White Paper

Class E_A and Class F_A Cabling for 10GBase-T and 40GBase-T

R&M
Convincing cabling solutions

Class E_A and Class F_A Cabling for 10GBase-T and 40GBase-T

Content

Copper Cabling for Next Generation Data Transmission Technology

Application:	Data center networks, 10-GBit and 40-GBit Ethernet
Technology:	Cat. 6_A/Cat. 7_A connection modules, RJ45 connectors, twisted pair copper cabling
Format:	White Paper
Subjects:	Transmission capacity of Class E_A and F_A cabling, suitability for 40GBase-T and 100GBase-T
Objective:	Provide basic understanding of the physical limitations in order to be able to plan a future proof cabling system
Target group:	Data center planners, network managers, decision makers
Author:	Matthias Gerber
Published:	June 2011

There is a need for ever-faster data transmission technologies for connecting servers in data centers. This need has become even more widespread since the introduction of the 10-GBit Ethernet 10GBase-T. In this White Paper, the author investigates the capabilities of Class E_A and F_A cabling and of Cat. 6_A and Cat. 7_A components to support next generation data transmission protocols. In the process, he compares the possible transmission capacities of the different classes.
Next, he investigates which critical cabling parameters limit the capability for fast data transmission.
The author then presents a possible approach to a future 40GBase-T and determines the possible effects it could have on cabling.

In the final section of the White Paper, the author gives a recommendation on how cabling could be specified so it would satisfy future needs.

1. Initial situation

Cabling is not an end in itself. Its purpose is to transmit data. When a new class of cabling comes along, an application that requires this class should already exist or at least be visible on the horizon. An application of this kind is often referred to as a killer application.
Some cabling manufacturers frequently cite 40GBase-T as the killer application for Class F_A and Cat. 7_A components. Other applications to legitimize Class F_A are not in sight. There were various earlier discussions on broadcasting cable TV over twisted pair (CATV over TP) or on using one cable for several applications (cable sharing). Lower classes and RJ45 connector systems can demonstrably handle these applications. The standardization committees also failed to require more stringent coupling attenuation for higher classes, so EMC protection cannot be used as an argument either.
When Cat. 6 was defined, there was no application for it either, but Cat. 6 ultimately paved the way for the development of 10GBase-T. But compared to then, there is so much more knowledge now about the capabilities and limitations of active transmission technology than back then. 10GBase-T is approaching the theoretical transmission capacity of Class E_A as no other application before.

In order for 10GBase-T to be able to run on Class E_A cabling, the application must have active echo and crosstalk cancelation. For this, a test pattern is sent over the channel during set-up and the effects on the other pairs are stored. In operation, the stored unwanted signals (noise) are used as correction factors in digital signal processing [DSP] and subtracted from the actual signal. The potential improvements that are achieved in 10GBase-T are 55 dB for RL, 40 dB for NEXT and 25 dB for FEXT.
Adjoining channels are not connected or synchronized, so no DSP can be conducted. Active noise cancelation for crosstalk is therefore impossible from one channel to the next (alien crosstalk).

2. Signal and noise spectrum of 10GBase-T

The data stream is split up among the four pairs for 10GBase-T and then modulated by a pseudo random code (Tomlinson-Harashima Precoding [THP]) to obtain even spectral distribution of power independent of the data.
Using a Fourier transformation, one can calculate the power spectrum density [PSD] of the application from the time based signal that is similar to PAM-16. IEEE specified this spectral distribution of power over the frequency in the standard for 10GBase-T. That is important in this context because all cabling parameters are defined as a function of the frequency and their influence on the spectrum can thus be calculated.
If attenuation is subtracted from the transmission spectrum, for example, the spectrum for the receiving signal can be calculated. The parameters RL, NEXT, FEXT, ANEXT, AFEXT etc. can be subtracted to obtain the spectrum of the various noise components. With active noise cancellation from DSP taken into account, one can calculate the actual signal and noise distribution at the receivers. Figure 1 contains a diagram showing these interactions.

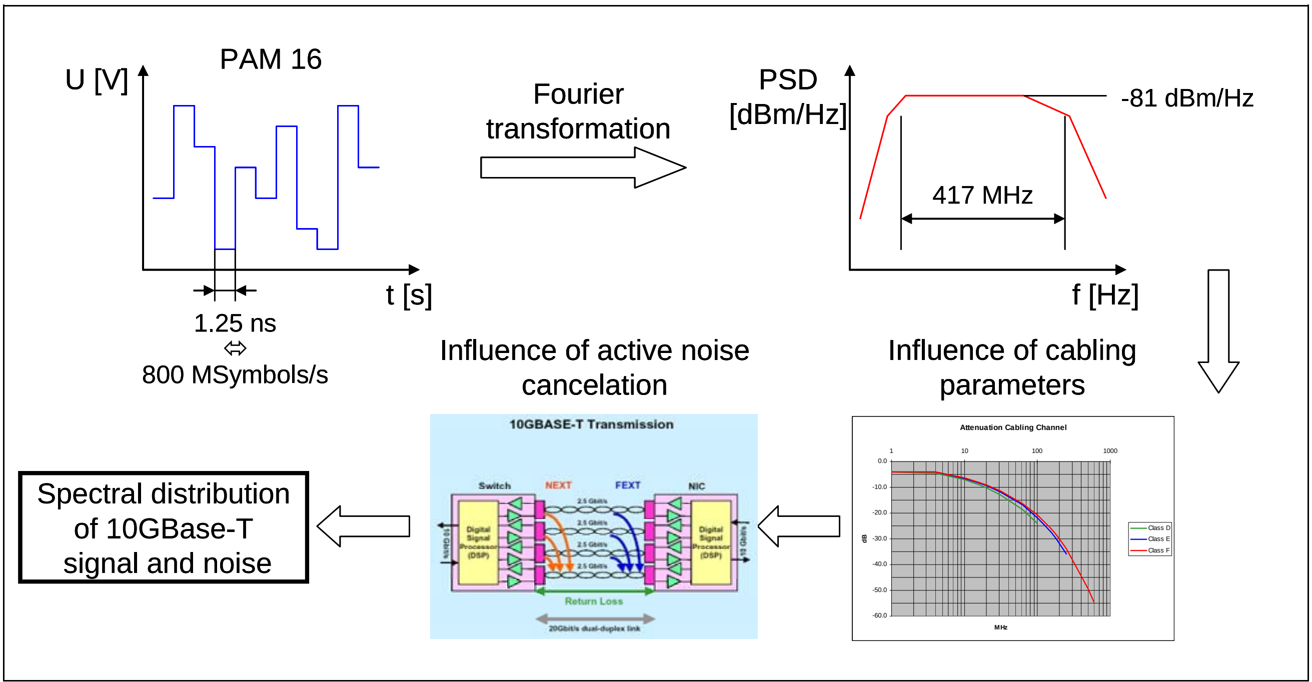

Figure 1: Theoretical procedure for determining the spectral distribution of signal and noise

With this PSD the relative magnitudes of signal and different noise source contributions can be compared with each other. That is what makes this procedure particularly interesting. Figure 2 shows the signal spectrum, the total noise spectrum and the different components of noise for an unscreened 100-m Class E_A channel. IL and RL serve as examples to show how the cabling parameters are subtracted from the transmission spectrum. In the case of RL, the influence of active noise cancelation is also taken into account. The intersection between signal strength and noise strength often serves in cabling technology to define the bandwidth. If no active noise cancelation is done, return loss is the parameter which is defining the noise power. In this case, the bandwidth is around 50 MHz. In order to ensures the bandwidth of 66 MHz needed for the 1-GBit Ethernet 1000Base-T active noise cancelation of return loss is needed already at that level.

Using the active noise cancelation realized by 10GBase-T, bandwidth improves to 450 MHz (see Figure 2).

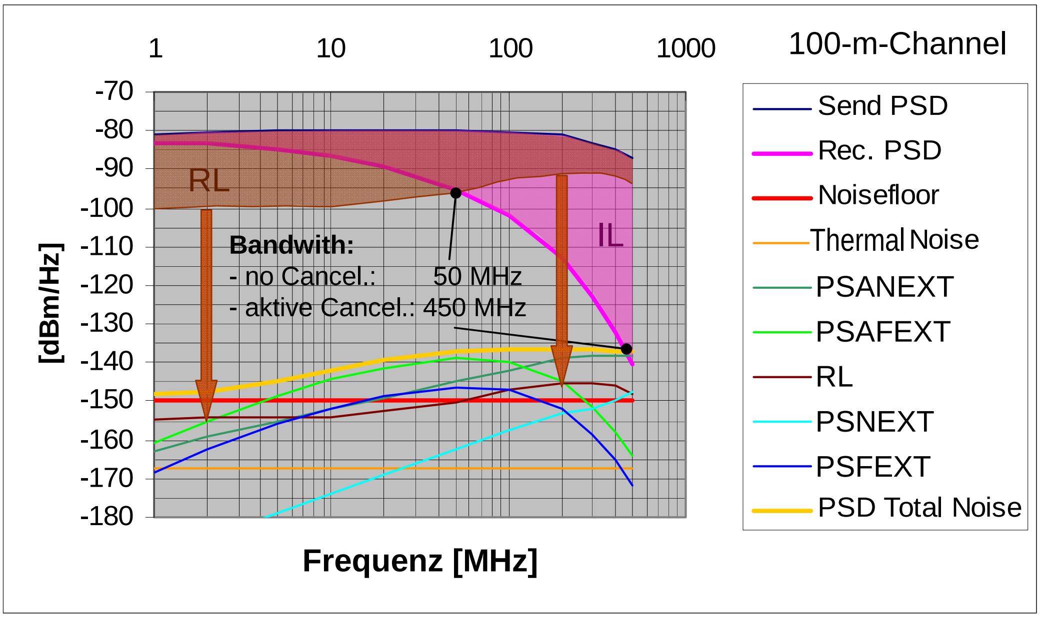

Figure 2: Comparison of spectral noise components

If one compares the different noise parameters with each other, it is striking that alien crosstalk contributes the most to noise in Class E_A as it is defined today. With modern data transmission featuring active noise cancelation, this means the achievable bandwidth is limited by alien crosstalk which cannot be improved electronically. One can only increase bandwidth by improving alien crosstalk, i.e. ANEXT [Alien NEXT] and AFEXT [Alien FEXT]).

The cable jacket diameter required to meet the specification for alien crosstalk in unscreened cabling already hits users' limits of acceptance. In order to increase the bandwidths further, one has no choice but to switch to screened systems. With the effects of additional screening, alien crosstalk becomes so slight in these systems that it can be ignored for these considerations for the time being.

Return loss [RL] is the biggest source of internal noise in cabling, causing 61% of the total. It is followed by FEXT, which causes 27%, and NEXT, which generates 12%. Unfortunately, RL is precisely one of the parameters whose full potential is already nearly reached. Improvements are no longer so easy to achieve. This situation is underscored by the fact that RL is defined exactly the same for the Classes E_A and F_A. That means the biggest noise component remains unchanged when one switches from Class E_A to Class F_A.

3. Transmission capacity of different cabling classes

C.E. Shannon was one of the scientists who laid the mathematical foundations for digital signal transmission in the 1940s. The Shannon capacity is a fundamental law in information theory based on the physical limitations of the transmission channel (entropy). It defines the maximum rate at which data can be sent over a given transmission channel. The Shannon capacity cannot be exceeded by any technical means.

According to Shannon, the maximum channel capacity can be calculated as follows:

$$K_S = X_T * B * \log_2 (1 + S/N) \text{ [Bit/s]}$$

Abbreviations:

K_S = Channel capacity (according to Shannon)
X_T = Factor dependent on channel (dependent on media used, modulation methods and other factors; ranges from 0 to 1)
B = Bandwidth of signal used (3 dB points)
S = Received signal power in W
N = Received noise power in W

The higher the bandwidth of the signal and the transmission power used and the smaller the noise level, the higher the possible data transmission rate.
The noise level is usually derived from the transmission power in a fixed ratio in cabling, e.g. as with RL. In this case, the signal-to-noise ratio cannot be improved by increasing the transmission power.

One can now calculate the signal and noise power from the power density spectra of received signal and total noise. The integral of the area under the signal spectrum corresponds to the signal power S and the one under the noise spectrum to the noise power N. S and N can now be applied directly in the Shannon formula.
The interesting thing about calculating S and N from the power density spectrum is that one can change the individual cabling parameters independently of each other and investigate their influence on channel capacity. That means the Shannon capacities can be calculated for the different classes of cabling.

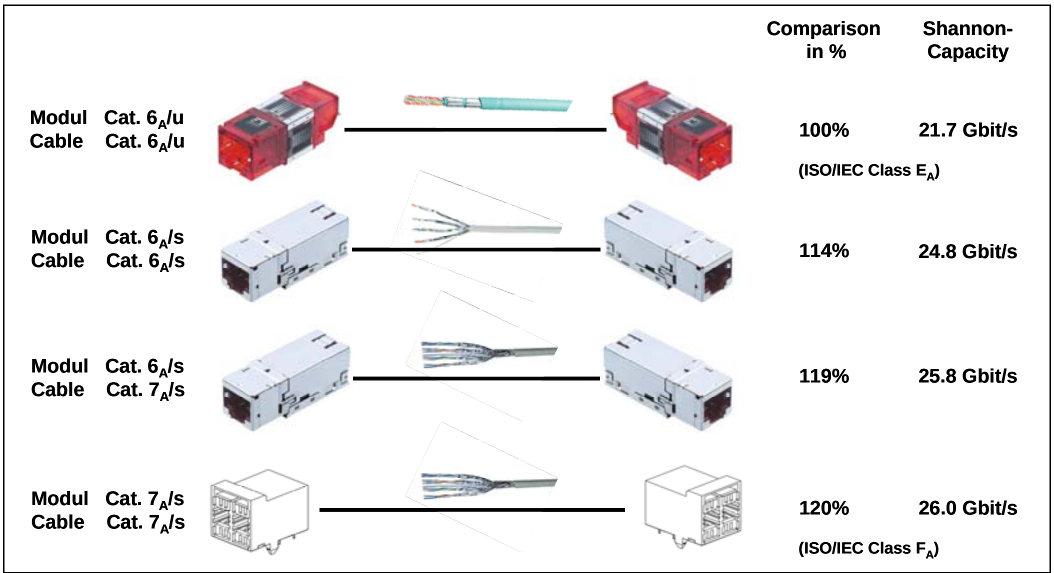

Figure 3: Comparison of the Shannon capacities of different cabling channels at 400 MHz

The Shannon capacities of different cabling configurations are compared in Figure 3. This comparison shows which changes will lead to a substantial increase in channel capacity and that are therefore cost effective and yield actual added value.
The first line in the picture corresponds to an unscreened Class E_A channel in accordance with the standard. This line serves as the reference for comparison with other configurations. The switch from unscreened to screened cabling improves alien crosstalk, thereby increasing the channel capacity by 14%. The switch from a Cat. 6_A cable to a Cat. 7_A cable mainly reduces attenuation and thus increases the signal level on the receiver side. The channel capacity increases by a further 5% in the process, to 119%. If one also replaces the RJ45 Cat. 6_A sockets with Cat. 7_A sockets, the channel capacity rises by only 1%. The explanation for this minimal increase is that the new socket improves mainly NEXT and FEXT but these values are already sufficiently low due to the active noise cancelation.

4. Outlook for possible 40GBase-T over 100 meters

IEEE specified that it needs a channel capacity of 20 Gbit/s to realize 10GBase-T. That corresponds well to the 21.7 Gbit/s capacity achieved with the Class E_A channel at 400 MHz. One can therefore assume that 40GBase-T requires a channel capacity of 80 Gbit/s.
Using the power density spectrum, one can now investigate what the ideal situation would be for signal and noise. The signal spectrum has maximum strength if one uses a cable with a maximum wire diameter. The considerations below are based on an AWG-22 cable, assuming customers would not accept cables with larger diameters for reasons related to handling and space consumption.
The lowest possible noise level achievable is limited by thermal noise. This noise is produced by the copper atoms in the cable that are moving due to their temperature. It equals –167 dBm/Hz at room temperature. Considering, it is practically infeasible to cool cabling artificially, e.g. with liquid nitrogen, this noise level cannot be reduced further.
To keep total noise in the range of non-reducible thermal noise, one must reduce all noise factors to the point where they are also under the level of thermal noise even in a worst case scenario. For Class F_A cabling, that is true if the following basic conditions are met:

Alien crosstalk:	PSANEXT = 30 dB higher than F_A level
	PSAFEXT = 25 dB higher than F_A level
Active noise cancellation:	RL = 90 dB (55 dB)
(values in parentheses: 10GBase-T)	NEXT = 50 dB (40 dB)
	FEXT = 35 dB (25 dB)

One can now calculate the Shannon capacity for this hypothetical cabling system based on the above assumptions (refer to Figure 4). One achieves a channel capacity of 80 Gbit/s at a bandwidth of around 1 GHz. For a PAM signal, one achieves a bandwidth of 1000 MHz with a symbol rate of 2000 MSymbols/s or 2 GBd (Baud). To achieve a throughput of 40 Gbit/s with this symbol rate per pair, one must have 5 bits per symbol. That corresponds to PAM-32 coding.

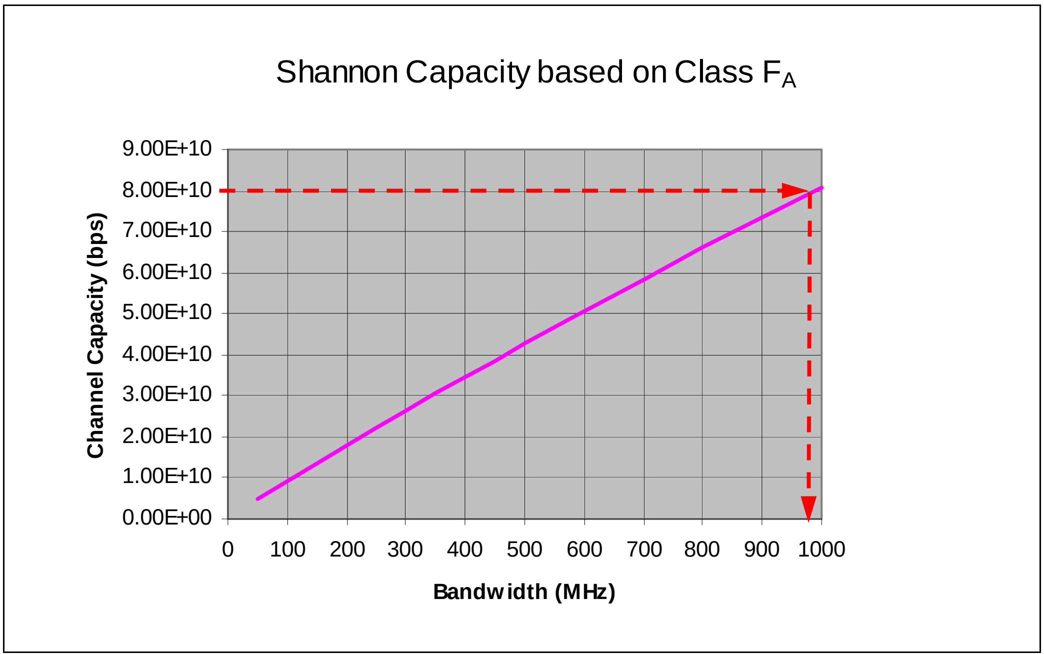

Figure 4: Channel capacity according to Shannon for the proposed 40GBase-T channel over 100 m

The channel bandwidth is approximately 1.4 GHz for the conditions mentioned above. That means the portions of the signal above 1.4 GHz that arrive at the receiver are less than thermal noise. At 1 GHz, the signal-to-noise ratio amounts to 14 dB. This should allow a 40GBase-T protocol to be operated.
On the other hand, the Shannon capacity at 1.4 GHz is just around 110 Gbit/s which is not sufficient for the operation of a 100GBase-T.

For 100-m cabling, one can conclude that it is physically impossible to develop a 100GBase-T. By contrast, 40GBase-T appears to be technically feasible albeit extremely challenging.

90 dB RL compensation → A/D converter with better resolution (+6 bits)
Clock rate 2.5 times higher than for 10GBase-T
Substantial heat generation → reduced port density in active equipment
Extremely low signal level → EMC protection needed

The cabling attenuation exceeds 67 dB at 1000 MHz. In addition, the available voltage range with PAM 32 is subdivided into 32 levels. That means the distance from one level to the next is just 0.03 mV. That is more than 20 times less than the distance in 10GBase-T. One must therefore also improve the protection from outside noise accordingly.

5. Alternative approaches for 40GBase-T

Many experts think the requirements for a 40G protocol over 100 m are too challenging for use under field conditions. Moreover, most experts consider the main use of 40GBase-T to be in data centers to connect servers in the access area and not in classic structured horizontal cabling. The cabling lengths required in the DC are much shorter and a reduced transmission distance is certainly reasonable.

For instance, if the PL is fixed at 45 m max and the patch cable lengths at a total of 10 m, attenuation falls to the point that there is the same signal distance at 1 GHz and PAM 32 from level to level as there is now with 10GBase-T (417 MHz and PAM 16). That seems to be a good compromise between achievable cable length and noise resistance and is a good basis for further considerations.

One positive side effect of a reduced attenuation is that somewhat more noise can be allowed and still have the same signal-to-noise ratio:

Alien crosstalk:	PSANEXT = 25 dB higher than F_A level
	PSAFEXT = 25 dB higher than F_A level
Active noise cancellation:	RL = 75 dB (55 dB)
(values in parentheses: 10GBase-T)	NEXT = 45 dB (40 dB)
	FEXT = 30 dB (25 dB)

A Shannon capacity of 86 Gbit/s is achieved based on the above assumptions.

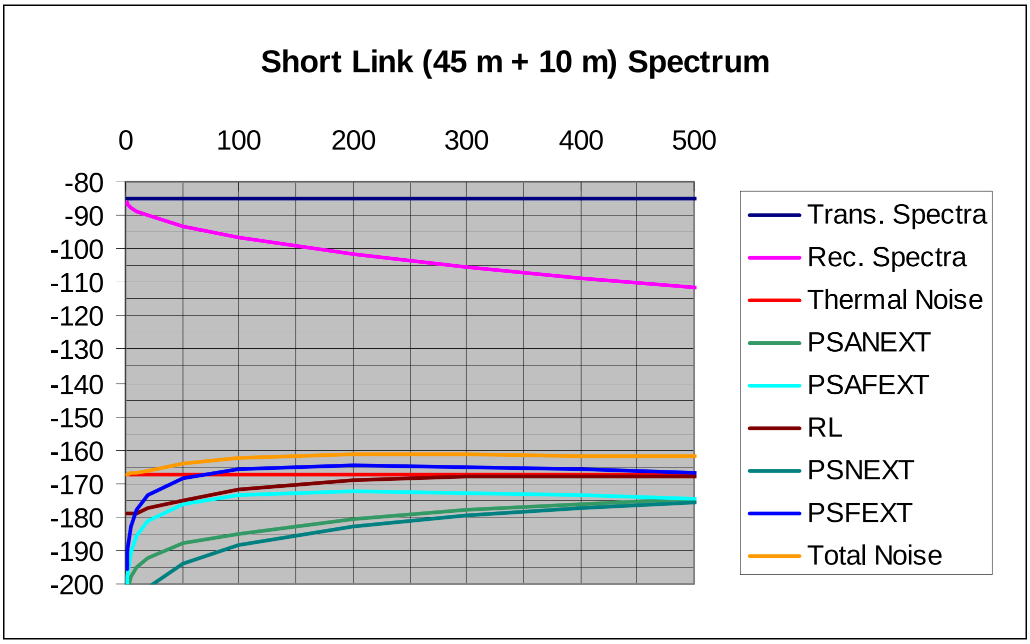

Figure 5: Power density spectrum of 40GBase-T cabling shortened to the greatest possible extent

Since one must increase alien crosstalk for the Class F_A channel by an additional 25 dB to achieve the required channel capacity, this means the Class F_A channel as it is defined today will not suffice to support a 40-Gbit/s connection.
Also an active noise cancellation of 75 dB for RL will be required. To achieve this level, one will probably have to use a higher resolution for the A/D converter than was the case with 10GBase-T. This higher resolution will also probably improve NEXT and FEXT to a similar extent and create a certain reserve. With this reserve the use of RJ45 Cat. 6A jacks could not be completely ruled out.

By applying the parameters as postulated in the power density spectrum and then calculating the Shannon capacity, one can now compare the suitability of the different types of cabling for the 40GBase-T channel.

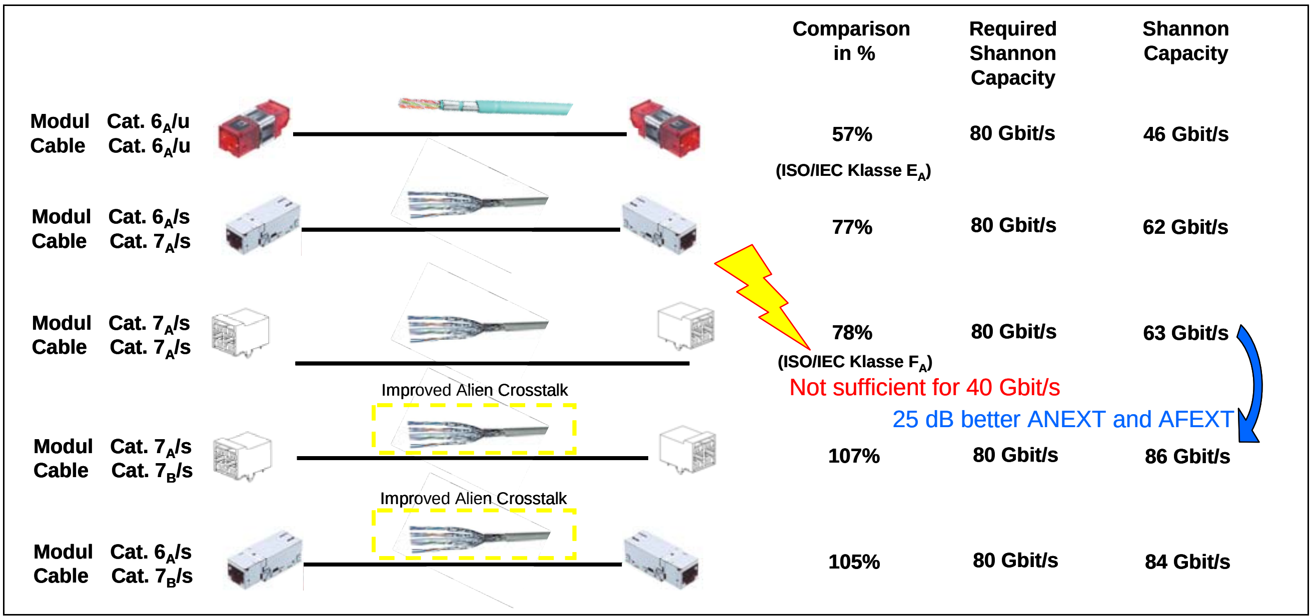

Figure 6: Comparison of channel capacities at 1000 MHz for 45 m PL and active noise cancellation of RL = 75 dB, PSNEXT = 60 dB and PSFEXT = 45 dB

Class E_A is only defined up to 500 MHz. The curves for the parameters between 500 MHz and 1 GHz was linearly extrapolated for these calculations and are thus debatable.
Figure 6 does clearly show, however, that Classes E_A through F_A cabling do not suffice to achieve the required channel capacity for 40GBase-T. Alien crosstalk (ANEXT and AFEXT) is the limiting factor for these cabling classes. By improving alien crosstalk by 25 dB, one could achieve the required channel capacity for 40GBase-T, regardless of whether one uses a Cat. 7_A or Cat. 6_A connector system. The Cat. 7_A cable has to be newly specified with better alien crosstalk characteristics in order to improve this parameter. To illustrate this difference, this newly specified cable is referred to here as Cat. 7_B. That designation is not based on any standard, however.

The key to future proof the cabling therefore lies in the specification of a new Cat. 7_B cable and not necessarily in the use of a Cat. 7_A connector system.

6. Summary

- 10GBase-T up to 100 m appears to be the limit of what is feasible for unscreened cabling.
- 40GBase-T up to 100 m is technically feasible but appears to be too challenging for field use. Presumably it will be defined with reduced cable length (e.g. with 45 m PL).
- 100GBase-T up to 100 m appears to be technically unfeasible.
- Today's Class F_A standardization does not support 40GBase-T because the specification for alien crosstalk is not stringent enough → a new Class F_B will be needed.
- It has not yet been shown that a Cat. 7_A connector system is necessary to achieve 40GBase-T.

Given the uncertainties about connector system requirements, one should wait for clarification in the standardization before using Cat. 7_A connecting hardware. Cat. 7_A cables with improved alien crosstalk (Cat. 7_B) can be used to be 40GBase-T ready.

Convincing cabling solutions

Additional information:

Go to the following website for additional information on the products and solutions R&M has to offer:
www.rdm.com