What’s in That Wire?
Dissecting HDBaseT

AV technology for residential and commercial applications has evolved dramatically in the last decade. The utility of established, tried and proven connectivity topologies faded as analog gave way to new digital media expectations. In 2009, the United States began the switch from analog TV broadcasts to a totally digital infrastructure. Along the way, the need for composite, component and VGA analog connectivity was lost as both source and sink devices were directed into a high-bandwidth digital content protection (HDCP) environment. The installation
limitations of high-definition multimedia interface (HDMI), DisplayPort and universal serial bus (USB) were quickly laid bare. In particular, the restrictive length limitations of those connections proved to be too confining.

HDBaseT was introduced by Valens Semiconductor in 2010, in cooperation with Samsung®, Sony® Pictures Entertainment and LG® Electronics. Now promoted and advanced by the HDBaseT Alliance, HDBaseT technology is a connectivity standard designed for the transmission of uncompressed digital video, audio, Fast Ethernet, control and power elements (collectively identified as 5Play™) over a copper category cable. The system uses the same 8P8C modular connectors as LAN connections, but operates in an ex-network space as a point-to-point signal pathway. It is a packet-based, switched networking standard designed to answer the need for high throughput, time-sensitive data and control streams.

HDBaseT is broadly identified as operating over standard category 5e/6 structured cabling. This has always posed a bit of a conceptual problem, as the common HDMI connection carrying a HDTV signal is designed to operate at speeds up to 10.2 gigabits per second (Gbp/s), and clearly category 5e is not considered 10 gigabit Ethernet (GbE) compliant. The question has always been “How are they getting a gallon into that quart bucket?” This article will attempt to answer that question.

HDBaseT was adopted as IEEE P1911.1 in 2015, the scope of which was to specify the HDBaseT link between HDBaseT source port device and HDBaseT sink port device. Focusing initially on peer-to-peer HD AV content, the ultimate HDBaseT expression is to enable transmission of 2160p ultra-high-definition multimedia payloads over a single 100 meter (m [328 foot (ft)]) category 6 cable, or up to 1080p over a 100 m (328 ft) category 5e cable. To further enable this capability, the HDBaseT standard is in the process of becoming a suite of standards, adding IEEE P1911.2 and IEEE P1911.3. The latter two are still in the IEEE project phase and are awaiting final adoption.

IEEE P1911.2 is specifically aimed at defining HDBaseT version 2.0 in order to ensure the technology remains compatible with HDMI 1.4 and HDMI 2.0 levels of performance, which raise the ante of high-definition content to include UltraHD 4:2:0 payloads. The scope of HDBaseT version 2.0 is to specify the following:

- HDBaseT link between two HDBaseT ports
- Services provided by the HDBaseT network to protocol/interface/application end point clients communicating over the network
- HDBaseT entities and devices
- Control and management scheme
- End point adaptor entities, which provide communication over HDBaseT for the following interfaces:
  - HDMI 1.4
  - USB
  - S/PDIF
  - Consumer IR
  - UART end node devices

Category 5e is a twisted-pair cable that provides up to 125 megahertz (MHz) bandwidth and is not used in 10 GbE applications. The category 6 cable standard specifies performance double that of category 5e (up to 250 MHz). When used for Gigabit Ethernet, the maximum length of category 6 allowed is 100 m, consisting of 90 m of solid cabling between the patch panel and the wall jack, plus 5 m of stranded patch cable between each jack and attached device. Category 6 may be used in 10 GbE (10Gbase-T) applications, but at a reduced length of 55 m. And yet, the HDBaseT standard allows for both category 5e and/or category 6 U/UTP cables for what appears to be a signal far too large to fit through the pipe. What gives?
For more than half a century, a technique known as multilevel signaling has been used to provide high-speed symbol transfer rates at line speeds inadequate for an unmodulated baseband signal. The key phrase here is “symbol rate.” Multilevel modulation is actually the opposite of compression; it is a very clever method of using what is available to the maximum effect.

In telecommunications, baud (Bd) is the unit used to measure data transfer in symbols or pulses per second. Specifically, it is the number of distinct signaling events per second in a digitally modulated signal or line code. Twenty-five years ago it was considered a state-of-the-art investment if you had a 14.4 kilobyte modem that could support a 2400 Baud rate. In fact, the implementation of baud, or symbol transmission, dates all the way back to 1958 and the Bell 101 modem for computers.

When considering modulation techniques for transmitting a payload over a carrier signal, there are a large number of commonly used solutions. Think of analog amplitude modulation (AM) and frequency modulation (FM) used in radio and TV broadcasting. The payload in a baseband digital system can also ride on the carrier’s pulse density, pulse width, pulse frequency or, as is used in HDBaseT, pulse amplitude modulation (PAM). 100Base-TX (Fast Ethernet) uses three-level PAM (PAM3). 1000Base-T (Gigabit Ethernet) uses five-level PAM (PAM5). And 10GBase-T (10 Gigabit Ethernet) uses 16-level PAM (PAM16). With all of these relevant applications, it is important to take a closer look at PAM.

PAM uses a system wherein each transmitted symbol represents different possible levels based on the amplitude (read as loudness or strength) of the pulse. PAM is specified by the modulation level identifier (e.g., PAM3, PAM5, PAM16). For example, the PAM5 system used in 1 GbE installations is also termed “quinary pulse amplitude modulation” because each transmitted symbol can represent one of five levels: -2, -1, 0, +1 or +2. It may also be identified as a 4b/5b line code because, in a 1 GbE system, four of the levels are used to represent two bits of data and the fifth level is used for forward error correction (FEC). If the bandwidth of category 5e is 125 MHz raw bit-rate (125 MHz can be defined as 125,000 pulses per second), and this 4b/5b iteration of PAM5 is applied, where each pulse equals two bits, then a through-put bit rate of 250 megabits per second (Mb/s) (125 MHz x 2) can be achieved for each of the four twisted-pairs in the cable. Four times the 250 Mb/s raw bit-rate equals the total 1000Base-T (1GbE) potential throughput.

One of the challenges of PAM is an ever decreasing tolerance of noise. If the total signal envelope of the link is defined as 4 volts (V), then a PAM3 signal will have three levels within that 4 V alternating current (ac) envelope. By definition, each pulse cannot be more than one-third of the total voltage. If a 1 GbE system uses a four-volt envelope (-2 V to +2 V) to describe the eye pattern window, each symbol must have sufficient signal-to-noise ratio (SNR) that the detector can effectively identify a symbol eye pattern that must be less than .8 V peak-to-peak (p-p). Upon consideration, we see that PAM3 must be less susceptible to noise than PAM5, because the p-p eye pattern (symbol) voltage of the former must be less than (4 V ÷ 3 levels) 1.3 peak voltage (Vp) compared to (4 V ÷ 5 levels) 0.8 Vp of the latter. There is a mathematical formula to describe the calculation of this SNR and it should look familiar to anyone holding an RCDD or CTS-D certification.

The increasing susceptibility to noise of a PAM system can be described by this formula: 20Log(V_p/V_s)

where \(V_p\) is the p-p voltage of the symbol eye pattern and \(V_s\) is the p-p total voltage of the signal envelope. Assuming our example above of a 4 V total envelope, then PAM3 has 20Log(1.3/4) or -9.8 dB of S/N degradation when compared to a straight baseband signal using the full 4 V p-p. A PAM5 signal has 20Log(8/4) or -14 dB of S/N degradation. Now imagine a PAM16 implementation in this same 4 V signal envelope. PAM16 has 20Log(2/4) or a whopping -26 dB of S/N degradation (Figure 1).

Like 10 GbE network technology, HDBaseT uses PAM16 modulation to shoehorn a payload that can exceed 10 Gb/s into a stream that can traverse a link of only 125 MHz bandwidth in the case of category 5e, or 250 MHz for category 6. While the system is quite robust, it is easy to see how noise can become an issue.

There are a number of noise profiles that must be considered in structured cabling installations. Some of the most common are:

- Near-end crosstalk (NEXT)
- Power sum near-end crosstalk (PSNEXT)
- Far-end crosstalk (FEXT)
- Equal-level far-end crosstalk (ELFEXT)
- Attenuation-to-crosstalk ratio (ACR)
However, HDBaseT is particularly susceptible to alien crosstalk (AXT), also known as radio frequency interference (RFI).

To combat AXT, the best solution is a properly shielded pathway. In the world of category cables, this function is fulfilled by an F/UTP design that offers a foil shield against RFI and electromagnetic interference (EMI) ingress. If dealing with grounding, bonding and shielded jacks and jumper cables is a problem, an alternative solution is to use a discontinuous shield category cable. There are a number of manufacturers who offer such a product for LAN applications, but at the time that this article was written, only one is an HDBaseT Alliance certified product.

**Conclusion**

HDBaseT is an advanced connectivity solution that supports a powerful feature set and transports digital audio, video, control, power and extended Ethernet connectivity over a single category cable. Looking at the future of the AV industry, it becomes evident that 4K UltraHD is more than just an option; it is the new normal. Since 4K video demands a 10 Gb/s pathway, it should be treated like a 10 GbE installation. Considering that power over HDBaseT is essentially an equivalent of IEEE 802.3at-2009 POE+, it makes sense to plan an installation with the same level of care as any 10GBase-T networking solution, and that extends to selecting the right category cable. Category 5e is not a good choice and category 6, while adequate, does not offer the protection from AXT necessary for a dependable, scalable commercial solution that can grow with advancing system demands. Shielded F/UTP category 6 is a good standard, but using a properly designed category 6a is far from overkill. After all, digital video payloads are not going to get smaller in the future.

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