White Paper

# Impact of 10GBASE-T on Cabling

R&M

Convincing cabling solutions

R&M

Convincing cabling solutions

# Impact of 10GBASE-T on Cabling

## Contents

## 1. Introduction

| Application: | Enterprise Cabling |
|---|---|
| Technology: | 10GBASE-T |
| Format: | White Paper |
| Subject: | 10GBASE-T, shielded – unshielded, Cat. 6 – Cat. 7, Alien NEXT, grounding system |
| Objective: | Investment protection, arguments for decision making |
| Target group: | Planners, end users, decision makers selecting future cabling |
| Author: | Matthias Gerber |
| Published: | September 2005 |

**With 10GBASE-T, IEEE is developing a protocol that will increase the transmission rate over twisted copper data cables in dimensions that seemed unattainable until recently. This progress has been made possible with today's signal processing and coding technologies.**

**However: The potential of the channel, e.g. copper cabling will be thoroughly exploited through this protocol. Consequently, weaknesses of the cabling will also be revealed.**

Information published by IEEE is helpful in recognizing the limits of the various cabling systems and in answering some of the most burning questions:

- Should shielded or unshielded cabling be used?
- If shielded, how good does the shield have to be?
- What are the requirements for the grounding system?
- Does Cat. 7/ Class F provide more security for the future?

This white paper is intended to be a product-neutral support for answering the above questions and to be helpful in choosing a cabling system which is optimally adapted to customer needs.

The arguments are based on comprehensible physical laws and specifications of the relevant standards.

## 2. Brief summary

Below it will be demonstrated that:

- the grounding system in a building or the disturbances which are transported and transferred on the grounding system, are a crucial factor for the error-free operation of 10GBASE-T.
- an unshielded (UTP) system also picks up disturbances from the grounding system and, therefore, a well shielded system tolerates up to 50 times greater disturbance levels.
- with a well shielded system a grounding system which works in compliance with the standards (potential difference of 1V) is sufficient to guarantee 10GBASE-T functionality.
- a grounding system which works in compliance with the standard is insufficient to guarantee 10GBASE-T operation with a U-UTP system and, therefore, additional expense is imperative for the grounding system
- Return Loss is the internal parameter that limits the transmission performance.
- compared to Class E cabling, Class F cabling does not potentially provide greater bandwidth or added value.
- Class E cabling has the optimal price/performance ratio.
- shielded Class E cabling is the reliable solution for attaining 10GBASE-T performance.

## 3. The 10GBASE-T protocol

The most important parameter for transmission equipment is the insertion loss of the channel. It determines the magnitude of the signal strength available at the receiver for information detection.

In a twisted data cable, this insertion loss (in dB) increases considerably with increasing frequency. Unfortunately, the options for cable manufacturers to improve this characteristic are limited: through larger copper cross sections, special insulation material, etc. Accordingly, the values of the various cabling classes defined in the standards differ only slightly from one another (see Figure 1).

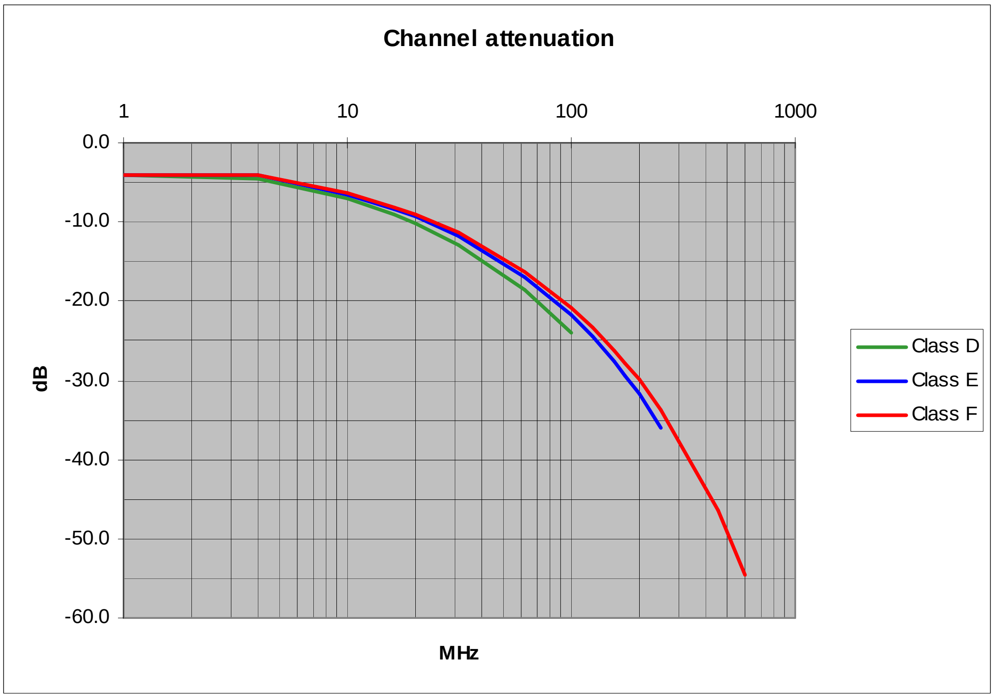


Figure 1: Insertion loss according to ISO/IEC 11801(2002)

IEEE is making every effort to keep the necessary transmission frequencies as low as possible in order to ensure as large a signal as possible at the receiver. This is achieved with the use of more and more sophisticated modulation and coding methods. They are trying to pack more and more bits in a change of state of the transmission signal. In addition, with 1000BASE-T and 10GBASE-T, all 4 pairs function simultaneously in full-duplex mode. This means, data sending and receiving takes place on the same pair and each pair transmits ¼ of the total data rate. For EMC reasons, transmitting signals larger than ± 1V is to be avoided.

For 100BASE-TX the MLT 3 method is used, which uses a change of state of 1V for the transmission of a bit 1. The result is a transmission frequency of 31.25 MHz. 1000BASE-T uses a PAM 5 coding (Pulse Amplitude Modulation), which means that the transmitting signal can have 5 different states and each state represents 2 bits. A minimum change of state is only 0.5V at a frequency of 62.5MHz.

10GBASE-T will probably use a DSQ 128 so-called special form of PAM16 (in principle it comprises 16 levels, whereby based on a sophisticated function, not all possible states are used). The minimum change of state is 0.13V at a frequency of 400MHz (see Figure 2).

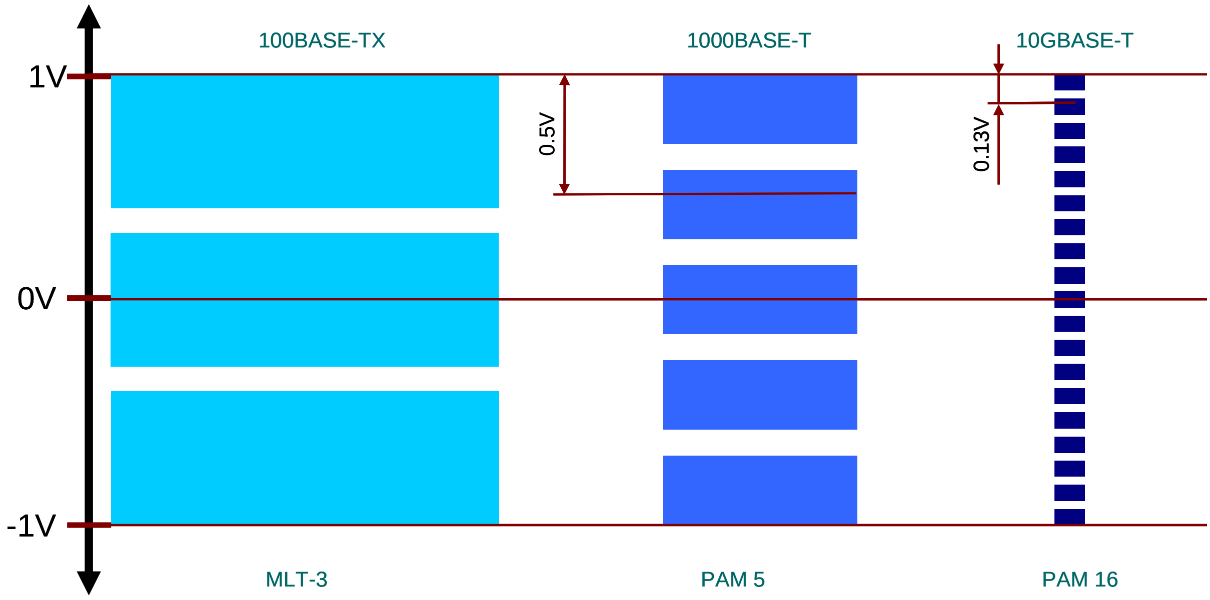


Figure 2: Representation of the transmitted signal of various transmission protocols

By looking at the signal at the receiver end after 100 m of cabling, the difference is immediately apparent. Due to the higher attenuation at higher frequencies, the signals are reduced in different degrees. Where the receiver with 100BASE-TX has a signal difference of 0.24V available, with 1000BASE-T it is 0.07V and with 10GBASE-T only 0.0006V remain (see Figure 3).

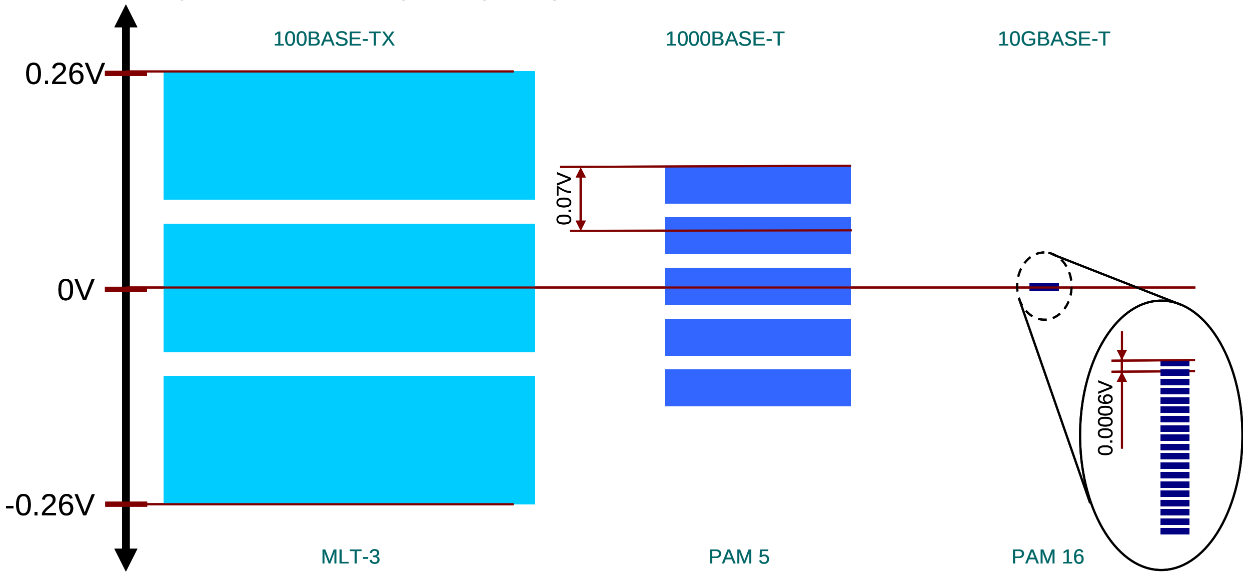


Figure 3: Representation of the received signal of various transmission protocols

Based on this signal strength difference, it is clear that with 10GBASE-T preferably no disturbing signal should reach the receiver.

With a highly developed disturbing signal reduction IEEE has laid the foundation for attaining a 10 GBit/s data rate. The internally generated disturbances – near-end crosstalk NEXT, far-end crosstalk FEXT and return loss RL – can be calculated out using digital signal processing (DSP). During an initialization phase, the disturbances from the data transmission over a pair on the pair itself or on the other pairs are measured and stored. Subsequently, when data is transmitted over this pair, the stored values are subtracted from the other pairs.

In other words, the electronics artificially improve the transmission behavior of the cabling. Based on IEEE information, the following improvements can be obtained with this method:

- NEXT 40 dB
- FEXT 25 dB
- RL 55 dB

This type of noise reduction can only function if the receiver knows precisely at which point in time it must subtract the correction signal and the size of the correction signal. Understandably, these conditions are only present within a transmission system.
External disturbances, such as common mode noise from the grounding system or crosstalk between adjacent cables, cannot be suppressed with this method.

Therefore, parameters which were not previously specified have gained significance with 10GBASE-T. This concerns particularly alien crosstalk at the near-end (Alien Near End Crosstalk, ANEXT) and alien crosstalk at the far-end (Alien Far End Crosstalk, AFEXT). For further information, please refer to separate white papers from R&M on this topic.

IEEE has defined the requirements for 10GBASE-T capable cabling in the standard currently being developed. The latest version is 802.3an Draft 2.1. The appropriate cabling standard groups have also started work on standards and technical reports, e.g. ISO/IEC TR 24750. Adherence to these specifications is not at all insignificant but it is assumed for the following discussion.

## 4. The grounding system

### 4.1. Coupling behavior between cabling and the grounding system

Often the user expects, or some manufacturers suggest, that an unshielded cabling system is operated completely independently from the grounding system of the building. However, this is only the case when cabling is carried through the air or in a wooden structure and the active components (e.g. switch, router, etc.) are battery operated. Obviously, this is rarely found in real applications!

If unshielded cabling is carried in a metallic conduit or brought near the building structure, there will be coupling between the cabling and the grounded building structure.

Measurements made in the R&M laboratory show the size of the coupling between a metallic conduit and a U-UTP cable in it (Figure 4). A 0dB result corresponds to total coupling; the disturbance on the U-UTP cable and the conduit are the same size. A 100dB result corresponds to no coupling whatsoever; the disturbances on the conduit do not transfer to the U-UTP cable.

The Cat. 5e (Cable1) as well as the Cat. 6 cable (Cable2) demonstrate only marginal protection against coupling in the important for 10GBASE-T frequency range from 1-100 MHz. This signifies that any disturbing signal in this frequency range which is present on the grounding system is transferred practically unattenuated as common mode noise to the U-UTP cable.

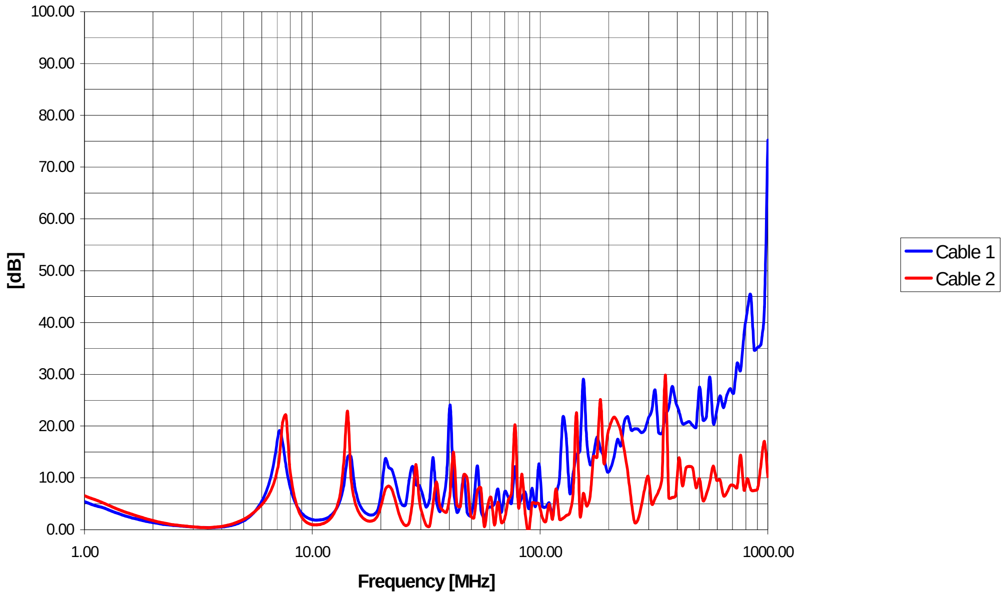


Figure 4: Coupling behavior of a metal conduit on two different U-UTP cables

### 4.2. Common mode noise from the grounding system

Based on the coupling behavior between the cable and conduit and the knowledge of the transmission protocol, the amount of noise which can be on the grounding system before the data transmission is adversely affected can be estimated.

In principle, it can be assumed that a misinterpretation of the transmitted data can occur at the receiver if the disturbing signal is about the same size as the receiving signal. With 10GBASE-T this is – see above – the case at 0.0006V @ 400MHz. At lower frequencies, due to the slower rise time of the disturbance, a greater noise level is allowed (blue line in Figure 5), for example 0.0024V @ 100 MHz (400MHz/100MHz*0.0006V).

This noise level corresponds to the voltage that may occur between the two conductors of a pair (differential mode). However, these external disturbances affect both conductors of a pair simultaneously (common mode). In a cable, the two signal types can convert into each other. The conversion is described with the symmetry factor (Transverse Conversion Loss; TCL). The latter is defined in the cabling standards and is the same for all cabling categories (e.g. 20 dB @ 100 MHz). Thus, the permitted common mode noise level on both conductors of a cable is 0.024V @ 100 MHz (red line Figure 5).

The input transformer of the receiving system also has only a limited symmetry. Therefore, IEEE allows only one defined level of common mode noise (turquoise colored line in Figure 5). The lower requirement (red and turquoise lines in Figure 5) is application relevant.

Assuming an average coupling attenuation of 6dB between the U-UTP cable and the conduit / building structure, this, for example, results in a permitted disturbing signal on the grounding system of 0.048V @ 100 MHz (green line).

In addition to the cable symmetry, shielding attenuation also has an effect with shielded systems. Based on experience, its value is between 20dB (for F-UTP) and 40dB (for S-FTP) for the entire cabling system. Since the shield is grounded, the 20dB or 40dB replace the 6dB coupling attenuation of the conduit of the unshielded system. Therefore, noise levels of 0.24V @ 100MHz or 2.4V @ 100MHz on the grounding system are allowed (pink and purple lines in Figure 5).

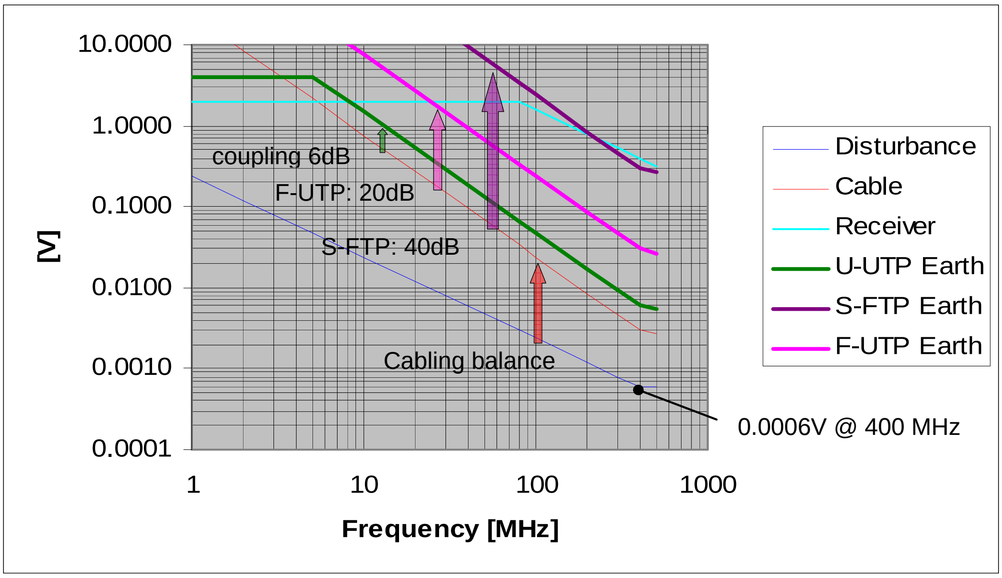


Figure 5: Permitted noise level on the grounding system for 10GBASE-T cabling

The comparison of these curves shows that well-shielded S-FTP cabling provides approximately 50 times greater disturbance protection on the grounding system than unshielded cabling (see Figure 6). The cabling standards require that the grounding system within a building be configured so that during operation a voltage greater than 1V never occurs between any two points of this system. From the comparison of the curves in Figure 6 with this limiting value of 1V, it can be determined that the standard-compliant configuration of the grounding system with U-UTP protects against disturbances of up to approximately 13MHz, with F-UTP against disturbances of up to approximately 40MHz and with S-FTP against disturbances of up to approximately 180MHz.

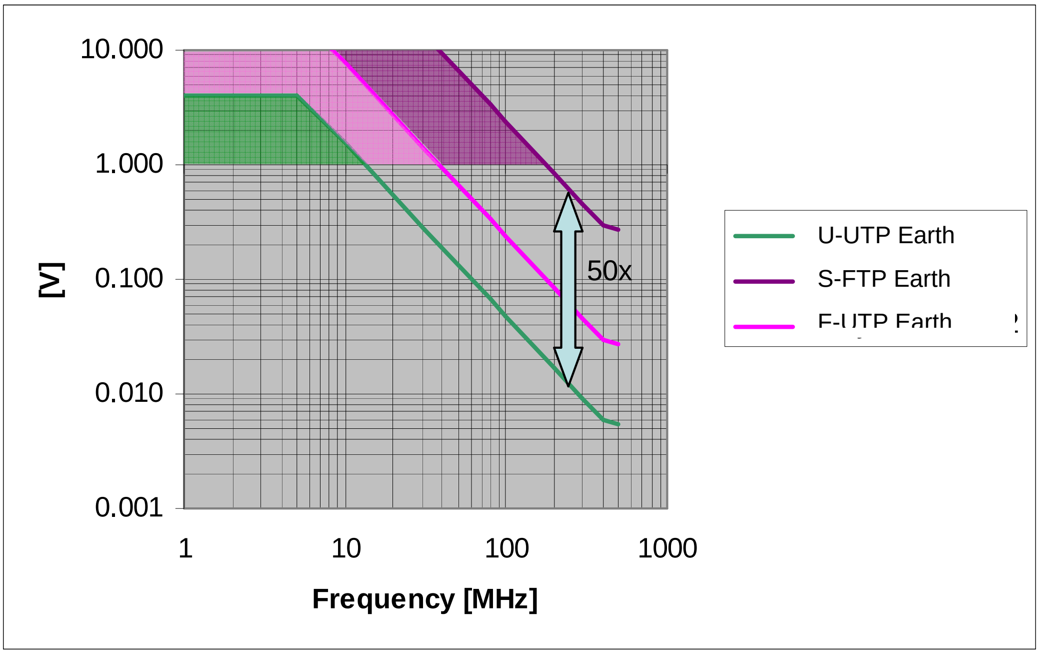


Figure 6: Comparison of the permitted disturbance levels for various cabling types

None of the studied cabling systems can guarantee a standards compliant operation up to 400MHz. However, from independent studies it is known that semiconductor technologies used today in potential sources of noise (such as power supplies, series connection units, motor control units, etc.) produce disturbances up to approximately 50MHz. With technical progress, components are becoming faster and faster and it can be assumed that they will produce higher noise levels in the future.

Considering the behavior at 50MHz (Figure 7), it is demonstrated that only the S-FTP cabling with a permitted noise level of 6.5V allows a standard compliant cabling. The grounding system for F-UTP cabling with 0.65V must be better configured than provided for in the standard. In order for a U-UTP cabling to function without problems, the grounding system must have a noise level of 0.13V, or 8x better than required by the standard.

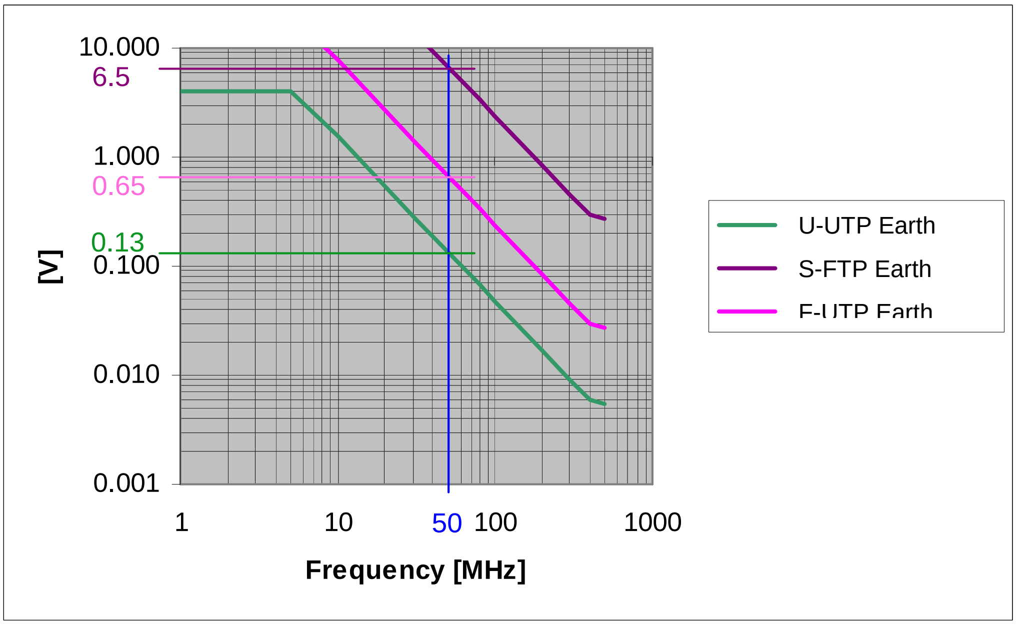


Figure 7: Comparison of the permitted noise levels at 50MHz

For investment decisions it should be taken into account that F-UTP and in particular U-UTP cabling requires a better grounding system in the building. This can result in significantly higher expenses.

The question may arise as to why these interrelationships were not clearly recognizable in previous transmission protocols. An easy way to explain this is simply to replace the 0.0006V @ 400MHz for 10GBASE-T with the values for the other protocols, e.g. 0.07V @ 62.5MHz for 1000BASE-T or 0.24V @ 31.25MHz for 100BASE-TX. It is immediately evident that the sets of curves shift upward by a factor of 10 to 30. Thus, in the past it was guaranteed that the permitted noise level for U-UTP cabling was above 1V in the relevant frequency range.

100BASE-TX and 1000BASE-T can operate without problems with all cabling versions, provided the standard value of 1V is maintained for the grounding system. For 10GBASE-T this can only be achieved with an S-FTP system. For other cabling options, the grounding system requires a corresponding additional expense to attain in part significantly lower values than 1V.

## 5. Does Cat. 7 make greater system reserves possible?

As demonstrated above, the various disturbances are reduced as much as possible with the 10GBASE-T protocol. The following method can be used to estimate the size of the different disturbances.

IEEE has specified the power spectral density of the transmitting signal of 10GBASE-T. This value describes how the power of the DSQ 128 signal distributes itself over the frequency. A signal of approximately 80dBm/Hz is produced over the frequency range of approximately 1MHz – 400MHz. Outside of these limits, the energy content of the frequency drops sharply.

Since this representation of the signal is in the frequency range, the various derived power spectra can be calculated using the standard specifications. If the cabling insertion loss – as defined in the standards – is subtracted from the transmitting signal spectrum, the signal spectrum arriving at the receiver is obtained (Figure 8). This corresponds to the usable signal. If, on the other hand, the value for ANEXT is subtracted from the transmitting signal, the spectrum of the disturbing signal, which reaches the receiver due to alien crosstalk, is directly obtained.

If this calculation is carried out for all relevant parameters, a comparable overall picture results of all disturbances reaching the receiver (Figure 8). It must also be noted that with the internal parameters PSNEXT, PSFEXT and RL, in addition to the standard values, the active noise reduction (40dB, 25dB, 55dB respectively) performed by the protocol must taken into account.

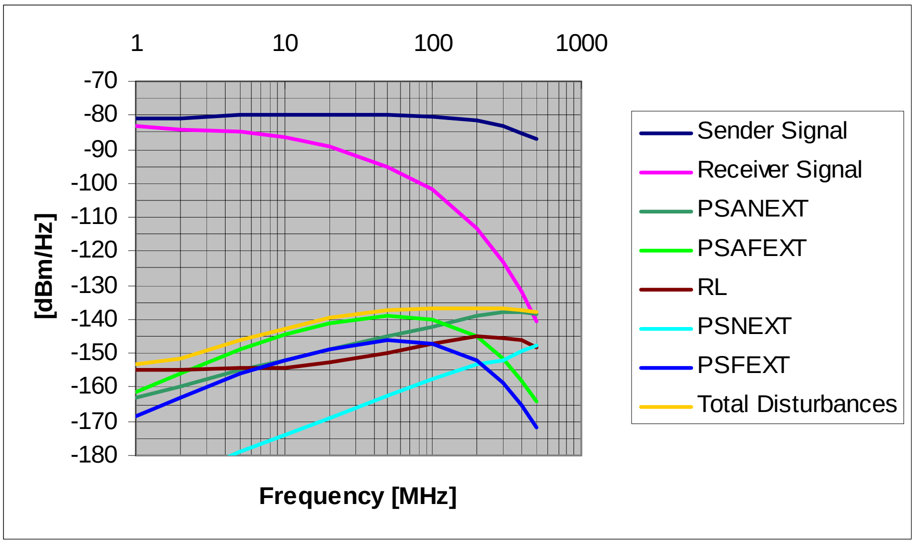


Figure 8: Spectrum of disturbance contributions caused by various parameters

If all individual disturbance contributions (according to performance) are added, this results in the total of all disturbances.

A comparison of the individual influences shows where there is potential for improvement and which parameters are already sufficiently low (Figure 9).
It is obvious that the overall disturbance is dominated by the parameters RL, PSAFEXT and PSANEXT. An improvement of these parameters would significantly reduce the size of the total disturbance, however, better PSFEXT and PSNEXT values would not result in much improvement at all.

R&M
Convincing cabling solutions

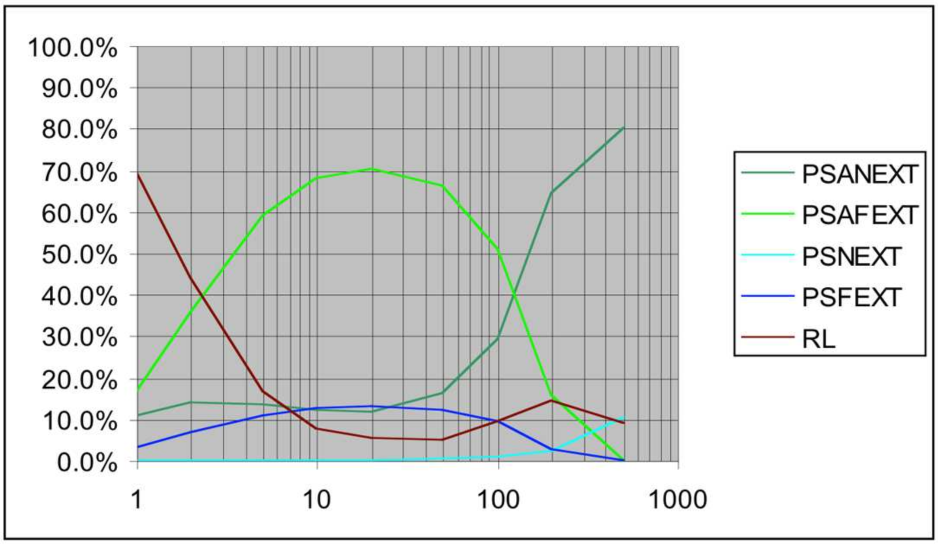


Figure 9: Percentage contribution of the individual influences on the overall disturbance

From studies on alien crosstalk it is known that a shielded cabling system with individual module shielding can improve alien crosstalk (PSANEXT as well as PSAFEXT) by 20 to 40dB. The remaining disturbance is for the most part attributed to the return loss. RL is specified with exactly the same values for Class E and Class F. Therefore, Class F cabling does not provide a significantly higher possible transmission rate than Class E. Class F improves only PSFEXT and PSNEXT, which are already sufficiently low, as well as the attenuation.

## 6. The Shannon channel capacity

By using the Shannon theorem, the potential data transmission rate of various cabling systems can be compared. Using the formula for the maximum possible data transmission rate over a given link (channel capacity), the physical limit of the transmission rate can be calculated:

$$Channel\ capacity = B \times Log_2\left(1+\frac{S}{N}\right)[Bit/s]$$

B: Bandwidth in Hz
S: Received signal power in W
N: Noise level in W

The transmittable data rate rises with increasing bandwidth, which is used for signal detection. The greater the received signal is compared to the disturbing signal, the higher the capacity.

S and N can be calculated from the spectral distribution of the usable signal and disturbing signal by integrating the areas under the relative curve on the above diagram. For a cabling link which meets the requirements of IEEE 802.3an, a maximum transmission capacity of 21.3 GBit/s is possible for the frequency range from 1 – 400 MHz (Figure 10). This corresponds almost exactly to the minimum requirement of 20 GBit/s communicated by IEEE.

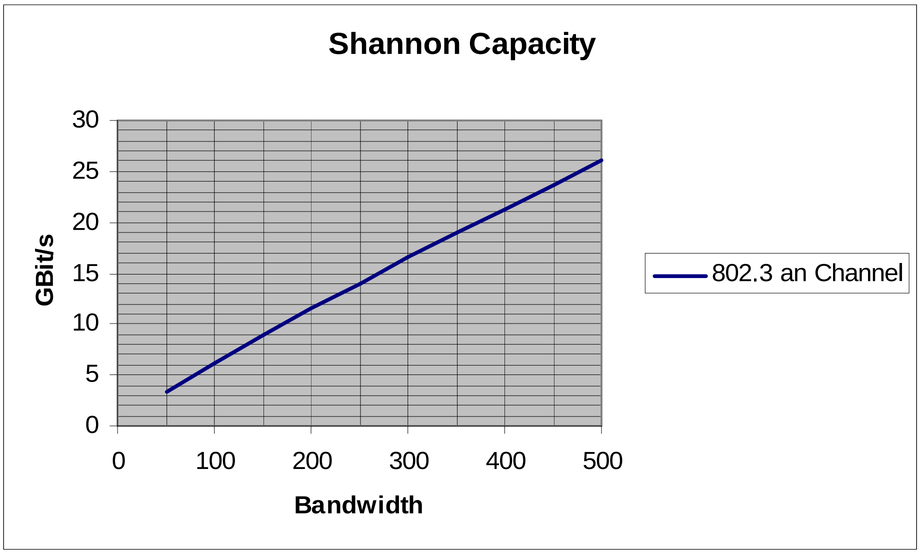


Figure 10: Maximum channel capacity depending on the bandwidth

Of interest is not necessarily the behavior over various frequency ranges but rather the comparison of different cabling systems at same bandwidth.

If shielded cabling is installed instead of the 802.3an conforming (U-UTP) cabling (PSANEXT and PSAFEXT are reduced by at least 20 dB, all other characteristics are the same), the channel capacity is improved at 400MHz to 25.4 GBit/s or by 19%.

If a Cat. 7 cable is used instead of a Cat. 6 shielded cable (insertion loss is reduced and PSFEXT is slightly improved), the channel capacity at 400MHz is increased to 25.8 GBit/s or by 21% compared to U-UTP.

A complete Class F cabling with a Cat. 7 connector system (PSNEXT and PSFEXT are further reduced) improves the channel capacity at 400MHz to 25.9 GBit/s or by 22% compared to U-UTP.

| **Cabling link** | **Channel capacity** | **Comparison** | **Attainable data rate** |
|---|---|---|---|
| IEEE 802.3 cabling (Cat. 6 U-UTP) | 21.3 GBit/s | 100% | 10 GBit/s |
| Shielded Cat. 6 cabling | 25.4 GBit/s | 119% | 11.9 GBit/s |
| Cabling with Cat. 7 cable and Cat. 6 connector system | 25.8 GBit/s | 121% | 12.1 GBit/s |
| Cat. 7 cabling (Cable and connector) | 25.9 GBit/s | 122% | 12.2 GBit/s |

Thus, the largest increase in channel capacity can be accomplished by using shielded cabling. Due to the low insertion loss and the frequently better shielding properties (see Chapter 4), a Cat. 7 cable can make sense. However, a Cat. 7 connector system only marginally increases the maximum transmission rate and, from that point of view, is not cost effective.

## 7. Conclusion

Common mode disturbances, which are coupled to cabling from the grounding system, have a significant effect on the function of 10GBASE-T. For U-UTP cabling a standard conforming configuration of the grounding system with adherence to the 1V regulation is insufficient to guarantee the 10GBASE-T function. Therefore, additional expenses for the grounding system must be expected.

The same applies to shielded cabling, i.e. the adherence to the standard “per se” is insufficient. Components with the best possible shielding properties must be considered in order to be ready for future developments. S-FTP cabling with individually shielded RJ45 modules offers the best attributes long term to guarantee 10GBASE-T function.

Class E cabling provides – from the point of view of transmission technology – a balanced mix for the performance of all parameters. Thus, it offers an optimal price/performance ratio. Through the reduction of alien crosstalk, shielded Class E cabling with individually shielded modules provides needed margin to assure proper functionality.

One-sided improvements of individual parameters alone, as is the case with Class F, only marginally improve the potential data transmission rates and thus are not cost effective.

**The most important findings from the point of view of a planner or end user!**
In the future there will be shielded as well as unshielded cabling systems for 10GBASE-T. However, more time and material will be needed for a “clean“ grounding system. For investment decisions the total costs must be taken into account and not just the cost of the cabling. The use of apparently higher performance components (Cat. 7) does not in the end benefit the user if the improvement is not implemented in the proper place.

## 8. Recommendation

The properties of 10GBASE-T will tax cabling to the limit. Therefore, only the best quality cabling components should be used. For operational reliability and investment protection compliance to the standards alone is insufficient and additional criteria must also be considered.

For the 10GBASE-T application, R&M recommends the use of the STAR Real10 STP components with shielded Cat 6 components. This system provides the user with a maximum of reserve, flexibility and reliability. More than 3 million cabling links have been installed that are 10GBASE-T-capable, thus, this system already provides a broad and proven base.

R&M recommends the new STAR Real10 UTP components with Cat. 6 components equipped with the innovative WARP technology for customers who have decided on U-UTP or who for compatibility reasons wish to remain with U-UTP systems. This solution provides excellent protection against alien crosstalk and the well-proven R&M quality advantages.

## 9. Additional information

For additional information on R&M products and solutions, visit www.rdm.com