

**The Hollywood Post Alliance
2005 Technology Retreat**

Skew

What it is, What it Means, Why You Should Care

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ABSTRACT

There are a number of signal delivery systems that require multiple cables. Among these are component RGB, and related VGA systems. In the data world, 1000baseT is also delivered on multiple simultaneous pairs. These UTP data cables began to interest some as possible delivery mechanisms for what had historically been coaxial cables.

However, twisted pairs are very different from coaxial cables in a number of ways. This paper will explore how they are the same, and how they are different, and outline the limitations of each type of cable, UTP and coax, for different applications.

SKREW AND TIMING

Skew describes timing difference where multiple cables deliver multiple signals that must arrive at the same time. It is sometimes called “delay skew” or “skew delay”. In the coaxial world, it is most often referred to as timing.

1000baseT data signals, because of the large signal bandwidth, are divided between the four pairs of a Category 5e or Category 6 cable. These four pairs transmit and receive simultaneously, called “duplex” mode. Where previous data transmission had been single pairs (100baseT is one pair transmit, one pair receive), many of the noise-filtering techniques cannot be used. Therefore the quality of the four-

pair cable is critical to successful system operation. Compression of the data signal helps reduce the bandwidth, but adds to the cost.

Because all four pairs work simultaneously, and each delivers a part of the signal, the timing or 'skew' of the pairs is also critical to system operation. The maximum skew, as set out in the TIA/EIA 568B.2 standard is 45 nanoseconds in a 100-meter circuit.

COMPONENT SIGNALS

RGB or "component" signals also require sync. In classic RGB systems, sync is included with the green signal. RGBS systems include one cable for the combined sync signals. RGBHV split the horizontal and vertical sync into two separate additional cables. In all these, the timing requirements for the color components (RGB) allow for a maximum timing error or 40 nanoseconds (nsec).

Computer monitors are often run with VGA (Video Graphics Array) signals. Extensions of this type of signal include higher resolution versions such as SVGA, XGA, SXGA or UXGA. While these signals are very similar to component systems, the maximum timing error is not established. Most of the time, the cables used for these systems are very short, perhaps a meter or two long, and are therefore of little consequence in timing errors. This also accounts for the very low quality of many of these cables. Many VGA cables do not even have impedance-specific pairs or coaxial components, because they are shorter than a quarter of a wavelength at the frequency of operation.

COAX AND TIMING

Multiple coaxes are the oldest style of component delivery. The fact that the entire color spectrum can be represented by three primary colors has been known for many centuries. Sir Isaac Newton knew about color components and wrote about them in his 1672 treatise, "A New Theory about Light and Colors".

There were a number of early attempts to reproduce color in electronic form. A German patent in 1904 described color television, as did a 1925 patent disclosure by famed RCA engineer Vladimir Zworykin.

His was the first all-electronic color television system. Both of these systems were not successful. It took much more work at RCA Laboratories from 1946 to 1950 to produce the world's first successful commercial electronic color system. First commercial color television broadcast December 17, 1953

This 1953 system included and well understood RGB-based screen elements. Work by Edwin Land of Polaroid fame, also employed separate RGB color elements. The idea of multiple coaxial cables delivering a color image soon followed. It soon became apparent that component delivery relied heavily on the precision of the cables used.

CABLE DELAY

It was immediately recognized that cable performance was related to a number of factors in the manufacture of cable such as the quality of the plastic used around the conductor, called the "dielectric constant". Related to that is the Velocity of Propagation (Vp) describing the speed of the signal down the cable compared to the speed of light.

And both of these are related to "signal delay", the time it take a signal to propagate down a cable. Figure 1 and Figure 2 show the relation between dielectric constant (DC), velocity of propagation (Vp) and signal delay in nanoseconds (Dn).

$$D_n = \sqrt{DC}$$

Figure 1

$$D_n = \frac{100}{V_p}$$

Figure 2

While all cables have delay, and such delay can be easily calculated, the key to component delivery was that the delay of each cable be *identical*. Experiments showed that the minimum perceivable timing error between RGB cables was 40 nanoseconds, and this because the *de facto* standard for all RGB component displays.

Where multiple cables, whether twisted pairs or coaxial cables, are used to deliver component signals, it is clear that all the cable must

have identical *electrical* length. This length may, or may not, be different from the physical length. The electrical length requires that the cables have identical dielectric and, therefore, identical velocity.

This requirement for identical cables requires very tight manufacturing tolerances. Since every cable is different, this makes component cables very difficult to manufacture. It is interesting to note that classic RGB-component cables, consisting of bundled coaxes color-coded to the RGB signals, clearly indicate the problem. Since each of the cables has a different color, they were obviously manufactured at different times. It is therefore incumbent on the manufacturer to control the process with great precision.

The first indication of precision is the impedance tolerance of the individual cables. The wider the tolerance, the further out in time the cable could be. Measurements such as return loss of the individual cables can be extremely valuable when trying to ascertain the quality of manufacture.

THE ORIGINAL RGB

With the first component systems, groups of cables were loosely gathered, cut and connectorized. If they were short, any variation in cable performance was probably below the 40 nsec threshold. However, with longer runs, these timing errors became more and more apparent, requiring installer to time cables by hand.

This required use of a Vectorscope, which could show the relationship of the primary colors and allow the installer to adjust cables to compensate for less-than-ideal manufacturing quality. A Time-Domain Reflectometer can also be used, where it reads the actual electrical length and allows cables to be cut to match.

On some older cables, especially in long runs, the component cables have very different physical length required to match electrical length. It then became necessary to 'store' the excess cable in the installation. These extra lengths, while absolutely required, gave many installations a 'messy' appearance and the ability to hide the excess cable became a valuable talent.

With the advent of Belden 8281, first introduced in 1956, many of these problems of timing and excess cable began to disappear. This was the first 'precision' video cable with a maximum impedance tolerance of $\pm 1\frac{1}{2} \Omega$, and a typically impedance tolerance of $\pm \frac{1}{2} \Omega$. That meant an installer could just cut and connectorize multiple cables, that the physical length was very close to the electrical length.

BUNDLED COMPONENT CABLES

A recent addition has been pre-bundled cables, where three, four, five, or more cables are assembled with an overall jacket. Of course, this means that you are now trusting the manufacturer and his quality control. Simply building multiple cables means nothing if they are not assembled with precision and with specifications to show accurate timing. If you are intending to simply cut and connectorize these cables, then surely they must be well within the 40 nsec window at the length you wish to use them.

Beside jacketed cables, there is an emerging new technique called "banana peel" where the component cables are glued around a central core. Such an assembly is especially effective for timing/skew since the component cables are connected the entire length of the run. Movement and slippage between components is a major source of timing errors. When they are 'locked' together, such variations are minimized.

While the skew or timing is determined by impedance, the effective distance in a cable is determined by gage size. Generally, the larger the gage, the greater the effective distance. So the distance at which the 40 nsec window has been reached is not an indication of maximum cable length. That number is more appropriately based on attenuation of the individual cables

Table 1 below shows a number of common component cables. Note that the attenuation is based clearly on gage size of the individual cables.

RGBHV Cable Comparison

Belden Part #	Conductor Gage	Attenuation at 10 MHz per 100 ft.	Attenuation at 50 MHz per 100 ft.	Timing
1522A	30 AWG	2.2 dB	5.4 dB	5nsec/100 ft.
1417B	26 AWG	1.8 dB	3.9 dB	5nsec/100 ft.
1279R	25 AWG	1.5 dB	3.7 dB	4nsec/100 ft.
7789A	23AWG	1.2 dB	2.8 dB	4nsec/100ft.
7796A	20 AWG	0.9 dB	1.8 dB	4nsec/100ft.
7712A	18 AWG	0.7 dB	1.4 dB	4nsec/100ft.

Table 1

Table 2 below shows the relationship between VGA (Video Graphics Array) signals and related systems and the required resolution. Note especially the bandwidth. The cables employed must have specifications that cover the appropriate bandwidth, if not harmonics of that bandwidth

Signal	VGA	SVGA	XGA	SXGA	UXGA
Resolution	640x480	800x600	1024x768	1280x1024	1600x1200
Maximum Horizontal Scan	45 kHz	54 kHz	68 kHz	91 kHz	107 kHz
Bandwidth	43 MHz	61 MHz	100 MHz	167 MHz	245 MHz

Table 2

TWISTED PAIRS

Twisted pairs, historically, were not considered for delivery of high quality parallel signals, such as RGB/component video. Twisted pairs had significant impedance variations, caused by resistance and capacitance variations. This made them inappropriate for any

application where impedance was a consideration. This began to change with the introduction of IBM Type 1, the first data twisted pair. IBM Type 1 had a specific impedance (150Ω) and very low capacitance (8.5 pF/ft.) It carried Token Ring data at speeds of 4 MHz and later 16 MHz, unheard of on paired cables. However, these cables were very large, expensive, and hard to install.

This changed with the introduction of UTP, unshielded twisted pair cables, based on cables used by the telephone industry. These were four-pairs to a bundle, 24 AWG, 100Ω impedance, 15 pF/ft. Since these cables were lower impedance than the IBM cables, this allowed for smaller cables that were cheaper and easier to install. The compromised capacitance, 15 pF/ft., accommodated a 100-meter (328 ft.) maximum working distance.

Later, the TIA/EIA standards groups stratified these cables into 'Categories'. Category 3, 4 and 5 soon followed. The standard now only recognizes Category 3, for telephone wiring, and Category 5e and Category 6 for data.

The key to category cables is truly the twisting technology used to produce these cables. They can now be made with such precision that bandwidths of 100 MHz (Category 5e) or 250 MHz (Category 6) are routine. A number of specifications, such as resistance unbalance, and capacitance unbalance, attest to the quality of these cables. Return loss, once exclusively the territory of coaxial cables, is now applied to these twisted-pair constructions also.

Category 5e UTP provide for enhanced specifications over Cat 5 UTP. These enhanced specifications are specifically for 1000baseT "Gigabit" applications. All four pairs are transmitting and receiving at the same time, in "duplex" mode.

Reflections and return loss, caused by impedance variations, are now critical to system operation. Skew is now important and set at a maximum of 45 nanoseconds per 100 meters. It is interesting to compare the 45 nsec of premise/data cables to the 40 nsec of component video.

Category 6 UTP is an entirely new cable design, with a new set of specification. Many of these specifications are 10-12 dB better than Cat 5e, attesting to the new design. Category 6 cables are large. They include dividers or other isolators to provide the greatly improved pair-to-pair crosstalk.

Skew, however, is still 45 nsec/100m. The reason is quite simple. All four pairs *must* have different twist ratios (“lay length”) to reduce pair interactions or crosstalk. Twisting like crazy, often done in the early days of Category 5, reduces crosstalk even further but dramatically increases skew since the pairs are now very different lengths!

THE QUEST FOR LOW SKEW

The quest for low skew category cables started with Belden 1872A MediaTwist introduced in 1995. Its unique design featured bonded pairs, which greatly improved impedance variations, impedance tolerance, and return loss. Each pair is in an individual channel, and the shape and size of the channel can be made to offset the velocity of each pair. This resulted in a cable with a maximum skew of 25 nsec per 100m, and typically 8 nsec.

The name ‘MediaTwist’ asserts the multimedia specs of such a design and this was not lost on companies such as Extron, which was looking for a simple and effective way to send component video. Category 5e and 6, compared to multi-coax component cables, were easy to connectorize, easy to install, and cost-effective, especially in plenum versions. The huge volume and low prices dictated by the networking market could be used as a low-cost alternative to RGB coax.

Extron and other felt the need to continue the quest for low skew cables, bringing out “No Skew” UTP. This cable contained four *identical* pairs. Skew was vanishingly low, limited only by the manufacturers art. Cable such as Belden 7987R (7987P) Nanoskew™ became available with a skew of <2.2 nsec, typically <0.5nsec. However, since the pairs are identical, the crosstalk is very poor and such a cable doesn’t even pass Category 3 specifications. These cables are not suggested for use as a data

cable. They may look like, and connect like, a data-style UTP, but they are strictly an RGB or VGA component cable.

One unanswered question is color subcarrier bleed. If the crosstalk is poor on these no-skew designs, what effect does this have on the color subcarriers? Surely they must bleed into each other. However, no problems of this type have ever been reported. Perhaps this is due to the inherent poor registration of NTSC component signals.

Compromise cables have recently appeared in the form of low-skew cable designs. These are UTP cables made with skew as the key such as Belden 7988R/7988P. These are Category 5e cables with a skew of <9 nsec/100m. There is also a Category 6 version, Belden 7989R/7989P, with a skew of <10 nsec/100m.

Table 3 shows a comparison of all the mentioned skew/timing numbers. One will note that the ultra-low skew numbers have huge distances attached to them. Does this mean that these cables can go thousands of feet? Absolutely not! This simply means that timing is not an issue, and that the basic attenuation of such a cable is the deciding factor in distance.

Skew Comparison

Skew/ 100 ft.	Skew/ 100m.	Distance to 40 nsec (ft.)	Distance to 40 nsec (m)
0.15 nsec	0.5 nsec	26,666 ft.	8,000m
0.67 nsec	2.2 nsec	5,970 ft.	1,818m
2.7 nsec	9 nsec	1,424 ft.	444m
3 nsec	10 nsec	1,333 ft.	400m
4 nsec	13 nsec	1,000 ft.	307m
5 nsec	16 nsec	800 ft.	250m
8 nsec	25 nsec	500 ft.	160m
14 nsec	45 nsec	285 ft.	89m
40 nsec	131 nsec	100 ft.	31m

Table 3

It should be mentioned that systems that provide RGB component outputs in coaxial form must be converted with baluns to take advantage of UTP. The cost, availability, and reliability of these baluns must be added to the equation of each installation.

CONCLUSION

The installer of RGB component systems has a number of cable choices. These include classic coaxial cables or unshielded twisted pair cables. These provide a wide range of cost, installability, connectorization, and signal quality.