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Addressing REAL WORLD COPPER CABLING CHALLENGES

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In the real world, what happens when an off-the-shelf legacy category 5e is installed in a video application?

Copper cable is a staple in any networking system, and it is here to stay. However, it is constantly being put to the test in a changing landscape. Due to its high electrical conductivity and relatively low cost, copper has become the signal-carrying medium of choice. Now carrying voice and data communications, signaling, video and power for many applications, twisted-pair copper cables have evolved and address many performance obstacles.

Twisted-pair copper cables provide a solid foundation on which to build technological advancements for the 100 meter (m [328 feet (ft)]) horizontal channels in enterprise networks. But how can network designers and end users be assured that the installed base of twisted-pair copper cable standardized nearly two decades ago can perform in today's real world environments and support many new applications? With expanding bandwidths, added power and connecting unrelated devices via Internet protocol (IP), twisted-pair cable is being pushed to its operational and electrical signal-carrying limits. Inhibiters such as crosstalk, static, heat and electrical noise can affect transmission line properties and cause dropped data packets, ultimately affecting the performance of an application.

Copper cabling standards developed by the Telecommunications Industry Association (TIA) and the International Organization for Standardization (ISO) have evolved significantly since the early 1990s. The main purpose of these standards is to create multiproduct, multivendor, interoperable solutions for cabling components and eliminate previous proprietary cabling systems. The main purpose of Institute of Electrical and Electronics Engineers (IEEE) standards is to define systems and component requirements needed for specific applications (e.g., gigabit Ethernet data transmissions, wireless systems, power over Ethernet [PoE]). This includes identifying the end-to-end channel electrical characteristics needed for data transmission. Existing cabling standards address the system components and installation best practices, but do not always address specific issues that could hamper the electrical properties of the cable when installed in real world environments.

The TIA-568-C.0 standard includes environmental classifications that describe areas in which the cable can be placed and address factors that may inhibit performance. These specifications are known as MICE—M for mechanical, I for ingress, C for climatic and E for electromagnetic. The standard provides thresholds for various environmentally-controlled areas (e.g., office buildings) as well as industrial environments, and it provides different levels

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based on the characteristics of each. The standard points out that if a cabling system component crosses an environmental boundary, the component or mitigation technique selected should be compatible with the worst-case environment to which it is exposed. It is important to understand the environmental effects on the cable and its components (e.g., primaries, insulation, jacketing), which can ultimately affect the cable's overall electrical performances and result in delayed or lost transmission due to dropped packets.

As more IP devices and network services attach to installed copper cabling systems, evolving applications such as electronic safety and security (ESS), building automation systems (BAS), intelligent building systems (IBS) and PoE, are defining some new requirements. However, the capabilities of the installed cabling systems require further re-evaluation and testing to ensure they perform under the additional stresses of unique environments and simultaneously support multiple applications.

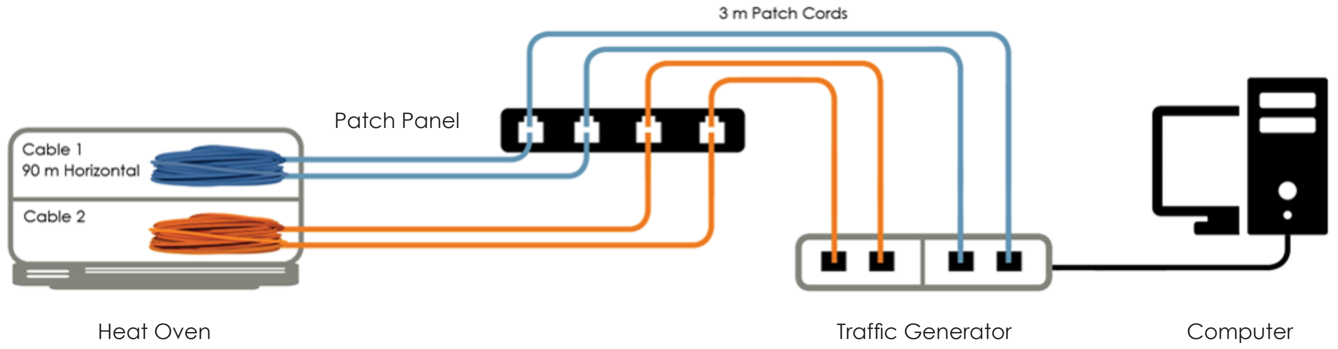
This article presents three different real world installation scenarios that were recreated in a lab to study the effects on the installed cable and provide network designers with considerations that may be overlooked during their cable selection. Since the majority of the installed base of horizontal cables is category 5e and category 6 unshielded twisted-pair (UTP), these tests look at how the environment can create disturbances that would affect the transmission properties of these cables. Standards have evolved between category 5e and category 6 cables. These include additional testing of both cable and channel standards to address tighter parameters on the cables, such as balance. This article will demonstrate that the installed base of cables might not meet current and future environmental and application challenges, calling for higher grade cables such as category 6A UTP that have been subjected to tighter controls during the manufacturing process.

Calculated Testing

In the Ethernet world, transmitted packets of data do not always reconstruct properly when they are received. At the receiving end, the switch or network interface card (NIC) measures dropped packets, or errors, through a computational process to detect whether equal numbers of packets are sent and received. This mathematical analysis is performed through cyclic redundancy checks (CRC), which is a binary error-detecting code used in digital networks to detect changes to the raw data and the validity of packets. If packets are received with CRC errors, packets and frames may be discarded by the switch or NIC, whether it contains one or many incorrectly transmitted bits.

Each test set up described in this article features results that are calculated through CRC errors. However, they use distinctive methodology due to the different extenuating circumstances of the environmental factors, cable types and applications. Primarily, the two most detrimental environmental

FIGURE 1: Elevated Temperature Test Set Up



factors that alter the electrical performance of the twisted-pair copper cabling and subsequently affect system performance are temperature (i.e., heat) and noise (i.e., electrical fast transients). As the industry expands beyond transmitting just voice and data signals, additional challenges have been identified. This article will give an example of putting cable to the test in a complex video scenario where the cable is expected to simultaneously transmit data, video and power.

All of the tests outlined in this article were performed at the Nexans Data Communications Competence Center (DCCC) at the Berk-Tek headquarters in New Holland, Pennsylvania. The DCCC focuses on advanced product design, applications and materials development for networking and data communication cabling solutions.

Taking the Heat

Structured cabling is installed in many differing locations with varied environmental challenges (e.g., plenum spaces above suspended ceilings, under industrial factory floors, on electrical poles or in portable classrooms). The temperature of these environments can fluctuate greatly depending on building design, location, time of day and the efficiency of the heating, ventilation and air conditioning (HVAC) systems.

Another contributor to elevated temperature within a cable is running power over the twisted pairs for PoE applications. PoE allows both power and data to be sent through the same twisted-pair cable (sometimes over the same pair). With emerging IEEE standards, the heat generated from the additional wattage needed to power devices up to 60 watts (W) can increase the temperature of the copper conductors within the jacket by as much as 10 degrees Celsius (ºC [18 degrees Fahrenheit (ºF)]).

To analyze the influence of temperature fluctuations on Gigabit Ethernet performance, the lab conducted a series of experiments where 1000BASE-T signals were transmitted over a category 5e, category 6 and above-standards enhanced category 6 cabling system. The temperature was varied from 20 °C to 70 °C (68 ºF to 158 ºF), topping at 80 °C (176 ºF).

A 90 m (295 ft) sample of each cable was spooled onto reels, which were placed in an environmental chamber. Both ends of each cable sample exited the chamber through a 5 centimeter (cm [2 inch (in)]) hole on the side. Each end of the horizontal cable was terminated to a patch panel port and connected through the patch cords to the ports on the data traffic generator equipment (see Figure 1).

The following temperatures were used during testing:

- Baseline settings under room-temperature conditions: 20 °C to 25 °C (68 ºF to 77 ºF).
- Elevated settings: varied from 30 °C to 70 °C (86 ºF to 158 ºF).

Tests were allowed to run for at least four hours until the temperature of the cable was considered stable. CRC errors were recorded and averaged during the four-hour test period of each temperature elevation. If a packet was received with an invalid CRC, it was discarded.

FIGURE 2: CRC Errors at Elevated Temperatures

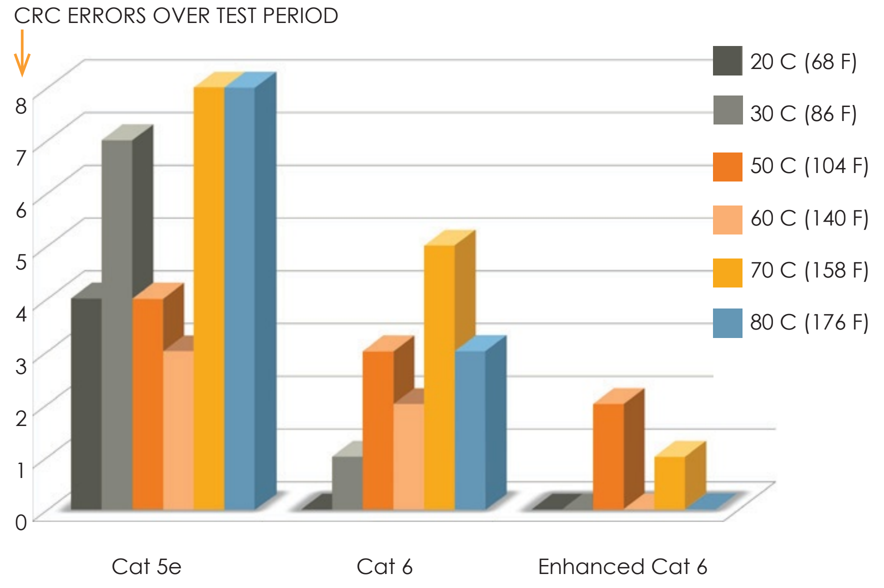


FIGURE 3: EFT Test Set Up

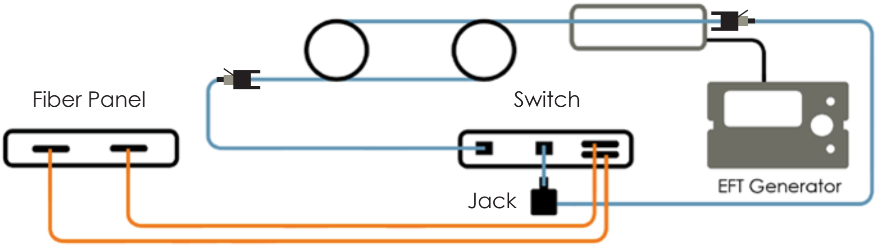


Figure 2 shows CRC errors for the four-hour test period for each elevated temperature increment of each cable type. The test results show that there were significantly higher occurrences of CRC errors at higher temperatures using category 5e cable as compared to category 6, and using category 6 compared to an enhanced category 6 cable.

A number of the errors observed in these trials were a result of the inability of the Gigabit Ethernet transceivers to continue to maintain a link due to the increase in cable attenuation during the heat rise. NICs are forced to renegotiate through the adaptive equalization process to stabilize the network. These tests prove that the higher grade of cable is vastly superior in regards to allowing the Gigabit Ethernet electronics to operate more reliably when temperature conditions are varying over time—as is the case in many real world situations.

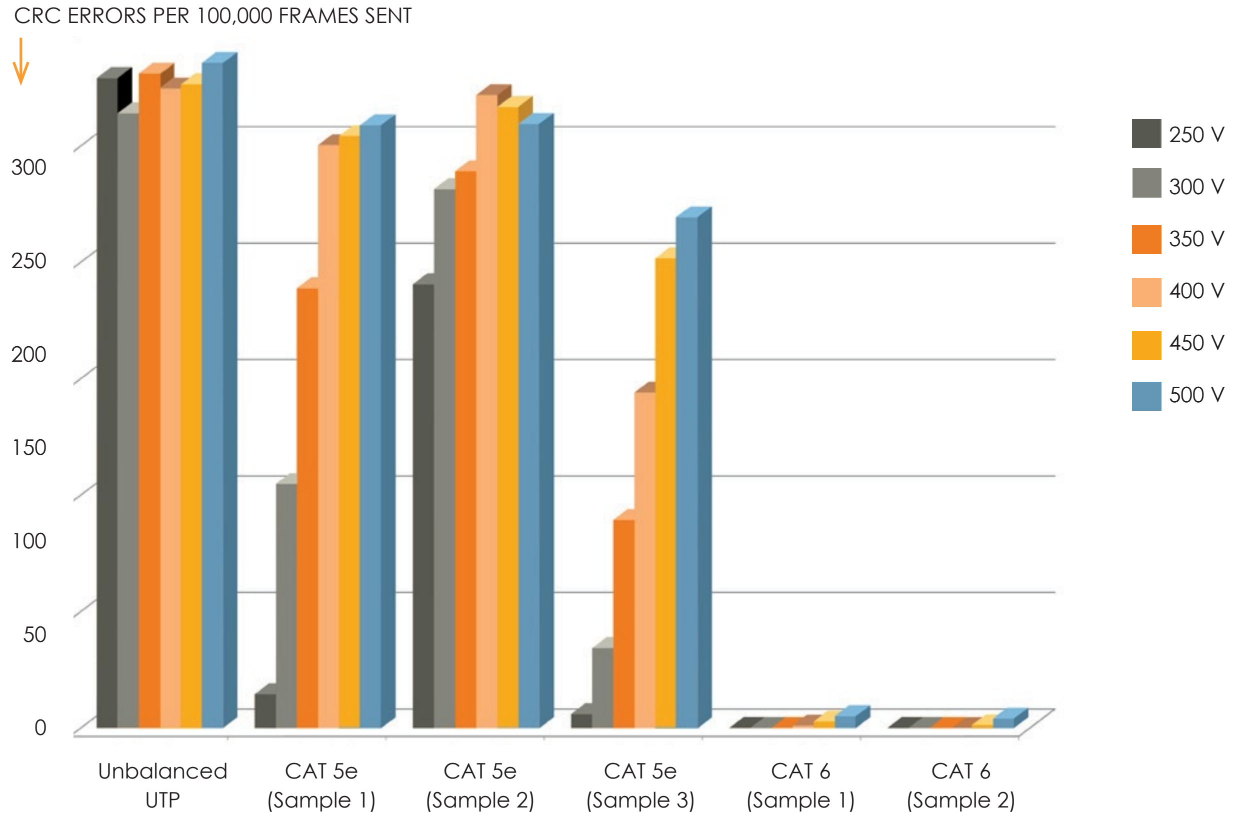
Noise Interferences

Noise can come from many different sources—electrical surges, motors, power lines, elevators or interference from adjacent cables. Spikes of voltage are also referred to as electrical fast transients (EFT). Increased susceptibility to external noise becomes critical with increased data rates, which require higher signaling speeds and more complex encoding.

To analyze the performance of data cable when exposed to power spikes, CRC errors were again used to detect transmission errors. The lab conducted testing of six different cables—from an unbalanced UTP (i.e., a cable that did not meet minimum category 5e standards) to different grades of standards-based category 5e and category 6 cables. As shown in Figure 3, each test set up includes 90 m (295 ft) of the data cable installed in raceway connected to a switch and into the data traffic generator that monitored the traffic across the data cable and measured the Ethernet packets.

The test consisted of 1400 byte frames with a 0.16 micron inter-packet gap, which were run in continuous packet mode at full duplex through the multimode optical fiber links. The data traffic passed through the switch, which contained a network performance analysis system with gigabit modules and was connected with multimode optical fiber cable onto the copper cable channels under test, then returned back to the switch to perform and record the transmission and errors.

FIGURE 4: Normalized Frame Errors per 100,000 Frames Sent



Power cable ran adjacent to the data cable. An EFT pulse generator was connected and injected current onto the power cable through EFT pulses starting with 250 volts (V). The voltage level of the EFT pulse was constant for each 300-million packet test, with the voltage increasing in each consecutive test and reported to 500 V.

The CRC errors were compared to 100,000 frames sent, which allowed the comparison of tests of different lengths of time. This meant that the errors occurring during each test were normalized using the following equation:

(number of CRC errors counted in a test) / [(number of frames sent)/100,000]

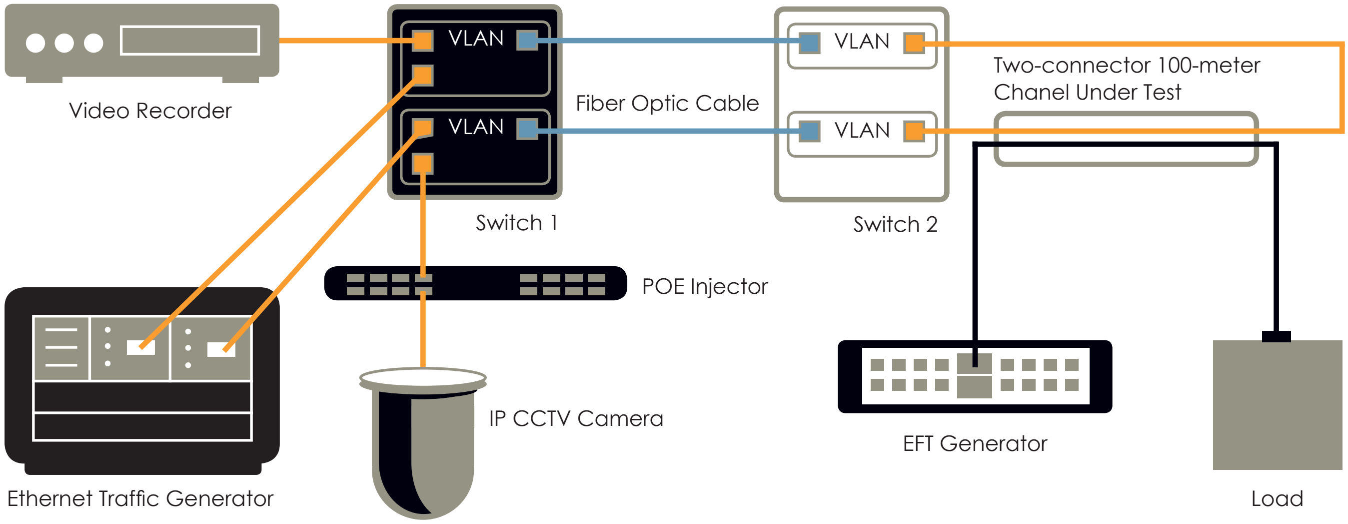
Figure 4 shows that Category 5e cables consistently demonstrated CRC errors due to EFT pulse interferences. As a point of reference, the test result at 400 V is defined as the greatest inhibitor by IEEE (i.e., pencil sharpener spikes) and at 500 V (i.e., Level One in the M.I.C.E. electromagnetic listing in the TIA-568-C.0 standard). This test shows that there are varying degrees between different types of the cables.

The large differences between the results of the unbalanced cable and category 5e cables compared to the category 6 cables are directly a result of cable balance, which was only identified by the standards as a performance parameter when category 6 was ratified.

Disturbances on IP Video

In the evolving world of network integration, IP devices being connected over a structured cabling system have created new challenges. These include maintaining signal integrity during simultaneous transmission

FIGURE 5: IP Video Test Set Up



of data, video and power compounded with environmental hindrances due to the location of these devices (indoor and outdoor). Stresses of temperature fluctuations and noise become even more important when looking at the critical reliability of applications such as security cameras.

Previously, security integrators were responsible for planning and installing the cabling infrastructure for video surveillance cameras. However, when IP cameras were developed and could utilize network cables, most security integrators were unaware of the effects of the installed environment on a UTP cable, as well as the differing installation practices versus previous coaxial cable.

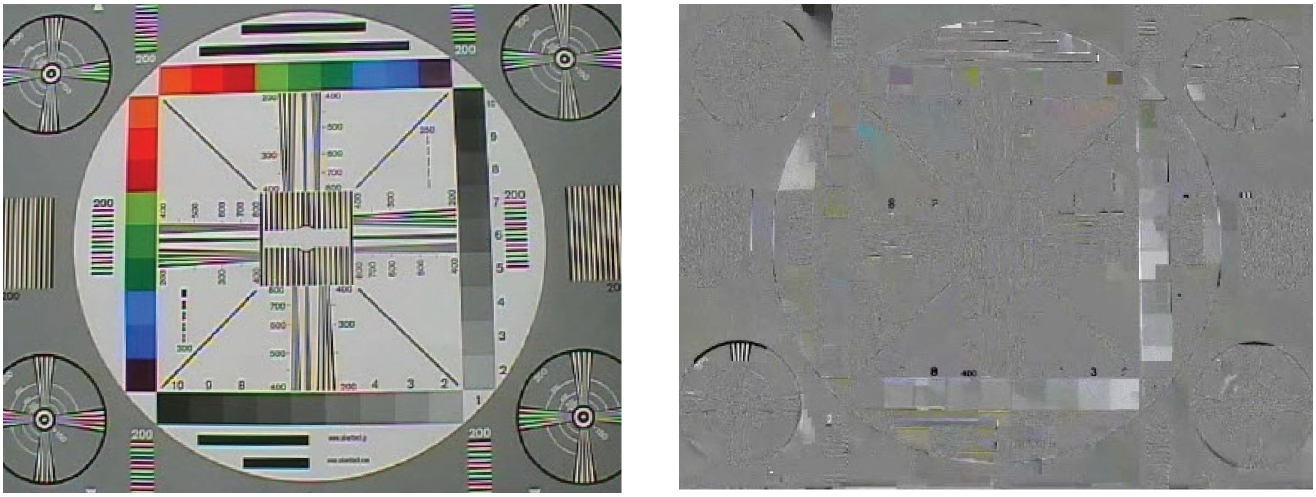
During the transition from coax for analog cameras to twisted-pair copper for IP cameras, security integrators and installers were faced with the diversity of electrical characteristics and installation practices. It was a learning curve to grasp and understand that these differences affect the signal quality, which ultimately affect the picture and reliability of the entire security system. Many security installers also thought that one UTP cable was the same as another, so they were not concerned with differences between cables or aware that cabling test results are crucial to the overall system reliability. Often they would buy the least expensive, off-the-shelf cable available. Many were quick to learn that the cable does make a difference in video quality, and there are differences between cables due to manufacturing processes.

In the real world, what happens when an off-the-shelf legacy category 5e is installed in a video application? The lab created a test bed to test different cabling systems—one utilizing a legacy off-the-shelf category 5e cable and another using category 5e cable that was manufactured to meet balance parameters. Remember, balance parameters were not included in TIA standards until category 6 was defined.

The lab wanted to see if there was a performance deviation between the cabling when running data, video and power simultaneously for IP cameras. The results measured the impact of the cabling solutions and the camera on the quality of the recorded stream. The streams were recorded while a 10 m (32 ft) section of a 100 m (328 ft) two-connector channel was subjected to EFT interference injected onto nearby wires.

In the test set up shown in Figure 5, an IP camera, powered by a PoE midspan injector, streamed MPEG-4 video over a Layer 2 Ethernet data switch. The switch was supplied by one port on a traffic generator and then sent

FIGURE 6: Undisturbed video on a category 5e cable built to incorporate balance parameters (left) versus dropped packets resulting in loss of video in a legacy category 5e (right).



data to a second switch via a 1 gigabit per second (Gb/s) optical fiber link. The data was then transferred between two different virtual LANs (VLANs) on the second switch by the cabling solutions under test. The first 10 m (32 ft) of horizontal cable were placed in one compartment of a plastic raceway. The second compartment of the raceway contained three electrical wires (hot, neutral and ground) that were carrying 120 V of alternating current power provided by the an EFT generator. The generator also added high voltage spikes to simulate noise, such as printers and fluorescent lights. As previously mentioned, EFT noise sources exist in typical commercial environments. The installed cable needs to provide superior noise rejection, which helps isolate and protect network equipment and provides higher quality images in the recorded stream.

The far ends of the electrical wires were terminated in a resistive load, which dissipated the electrical power as heat. The data was then received back on a different VLAN of switch 1, and the data on a traffic generator was forwarded to another port and the camera data was forwarded to the recording device. The tests recorded actual videos of a test pattern for each of the two cabling systems being tested, which were viewed to determine if errors in the MPEG-4 streams (at 30 frames per second) caused visual degradation in the quality of the video.

The results of these tests show that legacy category 5e cable demonstrated enough errors to drop packets, resulting in lost or distorted video frames. The other system, which utilized a category 5e cable manufactured to incorporate balance parameters, did not display any errors. The unrecognizable images recorded in the legacy category 5e solution represent a potential large liability for an end user since the error in the stream lasted for approximately one second and often occurred more than once in a 30-minute interval. If these solutions are employed as part of a security system, the errors in the second cabling solution could compromise one of the basic functions of a security system: the protection of personnel and assets. Therefore, it would be safe to conclude that installing a category 6 cable (or better) would assure better video transmission because of the balance requirements set by the standards.

Mitigating Real World Cabling Challenges

Moving forward into the evolving world of IP convergence, there will be additional inhibitors yet to be discovered. Before IP, most IT managers were only concerned with providing reliable data transmission, mainly for email and Internet. With the addition of other applications now attaching to the IP network comes new "what if" scenarios and environments that could affect the installed copper cabling system.

More and more unrelated applications and devices will continue to attach to the data network to take advantage of the benefits of structured cabling (e.g., easy migration, uninterruptible power supply back up, 24/7 support). However, the information and communications technology (ICT) industry must be aware of the additional stresses on the existing copper cable system that might arise when transmitting data, power and control onto devices. In addition to IP cameras, these can include access control, HVAC controllers, camera heaters and blowers, lighting, audiovisual and Internet protocol TV—just to name a few. It is critical that network designers and IT managers are prepared to assure that the twisted-pair copper cabling system will not inhibit the application itself.

Twisted-pair copper cables manufactured to meet standards created two decades ago might not perform under the pressure of today's application stresses. We have also seen how detrimental a legacy cable system, which did not meet newer, defined electrical parameters for higher grade cables, can degrade an entire system. The solution is to assure that the copper cable being specified meets the tightest parameters for superior balance, which is now defined in the standards. Cable balance has become the most important cable characteristic affecting network reliability—the better the balance between the conductors of a pair, the greater the reduction in noise within the pairs and from external noise and interferences.

Tighter manufacturing controls in cable production contribute to the overall cable performance and cable reliability due to superior balance. Engineered in-line monitoring and quality controls are necessary for the following manufacturing consistencies to assure maximum balanced cable performance:

- ▶ Conductor uniformity in size and American wire gauge (AWG) in all primaries, which takes place during precise copper drawing.
- ▶ Centered insulation diameter and concentricity, which occurs during the insulation process.
- ▶ Precise twist ratio for consistent length to eliminate skew issues, which is affected by the cabling and twisting operation.
- ▶ Concise control of differential mode testing and common mode testing during quality control during and after production.

In addition to installing higher grade cables, testing of cable and cabling channels in real world environments before installation may save thousands of dollars, especially if the network fails due to the cable or the environment. While field testers can provide a pass or fail reading once the cable is installed, this does not provide specific electrical characteristics that could become compromised or fail when adding IP devices to those channels at a later date.

End users, IT managers and system consultants need to take heed of potential issues to assure that the cabling system that they install today will truly perform beyond the next generation. Selecting cable that meets existing standards may not be enough to provide peace of mind for network reliability. Both lab and real world environmental testing becomes critical for all IP installations.◀

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