EMC Performance Comparison of Shielded and Unshielded Data Transmission Systems

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Abstract - EMC emissions and immunity tests were performed on several shielded and unshielded twisted pair cabling systems for data transmission. Results are presented that show a properly designed unshielded system can equal or exceed the performance of shielded systems. Surprisingly, all of the shielded systems tested had immunity problems that were not present at any level of stress achievable by the test equipment for the unshielded system tested.

I. BACKGROUND

Data transmission over local area networks, LANs, typically use either shielded twisted pair, STP, or unshielded twisted pair, UTP, cable and utilize balanced transmission. Testing was undertaken at an independent EMC test facility in Switzerland to determine the relative EMC performance of several cabling systems using STP cable and one system using UTP cable.

There is much misunderstanding about shielding in the LAN community, and it was hoped that this test would clear up EMC issues related to emissions and immunity for STP versus UTP systems. I believe that this objective was met and indeed yielded surprising information regarding the immunity of STP systems.

II. OVERVIEW OF TESTS

II.1 The Test Configuration

The equipment configuration for the test is shown in Figure 1. It consisted of a 16 Mbps IBM Token Ring LAN utilizing 3 PCs, a server, a client, and a monitor (on an optical link outside of the test chamber). Except for the optically coupled monitor, the rest of the equipment was inside an anechoic chamber.

The client, PC A in Figure 1, and server, PC B, were connected using 2.4 meter cords to a wall outlet suitable to the cabling system being tested on the end of a length of cable of the cabling system tested. The server PC was connected with 5 meters of cable to a patch panel and the client PC was connected through 15 meters of cable to the same patch panel.

The patch panel was connected to a Lobe Attachment Module, LAM, and an IBM 8230 Media Access Unit, MAU (also referred to as a CAU, Controlled Access Unit), through 2.5 meters of cable. The rest of the system, associated with the monitor, was connected via an optical fiber and was not part of the test. The monitor was used to observe system operation and detect error conditions during the immunity tests.

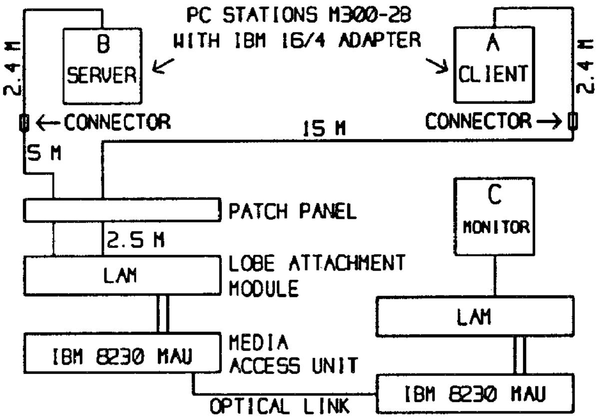

Figure 1 - Typical Test Setup

The standard test configuration described above was used for all tests except where the test required changes. Five different cabling systems were tested using this configuration. Slight deviations from the standard test setup were necessary for some tests and configurations, such as adding a ground wire called for in the manufacturer's installation instructions. These differences are not important to the results presented here and in the interest of brevity are omitted.

II.2 Tests Performed

II.2.1 IEC 801-3

This is one of the series of immunity tests specified by the International Electrotechnical Commission, IEC, for industrial process control equipment. The IEC series of tests have been applied to a wide range of electronic equipment and forms the basis of many CENELEC requirements for marketing electronic equipment in Europe.[1]

IEC 801-3 covers radiated immunity from 26 to 1000 MHz. The radiated field is modulated with a 1 kHz signal to a depth of 80%. The radiating antenna is positioned 2 meters from the EUT. It is meant to insure immunity from radio broadcast stations and other sources of strong radio frequency emissions such as cellular phones, for example. Level 2, 3 Volts/meter, was applied to the equipment.

II.2.2 IEC 801-4

This test covers immunity to electrical fast transients, EFT. EFT noise is generated by sparking contacts, usually on the power line, from sources such as motor commutators and switches. The noise is coupled directly on power lines and radiates into I/O lines such as those of a LAN.[2]

The generator output, into 50 ohms, is comprised of bursts of pulses. Each pulse has a 5 ns risetime and 50 ns pulse width at half peak amplitude. These pulses are repeated in a burst at several kHz for 15 ms. The burst is repeated about 3 times per second for one minute for both positive and negative polarities.

The IEC 801-4 test couples common mode noise bursts onto I/O cables, STP or UTP in this case, via a capacitive clamp which can have a coupling impedance to the I/O cable of as little as a few tens of ohms in the 100 MHz region, the spectral bandwidth of the pulse waveform. The generator level is specified at several levels for injection on power lines and I/O leads. For I/O leads, the levels are: 250, 500, 1000, and 2000 volts.

The interference potential of a current can be estimated by calculating the inductive drop, L·di/dt, across one centimeter of wire. A current that generates tens of millivolts/cm is generally not dangerous to digital logic whereas a current capable of more than one volt/cm can be a problem. Interference on a LAN can take the form of data corruption or upset of the equipment sending or receiving the data.

Conversion of common mode noise, such as generated by the IEC 801-4 test, to differential mode noise is controlled in large part by the inherent balance of the data pairs, a media adapter to improve balance and provide filtering (if present), and by the shielding effectiveness of the cable shield (if present). Differential mode noise tends to corrupt data. Thus, data corruption is a function of all three of the above factors, whereas system upset is more a function of the common mode current on the cable alone. STP systems must dump this current unattenuated on the metal strip attached to a PC card. Care must be taken to see that this current cannot get into the PC and upset the logic. The media adapter used with UTP systems reduces this common mode current significantly.

The capacitive clamp is capable of coupling amps of noise current onto conductors even at the 500 volt level of the generator, the required level for CENELEC compliance. If one assumes a value of inductance for a wire of 10 nh/cm then a 2 amp change in current in 5 ns yields an inductive drop of 4 volts per cm, a dangerous level for both data corruption and equipment upset.

II.2.3 CISPR-22

This test covers radiated emissions from 30 MHz to 1000 MHz. The limits, magnitude of the electric field of a plane wave in free space, are intended to insure a low level of interference to broadcast services from electronic equipment. The Class B limits are (at a 10 meter measurement distance) 30 dBμV/m from 30 MHz. to 230 MHz. and 37 dBuV/m from 230 MHz. to 1 GHz.[3]

III. RESULTS

Results for each of the tests performed is described in this section. Interpretations and discussion of the results are included for each test.

III.1 IEC 801-3

Table 1 summarizes the test results. Only one STP system, from a Swiss vendor, was tested. The ring leaves that occurred on the STP system resulted in lockup of the complete network. The "Notes" column indicate the hardware used to interface the PCs to the wiring system. The TR filter used was a particular AMP filter that is used with that system. The 370C1/372A units are media adapters used with UTP to provide impedance matching, improved balance, and additional common mode filtering.

These results show that the UTP system is capable of equivalent performance to a popular STP system used in Europe for radiated immunity.

III.2 IEC 801-4

Table 2 summarizes the results. The error threshold level refers to the EFT level at which the system started making correctable errors. These errors resulted in retransmitted packets with no data loss. In those cases, system operation returned completely to normal after the EFT was removed. This is contrasted with the ring failure level. At that level, the complete network locked-up and all of the PCs had to be rebooted and the network restarted, a time consuming procedure that was required on all of the shielded systems and did not happen on the unshielded system to the limit of the generator output.

System	Polarization	Results	Notes
STP	vertical	ring leaves and code 22 on 8230 at 33.86 MHz	4/16 TR filter
STP	horizontal	no problem	4/16 TR filter
STP	V + H	no problem	shielded outlet cords
UTP	V + H	no problem	370C1/372A

Table 1 - Radiated Immunity Results

All of the cabling systems tested passed the CENELEC level 2 requirement for EFT on I/O leads of 500 volts with considerable margin.

III.3 CISPR-22

Measurements were made in an absorber loaded room for all of the systems. In addition, an open field measurement was made on the UTP system to make sure the system passed CISPR Class B since the region of 30 to 120 MHz the absorber loaded room did exhibit reflections which affected the data. The absorber loaded room test used the standard two PC configuration while the open field test had only one PC in the field and the other in a Faraday cage, another valid configuration. The PC in the Faraday cage communicated with the first over an optical link.

Figures 2 and 3 show emission plots from 30 MHz. to 1 GHz. taken in the absorber loaded room for the UTP system and one of the STP systems (system C of Table 2) respectively. Both figures represent the raw data taken by the test engineer. For both systems, two PCs as well as the cabling and the LAM/CAU were in the anechoic room. The vertical line at 120 MHz. on both plots show the minimum frequency for valid data in the absorber loaded room.

The UTP system was well within the Class B limit of 30 dBuV/m over the range of 120 MHz. to 230 MHz. whereas the STP system was well above the limit over the same frequency range. From this data, the STP system, which has a few peaks very close to the Class A limits near 120 MHz. and 200 MHz., may even be failing Class A! Both systems appear to pass above 230 MHz.

Table 3 summarizes the results for the absorber loaded room test with two PCs, cabling, and the LAM/MAU in the room. The data, above 120 MHz., shows that the UTP system and several STP configurations pass the Class B limits. Those STP configurations that pass used a filter on the data leads. For one configuration of STP System C and STP System E, the Class B limit was exceeded by more than 10 dB at 208 MHz. indicating a Class A failure as well. It is likely that common mode noise from the PC interface board flowing on the cable shields is possible for some of the failures on STP configurations.

Table 4, an actual page from the test report, shows the radiated results in the open field using one PC in the measurement field and the UTP cabling system. The right-hand most column labeled "QP" are the quasi-peak radiation numbers in dBμV/m and range from 13.8 to 27.2. In all cases, the configuration passed.

With minor changes to the UTP system, the radiation could be reduced further, although the test shows that this is not necessary.

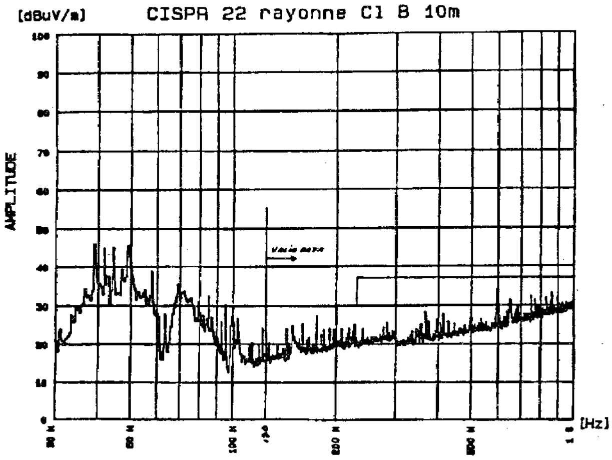

Figure 2 - Emissions Plot for UTP System

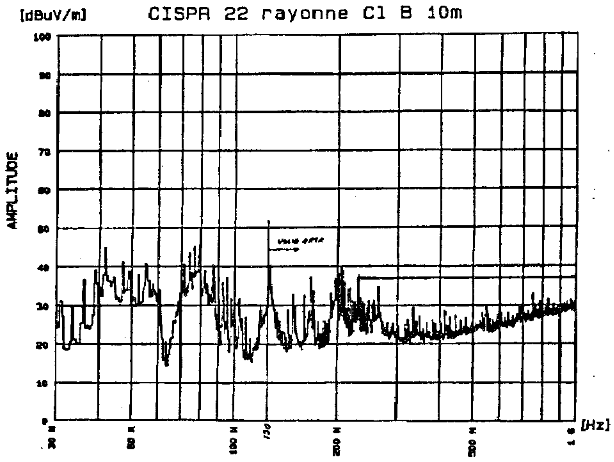

Figure 3 - Emissions Plot for STP System C

Cabling system	System A (STP)	System A (STP)	System B (UTP)	System C (STP)	System D (STP)	System E (STP)	System F (STP)	System F (STP)
Outlet Cord Shield	none	none	none	present	none	none	present	none
Adapter/filter on PC	4/16 TR	none	370C1	none	4/16 TR	4/16 TR	none	4/16 TR
Adapter/filter (IBM8230)	none	none	372A	none	none	none	none	none
Notes		poor shield at patch panel		no shield at patch panel				
Errors threshold level +	1000	750	1500	1000	1000	1000	1000	1000
Errors threshold level -	1000	750	1500	1000	1000	1000	750	1000
Ring failure level +	3000	750	>4000*	1500	3000	2500	1000	3000
Ring failure level -	3000	750	>4000*	1000	3000	3000	750	3000

* limit of generator was 4000V

Table 2 - Electrical Fast Transient Results

Cabling System	Emission (above B)	Notes
A (STP)	*	4/16 TR filter
A (STP)	+6 dB at 192 Mhz	shielded
B (UTP)	*	370C1/372A
C (STP)	+9 dB at 168 MHz +11 dB at 208 MHz	shielded
D (STP)	*	4/16 TR filter
E (STP)	*	4/16 TR filter
F (STP)	+5 dB at 152 MHz +12 dB at 197 MHz	shielded
F (STP)	+4 dB at 197 MHz	4/16 TR filter
F (STP)	*	4/26 TR filter horizontal pol
F (STP)	+5 dB at 200 MHz	4/16 TR filter Token ring off
F (STP)	+5 dB at 197 MHz	4/16 TR filter ring and 8230 off

* data not taken under 120 MHz

Table 3 - Radiated Emission Results for Anechoic Room
(Two PCs in field)

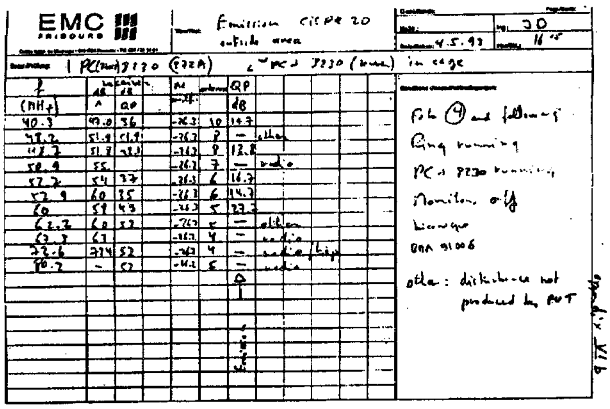
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Table 4 - Radiated Emission Results for Open Field
(One PC in field)

IV. CONCLUSIONS

The data presented clearly shows that the use of a shielded twisted pair cabling system for data does not necessarily yield advantages over an unshielded system. Also STP systems may even carry significant operational disadvantages in addition to the cost of the cable. The IEC 801-4 results are a case in point. In all of the shielded systems, the LAN crashed at some test level requiring rebooting of the PCs. The unshielded system did not exhibit such behavior even at the highest level obtainable from the burst generator.

The radiated emission results, either in the absorber loaded room or the open field test, indicated that the UTP system passed Class B at all frequencies and in several different configurations. Some of the shielded systems grossly violate even the Class A limits for the 16 Mbit Token Ring System. This significant result helps pave the way for widespread use of UTP systems in Europe and dispels the myth that use of a shield automatically affords electromagnetic compatibility to a data communications system.

It is clear that using a shield in a cabling system for data transmission can give a false sense of security. What really matters for both unshielded and shielded systems is good design. The design of the unshielded system tested was such that it equaled or exceeded the performance of all of the shielded systems tested.

IV. AREAS FOR FURTHER WORK

The exact mechanism that caused the PCs using the STP cabling systems to crash during the IEC 801-4 test should be determined. My thought is that the cable shield conducted the noise into the PC through slots near the data connector and corrupted logic circuits inside the PC. The media adapter used in the UTP cabling system prevented this from happening.

If this effect is confirmed, it could point to possible design improvements in the shielded systems tested and in the PCs. These design improvements might bring the shielded cabling system performance in the IEC 801-4 test up to the level of the unshielded system tested.

That level of performance could be a moving target. Improvements in UTP systems, such as common mode terminations at the PCs, could improve performance still further.

REFERENCES

[1] The Guide to the EMC Directive 89/336/EEC, Chris Marshman, 1992, IEEE Press, ISBN 0-7803-0445-4, pp.137-154.

[2] The Guide to the EMC Directive 89/336/EEC, Chris Marshman, 1992, IEEE Press, ISBN 0-7803-0445-4, pp.154-161.

[3] The Guide to the EMC Directive 89/336/EEC, Chris Marshman, 1992, IEEE Press, ISBN 0-7803-0445-4, pp.80-82,85-92.