Understanding the Electrical Performance of Category Cables

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C&M CORPORATION

Obsessed with cable solutions.

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In today's electronic world, the following statement could accurately summarize the rules for data transmission: *More data, going longer distances, at a faster rate*.

This rule makes perfect sense when you consider the technology of today that includes products, ranging from high definition televisions to cell phones, on which you can perform tasks that include watching movies or browsing the internet. At some point in the data transmission system that enables these and other technology driven products to function properly, we will find wire and cable.

In a majority of these cable applications, Category cable will be the product of choice.

For many users of Ethernet products, terms like Category Cable, NEXT, Insertion Loss, and Return Loss are terms that appear to require an electrical engineering degree in order to understand. While an electrical engineering background would add the ability to comprehend these terms with great depth, this paper is written to help the non-technical user better understand the performance characteristics that drive their Ethernet cable products.

A couple of terms that are often used interchangeably are Ethernet cable and Category cable. In actuality, the term Ethernet and Category are quite different. Generally, Ethernet refers to a LAN (Local Area Network) method of accessing data. Defined by the IEEE 802.3 standard, Ethernet technology is used to connect computers to each other, to a network, or to a modem for Internet access, for example. Many electronic products have Ethernet capabilities built in, such any newer model computers or today's high definition televisions. Category cable refers to the cable used in Ethernet based systems. Some popular types of Category cable include Category 5, Category 5e, and most recently, Category 6. Category cables are usually constructed using four pairs. As with many products of this type, their electrical and data carrying performance is outlined by industry standards, such as TIA/EIA-568-B in the case of Category 5 cable.

Some of the most common high-level terms around the performance measurements of Category cables include EMI, cross talk, and alien cross talk.

Electro-Magnetic Interference (EMI): EMI can be defined as an undesirable electromagnetic emission, man-made or natural, that negatively affects the signals and/or equipment around it. EMI impedes, disrupts, or degrades the electromagnetic field of another device in which it comes in contact. Proper design, adequate isolation, and the proper shielding of cables and equipment can control this problem. In grammar school science classes, there is a common experiment where a nail is wrapped with a wire that is attached to both terminals of a battery. A compass is then placed near the nail and the students observe the compass needle begin to spin. The electricity running through the nail creates a magnetic field, which attracts the compass needle and causes the movement. This is one example of EMI and how it can be generated.

Crosstalk: Crosstalk is simply the migration of energy from one wire to another via electro-magnetism, as described in our nail and compass experiment. Crosstalk results when a magnetic field creates an unwanted electrical signal in a neighboring device. As an example, suppose you were in a hotel room watching television. The guest in the next room is watching television as well and has the volume turned up to a point where you can hear their television as you are trying to listen to yours. While that unwanted noise may make the show you are watching less than enjoyable, when this phenomenon occurs in an electrical circuit, the noise generated from one signal can affect another around it – via crosstalk –to the point where that signal becomes degraded and 'unclear' to the receiving device. When that happens, the performance of the device or circuit can be compromised. Another term that can be used to describe crosstalk is "coupling".

Alien Crosstalk: Alien crosstalk is not a characteristic that is covered by any of the formal standards but has nonetheless become a common industry term. As in many larger installations Category cables are bundled for ease of routing and wire management, noise can be generated between these cables within the bundle. Much like wire-to-wire interference, this unwanted electrical noise generated outside of the cable – called alien crosstalk - can degrade signals and negatively affect the quality of the delivered data.

Most Category cables, as part of their specification, carry measurements of certain performance characteristics. While some performance reports may be more in depth than others may, the following characteristics are relatively common across the documentation for most Category cable products:

Frequency: Frequency is the measure of how many repeating waves – in the case of Category cable, electrical energy waves – are generated in a second. Frequency is measured in hertz (Hz). The higher the frequency, the more waves are created. As each wave has the ability to carry data, generally the higher the frequency the more data can be transmitted. A good example of this is a high definition television that operates on a much higher frequency than standard definition television. The high definition television utilizes the additional data contained in the higher frequency signal to create a picture that is far superior to a picture generated by a standard definition television.

Bandwidth: Closely related to frequency, bandwidth refers to the range within a band of frequencies. In computer related systems, bandwidth often refers to how much data can be transmitted within a given period. Bandwidth is measured in bits per second (bps). The high frequencies required to carry the information necessary for the proper operation of today's digital equipment call for a large bandwidth in order to support it. An example of bandwidth might be a highway in the heart of a large city. If all the cars are to move as quickly as possible during rush hour, they will need a road large enough to accommodate the volume of vehicles. If the road is too small, the result is gridlock. In that way, bandwidth and frequency are directly related – the more information, the higher the frequency, and, therefore, the larger the bandwidth required to support it.

Insertion Loss: This characteristic is also referred to as "attenuation". It measures the loss of signal from one end of the circuit to another. It is measured in decibels (dB) and is usually preceded by a 'minus' sign. An example of an insertion loss measurement might be -3.1 dB. A good way to understand this is to think about what happens to the waves in a pond after you drop a rock into the water. The waves start out strong from the point where the rock entered the water, then lose energy as they travel farther from that point. They become weaker – or attenuate - until they have lost their energy are finally gone. In an electrical circuit signal is lost through the resistance of the copper conductor, the insulation, and termination points within the connector. The higher the insertion loss, the more a signal will begin to degrade as it travels along the cable's conductors.

Return Loss: Return loss is measured in decibels (dB) and represents the amount of signal reflected back towards the transmission source. As an example, picture a pipe of a 1-inch diameter that is full of running water. At the point where that 1-inch pipe joins with a ¾-inch pipe, there will be a loss of water due to the interruption of the flow at this transition point in the pipes. It may spill outside the pipe or it may reflect back as there is not enough room in the ¾-inch pipe to handle the volume of water being delivered by the 1-inch pipe. In a circuit, this type of electrical loss is usually attributed to the quality of the connection of the wire to the connector. A specific cable example would be a product that has been crushed or deformed in places along its length. In each compressed area, signal will be reflected and lost. Even the highest quality connection will result in some degree of return loss.

Propagation Delay: Propagation delay is simply the time it takes for a signal to get from the transmitter on one end of the wire to the receiver on the other. The larger the delay time, the slower the signal is traveling. It can be measured in microseconds, nanoseconds, or picoseconds.

Delay Skew: Generally part of a Category performance specification, delay skew is a characteristic worthy of explanation. As signals are introduced across each pair in a Category cable, the propagation delay between the pairs will differ. This difference in the signal speeds is called delay skew. Some factors that may affect delay skew include conductor insulation and the twist length of the individual pairs. Delay skew is relevant to this discussion because in many systems not only is the quality of the data received important to proper operation, but the time it takes for the signals to arrive from all the cable pairs is equally as important. Most systems require all the signals to arrive within a certain time window. When one or more signals arrive 'late', the result can be a system failure typically resulting in an error flag that requires the data to be resent. An accumulation of error message and resend requests can significantly slow the system's performance.

Near End Crosstalk (NEXT): Near End Cross Talk measures the signal energy radiating from one pair within a Category cable to another of the pairs. The term "near end" is applied because the measurement is taken using the pairs at the end of the cable closest to the transmitter. NEXT is most commonly evaluated within distances of 20 to 30 meters from the transmitter. NEXT is measured in decibels. (dB)

Power Sum Near End Crosstalk (PSNEXT): As mentioned earlier, most Category cables utilize four pairs of wires. PSNEXT is the sum of the crosstalk on three of the pairs as they affect the remaining pair. The values are determined by measuring each pair of wires against the other pairs in the cable. One way to think of this would be a "three against one" type measurement between the four pairs in the cable, with each pair having a turn being measured alone against the other three. In high bandwidth cables (carrying high frequencies) that use all four pairs to transmit signals, a significant sum of crosstalk energy from three pairs could 'over power' the signal in the remaining pair resulting in equipment failure (error flags) due to the degraded data.

Far End Crosstalk (FEXT): Far end cross talk is measured at the end of the cable farthest from the signal transmitter and measures the energy radiating between pairs within the cable. Because the signal will have traveled the length of the cable – and therefore will have attenuated – FEXT measurements are generally weaker in strength than NEXT measurements within the same cable. FEXT measurements are often used to calculate ELFEXT, which we will discuss next. As with other crosstalk measurements, FEXT is measured in decibels.

ACRF (Attenuation to Crosstalk Ratio, Far-end): Formerly called Equal Level Far End Cross Talk (ELFEXT), the value for ACRF is calculated not measured. The ratio used to determine ACRF compares the level of electrical disturbance – cross talk - to the intended signal strength. In other words, it is a signal to noise ratio. Too much noise and not enough signal, occurring together, are the main ingredients for a system failure. ACRF is a calculation used to average the crosstalk value across the entire cable length. To understand this better, let's think about two radios. One is a portable AM/FM with a pull up antenna while the other is part of a stereo and is wired to a large roof based antenna. With a local signal that is very strong compared to any interference, reception is good on both radios. As you try to tune in more distant stations, the smaller radio signal suddenly has a lot of static and maybe even other stations 'cutting in' to the reception. The larger radio picks up the same station 'loud and clear'. The reason is the signal received by the larger radio is stronger than the noise, resulting in an enjoyable experience, while in the case of the smaller radio, the noise is stronger than the signal, resulting in poor reception. (Remember, the amount of noise in the environment is the same for both radios!) This is similar to a system that can meet with failure if the data signal is overpowered by crosstalk noise.

Attenuation to Cross Talk Ratio (ACR): This ration is also called "headroom". It compares the strength of attenuated signal arriving at the receiver to the cross talk – or noise – at that end of the circuit. Measured in decibels (dB) if the ACR measurement is not large enough – which would indicate the signal is not strong enough to 'over power' the noise the system is experiencing due to cross talk - the signal will be susceptible to degradation and the system will be susceptible to errors based on the poor signal quality. One example of this might be trying to ‘drown out’ the noise from a road crew working outside your house by turning up your stereo. If your stereo system is strong enough, it can generate enough volume to block the noise. If not, the noise from the roadwork will negatively affect the quality of the music you are trying to hear.

As with any intricate subject, an attempt to reduce complex data to simplistic terms often leaves out information that could be considered important. The intent was not to replace the expertise of a trained engineer but rather to give those with limited exposure to the technical aspects of these products a document that provides a high level understanding of the performance criteria associated with Ethernet based systems and Category cables.