M, both 10-bit and 12-bit signals map into the 3 Gbps stream. Table 2 summarizes the scope of image formats handled in this dual-rate standard. The mapping structure supports various rates from 4:2:2 10-bit component up to 4:4:4 12-bit component and RGB. Increasing the bit depth improves the image's dynamic range.

Video Blanking Recycled

You might recall from the past HD-SDI article some discussion on the SMPTE 348M transport version called HD-SDTI, high definition serial digital transport interface. HD-SDTI is geared for general purpose data hauling at 1.5 Gbps. In the new release of SMPTE 292M, the roadmap shows this transport interface tied in to the taxonomy through SMPTE 291M, also updated in 2006, which describes how to format data for use within the ancillary data space supplied in all television serial digital standards. The ancillary space is the time interval previously devoted to horizontal and vertical blanking in the analog television system. Since horizontal and vertical synchronization timing occupied about 20% of the total timing allotment, re-use of this valuable timing slot allows a significant amount of additional data to be transmitted within the HD-SDI or HD-SDTI.

SMPTE 349M takes the transport concept back into the standard definition production environment for support of 525 and 625 line video. Instructions are provided for the repacking of standard definition into the HD-SDI transport space. Further, this standard sets the structure for transport of a variety of video data including MPEG-2 encoded video.

New Song: "What kind of HD-M-I?"

Yes, Mr. Sinatra would be asking himself just that if he were around to install and connect his own flat screen TV today. The big news is that HDMI version 1.3 finally released along with an additional smaller, adroit connector and a color depth increase from a paltry 16,777,216 colors to 68,719,476,736 colors. Yes, folks, 68.7 Gigacolors. One could fixate into a comma coma reading numbers like that. Can you imagine what a jump all the way to version 2.0 might bring? Welcome to Gigacolors.

I feel good about that. I'd feel even better if we had displays that could show all

continued on page 20

those colors, but that's another discussion for another time. At least we know that we can collect the colors, assign a number to them, and store them away in a large hard drive for future use… a kind of cryogenic color storage, figuratively speaking, to be thawed at a future date by the LED and the laser. Surely, the good ol' days are yet to come.

Nearby is a summary listing the salient new features offered by version 1.3. Of all the new features, the ones most likely to be noticed by most consumers are the improved color depth and the small form factor connector. The new mini-connector debuted recently on some camcorders as the new interface for direct connection to your home HDTV system. Like USB, devices having the new physical interface will provide a short cable with the standard HDMI connector on one end and the new mini on the other end to facilitate direct digital connection to a display system.

HDMI version 1.3 Feature List

- Higher speed: from 165 MHz to 340 MHz (4.95 Gbps to 10.2 Gbps)
- Deep color (24, 30, 36, 48 bit depth) for RGB and YC_BC_R
- Increased resolution range
- Higher frame rates to 120 Hz
- New, lossless audio formats
- Automatic audio/video lip sync
- New mini-connector for small electronics like cameras
- Broader color space – "xvYCC" as described in IEC61966-2-4
- Two classes of interconnect cable

The less noticeable, but important features are the higher interface speed, from 4.95 Gbps to 10.2 Gbps, which will support higher visual resolutions along with lossless audio formats like Dolby® TrueHD and DTS-HD Master Audio™. Systems providing 3D viewing capability have long used 120 Hz refresh rates, so that is now supported.

Another item not to be overlooked by all of us in the A/V community is the auto-magic audio/video lip sync feature. Lip sync is one of those things we don't talk about, but its preponderance is lurking within every high-end A/V system design. Typically, the video is delayed significantly by the processing encountered in most scaling and switching systems. The effect is compounded if additional scaling occurs in the display as well as externally. Audio could lag video by as much as three or four frames… a condition quite noticeable to the viewer. Many video processors control or include built-in compensation for this lag, but depending on the A/V system design, lip sync error may creep in.

Pixel Packing 101

But, let's get back to the deal closers… more resolutions and greater color depth. At slightly more than double the previous transmission rate, version 1.3 widens support for high resolution progressive scan rates along with the greater color depth. A comprehensive list of supported rates is covered in Consumer Electronics Association document CEA-861-D. For example, the regular single-link HDMI, or DVI, supports 1920x1080 progressive scan high definition video at 24 bits per pixel, bpp. To review, 24 bpp means that each of the three color channels (R, G, B) are assigned 8 bits, or 256 levels. If we multiply 256 to the third power, we achieve the 16.7 million colors. To achieve any of the greater color depth values, more pixel information must be transmitted.

The version 1.3 specification chapter 6 illustrates the methodology for increasing clock rate and packing pixels to achieve the additional data throughput. If you think about it a moment, it's straightforward in that the existing interface operates at 165 MHz to support 24 bpp. The new interface must operate at least twice as fast, hence 340 MHz, to support up to 48 bpp. With the increased clock rate, version 1.3 lays out the interleaving details that support orderly fragmentation, packing, and movement of the additional pixel information for each of the new pixel depths (30, 36, and 48) beyond the standard 24. Did I say "fragmentation"? That's right; there IS matter smaller than one pixel. The HDMI 1.3 is rampant with partial pixels tucked together within all the nooks and crannies of the three data channels. Pixel packing and keeping track of partial pixels is not only very interesting, but definitely recommended study for anyone experiencing difficulty falling asleep in the evening.

The Rules of Deep Color

- Support for deep color modes is optional.
- Only HDMI version 1.3 supports deep color.
- 30, 36, and 48 bpp are deep color modes.
- Devices discover pixel depth support via the E-EDID interface.
- A device's failure to indicate pack pixels initiates 24-bit mode.
- RGB 4:4:4 deep color always supported. d
- YC_BC_R 4:4:4 deep color support optional.
- YC_BC_R 4:2:2 does not support deep color.

Color Space — "The Final Frontier"

Color depth and color space are not the same thing. Color depth refers to a method for dividing a range of color, the red channel for example, into smaller graduated increments so as to attain smoother, shaded tonal appearance on a display device.

Color space describes the overall range of colors within the realm of human vision that a system can reproduce. Humans are capable of seeing more colors than our existing visual display systems can show us. The quest continues for larger

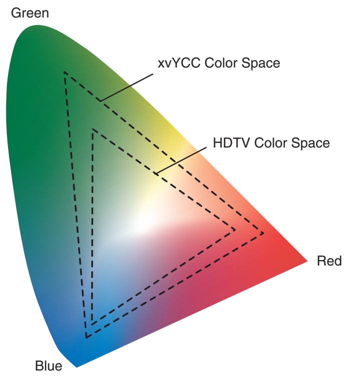

Figure 1: Conceptual presentation of the expanded xvYCC color space compared to the sRGB color space (not to scale).

color space and the ability to display it. HDMI version 1.3 takes a new step in that direction denoted as "xvYCC", or Extended-gamut YCC color space. The IEC 61966-2-4 defines this color space for video applications. Chapter 4.3 of the IEC standard describes xvYCC as an extension of ITU-R BT709-5, but extends the gamut of that standard much wider. The concept is illustrated in Figure 1 where the outer boundary of the color space "wedge" represents the limits of human visual capacity and the triangles represent the available colors within a region defined by primary red, green, and blue tristimulus values for a given color space. The larger the triangle, the more vivid are the perceived colors. Note that the HDTV (ITU-R 709) color space and the sRGB color space used in computer applications and by most all JPEG-based digital cameras are the same color space. This means that images in the sRGB space will directly match the color space of displays capable of displaying the HDTV space.

Getting Physical

Chapter 4 of the HDMI specification 1.3 defines the physical layer, or the connector and cable interface. In the connector department, there are now three types: A, B, and C. Type A is the popular 19-pin version in widespread use. Type B is the lesser known 29-pin dual link connector. And, Type C is the new compact 19-pin version for portable devices. Refer to Figure 2, which shows approximately 33% miniaturization compared to Type A. Table 4-13 in the HDMI 1.3 specification lists the pin alignment between Type A and Type C as they are not pin-to-pin compatible in the interest of Type C connector design optimization. Some new digital camcorders utilize the Type C connector so that the user may plug directly into HDMI-equipped displays for that high quality direct digital RGB or YC_BC_R video rush.

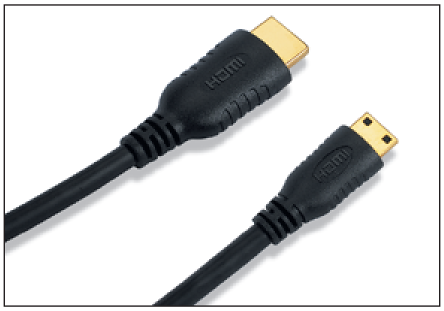

Figure 2: Relative size comparison between Type A (left) and the new Type C (right). Type C is about 33% smaller.

Interface cabling continues to boggle the senses. The first thing we need to take care of here is this: the HDMI specification only provides us with the electrical performance requirements for a functional interface. It does NOT specify cable design or cable length maximums. Everyone has but their own ingenuity using available raw cable materials and active electronics to solve the distance issues. However, version 1.3 does establish two classes of cable assemblies called Category 1 and Category 2. These "category" designations have nothing to do with the same nomenclature used for network cabling. Version 1.3 outlines detailed electrical design and testing requirements for both categories with Category 1 cables supporting HDMI clock frequencies to 74.25 MHz and Category 2 cables supporting the entire specification through 340 MHz. So, what does this mean to us? Table 4 of the CEA-861 companion standard lists all the supported resolution rates and the corresponding clock rate required for the HDMI. All television video rates, including standard definition and high definition through 1080i and 1080p at 30 Hz frame or below operating at 24 bpp, are serviced by the 74.25 MHz clock rate. This means that the supposedly cheaper, existing Category 1 cable will suffice. The higher performance cable is therefore required to realize any of the deep color rates.

Attenuation limit charts and eye diagram masks provide the tools to guide the cable designer between the two categories. It is obvious that, since cable length cannot be tied to the specification, we are highly dependent on the cable manufacturer to accurately design, test, and label the cable assemblies appropriately for the given length sold. While a short length of a particular cable type may perform to Category 2, it does not mean that a longer version of the same cable type will perform to Category 2. As cable length increases, we all know that attenuation effects limit performance rapidly. For critical applications, A/V designers should pre-test cables regardless of category labeling.

Tempus Fugit — Time Flies

Well, it certainly has. While being a glimpse of the expanding HD-SDI arena and HDMI version 1.3 new offerings, this article locks in time a small moment where we discuss the new, yet dream about what might be in store for our future. Likely a year or two from now I'll need to revisit some aspect of these interface topics. Oh, don't forget to download your own free copy of version 1.3 at www.hdmi.org … all 276 pages of it. It will be some time before all devices make full use of version 1.3.

Meanwhile, I've got to figure out how we're going to make a cable that supports 340 MHz and a 10.2 Gbps data rate for any reasonable distance. So, while I'm off the street working on that, pay attention to those new HDMI cable assemblies. Don't buy anything with peel-off category labels!