Two Sided Earthing Versus one Sided Earthing for Ethernet Cables

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***Abstract*—The discussion about the earthing method of Shielded Twisted Pair (STP) cables never stops. There is a difference in opinion between Local Area Network (LAN) equipment manufacturers and Electromagnetic Compatibility (EMC) specialists. LAN equipment manufacturers state that the cable screen should only be earthed on one side of the cable, because it can prevent a ground current loop. EMC specialists advise multi-point earthing, since it is the best way to increase immunity to different kinds of disturbances. To find out which earthing method gives better results, a few measurements are performed. Three kinds of test methods are used: a direct current injection (50 Hz) test, an electric fast transient bursts (EFT-B) test with a capacitive clamp and a continuous wave (CW) test using an Electromagnetic (EM) clamp.**

I. Introduction

Shielded cables are often used in harsh environments to improve the level of immunity against Electromagnetic Interference (EMI) [1]. As an example take naval ships, in these kinds of environments Electromagnetic Compatibility (EMC) specialists advise to connect the screen of the cable on both sides to the common reference [2]. Local Area Network (LAN) equipment manufacturers state however that the screen should only be connected to one side of the cable. The reason for this single-ended earthing, they state, is to prevent ground current loops [3].

Cable screens which are only bonded at one end cease to provide shielding when their length exceeds one-tenth of the wavelength of the frequencies to be shielded against. For example, a cable with a length of 10 meter only provides any significant shielding for frequencies below 3 MHz. When cable lengths exceed one-quarter of a wavelength, shields which are bonded at only one end can even become very efficient Radio Frequency (RF) antennas, radiating RF noise and picking up RF from the environment more efficiently than if there was no shield at all [4].

Unfortunately, from the above it might be concluded that there is an impasse. Products, systems and installations that use single-ended earthing will avoid Common Mode (CM) current but fail EMC compliance. Or they use both-ended earthing and achieve EMC directive compliance but lose the guarantee from the manufacturer [5], [6]. The best practices to use for earthing and cabling to achieve EMC in installations are described in [7]. However that is not a standard but a practice. Applying the techniques described in it require that the cable screen is directly earthed to the low-impedance enclosure, at each end of the cable. Regrettably, the above screen earthing technique is not used often and is certainly not common practice. This is often caused by a third party, i.e., the equipment provider, who imposes other conditions, i.e. applying a single point earth for eliminating and reducing ground loops in the shielded cable.

Nowadays, the discussion still exists; to earth the LAN cables (Ethernet cables) with single-ends or with both-ends. The recommendation from ICT suppliers vary from using Unshielded Twisted Pair (UTP) or Shielded Twisted Pair (STP) with single-ended earthing, or with both ended earthing, but how to integrate the equipment from different suppliers in one network and meet the requirement of the EMC specialists? To find out which earthing method gives better results, a few measurements are performed. Three kinds of test methods are used: direct injection by 50 Hz, Electric Fast Transient Bursts (EFT-B) tests with a capacitive clamp, and Continuous Wave (CW) tests with an Electromagnetic (EM) clamp. During the measurement the goodput transmitted by Ethernet [8] is used as a reference to check if the data transmission is affected by the generated interference. The goodput is the amount of useful data that can be processed by a system when operating at maximum capacity and which is received at the correct destination address, excluding packet headers and duplicate transmissions. In the first measurement, the 50 Hz (CM) current, is directly injected to the cable screen. This is done to find out if the ground current loop really influences data transmission. The other two measurements are selected, because EFT-B and CW are the most common disturbances in harsh environments. An EFT-B disturbance is primarily generated by switches and relays while also pulse width modulation (PWM) can cause similar disturbance. CW disturbance is caused by the antenna transmitters. Tests were done on different types of cables, the results give reason to why EMC specialists advise to connect the cable screen on both sides.

This paper starts off with elaborating on the setup which was used for each measurement. This section is subdivided in the three different tests, 50 Hz injection, EFT-B and CW. This is then followed by by the results which holds the same structure. After this a conclusion of the paper is presented.

II. MOTIVATION

The reason for using shielded cables is the protection it has against the electric and magnetic fields coupling in. In Fig. 1 the effect of a shield on the loop area of a circuit is illustrated. The area of interest is the total area enclosed by the flowing current in the circuit, where the protection is provided when this area decreases. In Fig. 1B a shielded cable earthed at both sides is shown, where the area decreases compared to the area in Fig. 1A. On the other hand, if the shielded cable is only earthed at one side, as shown in Fig. 1C, the loop area does not decrease significantly. This means that the shield provides no magnetic protection due to no significant reduction of the area. This is one of the reasons EMC specialists prefer Fig. 1B, with the both-ended earthing.

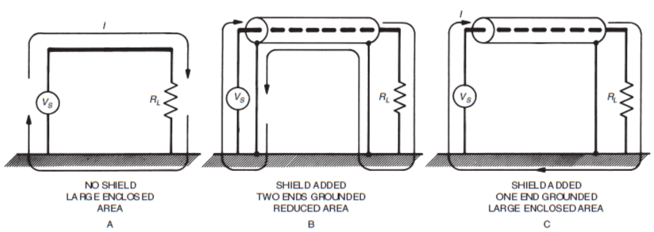

Fig. 1: Effect of shield on receptor loop area [2]

With two sided earthing a noise current can occur in the screen however, due to potential differences between the two shield ends or a time-varying magnetic field, resulting in the often feared ground loop currents [9]. Ground loops carry the CM currents which is a major cause of EMI problems. The major contribution to emissions are due to CM currents, which are approximately 50 dB higher than emissions caused by Differential Mode (DM) currents [10]. Due to the possibility of introducing noise into the signal circuit, LAN equipment manufacturers want to avoid this ground loop. For this reason LAN equipment manufacturers advise to use the one sided earthing which was shown in Fig. 1C. However as frequency increases, the one sided earthing will get other problems, since the cable (screen) becomes a very efficient antenna. Furthermore, at frequencies above about 100 kHz, parasitic capacitance tend to still complete the ground loop, where control of where the currents run is lost [2].

When the cable shield is connected at two sides, a Faraday cage is formed. The electric and magnetic fields will not interact with the signal wires, since the electric field lines are terminated on the cable screen. A changing magnetic field will induce a loop of an electrical current within the conductor, which is called an Eddy current according to Faraday's law of induction. By Lenz's law, an Eddy current creates a magnetic field that opposes the change in the magnetic field that created it. Thus Eddy currents react back on the source of the magnetic field, which result in better immunity.

III. MEASUREMENT SETUP

In this section every test setup will be described, 50 Hz injection, EFT-B and CW.

A. 50 Hz Injection Test

The 50 Hz injection test is performed to investigate if a low frequency CM current on the shield of the cable will disturb a transmission. As previously mentioned, a CM current will occur when a conductor (cable screen) is connected to at least two points, that do not have the same potential (ground/earth) or when it is exposed to a time varying magnetic field. It will form a ground loop with an unwanted CM current. The measurement exists out of two parts, for the first part, cables will be injected with a current ranging from 1 A to 10 A. For the second part all the Equipment Under Test (EUT), either switches or computers, will be tested with a current limited up to 1 A.

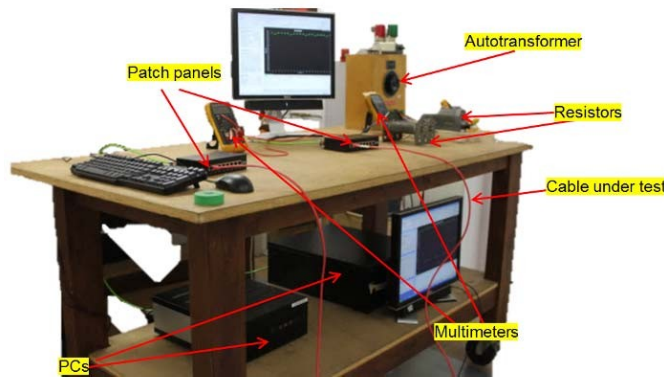

Fig. 2: Cable setup for 50 Hz injection test

1) Cable: For the test, two computers communicate with each other over an Ethernet connection, which consists of two patch panels as shown in Fig. 2. The computers are connected to the patch panels via UTP cables, where different cables are used between the patch panels. On the cable screen of these cables a 50 Hz CM current is injected using an autotransformer and resistors, see Fig. 3. The network goodput is measured with the program Jperf. The test begins at 1 A and increases in steps of 1 A up to 9 A. After every step of 1 A, the data traffic will run for 20 s. If everything is in order, meaning the goodput of data is not reduced during these 20 s, the current will be increased to the next current level and the same process is repeated up to the limit.

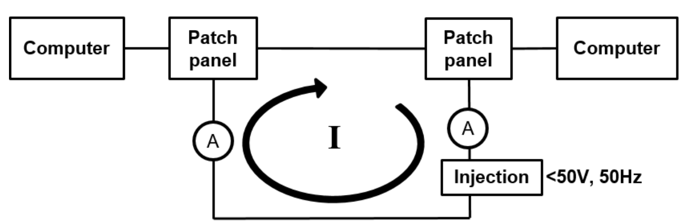

Fig. 3: Diagram of cable setup for 50 Hz injection test

2) Switch: During these measurements, the current is limited to 1 A, to avoid damage of the equipment. The measurement begins at a current level of 200 mA and is increased up to 1000 mA in steps of 200 mA. After every step the data traffic will run for 20 s. Two different types of EUT (switches and computers) are used in two different test setups, see Fig. 4 and Fig. 5. The test setups are kept similar to get comparable results. For the measurement where the switch was used, the entire measurement setup is exactly the same as the cable test, except that a patch panel is replaced by a switch. Switches from different manufacturers are measured, the cable between the switch and the patch panel is not changed during the whole measurement.

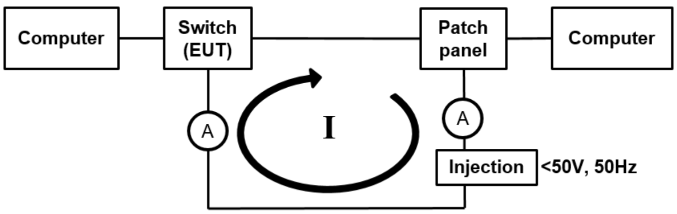

Fig. 4: Diagram of switch setup for 50 Hz injection test

3) Computer: This measurement was repeated when the computer was connected to the patch panel without a switch in between, effectively making the computer part of the current loop. The other computer is connected to the patch panel with a UTP cable like in all the other tests. The computer under test is connected using an STP cable.

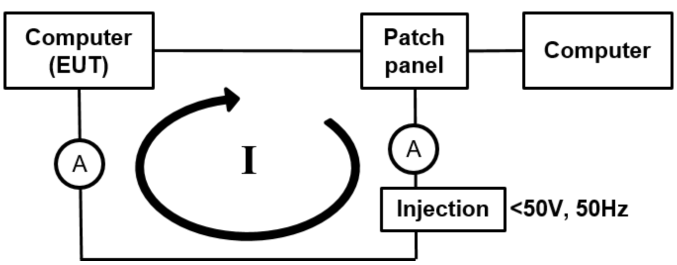

Fig. 5: Diagram of computer setup for 50 Hz injection test

B. Electrical Fast Transient - Burst (EFT-B) Test

The effects of an EFT-B in an Ethernet setup are investigated in order to get more insight in the coupling and interference mechanisms in a typical Ethernet installation. An earlier study [11] showed that EFT-B's are very effective in causing interference and loss of data on Ethernet cables. Observed effects are partial or complete loss in throughput during exposure and complete loss of connection. In paper [11], UTP cables were compared with STP cables when the screens were earthed on both sides. From this paper it was found that screened cables (STP) help to mitigate the interference.

This test is performed in accordance with IEC 61000-4-4, where the settings of the EFT-B generator are:

- Polarity: positive and negative
- Repetition frequency: 5 kHz ± 20%,
- Burst duration: 15 ms ± 20%, 5 kHz
- Burst period: 300 ms ± 20%
- Peak voltage: from 200 V up to 4.4 kV ± 10%
- Rise time t_r 10% ... 90% (50 Ω load): 5 ns ± 30%
- Pulse width t_d 50% level (50 Ω load): 50 ns ± 30%.

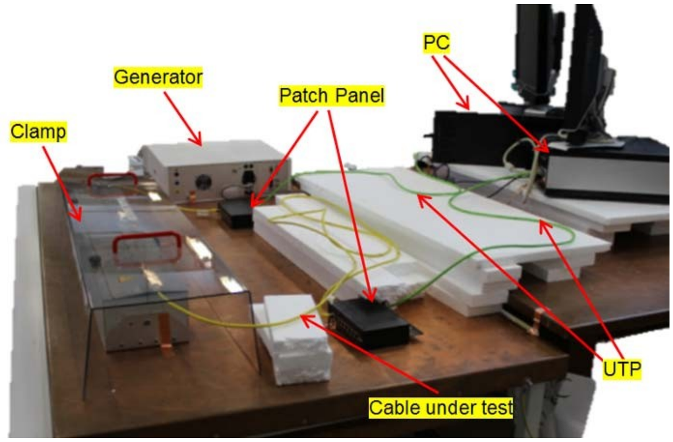

Fig. 6: Cable setup for EFT-B test

1) Cable: For the measurements of cables, two computers communicate with each other over an Ethernet connection, which consists of two patch panels. The computers are connected to the patch panel via UTP cables. Different cables are used between the patch panels. The cable is exposed to an EFT-B using an EFT-B generator and a capacitive coupling clamp. The patch panels and clamp are placed on an earth reference plane, see Fig. 7 and the network goodput is measured with the same program as during the previous test. For the cables two different situations are established, one sided earthing and two sided earthing. When one sided earthing is tested, one of the patch panels is placed 10 cm above the reference plane without earthing it. For two sided earthing, the patch panels are directly placed on the reference plane and earthed to it as shown in Fig. 6.

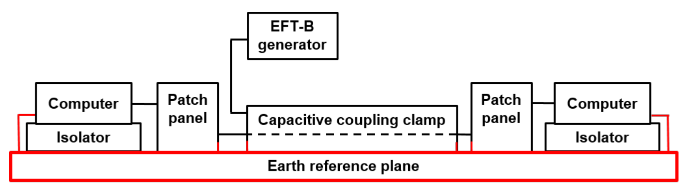

Fig. 7: Diagram of cable setup for EFT-B test

2) Switch: Fig. 8 shows the diagram of the test setup which was used to test the switches. The switch is placed on the side where the generator is connected to the clamp [12]. Two computers are still used as auxiliary equipment. Patch panels are used to decouple the computers and the ferrite cores are added to protect the computers.

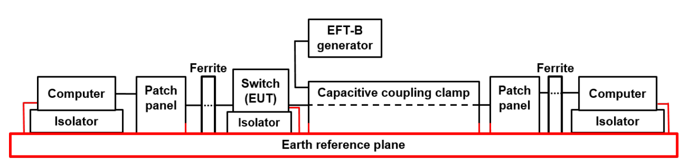

Fig. 8: Diagram of switch setup for EFT-B test

3) Computer: The test setup which was used to test the computers is illustrated in Fig. 9 . The generator was connected to the end of the clamp which is nearest to the EUT as required by the standard [12]. The STP or UTP cable which passed through the clamp is directly connected to the EUT. The other computer is protected with ferrite cores and decoupled with a patch panel.

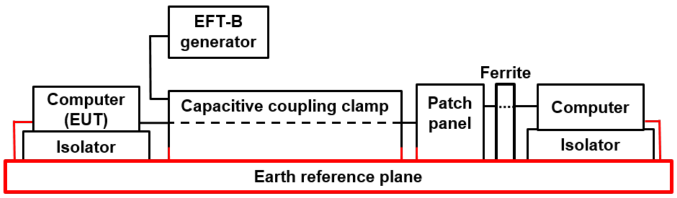

Fig. 9: Diagram of computer setup for EFT-B test

C. Continuous Wave Test

The principle of this test is to inject RF frequencies to the EUT with combined capacitive and inductive coupling. The test is performed according to the standard IEC 61000-4-6 [13]. It applies an RF disturbance signal over the frequency range from 150 kHz - 80 MHz on the cables to the EUT to determine the immunity level. In the applied test set-up, an EM clamp is used to perform the measurements. The advantage of the injection clamps in contrary to the Coupling Decoupling Network (CDN) is the non-invading character of the coupling [14]. More important, with the EM clamp injection low impedance between the cable screen and earth can be maintained which is not possible when a CDN is used. Since the purpose of the test is to check the effectiveness of a low impedance earth connection between earth and the cable screen a CDN cannot be used. This is due to the fact that the screen will first be connected to a defined impedance of the CDN, and then to the earth, resulting in a reduction of the screen current and an increase in the screen voltage.

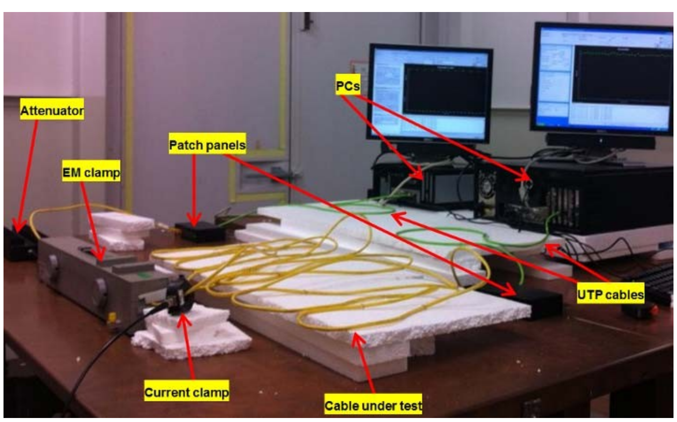

Fig. 10: Cable setup for CW test

The setting of the generator:

- Frequency range: 150 kHz - 80 MHz
- Amplitude modulation: Internal, 80% $\pm$ 5% in depth, 1 kHz $\pm$ 10% sine wave
- Frequency step: 5% of the preceding frequency value
- Test level: 30 V, 50 V, and 70 V (unmodulated RMS)
- Dwell time: 500 ms

1) Cable: The test bench of the cable test setup with two sided earthing is given in Fig. 10. The two patch panels are directly placed on the earth reference plane and earthed on it. Two computers, which are auxiliary equipment in this setup, are used to create the data traffic and to measure the goodput. They are placed on an insulating support 10 cm above the earth reference plane and decoupled with a CDN from the mains, this is to prevent the disturbance signal from entering the mains through the computers. The CDN is directly placed on the earth reference plane and is earthed on it. Between the computers and the patch panels, UTP cables are used and the EM clamp is placed on the earth reference plane and earthed on it. Fig. 11 shows the diagram for the situation where the cable is earthed on one side and Fig. 12 shows the situation where the cable is earthed on two sides.

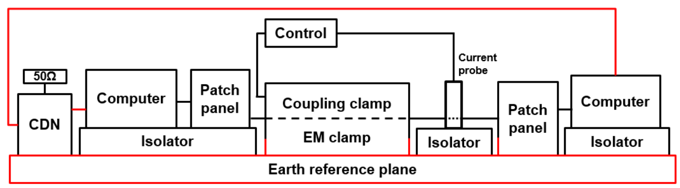

Fig. 11: Test setup cable with one sided earthing for CW test

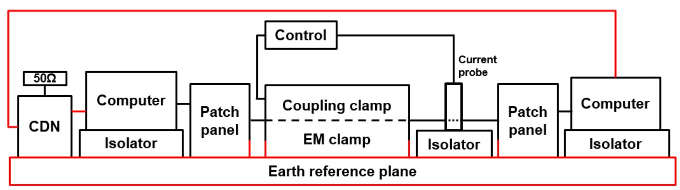

Fig. 12: Test setup cable with two sided earthing for CW test

2) Switch: The test setup for a switch is not changed too much compared to the previous cable test. The switch is placed between the patch panels and the power input of the switch is decoupled with a CDN from the mains. The ferrite cores are added to protect the computers and to make sure that a significant part of the disturbance flows to the switch. Every switch is tested with two kinds of cables (UTP and STP) and the current clamp needs to be placed between the EM clamp and EUT as shown in the diagram Fig. 13.

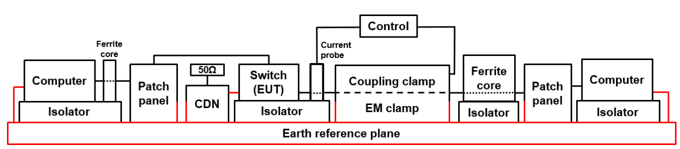

Fig. 13: Diagram of switch setup for CW test

3) Computer: Fig. 14 shows a diagram of the test setup of the computer. The computer which is the EUT will be decoupled with a CDN from the mains and the current clamp must be placed between the EUT and the EM clamp as shown in the setup. The ferrite cores and patch panels are used to protect the auxiliary equipment.

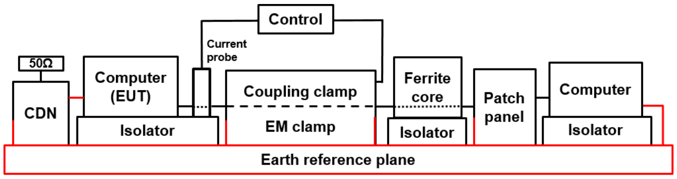

Fig. 14: Diagram of computer setup for CW test

IV. Results

In this section the results for every test will be described, 50 Hz injection, EFT-B and CW. For the measurements different cables, being either STP or UTP, have been used with different lengths.

A. 50 Hz Injection Test

For the 50 Hz injection test eight different STP Ethernet cables have been used. For all the cables under test the goodput did not reduce for any of the current levels. Two of the cables however, melted down from the inside at 8 A. The goodput up until this point remained the same, meaning that the ground current loop has no influence on the goodput of the STP cables, even at amplitude levels not expected in properly installed installations.

B. Electrical Fast Transient - Burst (EFT-B) Test

Fig. 15 shows the test results for the different cables used in the test. The graph shows the level of disturbance required in order to reduce the throughput. The maximum test voltage of the generator is 4.4 kV.

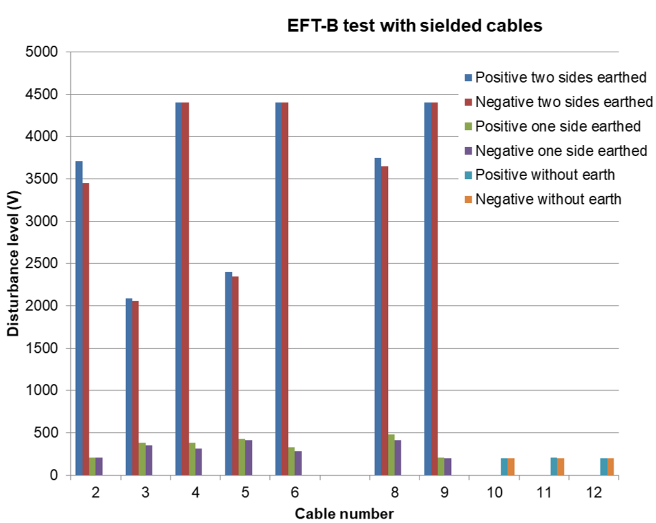

Fig. 15: Test results for all the cables used during the EFT-B test

The test results of the equipment, with the cable screen earthed at both ends if possible, are given in Fig. 16. Switch 3 gives extremely bad results, both with STP and with UTP cables. This is because this switch has a plastic enclosure, so it cannot be earthed anywhere. As a consequence there is no return path for the disturbance outside the circuitry.

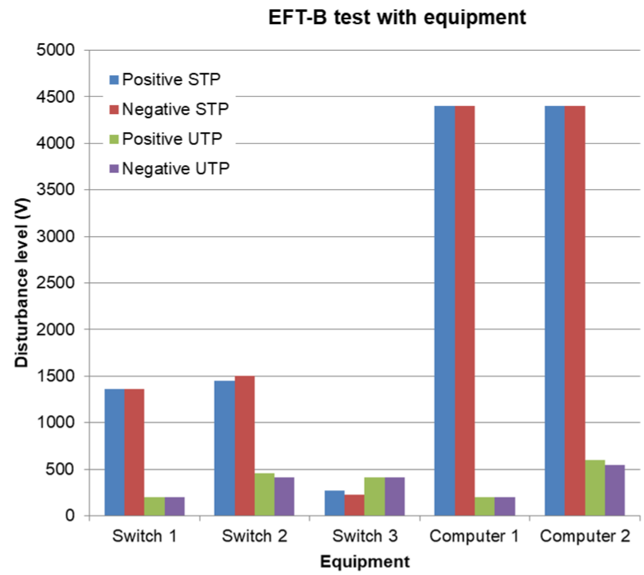

Fig. 16: Test results for all switches and computers during the EFT-B test

C. Continuous Wave Test

The interference level of this test is dependent on frequency and the voltage level. When a detrimental interference occurs at a certain frequency with 30 V, the same frequency will also have a detrimental effect with higher voltages. At these higher voltages, the interference might also occur at frequencies that are not harmful at 30 V. In this paper only the results with the test level of 30 V are shown. In Fig. 17, the blue bars indicate for which frequencies the goodput is reduced for a certain cable. The STP cable with the screen connected to earth at two sides gives the best results. Also STP cables with the screen connected at one side to earth give better results than the UTP cables.

Fig. 18 shows part of the test results of the EUT with a test level of 30 V. For almost all equipment the throughput is reduced at high frequencies (>20 MHz) when UTP cables are used. When STP cables are used, from which the cable screen is connected directly to earth at one side and through the EUT and a CDN at the other side, no problems occur.

V. Conclusion

The 50 Hz injection test has shown that concerns about ground loop 50 Hz CM currents over cable screens (enabled by earthing both screen ends) are unfounded since the CM current will not disturb the signal. For currents higher than 7 A there is a risk that the wires will melt, but these levels are not to be expected in real life. During testing this was observed, however data traffic (goodput) did not seem to be

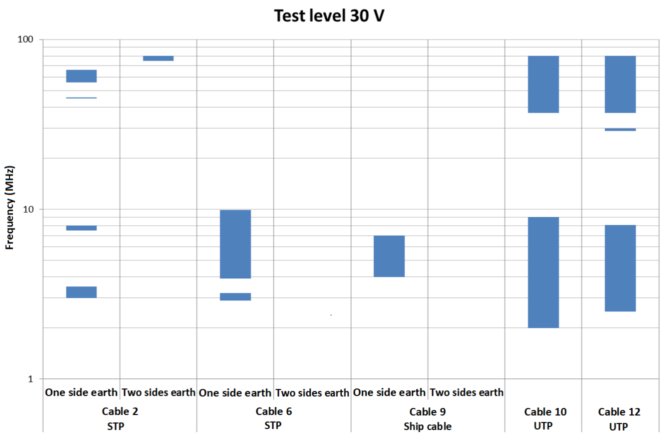

Fig. 17: Test results of all the cables used during the CW test

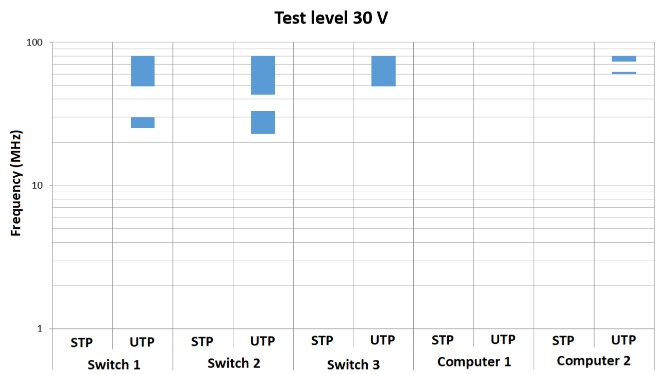

Fig. 18: Results of all the equipment used during the CW test

affected by the high CM current that was running over the cable screen.

The EFT-B test results have been compared for tests on UTP and STP cables in order to determine which type of cable can better withstand high frequency disturbances. For STP cables, both methods of earthing are also compared. The results show that STP cables with earthing at both-ends can withstand higher disturbance levels than all other tested configurations. The single-end earthed STP cables give similar results as an UTP cable. That means the screen of the cable, which was added for increased immunity is useless against EFT-B. This experiment proves the theory that earthing shielded cables on both cable ends, increases its immunity.

With the continuous wave test all the cables pass at a test level of 10 V, but with a higher disturbance level like 30 V, 50 V or even higher, the STP cables with two side earthing perform better than UTP cables or STP cables with only one sided earthing.

The overall conclusion of this paper is that the risk of interference on networking cables can be significantly reduced by using two sided earthing of cable screen. There still consist situations in practice however, where disconnecting the cable screen at one side leads to better results. In these cases however, we have the assumption that the cable screen is terminated at the PCB and not on the enclosure, which means that the crosstalk would occur within the equipment and not on the cable. The cable screens in the measurements performed in this paper were all terminated correctly on the enclosures to prevent crosstalk within the equipment. These seemingly contradicting situations should be correctly substantiated with further research.

ACKNOWLEDGMENT

The work presented in this paper is the result of the final bachelor-thesis project done at Amsterdam university of applied sciences. This project was facilitated by Imtech Marine, nowadays RH Marine, in Rotterdam the Netherlands.

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