Using Category 5/5e/6 for Audio and Video Applications

Steve Lampen
Multimedia Technology Manager
Belden Cable

ABSTRACT

With the rise of premise/data cables, such as Category 5, the possibility of using such cables for non-data applications was suggested[1]. Now it is common to find Category 5, Category 5e, or Category 6 routinely used in many alternate applications. This paper will concentrate on audio and video applications, both analog and digital, with emphasis on whether UTP data cable can meet the requirements of these systems, and what limitations there are.

APPLICATIONS

Table 1 shows the audio applications that will be examined. Table 2 shows the video applications that will be examined.

Application	**Format**	**Cable Type**	**Spec**	**End-User**
Analog audio	Unbalanced	Single-conductor shielded	N/A	Consumer
Analog audio	Balanced	Shielded twisted-pair	N/A	Professional
Digital audio	Unbalanced	Coaxial cable	S/PDIF	Consumer
Digital audio	Unbalanced	Coaxial cable	AES3-id	Professional
Digital audio	Balanced	Shielded twisted-pair	AES3	Professional

Table1

Application	**Format**	**Cable Type**	**Spec**	**End-User**
Analog video	Unbalanced	Coaxial Cable	Surveillance	Consumer
Analog video	Unbalanced	Coaxial cable	Home video	Consumer
Analog video	Unbalanced	Coaxial cable	Broadcast	Professional
Digital video	Unbalanced	Coaxial cable	SDI (601)	Professional
Analog video	Unbalanced	S-video (dual)	Y-C	Pro-Sumer
Analog video	Unbalanced	RGB	Component	Professional
Analog video	Unbalanced	VGA	Component	Professional
Analog video	Unbalanced	Coaxial cable	Broadband	Consumer

Table 2

UTP AND BALANCED LINES

Category cables are most commonly unshielded twisted pairs (UTP). The majority of domestically installed cables are UTP. These cables are balanced line. Balanced line performance is one of the major advantages these cables have over many other cables. The natural ability of twisted pairs to reject noise is due to a number of factors. The key is that the each conductor in the pair, and all other circuits attached to them, has the same impedance with respect to ground and to all other conductors. The entire path of both conductors is *electrically* identical.

To arrive at this, the conductors should be the same size (AWG), the same length, and as close together as possible (minimum spacing). Arriving at these requirements is much more difficult than most users might imagine. Being a manufactured product, there are natural variations in all these parameters, leading to impedance variations. Test parameters for each of these effects is shown in Table 3

Requirement	Variations in	Cable Parameter	Measured in
Spacing	Capacitance	Capacitance Unbalance	Picofarads (pF)
	Impedance	Return Loss	Decibels (dB)
Size	Resistance	Resistance Unbalance	Ohms (Ω)
Length			

Table 3

Twisting the wires together, and ultimately, by bonding the conductors together can control spacing between conductors. Spacing is also dependant upon placing the conductors in the center of the insulation. The size of the conductors can be controlled by precise drawing and re-drawing. Precise pair twisting and matching the tension on each conductor during the twisting process can control the length.

Many signal types we will analyze are unbalanced, such as consumer analog audio, consumer digital audio, video of all types, including RGB, VGA, S-video, and CATV/broadband signals.

Unbalanced cables, such as coaxial cable, have none of the requirements of balanced lines. The two conductors are not the same size, not the same length (the braid is much longer than the center conductor), and the two conductors are not close together. In fact, they are moved apart to arrive at a specific impedance, such as 75Ω coaxial cable.

To allow balanced-line UTP, a device is needed to adapt balanced UTP to unbalanced cable, called a "balun" (indicating its BALanced-to-UNbalanced application). Baluns are available from many manufacturers[3]. Pictures in this paper were provided by Energy Transformation Systems (ETS), Fremont, California.

COMPARING DATA CABLE TO NON-DATA APPLICATIONS

Parameters for data cables are well documented in TIA/EIA 568A. It is then a simple matter of comparing those specifications with the requirements for various audio and video applications. However, it is not as "simple" as it sounds. To start, specifications for premise/data cables don't start until 1 MHz. (Some start at 772 kHz.) Thus, analog audio requirements cannot be compared to existing parameters.

Further, many audio and video signal types do not have many 'standard' parameters. Therefore, we have inserted de facto standards. If the reader disagrees with a particular specification, it is a simple matter of inserting a different specification to come to an appropriate judgment regarding suitability of a particular cable for any particular application.

CONSUMER ANALOG AUDIO INTERCONNECTS

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	30pF/ft. 98 pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m
Impedance	N/A	100Ω	100Ω	100Ω
Gage	22/24 AWG (?)	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO

Table 4

Consumer audio interconnects exhibit a huge range in quality, consistency, and performance. Gage size varies greatly, but the resulting resistance has a very minor effect on performance, especially with the common distances of these cables, generally 6 ft. (2m) or less. These cables generally use RCA connectors.

While a capacitance for consumer audio cables is shown as 30 pF/ft, (98 pF/m) many cables exhibit much greater capacitance, often 50 pF/ft. (164pF/m) or more. Capacitance, and capacitive reactance, compared to the source impedance (usually 10k) means that, with a cable of even 15 pF/ft (49 pF/m), these cables are severely distance limited. (-1 dB at 20 kHz at only 28 ft.)

Since consumer audio interconnects are unbalanced, matching them to balanced Category cables therefore requires a balun, as shown in Figure 1. Single channel and two channel (stereo) baluns are shown.

Figure 1
Courtesy www.etslan.com

Note that this balun has an RCA connector on one side and connects to one pair of the 4-pair RJ-45 on the other side. Because only one pair is used, crosstalk is not a consideration. We will show data later in this paper regarding multiple audio signals on a single four-pair cable.

IMPEDANCE MATCHING AND DISTANCE

A balun used for unbalanced analog audio also effectively alters the source impedance from a typical 10kΩ to a much lower value. (600Ω for the balun shown in Figure 1). This then allows the user to escape the severe distance limitations (30 ft./9m) and go many hundreds of feet. Table 5 shows the distance limitation for audio cable based on the source impedance and the capacitance of the cable[2].

The *destination* (load) impedance must be at least ten times the source impedance for these distance numbers to be accurate. Table 5 shows the distance at which a 20kHz audio signal will be attenuated by 1 dB. Any other frequency or loss, or the loss of a cable with a different capacitance value, can be easily calculated.

Source Impedance	**15 pF/ft. (49 pF/m)**	**20 pF/ft. (66 pF/m)**	**30 pF/ft. (98 pF/m)**	**50 pF/ft. (164 pF/m)**
50 Ω	5406 ft. 1648m	4055 ft. 1236m	2703 ft. 824m	1622 ft. 495m
100 Ω	2707 ft. 825m	2030 ft. 619m	1353 ft. 413m	812 ft. 248m
150 Ω	1873 ft. 571m	1352 ft. 412m	901 ft. 275m	541 ft. 165m
600 Ω	451 ft. 138m	338 ft. 103m	225 ft. 68.6m	135 ft. 41.2m
1 kΩ	271 ft. 82.6m	203 ft. 61.9m	135 ft. 41.2m	81 ft. 24.7m
10 kΩ	27 ft. 8.2m	20 ft. 6.1m	14 ft. 4.3m	8 ft. 2.4m
50 kΩ	5.4 ft. 165cm	4 ft. 122cm	2.7 ft. 82cm	1.6 ft. 49cm

Table 5

Table 5 indicates that, at low audio frequencies where impedance-matching is not required, a low source impedance will get you a lot farther than a high source impedance. And Category cables, at 15 pF/ft. (49 pF/m) offer excellent analog audio performance based on their low capacitance alone.

ANALOG AUDIO FACEPLATE ADAPTORS

There are a number of manufacturers who are producing modules that fit into faceplates with the ‘footprint’ of an RJ-45 connector. Among these are modules that connect RCA, unbalanced consumer audio, to “110-block” twisted pairs.

However, these modules contain no balanced-to-unbalanced circuitry. These adaptors unbalance the balanced pair affecting pair-to-pair and cable-to-cable ‘alien’ crosstalk. They also connect directly to the source impedance of the audio consumer device feeding the line and, as shown in Table 5 above, are therefore limited to approximately 27 ft. before there is noticeable signal loss.

These are not baluns at all, and their use is not recommended. Whether these could be made with a true balun built in, or whether potential customers would pay the extra cost, has not been established.

BALANCED ANALOG AUDIO

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Balanced	Balanced	Balanced	Balanced
Capacitance	30pF/ft. 98 pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m
Impedance	N/A	100Ω	100Ω	100Ω
Gage	(?)	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO

Table 6

The two key differences between unbalanced consumer analog audio and balanced professional analog audio are level and format. Professional balanced analog audio systems run at peak levels of +4 dBm or +8 dBm, where consumer audio is typically –10 dBv. Thus moving between systems might require amplification in one direction and attenuation in the other, as well as a balun to match balanced to unbalanced.

The other difference with balanced audio is that it is, obviously, balanced. As shown in Table 6 above we are attaching balanced Category cables to a balanced-line system. This means that no adaptor or balun is required to use UTP in such a system. It does look a bit odd to an audio engineer to see unshielded twisted pairs going into a connector (such as an XLR), but applications like this work very well. The only consideration might be when four signals are run down the four pairs of UTP. What about crosstalk? Of course, these are unshielded twisted pairs. And every audio engineer has grown up with shields around ever pair.

To answer this question, tests were made on a Category 5 UTP cable. In choosing the cable, it was suggested that the poorest performance would be found in Category 5 patch cable. Most data installers are aware that patch cable is so much lower in performance that patch cable has its own standards within the TIA/EIA specifications. The cable used for these tests was Belden 1752A. The only added feature in this patch cable is the use of bonded pairs; otherwise it is standard Category 5 patch cable.

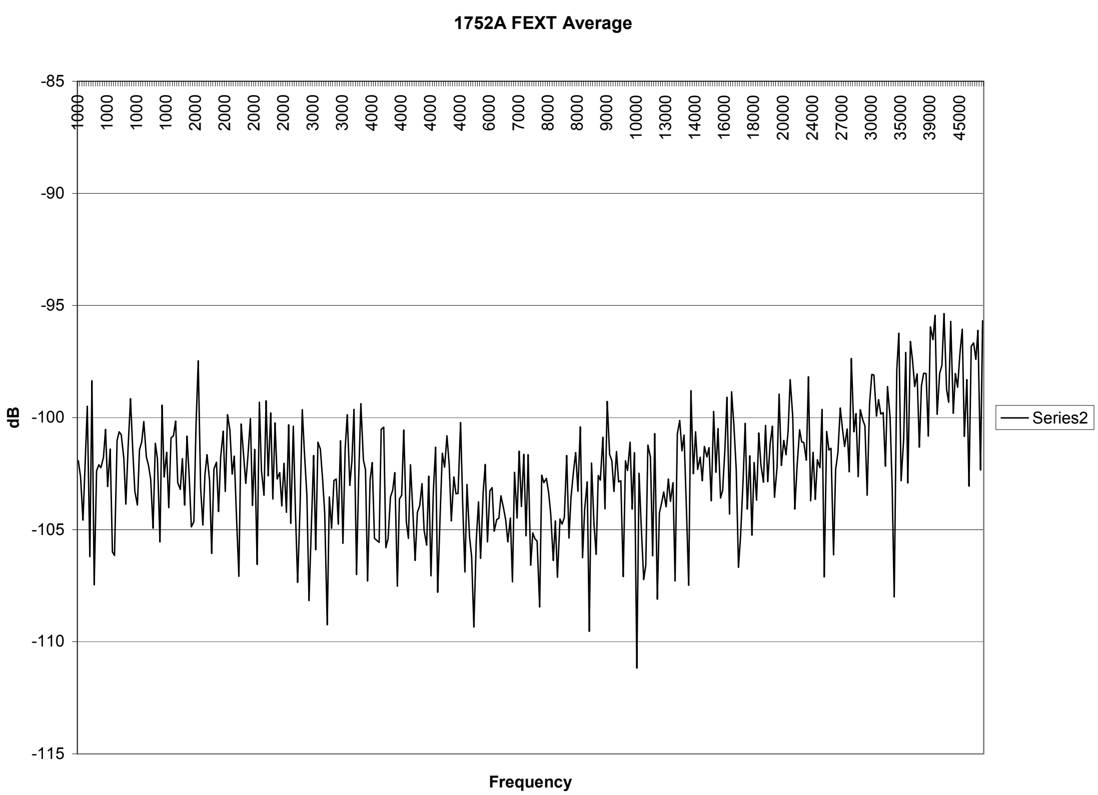

Figure 2

Figure 2 shows FEXT (far-end crosstalk) averaged between all four pairs between 1 kHz and 50 kHz. This is past the range of hearing, which typically ends at 20 kHz. You will note that the worst case is around 43 kHz, where the average crosstalk between all pair combinations is just under –95 dB. Some believe that the 'far end', where signals are weakest, may not be a true representation of audio, and that the 'near-end' crosstalk or NEXT would be more appropriate. Figure 3 shows the NEXT from 1 kHz to 50 kHz.
With the NEXT data, worst case is now at 48 kHz at –95 dB. In both cases, at 20 kHz, typical crosstalk is –100 dB.

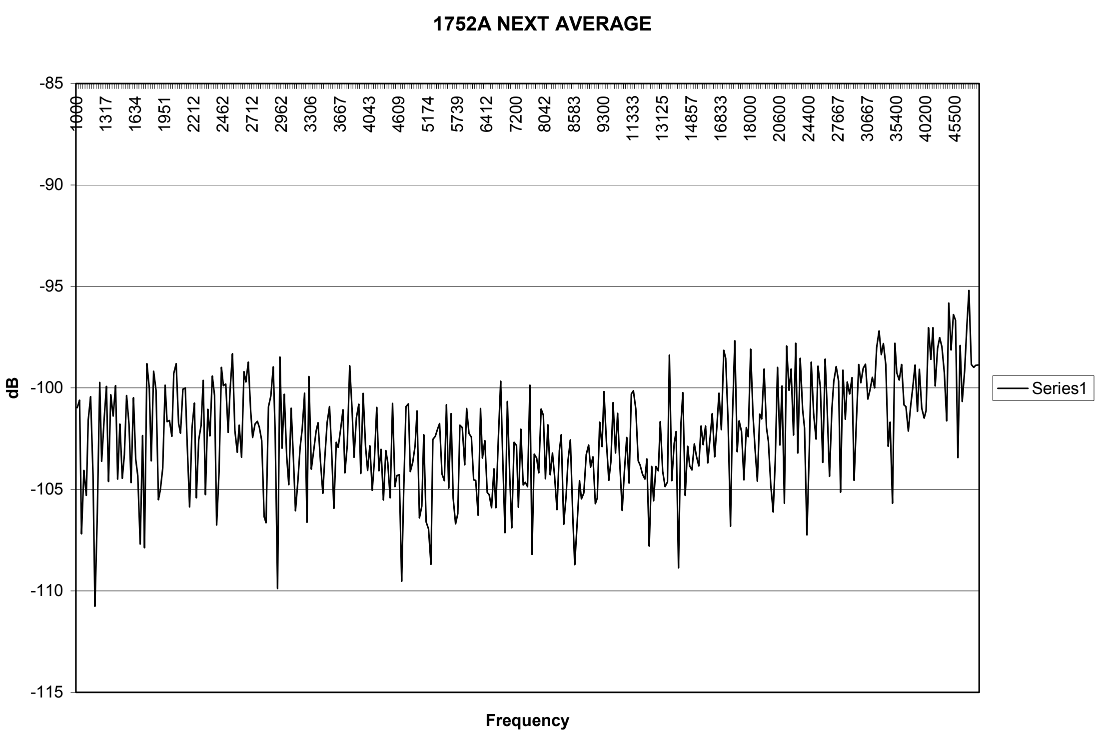

Figure 3

Further testing was done with Category 6 (Belden MediaTwist 1872A). Unfortunately, at 20 kHz the crosstalk pair-to-pair is below the noise floor of the network analyzer (-110 dB) so no data is available.

POORLY BALANCED PAIRS

Using unshielded twisted pairs shifts the noise rejection from a shield-twisted-pair combination, to a twisted-pair-only. Essentially, the user is depending on the common-mode rejection ratio (CMRR) of the source and destination devices to drive and receive the signals and reject the noise. Category cables make excellent balanced lines, but many older audio devices may not have good common-mode performance. Table 7 below shows what constitutes good or bad CMRR. If this performance figure can be obtained, the performance of this particular piece of equipment on UTP would be predictable.

CMRR	QUALITY
-50 dB	Poor
-60 dB	Good
-70 dB	Very Good
-80 dB	Excellent
-90 dB	Outstanding

Table 7

There are devices that can 'force' the balance on a balanced line. That is, they can re-balance a poorly balanced line to allow minimum CMRR and maximum noise rejection.

WHAT CROSSTALK DO WE NEED FOR AUDIO?

For many, many years, the ideal signal-to-noise requirement in broadcast, recording, and other audio applications was –60 dB. With the advent of digital, the noise floor requirement was changed to a *de facto* –90 dB. It should be noted that even lower-quality patch cable can easily meet this requirement, and high quality Category 6, gives in excess of 20 dB further noise floor.

Thus baluns, such as the four channel home audio balun shown in Figure 4, are eminently useable and provide more pair-to-pair isolation than required.

Figure 4
Courtesy www.etslan.com

From this point on, a crosstalk specification will be included with each signal type, assuming the user would want to put four identical signals down the four-pair UTP. Mixed signal 'shared sheath' will be examined at the end of this paper.

DIGITAL AUDIO

Digital audio comes in three variations:

1. Consumer, called S/PDIF (Sony/Phillips Digital Interface)
2. Professional unbalanced (AES3-id)
3. Professional balanced (AES3)

We start with RCA-based unbalanced consumer digital, or S/PDIF.

S/PDIF

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	20pF/ft. 66pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m
Impedance	75Ω	*100*Ω	*100*Ω	*100*Ω
Gage	23-24 AWG	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk 6 MHz	30 dB (?)	-52 dB PSNEXT	-52 dB PSNEXT	-62 dB PSNEXT

Table 8

There are three considerations in Table 8 (S/PDIF). First is the unbalanced nature of the signal (compared to balanced UTP). Second is the use of 75Ω source impedance, to allow the use of standard video coax. Our balun will have to match both the balance and the impedance. Figure 5 is an S/PDIF balun. From the outside, it looks the same as the single-channel analog balun in Figure 1.

Figure 5
Courtesy www.etslan.com

The last consideration is crosstalk. We are now into the megahertz, where required measurements on Category cables is easily available from the TIA/EIA standards. The crosstalk numbers shown are PSNEXT (power-sum near-end-crosstalk). This is an excellent choice for these applications because 'power sum' indicates that all pairs are driven with the signal except the pair being measured, precisely what we wish to do with our digital audio signal.

So what crosstalk is necessary? Until the use of UTP, this application was one signal per shielded cable. Now that we are using digital signals, it is very resistant to crosstalk. The –90 dB crosstalk of analog is not needed here. We have put –30dB in that box above, but many chip designers say this number is way too conservative and should be more like –3 dB. As long as you can resolve the bitstream, the amount of noise present is much less of a factor than in analog.

THE ADVANTAGE OF ONES AND ZEROS

As long as a digital bit stream arrives at its destination unchanged, the resulting audio (or video or data) will be as perfect as the original bit stream. This is one of the major advantages of digital signals; the thousandth copy, even having gone on tape, through a satellite, down a thousand miles of fiber, will be exactly the same as the original, as long as all the bits arrive as they left.

The quality of the resulting signal is determined the sampling rate, the quality and precision of the analog-to digital (A/D) and digital-to-analog (D/A) conversion, and the integrated circuits inside that equipment.

AES BANDWIDTH

Professional AES specifications allow a large number of sampling rates and bandwidths. Table 9 below shows the possibilities. In the following tables, 192 kHz sampling (24.576 MHz), is used to determine performance, and is simplified to 25 MHz for these comparisons. Lower sampling, and lower bandwidths, would make matching performance even easier. The standard for home digital (S/PDIF above) is 44.1 kHz sampling. For S/PDIF calculations, the bandwidth of 5.6448 MHz has been simplified to 6 MHz.

Sampling Rate	To Determine Bandwidth	Actual Bandwidth
32 kHz	x128	4.096 MHz
38 kHz	x128	4.864 MHz
44.1 kHz	x128	5.6448 MHz
48 kHz	x128	6.144 MHz
96 kHz	x128	12.288 MHz
192 kHz	x128	24.576 MHz
352.8 kHz	x128	45.1584 MHz
384 kHz	x128	49.152 MHz

Table 9

Each sampling rate has a specific purpose, shown in Table 10 below.

Sampling Rate	Bandwidth	Application
32 kHz	4.096 MHz	Low quality, answering machine/reportage
38 kHz	4.864 MHz	FM broadcast quality
44.1 kHz	5.6448 MHz	CD-audio
48 kHz	6.144 MHz	Audio channels with professional video
96 kHz	12.288 MHz	High-quality, recording studios
192 kHz	24.576 MHz	Ultra-high quality, cutting-edge
8x44.1, 8x48	352.8/384 kHz	AES5 *proposed* X-140 “SuperMAC”

Table 10

The highest sampling rate for digital audio, 192 kHz, results in a bandwidth of almost 25 MHz, more than a thousand times higher than the bandwidth of analog audio. Obviously, the requirements for digital audio cable are considerably different than analog audio cable.

The proposed X-140 “SuperMultipleAudioChannels” uses Category 5e, 6 UTP or Category 7 ScTP. (Category 7 is individually shielded pairs, currently available in Europe.)

We continue below with the unbalanced professional coax version of digital audio, known by its AES standard AES3-id. The key difference between S/PDIF and AES3-id is the source voltage. Consumer S/PDIF runs at a source voltage of 0.5v, AES3-id runs at a minimum of 2v and often as high as 5v, or even higher. Naturally, the higher voltage allows considerably extended distances.

AES3-id

This is professional digital audio on coax. Note that the crosstalk numbers on UTP are more than acceptable, especially when one considers that the –30 dB crosstalk requirement is very conservative.

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m	15 pF/ft. 49pF/m
Impedance	75Ω	*100Ω*	*100Ω*	*100Ω*
Gage	23-24 AWG	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk 25 MHz	-30 dB (?)	-41.4 dB	-41.4 dB	-51.4 dB

Table 11

BALANCED AES

Balanced digital audio requires shielded twisted pairs. Therefore, no balun is required. But the AES specifications clearly state, “shielded twisted pairs”. If your installation is required to meet these standards then, obviously, UTP cannot be used. If it is a question whether UTP will work in this application, the answer is clearly yes.

	System Specs	Category 5	Category 5e	Category 6
Format	Balanced	Balanced	Balanced	Balanced
Capacitance	13 pF/ft. 43 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	110Ω ±20%	100Ω ±15Ω	100Ω ±15Ω	100Ω ±15Ω
Gage	(?)	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO

Table 12

In Table 12 we have also added the tolerance to the impedance requirements of both the digital audio and the category cables. As can be seen in Table 13 below, there is a potential mismatch between the cable and the AES format. The resultant mismatch ‘return loss” and the match percentage is also shown.

	Category Minimum	Category Nominal	Category Maximum	Return Loss	Match
AES Minimum	88:85			-35 dB	99.97%
AES Minimum		88:100		-24 dB	99.6%
AES Minimum			88:115	-18 dB	98.42%
AES Nominal	110:85			-18 dB	98.42%
AES Nominal		110:100		-26 dB	99.75%
AES Nominal			110:115	-33 dB	99.94%
AES Maximum	132:85			-13 dB	94.99%
AES Maximum		132:100		-17 dB	98%
AES Maximum			132:115	-23 dB	99.5%

Table 13

When the two tolerances are at their most extreme, return loss is the worst value (-13 dB) with a 5% mismatch. This may not sound like a lot, but this is different than a resistive loss of 5%, used up as heat in the cable. In this case, we’re talking about a mismatch, where a portion of the signal is reflected back into the transmitting circuit. Many chips do not do very well with highly reflected signals and 5% can certainly have an effect on the signal produced.

It is more common to find the AES devices to have more precise impedance, since it can easily be adjusted by passive components in the source and destination devices, shown in Table 12 as “AES Nominal”.

It is much more likely that the cable has a very high or low impedance tolerance. The conclusion here is to obtain category cable with tighter impedance tolerance than the TIA/EIA standard, such as bonded-pair versions.

ANALOG BASEBAND VIDEO

	System Specs	Category 5	Category 5e	Category 6
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	20 pF/ft. 77 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100Ω*	*100Ω*	*100Ω*
Gage	20 AWG	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk 4.2 MHz	-60 dB (?)	*-53.3 dB PSNEXT*	*-53.3 dB PSNEXT*	-63.3 dB PSNEXT

Table 14

Analog video has a bandwidth of 4.2 MHz (NTSC). In other countries, where PAL is the standard, the baseband video signal has a bandwidth of 5.5 MHz. Some may choose to put 6 MHz in for comparison. This is the size of a video channel in both systems, as transmitted by cable or through the air. Any of these bandwidths can be substituted above and appropriate numbers calculated.

A balun is required for all unbalanced video signals. A typical one is shown in Figure 6. The key problem is crosstalk. There is no standard for crosstalk, since video is commonly carried on single coax cables. We have inserted a figure of –60 dB, as advised by a number of video engineers. Of course, any other number could be inserted instead and a comparison made.

Figure 6
Courtesy www.etslan.com

And crosstalk is the most interesting factor here, since ‘standard” Category 5 or even Category 5e cannot meet this –60 dB specification but Category 6 can pass this requirement. So, does this mean these lesser cables cannot be used for analog video? It depends on the actual application. Table 15 lists a number of analog video applications, with a suggestion to a crosstalk requirement for each.

Video Application	Suggested Crosstalk
Surveillance	-40 dB
Standard home video	-50 dB
Professional analog video	-60 dB

Table 15

Surveillance, the lowest quality video, requires minimal performance, and will easily work with standard category cables. Home video, whether over-the-air or cable, has very high noise levels, and marginal signal-to-noise. Only broadcast-quality video has a serious requirement even though, as previously mentioned, there is no standard specification for crosstalk.

The crosstalk shown in Table 14, and following tables, is “power-sum near-end-crosstalk” (PSNEXT). This is a test for data cables where all pairs are energized except the pair under test. Testing is done at the ‘near end’, the source end, where signal strength is greatest and where crosstalk is most likely to appear. This is an excellent test to verify the ‘shared sheath’ multi-pair performance of these cables and is especially appropriate to non-data applications.

A NEW TWIST IN SURVEILLANCE OVER CATEGORY 6

Anixter (www.anixter.com) is offering a video surveillance system that runs over UTP called CCTP (Closed-Circuit-over-Twisted-Pairs). This particular UTP is 22 AWG, larger than ‘regular’ Category 6. The larger gage, lower resistance, allows video signals to run for greater distances than standard cables. Made by Belden, it features bonded-pairs for excellent balanced-line noise rejection (CMRR), impedance tolerance and low return loss. The intent is to run analog video down such a network and be ‘future-proofed’ for digital or networked surveillance architecture in the future. To be sure, many surveillance video cameras now offer an RJ-45 connector, a data connector, instead of the standard BNC or other coaxial connector.

S-VIDEO, S-VHS™, Y-C

Super Video (S-video) is also called Super Video Home System (S-VHS) [VHS is a trademark of JVC], and also called Y-C. This last designation refers to the fact that the video signal is split into two signals, the (Y) or luminance (brightness) information, and the (C) or chrominance (color) information.

S-video, like consumer audio, is severely distance-limited, often as little as 50 ft. For most home applications, this is not a problem. When used in larger installations, such as feeding ceiling-mounted projectors, this distance limitation can be a problem.

However, just like analog consumer audio, a balun can not only match the balanced-unbalanced cables but can also reduce the source impedance and dramatically increase the effective distance, such as Figure 7. This balun also features stereo audio, which would then be the distance-limiting factor as shown in Table 5.

S-video cables are very small, most often 30 AWG center conductors, so they can fit into the 4-pin DIN connectors required. Adapting to 24 AWG category cables is a major improvement in ruggedness.

Figure 7
Courtesy www.etslan.com

Table 16 shows the requirements.

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	17 pF/ft. 56 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100*Ω	*100*Ω	*100*Ω
Gage	30 AWG	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk 4.2 MHz	-60 dB (?)	*-53.3 dB* *PSNEXT*	*-53.3 dB* *PSNEXT*	-63.3 dB PSNEXT
Timing (Delay skew)	40 nsec	45 nsec (292 ft.)	45 nsec (292 ft.	45 nsec (292 ft.)

Table 16

The other 'unknown' is timing, also know in the UTP world as "delay skew". Since the video signal is now divided into two parts, they must arrive and be combined at the destination at the same time. However, there are no standards for timing in S-video, since common cables are so short. The number inserted here (40 nanoseconds) is for RGB timing, the next application we will be examining.

If this number applies to S-video, then standard category cables cannot go the entire 100 meters (328 ft.) as outlined in the TIA/EIA standards. Instead, they can go 40/45 x 328 = 292 ft. Compared to the 50 ft. limit of standard S-video cable, is still a great improvement.

S-VIDEO FACEPLATE ADAPTORS

Just like consumer analog audio, there are a number of connector companies who are offering S-video jacks that fit into the footprint of an RJ-45. These connectors feature 110-style punch down blocks on the back to terminate UTP. However, these connectors have no conversion from unbalanced S-video to balanced UTP. Nor do they have conversion from 75Ω coax (S-video) to 100Ω UTP.

These 'adaptors' offer no increase in the limited distance of S-video and crosstalk pair-to-pair and cable-to-cable is compromised. Use of these adaptors is not suggested. Whether dual baluns, for the two channels of video, can fit into this footprint, or if users are willing to pay the increased cost, has yet to be established.

RGB COMPONENT VIDEO

RGB splits video signals into "component" parts, red, green, and blue. Well established in the professional video world, based on the BNC connector, RGB is also becoming common for high-quality home monitoring and other applications, based on the RCA connector.

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100Ω ±15Ω*	*100Ω ±15Ω*	*100Ω ±15Ω*
Gage	Wide range	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk 10 MHz @ 100m	??	-47.3 dB PSNEXT	-47 dB PSNEXT	-57.3 dB PSNEXT
Timing (Delay Skew)	40 nsec	45 nsec (292 ft.)	45 nsec (292 ft.)	45 nsec (292 ft.)

Table 17

Now we definitely have multiple signals to be converted to multiple pairs. An RGB balun is shown in Figure 8.

Figure 8
Courtesy www.etslan.com

RGB with a synchronizing signal (RGBS) can easily be accommodated on four-pair UTP. There are RGB systems with separate horizontal and vertical sync (RGBHV). One might think that is impossible to send down four pairs of UTP. Actually, this is quite possible, by adding one sync signal on top of the green signal, a common approach with general coax-based RGB systems.

You will note the crosstalk numbers are determined at 10 MHz. Many RGB systems are “wideband” to provide better linearity for each component, some as wide at 25 MHz per component. For consumer RGB, crosstalk numbers would most likely be the same as standard 4.2 MHz analog video. At 10 MHz, you will see that the crosstalk numbers for UTP are not particularly wonderful. Even Category 6 crosstalk at 10 MHz is not better than –60 dB.

The question then would be, how much crosstalk protection is necessary? Since these signals are all ‘components’ of one total picture, an argument could be made that protection between them may not be essential. An opposite argument, to avoid the color subcarriers ‘bleeding’ into each other could also be made. It is certainly true that RGB applications are among the most popular for UTP, as can be seen in the next section.

"SKEW-FREE" CABLE

Timing (Delay Skew)	**RGB Distance**
45 nsec	292 ft.
40 nsec	328 ft.
35 nsec	374 ft.
30 nsec	437 ft.
25 nsec	525 ft.
10 nsec	1312 ft.
9 nsec	1458 ft.
2.2 nsec	5963 ft.

Table 18

So what timing or delay skew is required for multiple-delivery applications? You would think that standard Cat 5 (45 nsec) with an effective distance of almost 300 ft., would be enough for almost any application. But apparently it is not, because very early on in the use of UTP, it was recognized that Belden MediaTwist (1872A/1874A) had the lowest skew (25 nsec max, typical skew 7 nsec) and is still widely used where tight tolerance and low skew are required.

This 'search for skew' eventually led to a new type of cable made by a number of manufacturers, including Belden, which has identical twists ("lay length") for all four pairs. Belden "Nanoskew" 7987R and 7987P (riser and plenum rated) are intended to reduce the delay skew (timing) to the lowest value possible for use with RGB and VGA applications. The delay skew on Belden's versions, for instance, is a maximum of 2.2 nsec/100m, and typically 0.5 nsec, for all four pairs. (Readers are cautioned that there is no four-pair UTP with *no* skew, despite what some literature may say.)

This construction, with identical lay lengths, renders the cable unusable for any premise/data application. It is not 'Category' anything, not even Category 3. If your intent is to use an installed cable as a data cable, and when needed, for any non-data component application, this skew-free cable would not be appropriate.

This led to other products such as Belden 7988R and 7988P, which are Category 5e UTP with an ultra-low 9 nsec of skew, and 7989R and 7989P, Category 6 with 10 nsec of skew. For obvious reasons these have been trademarked as Belden "VideoTwist" cables.

It's really a question of "closed" architecture, where each cable has a specific and unchanging application, or an "open" architecture, where cable applications can change as time goes on. These "VideoTwist" cables can have the low skew required of RGB or VGA systems and yet still be used as Category data cables.

So, does Table 18 mean that these cables can go a thousands of feet? Absolutely not! The basic attenuation of these cables, based on the gage size of the conductors, limit distances dramatically. What Table 18 indicates is that, as the signal disappears, it is almost perfectly in time. Timing and delay skew is simply not an issue. You can never go far enough for it to be a concern.

VGA – VIDEO GRAPHICS ARRAY

	System Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	20 pF/ft. 66 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100*Ω	*100*Ω	*100*Ω
Gage	Small (?)	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk VGA 39 MHz	??	-40 dB PSNEXT	-40 dB PSNEXT	-50 dB PSNEXT
Crosstalk SVGA 61MHz	??	-35 dB PSNEXT	-35 dB PSNEXT	-45 dB PSNEXT
Crosstalk XGA 100 MHz	??	-32.3 dB PSNEXT	-32.3 dB PSNEXT	-42.3 PSNEXT
Crosstalk SXGA 173 MHz	??	N/A	N/A	-38.8 dB PSNEXT
Crosstalk UXGA 245 MHz	??	N/A	N/A	-36.5 dB PSNEXT
Timing	40 nsec (?)	45 nsec	45 nsec	45nsec

Table 19

As frequencies and bandwidths increase, the ability to determine the performance of UTP becomes problematic. VGA, a common means to attach computers to monitors, or to projectors, can run at very high frequencies, as shown in Table 19.

The problem is that specifications for Category 5 or 5e end at 100 MHz, and Category 6 ends at 250 MHz. Table 19 shows that this limits installers to specific cable types when used for high-bandwidth high-definition signals. There are also cutting-edge cables, such as Belden 7851A 600e with specifications out to 600 MHz.

How can standard VGA work with cables of low quality? The answer is: distance. If your cable is less than a quarter-wavelength at the frequency of operation, it makes very little difference what is in the cable. As long as there is a connection ('continuity') and the cable is short, it will probably work. Some very short, and very cheap, VGA cables don't even contain coaxial cables or twisted pairs, just multiple conductors. You will note the lack of system specs on Table 19, and those specs that are listed are probably wrong also.

When UTP is substituted, it is most often for long distances such as ceiling-mounted projectors or multiple display devices. Then the performance of the cable becomes important, even critical. Belden has a data sheet on various VGA signal types and the distance they can run, based on display resolution.[4]

SDI - DIGITAL BASEBAND VIDEO

Among the more unusual applications for UTP is SDI 'Serial Digital Interface', also called CCIR 601. This is standard definition (4 x 3 aspect ratio) digital video (480 lines resolution) with a clock of 135 MHz. Since Category 5 and 5e specifications end at 100 MHz, only Category 6 (bandwidth 250 MHz) has applicable performance specs.

The digital signals on this cable run at a data rate of 270 Megabits-per-second, and a bandwidth of 135 MHz. Therefore, crosstalk at 135 MHz is shown. While this signal is component, the components run serially down a single coaxial cable. Therefore, only a single pair in the UTP is used and no delay skew or timing specifications need apply. An SDI-UTP balun is shown below in Figure 9.

	System Specs	Category 6
Format	Unbalanced	*Balanced*
Capacitance	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100*Ω
Gage	23-20-18 AWG	23 AWG
Shield	YES	NO
Crosstalk 135 MHz	-30 dB (?)	-40.9 dB PSNEXT @ 125 MHz

Table 20

Figure 9
Courtesy www.etslan.com

Again, we are in digital territory, where the cable easily passes the required –30 dB crosstalk, still a very conservative number. It is interesting to note that, due to the critical nature of broadcasting, this application is the *least* popular of all those discussed in this paper.

BROADBAND/CATV

This application is truly the 'king' of bandwidth. Typical broadband/CATV installations have a bandwidth of 1 GHz or more. One-gigahertz bandwidth is beyond the scope of current UTP designs. And yet, broadband/CATV is the *most requested* non-data UTP application on our list.

	RG-6 Specs	**Category 5**	**Category 5e**	**Category 6**
Format	Unbalanced	*Balanced*	*Balanced*	*Balanced*
Capacitance	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m	15 pF/ft. 49 pF/m
Impedance	75Ω	*100*Ω	*100*Ω	*100*Ω
Gage	20 AWG	24 AWG	24 AWG	23 AWG
Shield	YES	NO	NO	NO
Crosstalk	>80 dB @ 1GHz	-32 dB @ 100 MHz	-32 dB @ 100 MHz	-36 dB @ 250 MHz
Max Atten. @ **100m**	-21 dB @ 1GHz	-22 dB @ 100MHz	-22 dB @ 100MHz	-33 dB @ 250 MHz
Channels	158 @ 1 GHz	6 @ 100 MHz	6 @ 100 MHz	29 @ 250 MHz
SRL	-20dB @1GHz	-15dB@100 MHz	-20dB @100MHz	-17dB @250MHz

Table 21

The specification column in Table 21 now reads simple 'RG-6" since that is the industry standard drop cable for broadband/CATV applications. The gage size (20 AWG) is misleading since the coax center conductor is copper-clad steel, for applications above 50 MHz. (Channel 2 is 54 MHz.) A balun for broadband/CATV to UTP is shown in Figure 10.

Figure 10
Courtesy www.etslan.com

Crosstalk shown for the RG-6 is based on the shield effectiveness ("transfer impedance"). –80 dB shield effectiveness, as shown in Table 20, is easily met by a generic RG-6 cable with 40% braid/100% foil shield. With high-coverage shields, isolation can be –105 dB or even better. Basic attenuation of coax cable is dramatically better than even Category 6. To handle 1 GHz of bandwidth (158 channels), only coax is acceptable. So why would anyone be interested in this application?

The main customer for this application is schools. They already have a huge base of Category cables installed and would love to use them for other applications. The real question is how many channels do you need in a classroom? Twenty? Ten? Five? If you have dial-up control, the answer might be 'one' since any classroom cannot show more than one channel at any one time on any single television. And even Category 5 can handle six channels (100 MHz). Category 6 (250 MHz) is 29 channels, and high-bandwidth cables, such as Belden 7851A 600e (600 MHz) is channel 86.

Installers are cautioned, however. Twisted pairs are not coax cable. UTP has a completely different slope (attenuation curve) than coax cable. "Tilt amplifiers" intended for coax cables may be less effective with UTP. The author is unaware of any tilt amplifiers specifically for Cat 5, 5e or 6, although one could easily be built. There are active distribution devices that do contain equalization for UTP and can be found in another white paper[3].

SHARED SHEATH

We have previously discussed multiple signals on a four-pair premise/data cable. However, almost all of these were identical signals (i.e. four audio signals, four video signals, RGBS etc.) What about combining different signals? Audio *and* video ? Data *and* broadband/CATV?

It should be emphasized that 568A only mentions shared-sheath applications in regards to multiple 100baseT signals on 25-pair Category 5 cable. There is no mention of any *non-data* application. Therefore, if your installation must meet 568A standards, these suggested non-data applications cannot be tested or verified by that standard.

This does not prevent an installer from putting in a network, testing and certifying it to 568A, and then using a portion of the network to run non-data applications. That portion of the network simply won't apply to the standards, unless it is used at some later date to run 100baseT or some other recognized data application.

When considering multi-application shared sheath, there are four key parameters:

1. The frequency range or occupied bandwidth of that signal type.
2. The level or intensity of the signal on the pair
3. The analog or digital nature of the signal
4. The CMRR (common-mode rejection ratio) of the source and destination devices attached to each pair.

When considering (1) the occupied bandwidth, Table 21 below shows the typical occupied bandwidth of the various audio and video signals mentioned in this paper together with the occupied bandwidth of 10baseT and 100baseT networks. (1000baseT networks use all four pairs and therefore leave no room for shared sheath applications, even if they were possible.)

ABOUT THE AUTHOR

Steve Lampen is Multimedia Technology Manager for Belden Cable, a division of Belden/CDT. He has worked for Belden for fourteen years. Prior to Belden, Steve had an extensive career in radio broadcast engineering and installation, film production, and electronic distribution. Steve holds an FCC Lifetime General License (formerly a First Class FCC License) and is an SBE Certified Radio Broadcast Engineer. On the data side he is a BICSI Registered Communication Distribution Designer. His latest book, "The Audio-Video Cable Installer's Pocket Guide" is published by McGraw-Hill. His column "Wired for Sound" appears in Radio World Magazine. He can be reached at shlampen@aol.com

REFERENCES

(1) Paper given by the author "Category 5 and Audio-Video" at BICSI, January, 1997, Orlando, Florida.
(2) This table is taken from "The Audio-Video Cable Installer's Pocket Guide" (McGraw-Hill)
(3) A list of balun manufacturers both active and passive, can be found in the paper "Video and UTP", in the 'technical papers' section at www.belden.com
(4) To obtain technical data on display bandwidth, resolution, and cable distance, call 1-800-235-3364 (1-800-BELDEN4) and ask for a copy of NP 212