Analyzing the effects of ElectroMagnetic Interference on state-of-the-art copper twisted pair Ethernet cabling

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Abstract: - With the dramatic increases in desktop computing power driven by Intranet-based operations and the growing demands for time-sensitive delivery between networked users, office and production-level Ethernet LAN technology has rapidly evolved from a coaxial cable running at 10 megabits per second to twisted pair running data rates up to 1 gigabit per second. As a side effect of this evolution, the higher the transmission rate grows the more sensitive the communication system will be to external noise inducted by Electromagnetic Interference (EMI). Consequentially, the designers, installers and users of Ethernet networks must consider the effects of EMI as a key factor in cabling design, setup and operation. Operating and environmental conditions in terms of Electromagnetic compatibility, should be seriously taken into account when choosing materials and designing cable routing layouts especially in industrial plants and high density computer rooms. In this paper we performed a detailed analysis on the disruptive effects of EMI on the most common state-of-the-art copper twisted pair Ethernet cabling technologies. Transmission parameters, noise/disturbance levels and network errors have been extensively examined and compared under varying EMC environmental condition to provide clear and up-to-date installation practice guidelines in terms choice of materials and separation requirements from suspected sources of interference, aiming to optimize communication channel characteristics and yield the maximum possible throughput.

Key-Words: - EMI effects, Copper Twisted pair cabling, Ethernet, Cable Balance

1 Introduction

The modern telecommunications industry has standardized copper twisted pair Category 5 or higher cabling as the preferred media for Ethernet LAN and voice applications in commercial buildings. Network equipment designers are challenged to continually improve the network performance by boosting the transmission technologies while keeping unmodified the physical cable media to ensure investment protection for the existing widely installed legacy CAT 5 cable plants. Most of the cabling systems actually in use in offices and computer rooms, have been wired under the configuration outlined in the commercial building telecommunication standards (TIA/EIA 568A, ISO 11801 and EN50173) which have been originally conceived for low speed (10Mbps) Ethernets and don't always scale to higher data communication rates in the harsher operating conditions of industrial and high density production environments.

Furthermore, system integrators and plant engineers/designers can realize substantial savings in material costs or installation time by combining communications and power conductors into a single raceway or keeping them very closer in a high density equipment/computer room. However, this cost-saving practice leaves the cabling highly vulnerable to ElectroMagnetic Interference (EMI) coupled noise.

Of course, as communications speeds increase, together with transmission quality needs, concern grows over noise and its potentially disruptive effects upon balanced twisted-pair telecommunications cabling. In this scenario, Electromagnetic compatibility (EMC) describing a cabling system's ability to minimize radiated energy levels (emissions) and resist to noise interference from outside sources (immunity) become a key factor in cabling system planning, design and installation.

Often it is difficult to detect the presence of EMI. The tell-tale symptoms include transmission jitters, a decrease in the network's performance or a general lack of network reliability. It is often difficult to diagnose EMC as the source of the problem as the end-user will first perceive a network problem and overlook the EMI. Such investigations can prove costly as a lot of time and money is often invested before the root of the problem is discovered.

Historically, definitions of environments with "abnormally high ambient electromagnetic interference" have been vague. The field strength guideline most commonly accepted as the threshold for high EMI environments is 3 Volts/meter (V/m) [1]. However, this de facto requirement was selected because interference levels greater than 3 V/m typically exceed the noise immunity levels of digital devices and are above the sensitivities of analog devices, not because of a direct relationship to the capabilities of copper twisted pair cabling. Many cabling installation practice guidelines address this issue by mandating separation requirements from suspected sources of interference. For example, the National Electrical Code [2] specifies a 2 inch separation between communications cabling and conductors of any electric light or power circuits. Other "rules of thumb" are simply passed along from installer to installer. Unfortunately, many of these guidelines are unnecessary and generated as a result of fear, uncertainty and doubt.

In this paper we performed a detailed analysis on the sensitivity of the most common copper twisted pair cabling technologies to an external source of EMI, by setting up several channels running a shared IEEE 802.3u 100BASE-TX Ethernet [5] and exposing them to electrical line-generated noise. Sensitivity is determined by evaluating the cable transmission parameters, electrical noise levels and network packet/framing errors with the noise source placed at varying distance. As a result we provide clear and up-to-date installation practice guidelines in terms choice of materials and separation requirements from suspected sources of interference, aiming to optimize communication channel characteristics and yield the maximum possible throughput.

2 EMI coupled noise

Typical coupled noise sources include induction heaters noises coupled from adjacent conductors, motor control relays, ungrounded or poorly grounded systems and proximity to power lines. Some useful concepts that are usually used to describe this phenomenon are Common-mode noise and Common-Mode Rejection Ratio (CMRR).

Common-mode noise is the voltage (common-mode voltage, or CMV) present on all conductors with respect to ground.

Common-Mode Rejection Ratio is the ratio, expressed in dB, of common-mode noise rejected and subsequently prevented from converting to a differential mode voltage. Due to the number of common-mode noise sources present in some industrial environments and high density computer rooms, plant floor communications systems are highly susceptible to common mode noise related problems. In fact, the impact of combining conductors carrying high *dv/dt* transients to a communications cable carrying < 100mV signals can be enormous on the system performance. Consequently, the CMRR of an industrial or high density office cabling system is critical.

3 Coping with Interference

Commonly, factory-floor Ethernet cable runs near 220VAC and 380VAC power lines and noisy power supplies, or Variable Frequency Drives, getting exposed to high amplitude, high frequency common mode noise sources. In a transformer-coupled system such as Ethernet, the common-mode voltages should not be an issue. However, the voltages produced by poor common-mode performance can cause relatively large differential voltages, which can be destructive to communications. Consequently, Category 5 and 6 cabling uses four twisted pairs within an outer sheath for the purpose of reducing data bit rates and rejecting noise. The quality of cable twists becomes extremely important in minimizing noise susceptibility. Good CMRR of environmental noise sources come from well-balanced connector, cable shielding and capacitance. A poorly manufactured cable, exposure to harsh chemicals, or even high humidity levels can seriously degrade the capacitance balance of a Cat 5 or Cat 6 cable. Furthermore, if the twists in the twisted pairs become inconsistent from sharply bending the cable during installation or squishing it after installation (e.g. a forklift drives over the cable), then the cable becomes much more sensitive to EMI noise. The cable can no longer reject the common mode noise. Instead the noise gets induced more in one wire than the other, adds to the Ethernet data packets, corrupts the bit shape and causes transmission errors. Different types of Ethernet cables can vary by as much as 30 dB in common mode rejection ratio, so picking a well designed cable (at least 40 dB CMRR but preferably 50 dB or more) will minimize your bit error rate after installation.

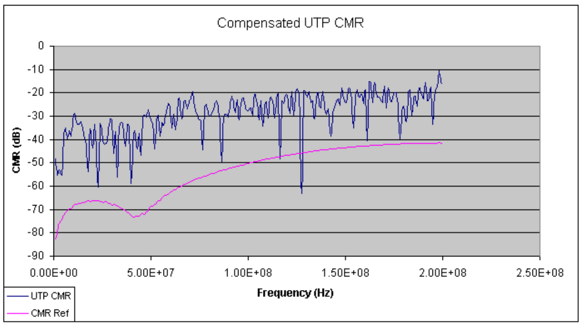

Fig. 1: Typical UTP cat5 compensated CMR

3.1 Balance

The most successful strategies for minimizing radiated emissions levels and improving noise immunity for twisted pair cabling are dependent upon the principles of balanced signal transmission along a pair of twisted wires. This technique effectively reduces both conducted and inductive interference. As a twisted wire pair approaches perfect "balance" (i.e. the two conductors appear to become geometric duplicates of each other), currents induced on the cable as a result of noise interference equalize and are subtracted out when detected by the receiver because the signal currents are in opposing directions and the fields created will cancel each other out, giving a cable that radiates very little EMI and is less susceptible to interference.

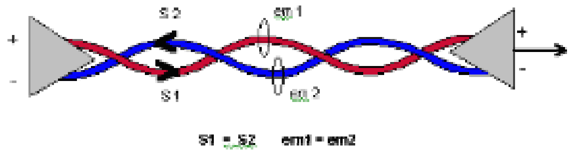

Fig. 2: TP Pair balance dynamics

Good pair balance also minimizes the tendency for a cable to radiate unwanted emissions. For example, currents induced on unbalanced cabling behave as miniature loop antennas, radiating a field whose magnitude is dependent upon the degree of mismatch between the conductors of a pair. Perfectly balanced cable will exhibit infinite noise immunity and radiate zero emissions. Although the parameter of balance is not addressed in ANSI/TIA/EIA-568-A [3] and is noted as an item for future study in ISO/IEC 11801 [4], it is commonly understood that the higher the performance category, the better balanced the cable. For example, category 6 cables would be expected to exhibit better balance characteristics than category 5 cable. It is interesting to note that shielded or foiled twisted-pair (FTP) cables rely on the same mechanism of balance in order to realize good EMC performance.

3.2 Shielding

Shielding the cable also helps reduce noise absorption. Although the twisted wire architecture of the four Ethernet wire pairs has been carefully designed to prevent noise reception as well as pair-to-pair crosstalk, metal shielding shunts the ambient electrical noise to ground protecting the twisted data wires from most of the common mode voltage, giving an excellent broad band of immunity and isolation to wires/pairs carrying signals, so the transceiver circuits never see most of the common mode voltage. This noise filtering effect can save Ethernet transceivers from damage and gives an excellent broad band of immunity and isolation to signal carrying wires and pairs.

4 Measuring the effects of EMI on TP Ethernet

In this section, we describe the experiments we performed and the results we obtained, including detailed explanations for observed performance.

We start by describing the experimental testbed and methodology and then analyze in detail, with adequate equipment, the effects of EMI-inducted noise on the electrical properties of the cables and on the network error rate of the four activated Ethernet channels.

4.1 The testing lab

All the experiments were conducted for 'generic' category 5, 'enhanced' category 5 UTP and FTP, and category 6 UTP cabling (Table 1), set-up to run a shared IEEE 802.3u 100BASE-TX and a switched IEEE 802.3ab 1000baseT Ethernet.

Cat	Cable properties	Vendor	Product code
5	UTP, 24 AWG, LS0H	Krone	6645 4 100-01
5e	UTP, 24 AWG, LS0H	Krone	6645 4 125-02
5e	FTP, 24 AWG, LS0H	Krone	6645 4 135-02
6	UTP, 24 AWG, LS0H	Krone	SC6L-ORII

Tab. 1: The testing lab cable types

All cables, each 50m. long, were loosely coiled (parallel shape) and secured to grounded raceways terminated in a standard freestanding equipment rack. The following picture shows the whole testing labs in which the parallel-shaped cable routing on the four raceways is clearly visible.

Fig 3: The testing environment

To maintain compliance with both international and national cabling requirements, all channels, as can be seen in the previuos figure were assembled in accordance with the worst case model defined in TSB-67 [6]. The test channels were uniformly subjected to an EMI interference source (electrical heavy-loaded power conductors carrying 220V voltages to power supplies, with a 30A cumulative load) by horizontally placing, at varying distance, the source along the whole testing cable length. This worst case configuration ensures that the entire horizontal cabling length can be subjected to the test source of EMI at the same time, making easier the observation of the EMI effects on the channel properties and behaviour.

The Electrical dispersion of the source (2 A) and the currents inducted at different distances on the four testing channel cables, were measured with an HT5080 electrical systems analyzer equipped with an HT97 current measurement clamp. Clearly, as expected, the electrical noise inducted into the Ethernet cables at different distance varied, depending on the type of cable tested.

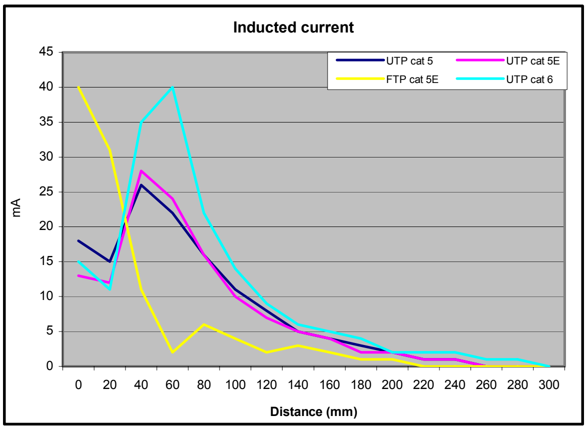

Fig. 4: Electrical Dispersion on the test plant cables

From the above figure it should noted that the inducted current, and hence the coupled voltages were greater and decay more slowly with the distance for higher performance cables (based on EIA/TIA category standards) than lower ones. Thus, the greater the cable bandwidth, the greater the noise power in the system. Amazingly, for some harsher environments, limiting the cable bandwidth can enhance the signal-to-noise performance, since the cable itself filters the high frequency noise. As a simple consideration, If most of the signal energy for Ethernet is below 70 MHz, reducing the cable bandwidth to below 100 MHz can provide up to 10-dB increase in the signal-to-noise performance.

4.2 Physical-layer analysis

To evaluate the effect of EMI on the physical cable properties, the most significant electrical performance parameters were measured at the three trasmission frequencies corresponding to 4-wire Ethernet, Fast Ethernet and Gigabit Ethernet, for each of the four testing channels with and without the effect of EMI-inducted noise (15 mA each, generated as previously described), with a Fluke DSP-4300 digital cable analyzer. In detail, the following properties and their powersum equivalents (calculated by simulating all four pairs being energized at the same time) have been examined:

- *NEXT*: The coupling of a signal from one pair to another pair measured at the same end that the signal is injected (Higher NEXT means less internal noise interference)
- *ELFEXT*: A measure of the unwanted signal coupling from a transmitter at the near-end into a neighbouring pair measured at the far-end relative to the received signal level measured on that same pair
- *ACR*: defined as *NEXT - Attenuation*, in dB's, represents the Signal-to-Noise ratio of pairs within a cable. The larger its value, the larger the difference between the signal at the receive end and the crosstalk noise, making it easier for the receiver to read the signal.
- *Return Loss*: a measure of the reflected energy caused by impedance mismatches in the cabling system (impedance consistency). It is an echo of the transmitted signal.

The results have been compared as in fig. 5 below:

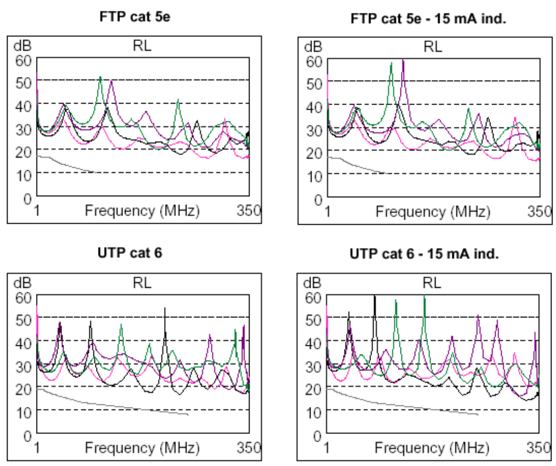

Fig. 5: EMI Effects on Return Loss

No significant effects have been observed on all the cables with the exception of some susceptible increments (max 10 dB peaks, as in fig. 5 below) in Return Loss, which can be due to inducted deviations from a nominal impedance on one or more segments of the channel. This can, clearly, adversely affect the link performance.

4.3 Network link-layer analysis

To observe the final effects of the EMI noise over ethernet transmission, MAC-level Network traffic errors due to radiated noise were monitored using a commercially available local area network (LAN) analyzer software program, NAI Sniffer Pro (see *www.sniffer.com*). A Traffic generator (NetIQ Chariot, see *www.netiq.com*) was used to generate enough traffic in the network for a more realistic scenario, simulating a utilization rates of approximately 40%. This rate was selected to be compatible with Ethernet guidelines that recommend a maximum utilization rate of 40% to ensure acceptable access times and collision rates. In this way an assessment can be made of how other network components will behave when the network is heavily used. Using these traffic generators, we can define the destination address, packet length, packet contents and repetition delay and ensure that the speed of the packages transferred is compatible with rapidity of ESD and electric fast transient tests. The most interesting types of errors that may be associated with full network utilization and EMI noise disturbances are:

- *Alignment*: Packets do not end on an 8-bit boundary.
- *Collision*: Two devices detect that the network is idle and try to send packets at exactly the same time. Collision errors are common in Ethernet systems and are expected as network utilization increases. Upon receipt of this error type, both devices hold, wait a "randomly" calculated amount of time (to avoid a second collision), and attempt to re-transmit.
- *Cyclic Redundancy Check (CRC)*: Packet size is correct, but the information contained in the frame check sequence (FCS) is corrupt.
- *Fragment*: Packet is undersized and contains corrupt FCS.

- *Jabber*: Packet is oversized and contains corrupt FCS.
- *Oversize*: Packets are greater than 1518 bytes in length.
- *Runt*: Packets are less than 64 bytes in length.

Under normal operating conditions (no known sources of EMI), no packet errors were detected for any cable type for both 100baseTX and 1000baseT Ethernet transmission.

Surprisingly, absolutely no packet errors were detected with 100baseTX Ethernet for either the 'generic' or 'enhanced' category 5 and category 6 channel configuration regardless of EMI source type, source location, or duration of exposure. This strongly confirms the excellent balancing behaviour of the TP cables in terms of noise immunity.

Some sporadic CRC errors were detected only on 1000baseT Ethernet category 6 channels with the source located very closer to the transmission cables. This result gives further confirmation to the above observations (depicted in fig. 4 and fig. 5) about the maximum achievable bandwidth (as a physical property of the cable) and the influence of inducted noise that becomes more and more significant when transmission rate increase. As a clear consequence, more strict and conservative rules and installation practices should be followed when network quality greatly scales, that is to say in presence of category 6 and higher cables and Giga-Speed transmission.

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6 Conclusions

Interference effects on the most common state-of-the-art copper twisted pair Ethernet systems have been analyzed in detail to demonstrate the increasing importance of EMC environmental parameters in scalable high-speed cabling designs. As a clear conclusion, to provide deterministic performance, which may be mandatory in production-level networks, the influence of environmental external interference on the cabling system should be seriously taken into account, particularly in presence of high quality cables, providing more bandwidth, and high frequency transmission techniques, with the strong objective to keep it near to minimum. This is accomplished by following proper installation guidelines, selecting the proper materials, and enhancing the electrical properties of the cabling infrastructure.

References:

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