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Research Article

Performance Testing of Twisted Pair Cables

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This work introduces characteristics of twisted pair cables which play an important role in transferring data. In this paper, category 5 enhanced as a type of unshielded twisted pair cables was selected to verify all tests on it according to ISO/IEC 11801 as one of international standard specifications. Random samples were selected from cables market. All tests were done on these samples to make sure of using validity and complying with the international standard. After testing the selected samples, it is found that 4% are not satisfying the international standard specification while as 96% are satisfying the international standard specification.

1. INTRODUCTION

Today, communication enters our daily lives in so many different ways that it is very easy to overlook the multitude of its facets [1]. In the recent years, most of us realized the crucial impact of the telecommunication systems in our modern life that destroyed the geographical boundaries between people everywhere in the world.

High-speed data transmission over twisted pair cables is indeed a challenging proposition and currently of great interest [2–5]. Twisted pair cables used for transport of telecommunication services consist of bundles of copper wire pairs connecting a wire center to customers [6]. Twisted pair cables also are commonly used for the connections between the different parts of the system in the telecom field [7]. Twisted pair cables are well known for computer networks designers and installers.

The cables after their production should meet some hard tests in the plant to verify their validation for usage. Main part in this paper is about these tests and comparing the characteristics of twisted pair cables in the cables market with the international standard specification.

The paper is organized as follows. Following this introduction, the international standard specification ISO/IEC 11801 used for twisted pair cable manufacturing is given in Section 2. Performance test parameters are given in Section 3. Experimental results and discussion are introduced in Section 4. Conclusion is presented in Section 5.

2. INTERNATIONAL STANDARD SPECIFICATION ISO/IEC 11801

In a real manufacturing environment, it's very sophisticated to obtain finished cables with the required performance which meets both the international standards recommendations and customer requests with minimum costs. This is the problem which the researchers are still doing their best to solve. International specification unified the developing, manufacturing, testing, and maintaining high quality of the products.

Standards make an enormous contribution to most aspects of our lives, although that contribution is invisible. People are usually unaware of the role played by standards in raising levels of quality, safety, reliability, efficiency, and interchangeability as well as in providing such benefits at an economical cost [8].

The international organizations that produce international standards are the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the International Telecommunication Union (ITU).

One of the international standard specifications the used in testing twisted pair cables is (ISO/IEC 11801), which is selected as an example to make tests according to it.

The ISO/IEC 11801 standard defines a generic cabling system which is application independent and supports an open market for cabling components. It is designed to provide users with a flexible cabling scheme such that changes are both easy and economical to implement. In addition, it provides the industry with a cabling system which will support current active equipment and provides a basis for future developments [9].

3. PERFORMANCE TEST PARAMETERS

3.1. Length

Length is defined as the physical or sheath length of the cable. It should correspond to the length derived from the length marking commonly found on the outside jacket of the cable. Physical length is in contrast to electrical or helical length, which is the length of the copper conductors. Physical length will always be slightly less than electrical length, due to the twisting of the conductors [10].

In the test, there is a limit which must not be exceeded. This limit is equal to 361 ft.

3.2. Propagation delay

Propagation delay, or delay, is a measure of the time required for a signal to propagate from one end of the circuit to the other. This measurement is to be performed for each of the four wire pairs. Delay is measured in nanoseconds (ns). Typical delay for category 5e is a bit less than 5 nanoseconds per meter (worst case allowed is 5.8 ns/m as illustrated in ISO/IEC 11801). A 100 meter cable might have delay equal to 500 ns (worst case allowed is 580 ns/m).

3.3. Delay skew

Propagation delay skew is the difference between the propagation delay on the fastest and slowest pairs in a UTP cable. A cable should have a skew less than 50 nanoseconds over a 100-meter link according to ISO/IEC 11801. Lower skew is better. Anything under 25 nanoseconds is excellent. Skew between 45 and 50 nanoseconds is marginally acceptable.

3.4. Attenuation

Electrical signals transmitted by a link lose some of their energy as they travel along the link as shown in Figure 1. Attenuation measures the amount of energy that is lost as the signal arrives at the receiving end of the cabling link. The attenuation measurement quantifies the effect of the resistance the cabling link offers to the transmission of the electrical signals.

According to ISO/IEC 11801, attenuation at frequencies that correspond to calculated values of less than 4.0 dB will revert to a maximum requirement of 4.0 dB and attenuation of each pair in category 5e will meet the requirements derived by the following formula [9]:

$$1.05 \times \left(1.9108\sqrt{f} + 0.022 \times f + \frac{0.2}{\sqrt{f}}\right) + 4 \times 0.04 \times \sqrt{f}. \tag{1}$$

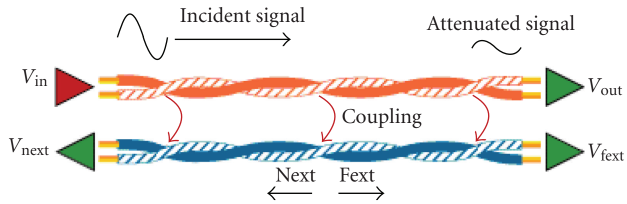


FIGURE 1: Electrical signals transmitted by a link.

3.5. Near-end crosstalk (NEXT)

When a current flows through a wire, an electromagnetic field is created which can interfere with signals on adjacent wires. As frequency increases, this effect becomes stronger. Each pair is twisted because this allows opposing fields in the wire pair to cancel each other. The tighter the twist, the more effective the cancellation and the higher the data rate supported by the cable.

According to ISO/IEC 11801, NEXT of each pair will meet the requirements derived by the following formula [9]:

$$-20\log\left(10^{(65.3-15\log(f))/-20} + 2 \times 10^{(83-20\log(f))/-20}\right). \tag{2}$$

3.6. Power sum NEXT (PSNEXT)

Power sum NEXT (PSNEXT) is a calculation, not a measurement. PSNEXT is derived from the summation of the individual NEXT effects on each pair by the other three pairs.

According to ISO/IEC 11801, PSNEXT of each pair will meet the requirements derived by the following formula [9]:

$$-20\log\left(10^{(62.3-15\log(f))/-20} + 2 \times 10^{(80-20\log(f))/-20}\right). \tag{3}$$

PSNEXT of pair k, PSNEXT (k), is computed from pair-to-pair NEXT (i,k) of the adjacent pairs i, $j = 1, \dots, n$, as follows:

$$\text{PSNEXT}_k = -10\log\sum_{i=1,i\neq k}^{n} 10^{-\text{NEXT}_{ik}/10}, \tag{4}$$

where, i is the number of the disturbing pair, k is the number of the disturbed pair, n is the total number of pairs, and NEXT_{ik} is the near end crosstalk loss coupled from pair i into pair k.

3.7. Equal level far end crosstalk (ELFEXT)

ELFEXT is a calculated result rather than a measurement. It is derived by subtracting the attenuation of the disturbing pair from the far end crosstalk (FEXT) this pair induces in an adjacent pair. This normalizes the results for length.

According to ISO/IEC 11801, ELFEXT of each pair will meet the requirements derived by the following formula [9]:

$$-20\log\left(10^{(63.8-20\log(f))/-20} + 4 \times 10^{(75.1-20\log(f))/-20}\right). \tag{5}$$

ELFEXT_{ik} of pairs i and k is computed as follows:

$$\text{ELFEXT}_{ik} = \text{FEXT}_{ik} - \text{IL}_k, \tag{6}$$

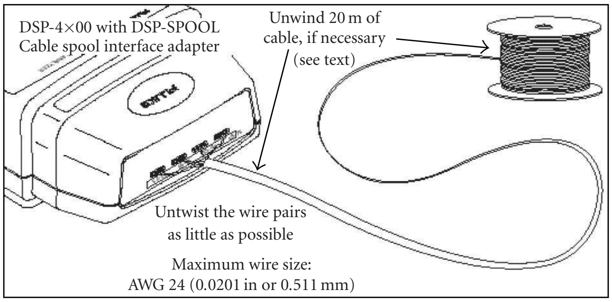


Figure 2: Testing cable spools with the cable spool interface adapter.

Length

Limit 361 ft

Pair	Result
12	293 ft
36	284 ft
45	286 ft
78	293 ft

Figure 3: The length of passed sample does not exceed the limit.

Propagation delay

Pair	Result
12	432 ns
36	418 ns
45	422 ns
78	432 ns

Figure 4: The propagation delay of the passed sample does not exceed 580 ns.

where, i is the number of the disturbed pair, k is the number of the disturbing pair, FEXT_{ik} is the far end crosstalk loss coupled from pair i into pair k, and IL_k is the insertion loss of pair k.

3.8. Power sum equal level far end crosstalk (PSELFEXT)

Power sum ELFEXT (PSELFEXT) is actually a calculation, not a measurement. PSELFEXT is derived from an algebraic summation of the individual ELFEXT effects on each pair by the other three pairs. There are four PSELFEXT results for each end.

According to ISO/IEC 11801, PSNEXT of each pair will meet the requirements derived by the following formula [9]:

$$-20\log\left(10^{(60.8-20\log(f))/-20}+4\times 10^{(72.1-20\log(f))/-20}\right). \quad (7)$$

3.9. Return loss (RL)

The impact of incorrect characteristic impedance is more accurately measured and represented by the quantity return loss.

Return loss (RL) is a measure of all reflections that are caused by the impedance mismatches at all locations along the link and is expressed in decibel (dB).

According to ISO/IEC 11801, return loss will meet the requirements derived by the following formula [9]:

$$30-10\log(f). \quad (8)$$

4. EXPERIMENTAL RESULTS

To obtain the optimum performance for the twisted pair cable, it must realize the characteristics of the cabling systems. To get closer to the cables manufacturing process, simply the raw copper is drawn to different rod diameters that will be later drawn to the required conductor diameters.

After that, it is insulated with a suitable insulation material to produce a single wire.

The first requirement is to provide electrical isolation of the wires from each other by insulating the individual wires [10]. Without proper insulation and the use of protection materials, wires and cables would not function properly or safeley, and they would not last very long [11].

These insulation wires will be assembled to create pairs which in turn are assembled together and then covered with a suitable sheath to produce a final cable.

The cable sheath will prevent any damage to the cable core due to the effects of external mechanical stress and, depending on the type of material used, it can also play a very considerable part in protecting the cable core from external electrical interference [12].

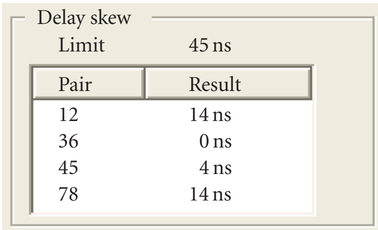
Figure 2 shows Fluke Networks DSP-SPOOL cable spool test interface adapters used for testing twisted pair cables [13].

The performance test parameters for Cat 5e are defined in ISO/IEC 11801. The test of each sample should contain all of the parameters as discussed before. In order to pass the test, all measurements (at each frequency in the range from 1 MHz to 100 MHz) must meet or exceed the limit value determined in the above-mentioned standard, otherwise the sample is failed.

When dealing with the cables market, it is found that a lot of samples of twisted pair cables were manufactured in many countries. After testing these selected samples, it is found that 96% are passed and satisfying the international standard specification while 4% are failed and not satisfying the international standard specification.

Passed sample of twisted pair cables is the sample in which all measurements (at each frequency in the range from 1 MHz through 100 MHz) must meet or exceed the limit value determined in ISO/IEC 11801.

The analysis of the passed sample is given from Figure 3 to Figure 11. There is a limit which must not be exceeded. All performance test parameters discussed before do not exceed that limit.



Delay skew

Limit 45 ns

Pair	Result
12	14 ns
36	0 ns
45	4 ns
78	14 ns

FIGURE 5: The delay skew of passed sample does not exceed 50 ns.

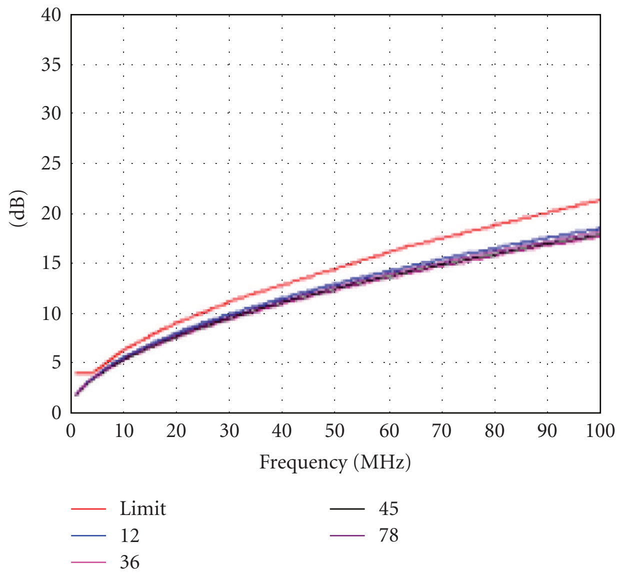


FIGURE 6: The attenuation of passed sample does not exceed the limit.

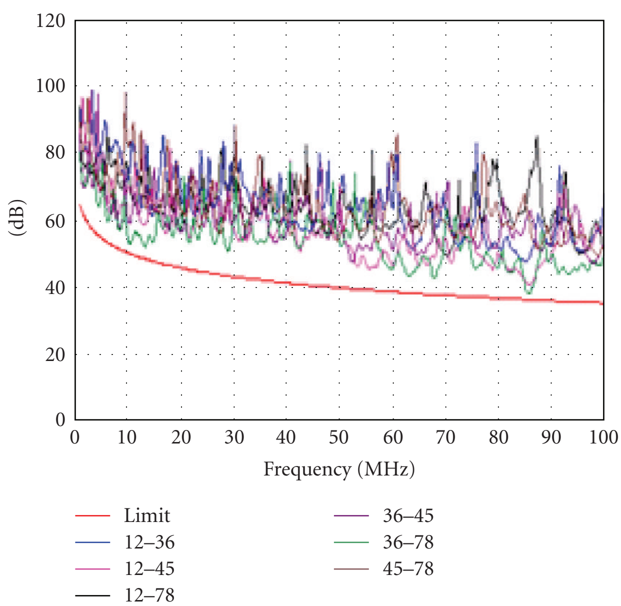


FIGURE 7: The NEXT of passed does sample not exceed the limit.

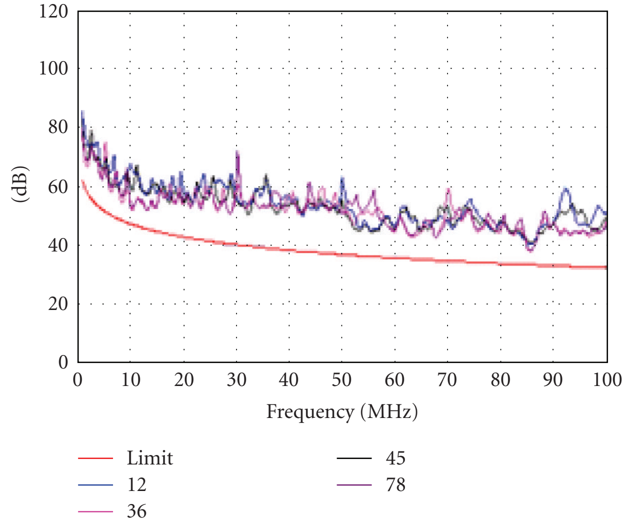


FIGURE 8: The PSNEXT of passed sample does not exceed the limit.

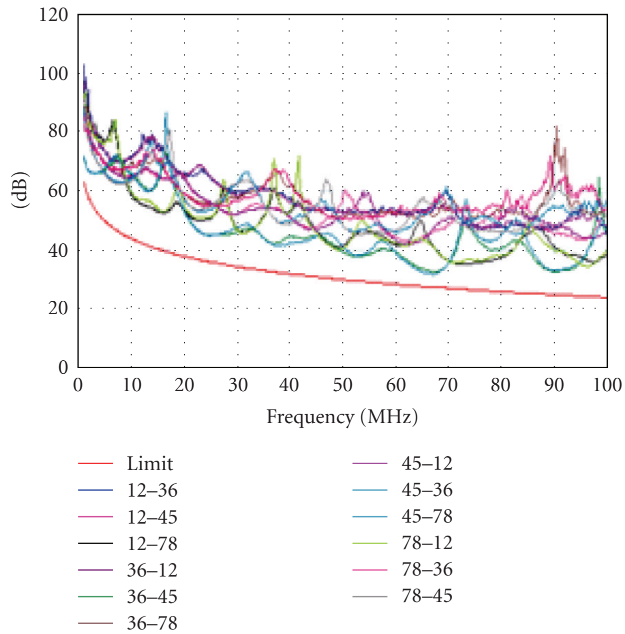


FIGURE 9: The ELFEXT of passed sample does not exceed the limit.

As shown in Figure 3, there is a limit that equals 361 ft, and the passed samples does not exceed that limit.

As shown in Figure 4, although propagation delay of passed samples has the worst values of pairs 12 and 78 that equal 432 nanoseconds, but these values of the propagation delay do not exceed 580 nanoseconds.

As shown in Figure 5, although delay skew of passed samples has the worst values of pairs 12 and 78 that equal 14 nanoseconds, but these values of the delay skew are excellent results as they do not exceed 25 nanoseconds.

As shown in Figure 6, attenuation of passed samples of pair 1,2, pair 3,6, pair 4,5, and pair 7,8, not exceed does the limit.

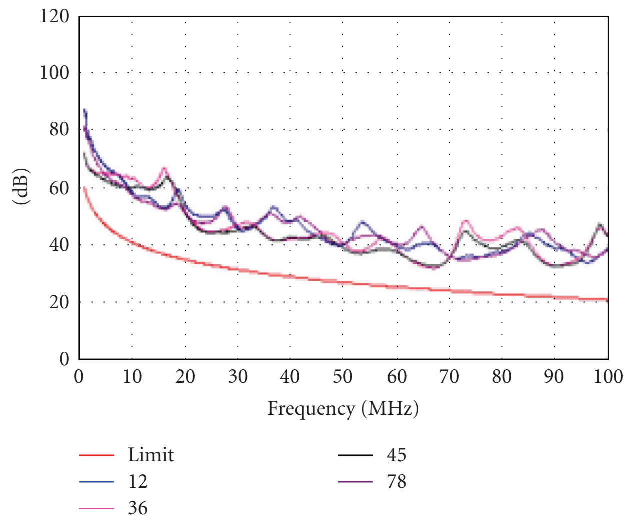


Figure 10: The PSELFEXT of passed sample does not exceed the limit.

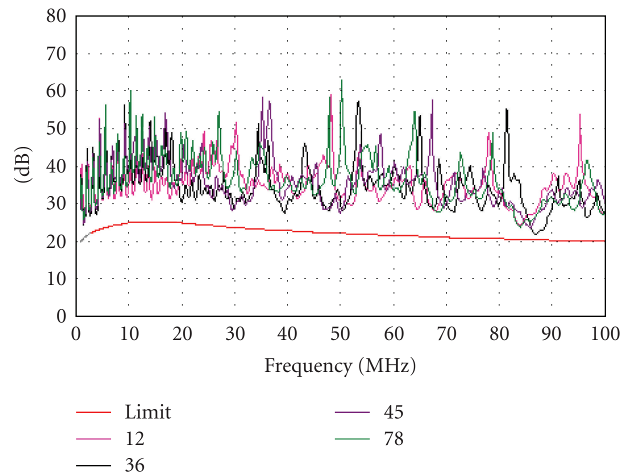


Figure 11: The return loss of passed sample does not exceed the limit.

As shown in Figure 7, although the NEXT between pair 3,6 and pair 7,8 has the worst value that equals 38.3 dB at 85.6 MHz, but it does not exceed the limit. NEXT of passed samples between each pair and the others does not exceed the limit.

As shown in Figure 8, although the PSNEXT of pair 36 has the worst value that equals 37.9 dB at 85.6 MHz, but it does not exceed the limit. PSNEXT of passed samples of pairs 12, 36, 45, and 78 does not exceeds the limit.

As shown in Figure 9, although the ELFEXT between pairs 45 and 36 has the worst value that equals 31.7 dB at 67 MHz, but it does not exceed the limit.

As shown in Figure 10, although the PSELFEXT of pair 36 has the worst value that equals 31.7 dB at 67 MHz, but it does not exceed the limit. PSELFEXT of passed samples of pairs 12, 36, 45, and 78 does not exceeds the limit.

As shown in Figure 11, although return loss of pair 36 has the worst value that equals to 21.9 dB at 86.8 MHz, but

Length

Limit 361 ft

Pair	Result
12	343 ft
36	341 ft
45	353 ft
78	337 ft

Figure 12: The length of failed sample does not exceed the limit.

Propagation delay

Pair	Result
12	505 ns
36	503 ns
45	520 ns
78	497 ns

Figure 13: The propagation delay of the failed sample does not exceeds 580 ns.

it does not exceed the limit. Return loss of passed samples of pairs 12, 36, 45, and 78 does not exceed the limit.

On the other hand, failed sample of twisted pair cables is the sample which some of measurements (frequency in the range from 1 MHz to 100 MHz) to don't have within the limit value determined in ISO/IEC 11801.

The analysis of failed sample is given from Figure 12 to Figure 20. There is a limit which must not be exceeded. Although propagation delay, delay skew, ELFEXT, and PSELFEXT do not exceed that limit, but the problem is in attenuation, NEXT, PSNEXT, and RL which exceed that limit, and of course that has an effect on transferring data.

As shown in Figure 12, there is a limit that equals 361 ft, and the failed samples do not exceed that limit.

As shown in Figure 13, although propagation delay of failed samples has the worst values of pair 45 that equals 520 nanoseconds, but this value of the propagation delay does not exceeds the worst case allowed that equals to 580 nanoseconds.

As shown in Figure 14, although the delay skew of failed samples has the worst value of pair 45 that equals 23 nanoseconds, but this value of the delay skew does not exceed the limit.

As shown in Figure 15, although the attenuation of pair 12 does not exceed the limit, but attenuation of pairs 36, 45, and 78 exceeds the limit.

As shown in Figure 16, although the NEXT between pairs 36-45 and 36–78 does not exceed the limit, but the NEXT of failed samples between pairs 12-36, 12–45, 12–78 and 45–78 exceeds the limit, and the worst value of pairs 12–45 equals to 29 dB at 47.6 MHz.

As shown in Figure 17, although the PSNEXT of pair 36 does not exceed the limit, but the PSNEXT of failed samples

Delay skew

Limit 45 ns

Pair	Result
12	8 ns
36	6 ns
45	23 ns
78	0 ns

Figure 14: The delay skew of failed sample does not exceed 50 ns.

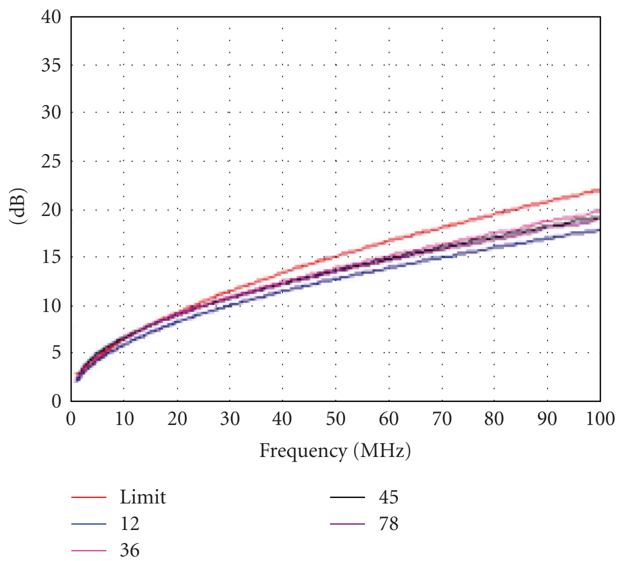


Figure 15: The attenuation of failed sample does exceed the limit.

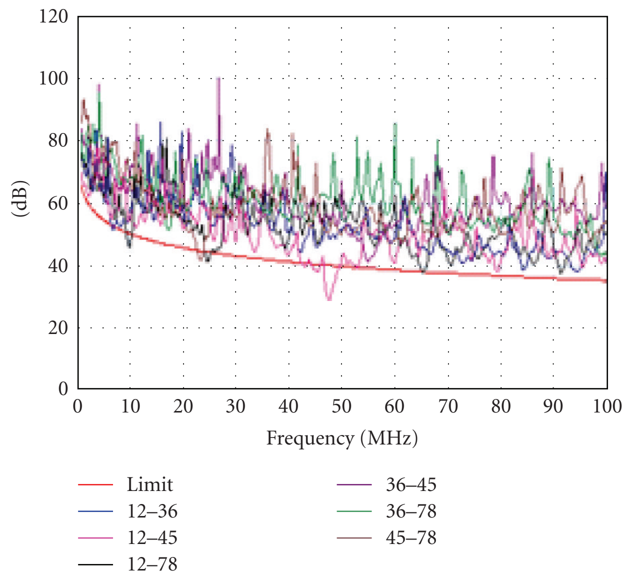


Figure 16: The NEXT of failed sample exceeds the limit.

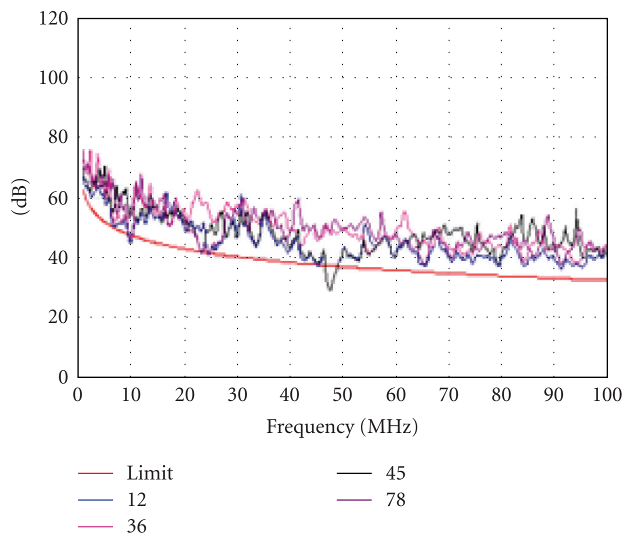


Figure 17: The PSNEXT of failed sample exceeds the limit.

between pairs 12, 45, and 78 exceeds the limit, and the worst value of pair 45 equals 29 dB at 47.6 MHz.

As shown in Figure 18, the ELFEXT of failed samples between each pair and others does not exceed the limit.

As shown in Figure 19, the PSELFEXT of failed samples of each pair does not exceed the limit.

As shown in Figure 20, although return loss of pair 45 does not exceed the limit, but the return loss of failed samples between pairs 12, 36, and 78 exceeds the limit, and the worst value of pair 36 equals 17.7 dB at 89.2 MHz.

There are other primary tests which can be done on each single wire of twisted pair cable as continuity, resistance, and elongation.

About continuity, to make sure that there's no short between wires, simply, that test can be done by using any device for short/continuity tester such as a multimeter. The cables selected for testing have continuity, and without continuity, there are no parameters for cables.

About resistance, all single wires of passed sample have resistance in the range from 81.76 Ω/km to 81.88 Ω/km. The maximum resistance allowed for each conductor is 84 Ω/km according to the international, standard and over that, the sample is failed.

About elongation percentage, all insulated materials of conductors of passed sample have values range from 550% to 690%. The minimum elongation percentage allowed for insulated materials of conductors is 400% according to international standard.

About tension force, all insulated materials of conductors of passed sample have values range from 24 N/mm^2 to 27 N/mm^2. The minimum tension force allowed for insulated materials of conductors is 22.1 N/mm^2 according to the international standard.

The primary test that every cable should pass is the dielectric strength test, where the cable is exposed to a higher voltage than that of the real operating voltage for a certain period. The purpose of that test is to insure the perfection of the insulation. If there's a weak point in the insulation, it should fail the test.

The main difference between types of twisted pair cables is the cable performance at higher frequency that means the

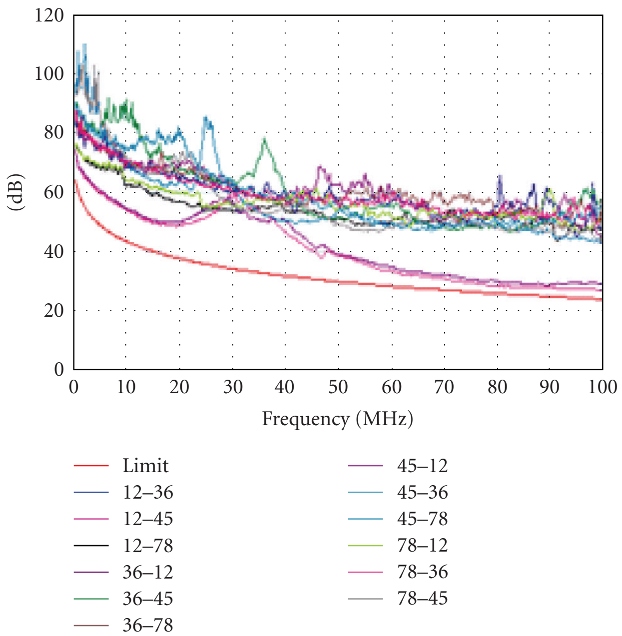


Figure 18: The ELFEXT of failed sample does not exceed the limit.

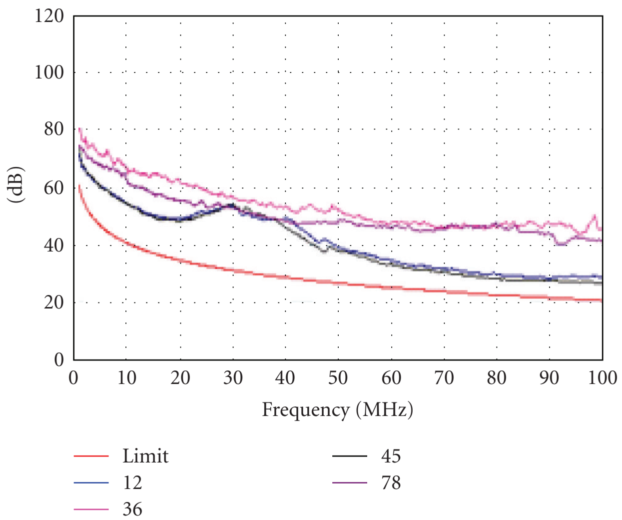


Figure 19: The PSELFEXT of failed sample does not exceed the limit.

higher category. With the greatest development in manufacturing cables, it appears that new types of twisted pair cables that have a higher category number than Category 5 enhanced. This implies that for performance improvement in twisted pair cables applications, all tests were done on them to make sure of using validity and complying with the international standard specification.

5. CONCLUSION

This paper presents Category 5 enhanced as a type of unshielded twisted pair cables and makes all the testing on it

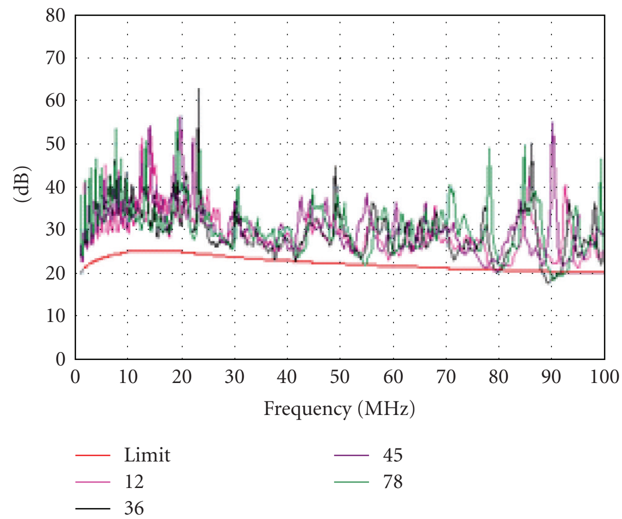


Figure 20: The return loss of failed sample exceeds the limit.

according to ISO/IEC 11801 as one of the international standard specifications.

The parameters used for performance test are propagation delay, delay skew, attenuation, near-end crosstalk loss (NEXT), powersum NEXT (PSNEXT), equal level far end crosstalk (ELFEXT), power sum equal level far end crosstalk (PSELFEXT), and return loss.

When dealing with random samples of twisted pair cables selected from the cables market, it is found that 96% of these samples have been passed and complied with the international standard. On the other hand, 4% of these samples have been failed and not complied with the international standard.

Quality pass samples should be acceptable at all tests according to the international standard specification.

Customer should review these tests according to the international standard specification.

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