Electromagnetic Couplings in Unshielded Twisted Pairs

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The present paper analyzes the Electromagnetic Compatibility for Unshielded Twisted Pair (UTP) Cables, recognizes crosstalk levels and relates a method that could be executed in the laboratory to find out the measurement of electromagnetic coupling. The mathematical model is coherent with the experimental results up to the break frequency, which is equivalent to one quarter of the wavelength.
Keywords: EMC Electromagnetic Compatibility, UTP Unshielded Twisted Pair, Crosstalk levels, electromagnetic couplings.

1. Introduction

Magnetic couplings in twisted pairs are produced by magnetic fields that depend on time varying currents. Electric couplings in twisted pairs are produced by electric fields that depend on time varying voltages. Electromagnetic coupling is the sum of both, magnetic and

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electric couplings, and it is originated from a transmitted circuit in the neighboring of the receptor transmission line.

The analysis of electromagnetic coupling is a common problem in Electromagnetic Compatibility because higher frequency signals produce higher radiations. The most important factor in the mechanism of electromagnetic interference is the operation frequency, which will be from 10 KHz to 100 MHz. At this range of frequencies, the electromagnetic couplings are called crosstalk. Crosstalk is the unintended induced coupling of two circuits, a transmitted pair and a receiver pair. The term of crosstalk is reserved for interferences that take place within the same cable, it means intrasystem.

There are two techniques to determine the performance of cables, according with the location of the measure reference, either the nearest end or the farthest end of the source.

2. Simulation of Electromagnetic Coupling

Crosstalk in twisted pair cables has been simulated considering the following conditions:

- The propagation wave mode must be transverse.
- The line length (L_{LT}) has been divided in strands.
- Every strand is constituted in two half strands.
- There are mutual inductances that model magnetic coupling in each half strand (L_m).
- There are mutual capacitances that model electric coupling in each half strand (L_m).
- The model approximates the crosstalk behavior, connecting both; mutual inductances and mutual capacitances in cascade.

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- The physical length of the transmission line must be greater than its electrical length.

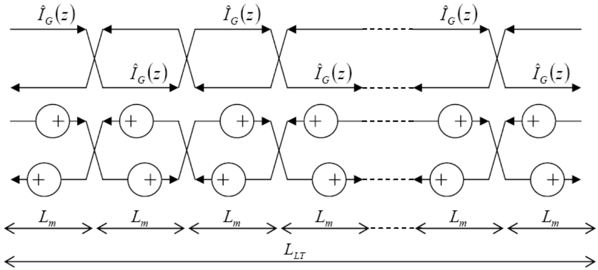

Figure 1. Magnetic Coupling in UTP.

Simulation has been based in the lump-circuit transmission line model, similar to the configuration in the work of Paul and McKnight [1,2], where mutual inductances can be represented by current source placed in serial, meanwhile mutual capacitances can be represented by voltage sources placed in derivate.

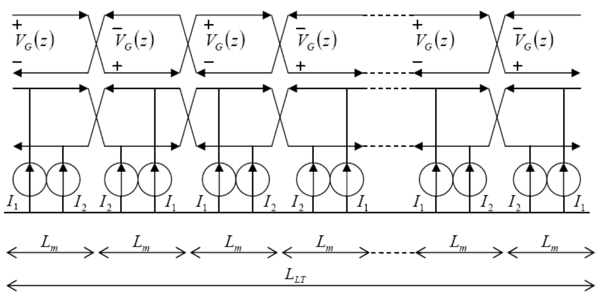

Figure 2. Electric Coupling in UTP.

Mutual inductance can be calculated as follows [3]

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$$\mathrm{l}_m = \frac{\mu}{2\pi}\ln\left|\frac{d_{G0}d_{R0}}{d_{GR}r}\right| \tag{1}$$

Mutual capacitance can be calculated as follows [3]

$$c_m = \frac{2\pi\varepsilon}{\ln\left|\frac{d_{G0}d_{R0}}{d_{GR}r}\right|} \tag{2}$$

where: d_{G0} is the distance from generator until reference, d_{R0} is the distance from receptor until reference, d_{GR} is the distance from generator until receptor, r is the radius of the conductor, l_m is the mutual inductance, and c_m is the mutual capacitance.

The voltage that represents each half strand source in the figure 1 is:

$$E = j\omega \cdot l_m \cdot L_m \cdot I_G\left(z\right) \tag{3}$$

The current that represents each half strand source in the figure 2 is:

$$I = j\omega \cdot c_m \cdot L_m \cdot V_G\left(z\right) \tag{4}$$

Both figures 1 and 2 show a transmitted circuit on the upper side, a receiver circuit on the down side, and current or voltage references that are varying each half strand [3]. Crosstalk results on electromagnetic energy induced by a transmitted pair through a receiver pair.

The generator pairs are identified as the blue color pair and the receptor pairs are identified as the orange, green and brown color pair.

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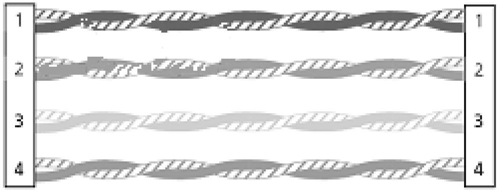

Figure 3. Assignation of Pairs in UTP cable.

In order to solve the differential equation system that contains constant coefficients, the twisted pairs have been represented by half strands. The strands are considered as uniform section with a physical length L_m and are connected in cascade, so that will approximate the behavior of the twisted pair if it solves the sum of the half strands.

Crosstalk levels are function of the source and load impedances on the transmitted circuit. In the case of the receiver circuit, there are two impedances: the near end side and the far end side, from the generator point of view. The point of reference, which must be specified at either beginning or ending side of the line, would be presented as near-end crosstalk or far-end crosstalk, respectively.

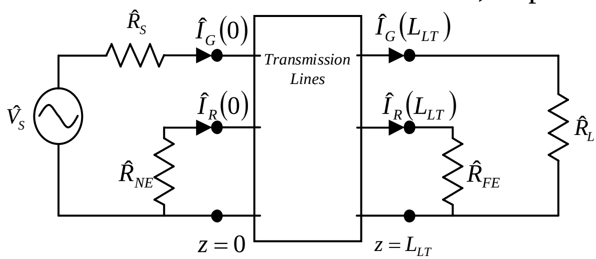

Figure 4. Configuration of Multi-transmission Lines.

The generator source that is located in the blue color pair it's going to be incorporated on the crosstalk solutions. The inductive coupling

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is proportional to the current of the source; meanwhile the capacitive coupling is proportional to the voltage of the source.

$$I_G = \frac{1}{R_S + R_L} V_S \tag{5}$$

$$V_G = \frac{R_L}{R_S + R_L} V_S \tag{6}$$

The solutions for the configuration of multi-transmission lines are two equation systems [5]: a matrix for the nearest end and a matrix for the farthest end, because of the source point of view.

$$\hat{V}(0) = \hat{V}_s - \hat{R}_S \hat{I}(0) \tag{7}$$

$$\hat{V}(L_{TL}) = \hat{R}_L \hat{I}(L_{TL}) \tag{8}$$

We have three receptor pairs, so it will obtain three equation systems, one per receptor conductor. The reference conductors can be the return thread for each twisted pair, and it will be grounded at the generator.

2.1. Near-End Crosstalk (NEXT)

NEXT is the coupled interference signal coming from the adjacent cable at the nearest end. The effects of NEXT are proportional of electromagnetic coupling that will be described as inductive and capacitive.

The inductive coupling is given as follows:

$$V_{NEXT}^{ind} = \frac{R_{NE}}{R_{NE} + R_{FE}} \cdot \frac{1}{R_S + R_L} \, j\omega \left(l_{m1} - l_{m2} \right) L_{LT} V_S \tag{9}$$

The capacitive coupling is given as follows:

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$$V_{NEXT}^{cap} = \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} \cdot \frac{R_L}{R_S + R_L} j\omega \cdot c_m L_{LT} V_S \tag{10}$$

2.2. Far-End Crosstalk (FEXT)

FEXT is the coupled interference signal coming from the adjacent cable at the farthest end. The effects of FEXT are proportional to electromagnetic coupling that will be described as inductive and capacitive.

The inductive coupling is given as follows:

$$V_{FEXT}^{ind} = \frac{R_{FE}}{R_{NE} + R_{FE}} \cdot \frac{1}{R_S + R_L} j\omega \left(l_{m1} - l_{m2} \right) L_{LT} V_S \tag{11}$$

The capacitive coupling is given as follows:

$$V_{FEXT}^{cap} = \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} \cdot \frac{R_L}{R_S + R_L} j\omega \cdot c_m L_{LT} V_S \tag{12}$$

2.3. Simulation Results

- The numerical solutions are given by two plots, the first one is representative of NEXT and the second one is representative of FEXT. The input data required for the computational programs are:
- Source Voltage, V_S= 1 Volt.
- Near-end Blue Pair Impedance, R_S= 50 Ohms.
- Far-end Blue Pair Impedance, R_L= 50 Ohms.
- Near-end Orange Pair Impedance, R_{NE}= 50 Ohms.
- Far-end Orange Pair Impedance, R_{FE}= 50 Ohms.
- Near-end Green Pair Impedance, R_{NE}= 100 Ohms.

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- Far-end Green Pair Impedance, R_{FE}= 100 Ohms.
- Near-end Brown Pair Impedance, R_{NE}= 1 Ohm.
- Far-end Brown Pair Impedance, R_{FE}= 1 Ohm.

The x-axis has been represented by the frequency on MHz units and semi logarithm scale. The y-axis has been represented by the coupling intensity on dB units.

The figure 5 describes the electromagnetic coupling for 10 meters in unshielded twisted pair category 5.

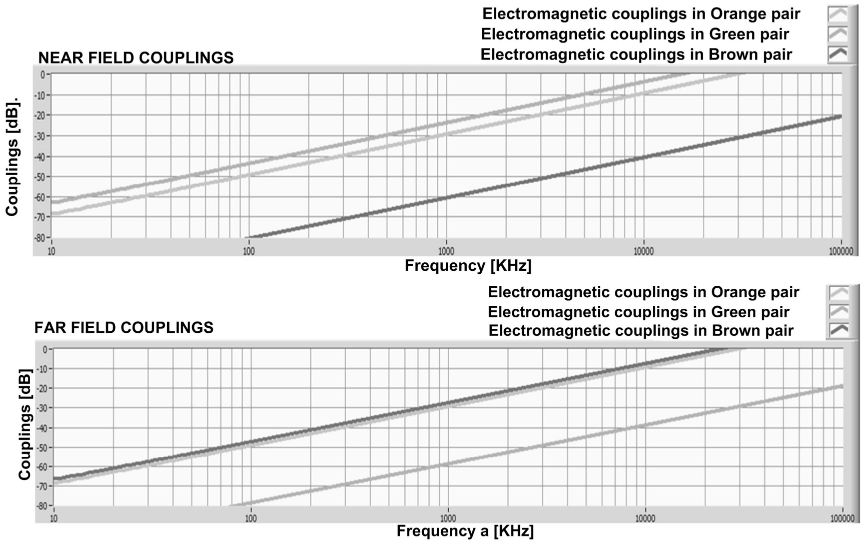

Figure 5. Electromagnetic Coupling for 10 meters in UTP

The figure 6 describes the electromagnetic coupling for 25 meters in unshielded twisted pair category 5.

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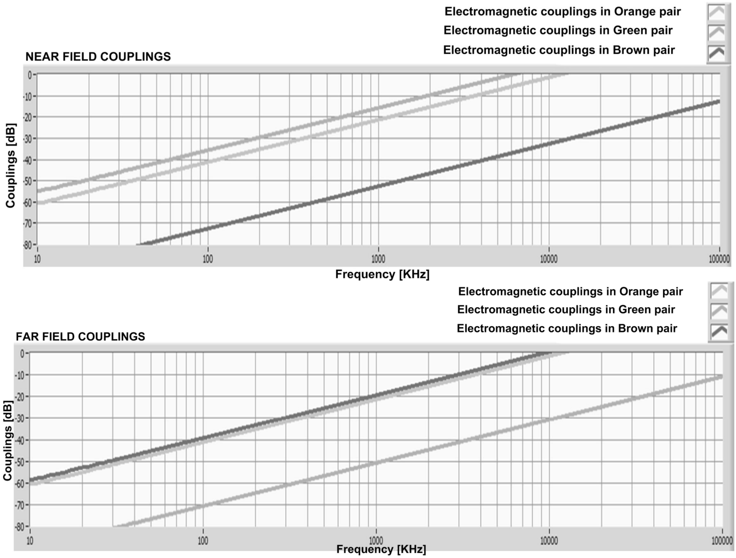

Figure 6. Electromagnetic Coupling for 25 meters in UTP

The figure 7 describes the electromagnetic coupling for 200 meters in unshielded twisted pair category 5.

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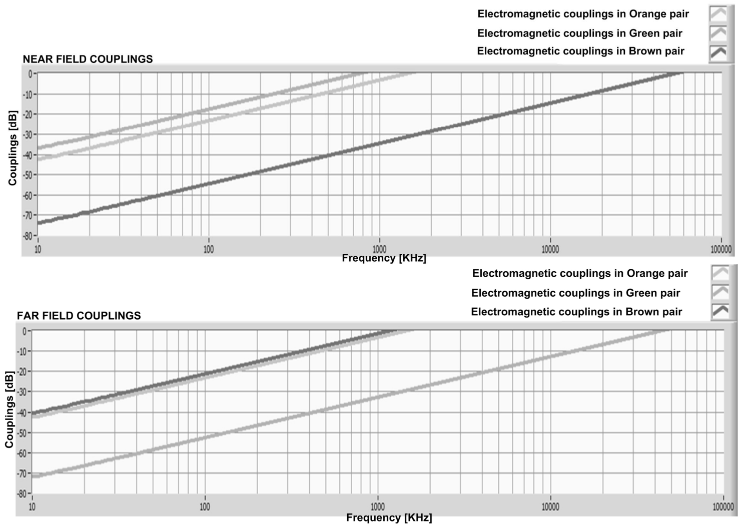

Figure 7. Electromagnetic Coupling for 200 meters in UTP

The color traces represent the crosstalk behavior from the receiver pairs: orange, green and brown, respectively. All the traces increase by factor 20 decibels per decade in frequency.

3. Experimental Development

The purpose of the measurement in laboratory is to recognize the break frequency at which, electromagnetic coupling can reach higher levels for a particular physical length.

The experimental setup that has been used to measure NEXT is explained in the figure 8.

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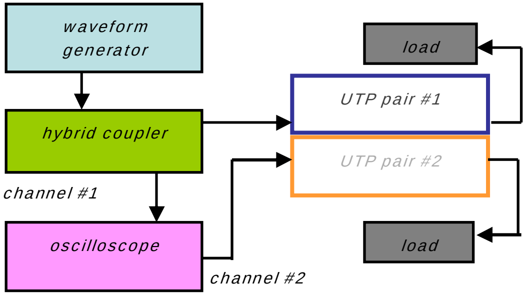

Figure 8. Setup of NEXT Measurements

The generator voltage is registered on channel 1 and the induced voltage in reference pair which is located in the nearest side, is registered on channel 2. The figures 9, 10 and 11 show the interference level for 10, 25 and 200 meters, respectively.

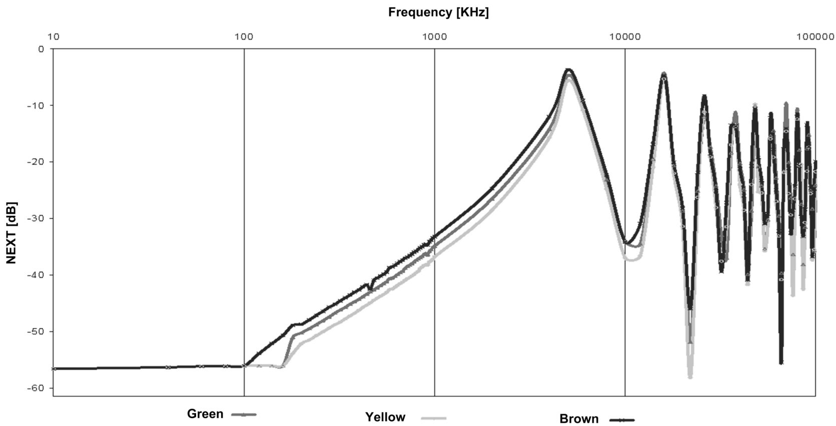

Figure 9. Measurements of NEXT Levels for 10 Meters

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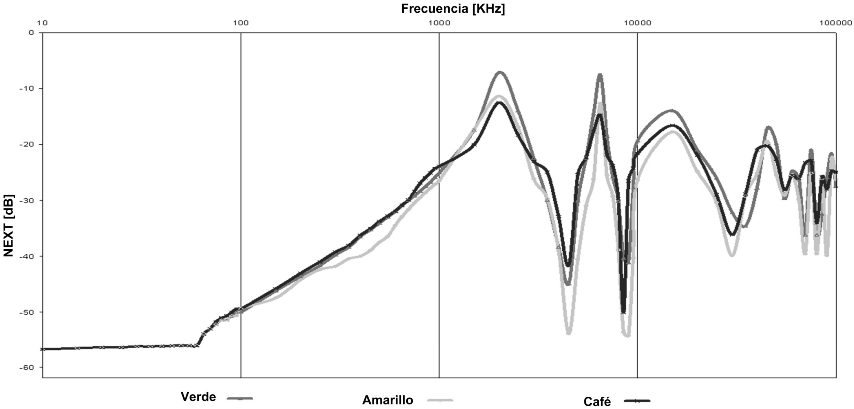

Figure 10. Measurements of NEXT Levels for 25 Meters

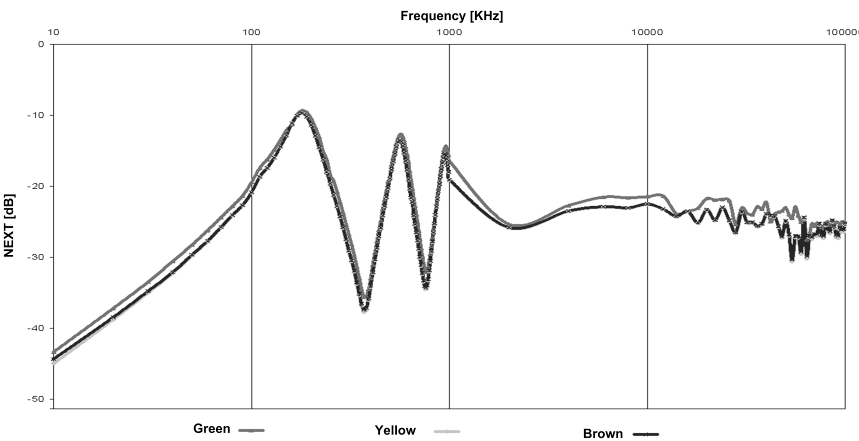

Figure 11. Measurements of NEXT Levels for 200 Meters

The experimental set up that has been used to measure FEXT is explained in the figure 12.

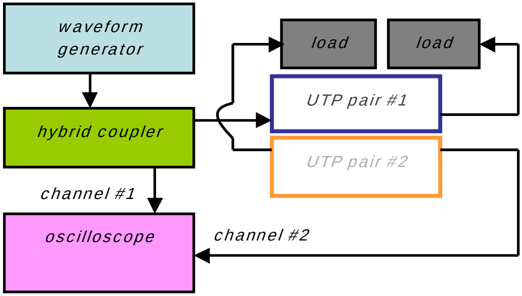

Figure 12. Setup of FEXT Measurements

The generator voltage is registered on channel 1 and the induced voltage in reference pair which is located in the farthest side, is registered on channel 2. The figures 13, 14 and 15 show the interference level for 10, 25 and 200 meters, respectively.

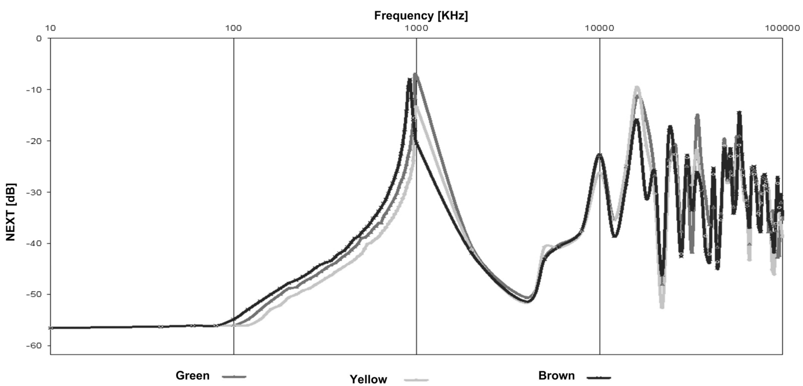

Figure 13. Measurements of FEXT Levels for 10 Meters

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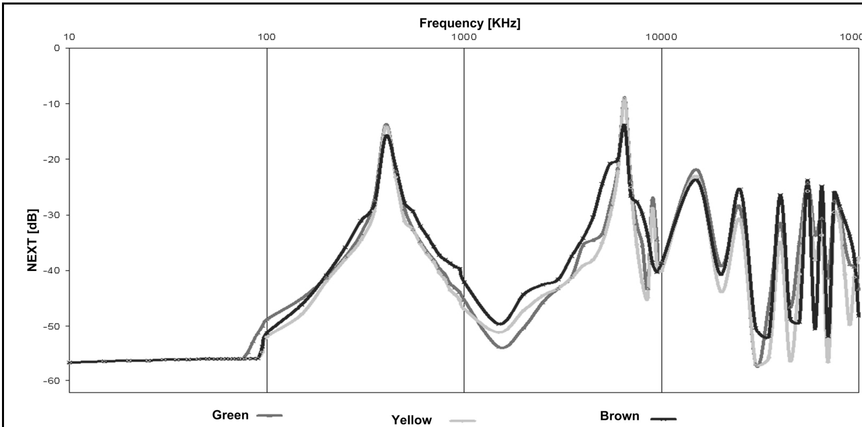

Figure 14. Measurements of FEXT Levels for 25 Meters

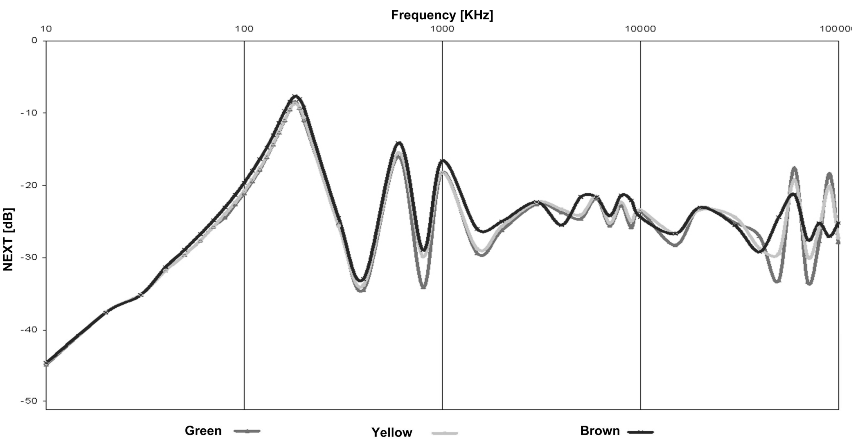

Figure 15. Measurements of FEXT Levels for 200 Meters

The value of the load used on the test was 50 ohms. The interference intensity that was indicated on the measurement plots were determined as follows

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$$dB_{NEXT} = 20 \cdot \log_{10}\left(\frac{V_{NEXT}}{V_{generador}}\right) \tag{13}$$

$$dB_{FEXT} = 20 \cdot \log_{10}\left(\frac{V_{FEXT}}{V_{generador}}\right) \tag{14}$$

4. Discussion and Conclusions

The analysis of electromagnetic couplings on UTP cables is divided into two sets of test parameters: near-end crosstalk and far-end crosstalk.

The crosstalk levels in UTP cables have been modeled by chain matrix based on a number of strands that describe parameters per unit length connected each other in cascade.

The factors that affect electromagnetic couplings [5] are: mutual inductance, mutual capacitance, source and load impedances on generator circuit, near end and far end impedances on receptor circuit, physical length and frequency.

Both mutual inductance and mutual capacitance can be determined by geometric dimensions. They are considered as constants.

The magnetic coupling is proportional to the source impedance. However, the electric coupling is proportional to the load impedance.

Both, near-end and far-end impedances on the receptor circuit affect NEXT and FEXT respectively. Now, once an associated topological network has been installed over UTP cables, it is kind of difficult to change impedance values. Therefore, impedances are considered as constants.

The simulation plots and the measurements results graphics have shown that electromagnetic coupling tendency increases by factor 20 decibels per decade in frequency. Even though, higher physical

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length corresponds to find readily the break frequency that implies the worst performance in the transmission line.

In terms of electromagnetic interference, higher the frequency, higher is the noise coupling in the receptor.

The relationship between physical length and frequency gives the way to calculate the break frequency:

$$f_0 = \frac{c}{4 \cdot L_{LT}} \tag{15}$$

According with the tests executed, the break frequency for 10, 25 and 200 meters of UTP cable will be 30 MHZ, 12 MHz and 1.5 MHz.

5. References

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