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Advanced Twisted Pair Cables for Distributed Local Area **Networks in Intelligent Structure Systems**

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Abstract. The possibility of a significant increase in the length of cable communication channels of local area networks of automation and engineering support systems of buildings in the case of their implementation on balanced twisted pair cables is shown. Assuming a direct connection scheme and an effective speed of 100 Mbit/s, analytical relationships are obtained for the calculation of the maximum communication distance. The necessity of using in the linear part of such systems of twisted pair cables with U/UTP structure and interference parameters at the level of category 5e is grounded.

1. The necessity of changing the requirements to the twisted pair cables of contemporary information systems

Contemporary real estate, originally designed or adapted for permanent or prolonged stay of people inside them is compulsorily equipped with an information and telecommunication system (ITS). The latter one is organizationally divided into a number of separate components, which, for reasons of serviceability, simplicity of expansion, increased operational flexibility, and other similar criteria, are built on common or ideologically very close to each other principles.

Traditional subsystems of the ITS are a local area network and a telephone network. The physical layer of these subsystems based on ISO/IEC 11801 standards is implemented on the basis of a structured cabling system (SCS). The horizontal subsystem of the SCS is built on the twisted pair cables, whereas on the backbone levels, fiber-optic technology is primarily used. The SCS, which serves the LAN and the telephone network of the enterprise, has a hierarchical structure.

Recently, the list of the ITS subsystems has expanded significantly. They were added by the subsystem of video surveillance, access control and several others. All of them are built on the basis of ip-technology [1], however, unlike their classical counterparts they gravitate toward a centralized construction scheme. In such a situation, the possibilities of typical balanced cable channels, taking into account the known 100-meter specification length of communication, do not meet the requirements of practice.

Typical for a LAN method to increase the limiting length of communication by switching to fiberoptic technology is unprofitable for the following reasons:

- higher cost of the line as a whole due to the additional conversion of the electric signal to optical one and vice versa;
- the complexity of ongoing maintenance and development of the system by the forces of operational staff;
- difficulties in implementing multiplexing due to low density of terminal devices;
- the impossibility of remote power supply of terminal devices with appeal for this purpose to the mass-market technology of PoE and PoE+.

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In addition, we will point out that the transport level of most new ITS subsystems does not require high performance and it can be implemented on the basis of 100Base-TX network interfaces.

2. The prerequisites for extending the length of the line and the design model

The following considerations are underlying the technical possibility of extending the length of a symmetrical cable channel in excess of the 100 m value specified in the IEEE 802.3u standard:

- Fast Ethernet network interface specifications were initially developed taking into account the capabilities of the Category 5 cable engineering, whereas a typical contemporary engineering provides significantly better parameters corresponding to the Category 5e;
- it is possible to use simple channel structures of the direct connection type;
- due to the unilateral nature of the transmission over individual twisted pairs and the use of a two-pair scheme of the transmission path, the noise level at the input of the receiver is significantly reduced.

Simultaneously, the transmission channel of the ITS subsystems under consideration is not the part of the SCS. It is not subject to the limitations of standards in the length of not more than 100 m.

In the future we proceed from the fact that

- the network interface complies with the IEEE 802.3u specification;
- the information transfer rate is 100 Mbit/s (application in the line of block code type 4B5B increases the speed of the line signal up to 125 Mbit/s);
- the transmission channel is built according to the direct connection scheme;
- the parameters of the interference of the line and patch-cord cables are the same, and the attenuation coefficient of the line cable is 1.5 times smaller compared to the patch-cord one;
- as part of the channel, the ISO/IEC 11801 standard connection hardware was used.

Linear signal of the LAN-interface has uniform spectrum [2]. This makes it possible to use the theory of K. Shannon and seek the limiting length of the channel as a solution to the following equation [3].

$$W(l, f_b) = \int_0^\infty \log_2[1 + ACR(f, l)] \, df,$$
(1)

where $ACR = NEXT - \alpha l - signal protection$; NEXT - the near end cross talk loss; α is the attenuation coefficient; l is the "electrical" length of the channel.

3. The determination the communications capacity of the channel

For convenience of calculation, it is convenient to represent expression (1) in a three-term, figure 1:

$$W = I_1 + I_2 + I_3 = \int_0^{f_b} \log_2 ACR(f) df + \int_0^{f_b} \log_2 \left[1 + \frac{1}{ACR(f)} \right] df + \int_{f_b}^{\infty} \log_2 [1 + ACR(f)] df.(2)$$

The upper frequency limit fb is the root of equation

$$NEXT - 15 \lg(f) - \alpha l\sqrt{f} = 0.$$
(3)



Figure 1. To calculation of the Shannon's capacity of a symmetric channel.

The solution of (3) has the form

$$f_{b} = \left(\frac{NEXT}{\alpha l} - \frac{13}{\alpha l} \cdot \ln \frac{NEXT}{\alpha l} / (1 - \frac{13}{\alpha l})\right)^{2}.$$
 (4)

Expression (4) provides approximately 10 percent accuracy of calculation. If necessary, the iterative process is repeated.

In expression (4), the total NEXT of the near end of the balanced channel appears. The cross-talk interference in the balanced channel on which NEXT depends is created by the line and patch-cord cables, as well as by the near end connecting hardware. Omitting the cumbersome intermediate calculations, taking into account the equality of the parameters of the interference of the line and patch-cord cables [4], and also the construction of the patch-panel by the interconnect scheme, we write the value NEXT in the form

$$NEXT = NEXT_0 - 15lgf - 20 \lg[1 + 0.13f_b^{0.25}],$$

where $NEXT_0$ is NEXT loss coefficient of the cable.

The calculated relationships, which can be used to determine the individual terms (2), are given in table 1.

Term	Calculated relationships	Note
I_1	$0.166 \cdot NEXT \cdot f_b - 1.08 \cdot f_b \cdot (lnf_b - 1) - 0.11 \cdot f_b^{1.5} \cdot \alpha l$	Lower bound
<i>I</i> ₂	$\left[\frac{2.88}{0.115\alpha l} \cdot 10^{-\frac{NEXT}{20}} \cdot e^{0.115\alpha l\sqrt{f_b}} \cdot [f_b - \frac{2\sqrt{f_b}}{0.115\alpha l} + \frac{2}{(0.115\alpha l)^2}]\right]$	Upper bound
I_3	$2.88 \cdot 10^{NEXT/20}$	Upper bound
	$0.144 \cdot lpha l \cdot f_b^{1.75}$	

Table 1. Calculated relationships for computing W.

4. Analysis of results

The results of calculations are shown in figure 2 and indicate the possibility of a significant, multiplied increase in the length of the channel. Two criteria were used for the calculation:

• congruence of Shannon's capacity *W* to 185 Mbit/s, which corresponds to the 33 percent service stock recommended by the IEEE Institute for operational inventory;

• reaching the upper limit frequency of 70 MHz.

For typical for the equipment of categories 5e NEXT values and α for individual *W*, we have $\frac{I_1}{I_1 + I_2 + I_3} \approx 0.6$. Hence we can state that I_1 is the main part of *W* and can be used as an effective estimate of the real communications capacity of the balanced cable channel over which the Fast Ethernet network interface operates.

From the expression for determining I_1 for the band $[0;f_b]$ we have

$$\frac{\partial^2 W}{\partial f^2} = -\frac{1}{f} (1.08 + 0.15\alpha l) < 0.$$
(5)

It follows from (5) that the communications capacity W of the channel is determined by its parameters in the low-frequency area and the increase in the accuracy of determining f_b with respect to the value (4) makes no sense when performing engineering calculations.



Figure 2. Limiting calculated path lengths: left column - 70 MHz criterion, right - 185 Mbit/s.

From the calculated relationship for (3) it follows that for typical values for contemporary equipment NEXT and α it is valid that

$$\sqrt{f_b} \cong \frac{NEXT}{2\alpha l}$$
 (6)

Hence it follows that the main directions for increasing l at $f_b = \text{const}$ are a decrease in α and an increase in NEXT. It is easy to obtain from (6) that

$$\left|\frac{\partial l/\partial \alpha}{\partial l/\partial \text{NEXT}}\right| = \frac{\text{NEXT}}{\alpha}.$$
(7)

Conclusion (7) does not take into account the dependence of f_b on NEXT and α . It can be shown that its presence does not have a significant effect on the estimate (7).

Equipment of categories 6 and 6a has the typical increase in NEXT is usually around 15%. Given that the "electrical" length of the channel is determined primarily by a line cable, it follows that

- the main means of increasing the extent of the balanced channel is to reduce the attenuation coefficient α , since the efficiency of this method based on (7) is approximately NEXT/ $\alpha \approx 30$ times higher;
- to achieve the desired effect, the attenuation coefficient α of horizontal cable must be reduced by at least 15%, which corresponds to units dB/100 m at a frequency of 100 MHz.

This situation is confirmed qualitatively by figure 2. From the data presented there it follows that when moving to the next category of equipment (typical increase in NEXT by 10 dB), the insignificant 15% increase in the limiting length of the channel is observed.

5. The attenuation of a twisted pair and the way of its reduction

The attenuation in the twisted pair is determined by the losses in: the conductors metal, insulation, the screen, separator, shell material and other similar cable components. The relationship between these components is shown at figure 3.

The main contribution to the final value of α is made by losses in the metal α_1 , the fraction of the remaining components does not exceed 12-15%/

Effective reduction of the value of α can be achieved by a rejection from the screens and a reduction in losses in the conductors metal. The attenuation coefficient of a twisted pair with a U/UTP structure is

$$\alpha = \frac{4.34R}{Z} + \alpha_2, \tag{8}$$

where *Z* is the impedance, a *R* is the active resistance, $\alpha_2 - loss$ in the insulation ($\alpha_2 = 0, 1 \alpha$).

An estimate of the expected value of α for different initial data is given in table 2. When performing calculations, the parameters of the standard [5] were used.



Figure 3. Ratio of individual components of the loss of a twisted pair: 1 – metal; 2 – the insulation of conductors; 3 – the screen (if any); 4 – other polymer cable components.

Conductor diameter, mm	0.5	0.52	0.55	0.6	0.64
Z = 100 Ohm	21.5	20.0	18.2	15.6	14.0
Length, m	185	202	226	258	288
Z = 120 Ohm	18.3	16.3	14.8	12.8	11.5
Length, m	221	251	268	311	345
Z = 150 Ohm	15.1	13.8	12.6	10.9	9.9
Length, m	263	293	315	366	402

Table 2. The attenuation coefficient and channels length of Fast Ethernet network interfaces

From the data of Table 2 we can see that the decrease in extinction due to the increase in the diameter of the conductor leads to a noticeably greater effect compared with the increase in impedance.

6. Conclusion

The obtained results make it possible to state the following

- 1. The length of the balanced cable channel of subsystems of contemporary ITS can be increased at least in two or three times.
- 2. Unlike classical office LAN, the function of the main means of achieving specified quality indicators goes from NEXT to the attenuation coefficient α .
- 3. It is expedient to achieve a reduction in α by increasing the diameter of the conductor.
- 4. Line cables must have a U/UTP structure and characteristics according to NEXT, RL and other similar parameters at the category level 5e.
- 5. In the case of a simultaneous increase in the diameter of the conductor and the impedance of a twisted pair with a U/UTP structure at a frequency of 100 MHz, attenuation coefficient of less than 10 dB / 100 m at a frequency of 100 MHz are attained, which makes it possible to increase the estimated channel length up to 400 m.
- 6. For the reduction of the cost of implementing the ITS, it is possible to use 2-pair versions of U/UTP cables.

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