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Red Bank, New Jersey, 18 – 22 March 2013

Question: 4/15

SOURCE[1]: TNO

TITLE: G.fast: Preliminary analysis of the transfer characteristics of the 104 m KPN Access cable

ABSTRACT

TNO has released measurements for the 12x12 transfer matrix for the 104m KPN Access cable. This contribution provides a first analysis of the released data. This contribution is for information only.

1. Introduction | 2. Transmission | 3. FEXT | 4. The cause of strong crosstalk | 5. Modelling the transmission | 6. Equal-Level FEXT | 7. Distribution of the EL-FEXT | 8. Conclusions | 9. Summary

1. Introduction

TNO has provided to Q4 the 12x12 forward transfer matrix for the 104 m KPN Access cable in the accompanying contribution [1]. This data may be used for G.fast performance studies, e.g. to compare the performance of linear and non-linear pre-coding schemes.

The physical properties of the cable and the measurements are described in [1] and in the references therein. This contribution investigates some of the measured transmission and crosstalk properties. In this contribution, the term "transmission" is used to denote the direct (or in-wire-pair) forward transfer, i.e. the transfer function from one end of a wire pair to its other end. The term "FEXT coupling" is used to denote the cross-wire-pair forward transfer from one end of one wire pair to the other end of another wire pair.

2. Transmission

Figure 1 shows the measured transmission of all twelve wire pairs in the cable. At low frequencies the curves are very similar, but at higher frequencies the spread becomes larger. This can be understood by noting that at higher frequencies, some of the FEXT couplings become comparable to the transmission, causing a significant part of the transmit power on the wire pair under study to "leak" into other wire pairs. In particular the transmission of wire pairs 5…8 are interesting: above 150 MHz fluctuations of more than 20 dB are visible (repeating the measurements proved the reproducibility). For further discussion on this see section 4.

All transmission curves exhibit systematic notches at 27, 54 and 81 MHz. It is plausible that these are caused by the presence of so-called 'waterplugs' in this type of cable: these plugs serve to prevent water from spreading throughout the length of the cable. These plugs are present at regular intervals of 4 meter. The propagation speed in the cable T05u in the relevant frequencies is around 0.73 of the speed of light. If we equal the distance of 4 meter to one half of the wavelength, the corresponding frequency is 0.73 x c / 8 = 27.4 MHz.

[1]

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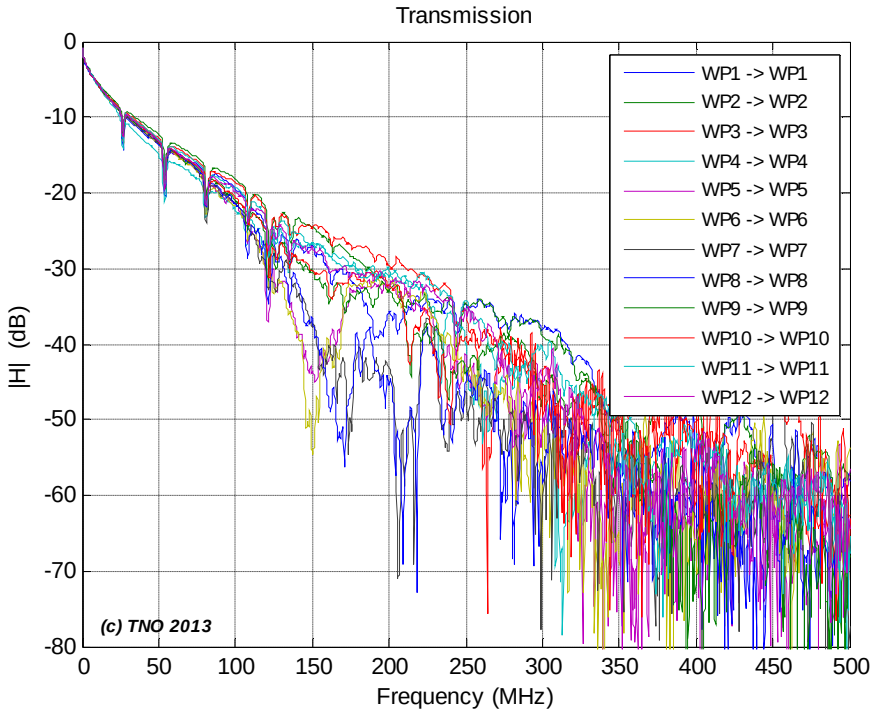

Figure 1: The twelve measured transmission curves.

3. FEXT

As a typical example, Figure 2 shows the eleven FEXT couplings to wire pair #7. The one FEXT coupling that sticks out above the rest is the FEXT coupling from wire pair #8 to wire pair #7, i.e. the in-quad FEXT. Note that this effect is particularly visible in the frequency range up to roughly 200 MHz.

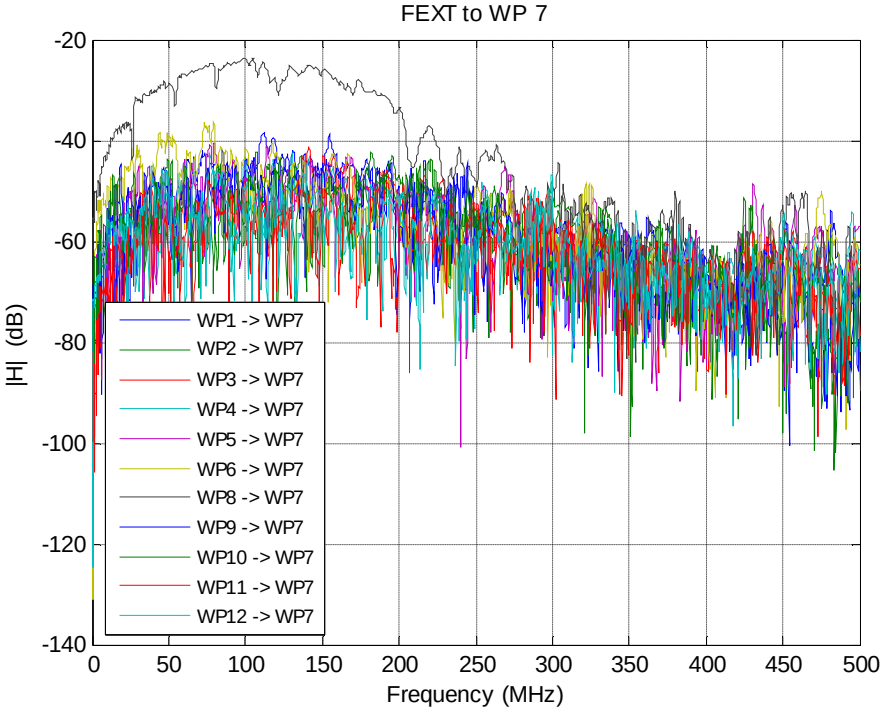

Figure 2: The 11 measured FEXT couplings to wire pair #7.

Figure 3 and Figure 4 show (on the same scale) respectively all the in-quad and all the out-of-quad measurements.

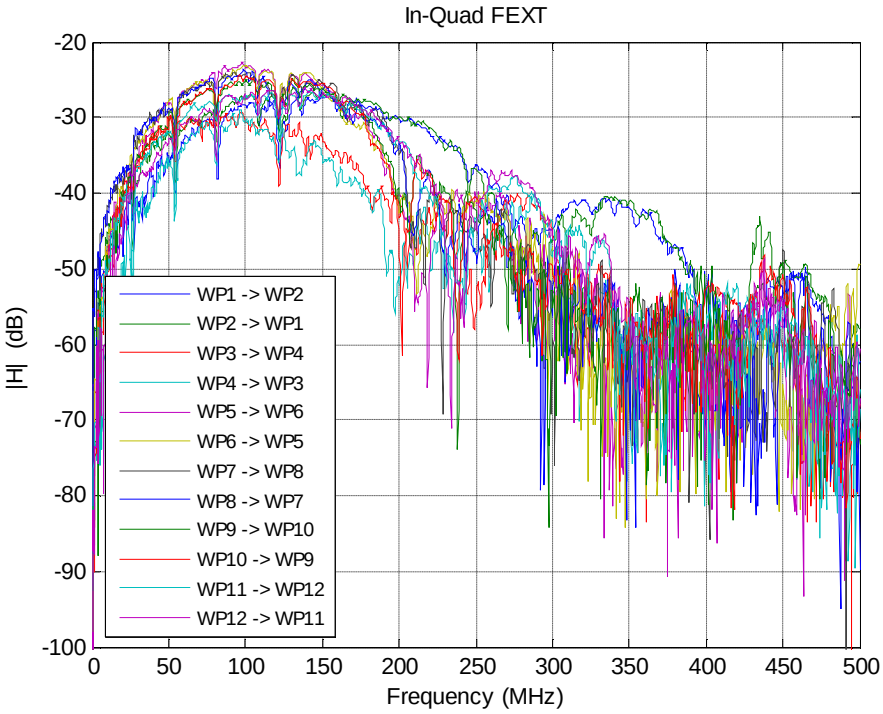

Figure 3: The 12 measured in-quad FEXT couplings.

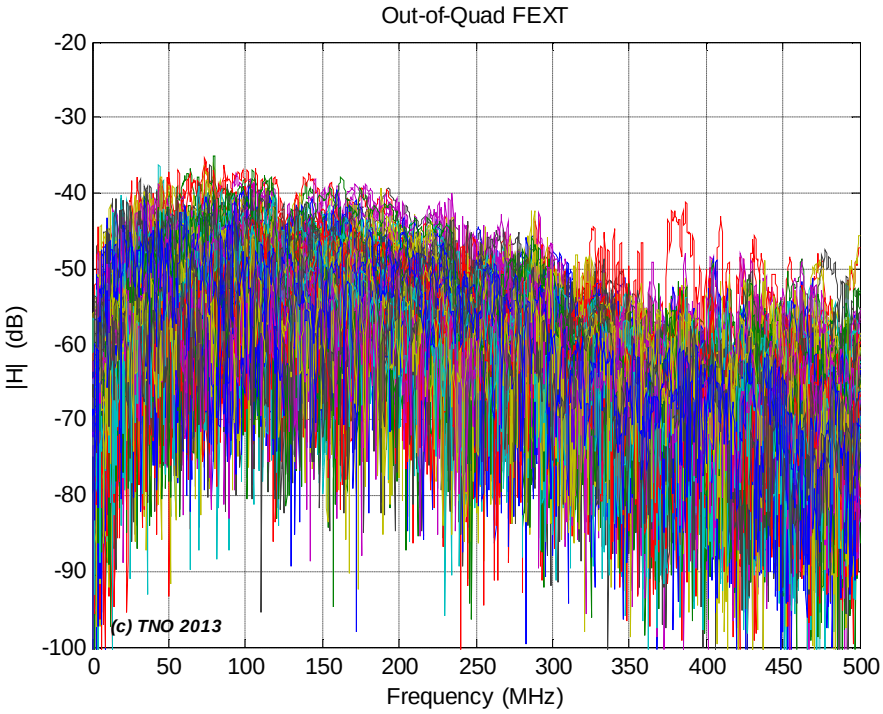

Figure 4: The 120 measured out-of-quad FEXT couplings.

4. The cause of strong crosstalk

The section above clearly shows that for *this cable* the in-quad FEXT couplings are much stronger than the out-of-quad couplings, especially in the frequencies up to 200 MHz. However, it must not be concluded that *in general* in-quad crosstalk will always be much stronger than all out-of-quad crosstalk.

The usual explanation for strong in-quad crosstalk is twofold:

- the close proximity of the two wire pairs in the quad.
- the fact that the two wire pairs in a quad necessarily have the same twist length.

It is well-known that the twist of the wire pairs in a telephony cable is a powerful means to reduce crosstalk. Using

different twist lengths in the cable is a technique to lower the crosstalk between wire pairs even further. Large cables with many wire pairs typically use a limited number (e.g. four to six) of twist lengths. Based on our experience of crosstalk measurements up to 30 MHz in such large cables, the dominant cause of strong coupling in this frequency range is definitely not proximity, but the fact that two wire pairs have the same twist length.

The twist length scheme in the measured cable is unknown. However, since there are only six quads in this cable, and because of the known benefits of using different twist lengths to minimise crosstalk, it is plausible that the manufacturer has used six different twist lengths in the investigated cable. If at G.fast frequencies it is still true that having the same twist length is the dominant cause of strong crosstalk between wire pairs, one should expect in larger cables to see crosstalk comparable to in-quad crosstalk for out-of-quad crosstalkers with the same twist length.

5. Modelling the transmission

Figure 5 compares the transmission curves to the strongest FEXT curves, i.e. the in-quad FEXT couplings. The black dotted curve in Figure 5 shows the T05u transmission model (as defined in Appendix I of [2]) evaluated for the loop length of the measured cable (104.1 m). This transmission model is a conventional two-port cable model: it aims to represent the transfer function of a wire pair as function of length and frequency in the absence of crosstalk. However, such a model should not be expected to still apply once the transmission becomes comparable to the crosstalk couplings in the cable.

Indeed, Figure 5 shows both aspects:

- At low frequencies, the match between the "T05u" two-port cable model and the measured transmission is very good.
- Once the FEXT becomes comparable to the transmission, the two-port cable model no longer applies.

An intuitive way to understand the second point is to note that once the FEXT approaches the transmission, a significant part of the transmit power on the wire pair under study starts to "leak" into other wire pairs, causing reductions (and spread) of the transmission.

In general, conventional two-port cable models do not account for spread in the transmissions. The investigated cable shows that once the transmission becomes comparable to the FEXT, the transmission is no longer a single deterministic function of the loop length. Rather, an intrinsically statistic spread may need to be added to such a deterministic description, or more complicated cable models may be needed. This is left for further study.

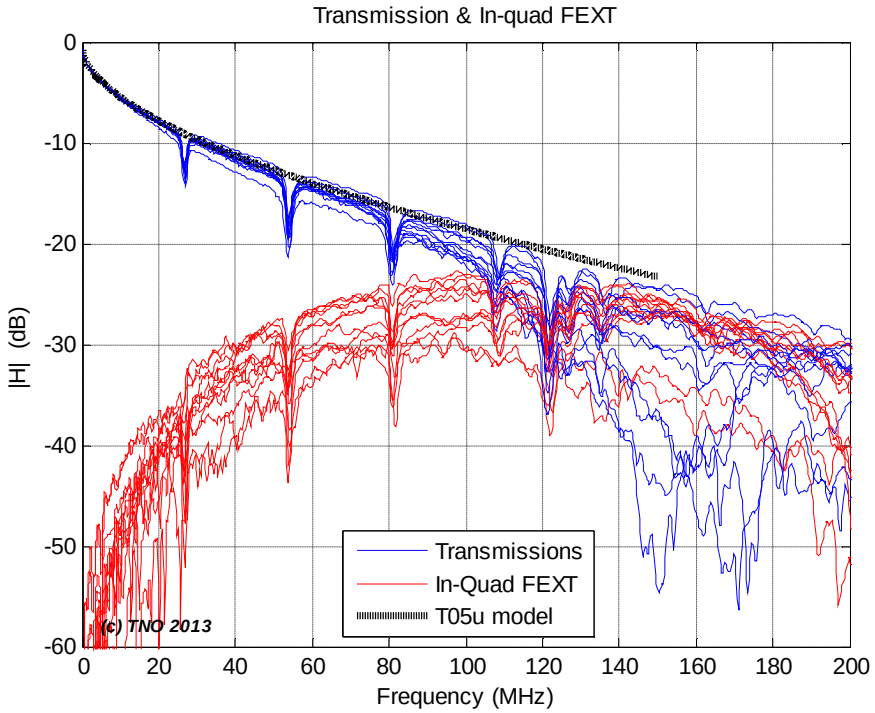

Figure 5: The measured transmission curves and in-quad FEXT. The black dotted curve is the parameterised T05u model as defined in Appendix I of [2].

6. Equal-Level FEXT

The EL-FEXT to a wire pair is obtained by dividing the FEXT to a wire pair by the transmission of that wire pair. As another typical example, Figure 6 shows the eleven EL-FEXT couplings to wire pair #5. The dominant coupling is the

in-quad coupling (the magenta curve, WP6 **à** WP5). The dotted curve is the power sum of all the EL-FEXT to this wire pair. Note that above roughly 10 MHz, the EL-FEXT power sum is dominated by the in-quad coupling.

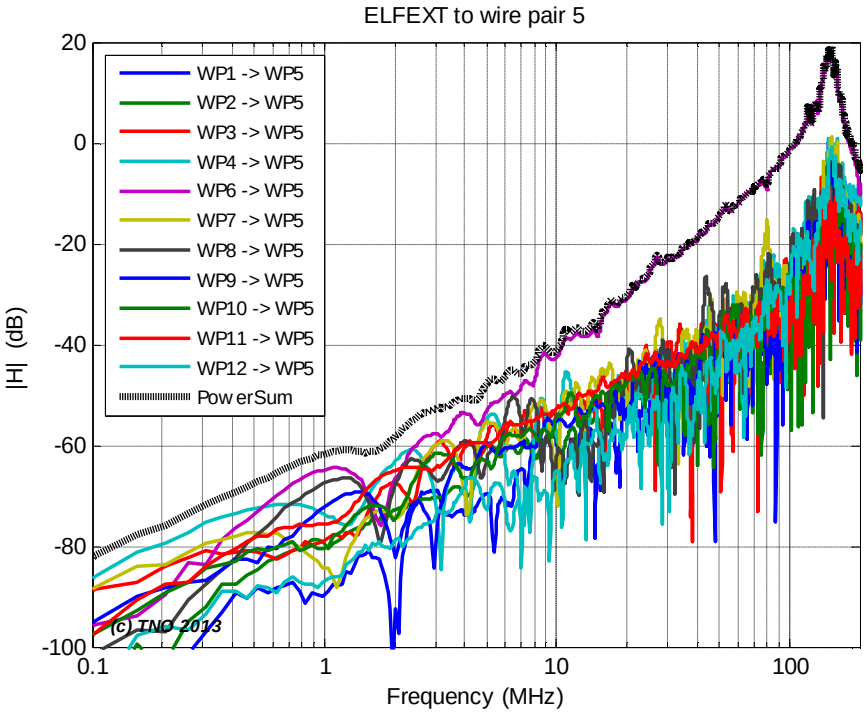

Figure 6: The 11 measured ELFEXT couplings to wire pair #5. The dotted curve is the power sum of all the EL-FEXT to this wire pair.

Since the in-quad and out-of-quad EL-FEXT differ so much in strength in this cable, the further analysis of the EL-FEXT is done separately as well. Figure 7 and Figure 8 show (on the same scale) respectively all the in-quad and all the out-of-quad EL-FEXT couplings. At high frequencies, a couple of the in-quad EL-FEXT curves strongly exceed 0 dB, meaning that the received FEXT on those wire pairs is larger than the received direct signal[2]. The strongest examples of this occur in cases where the direct transmission shows a dip/fluctuation (see section 2).

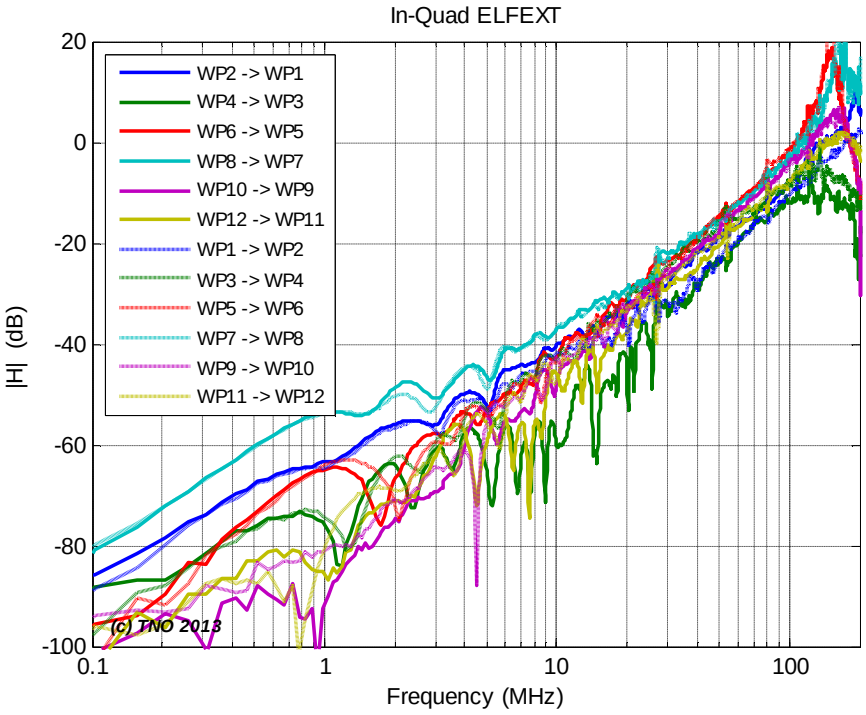

Figure 7: The 12 in-quad EL-FEXT couplings.
Note the approximate symmetry of the two in-quad couplings.

[2] Note that also some of the out-of-quad EL-FEXT values exceed 0 dB.

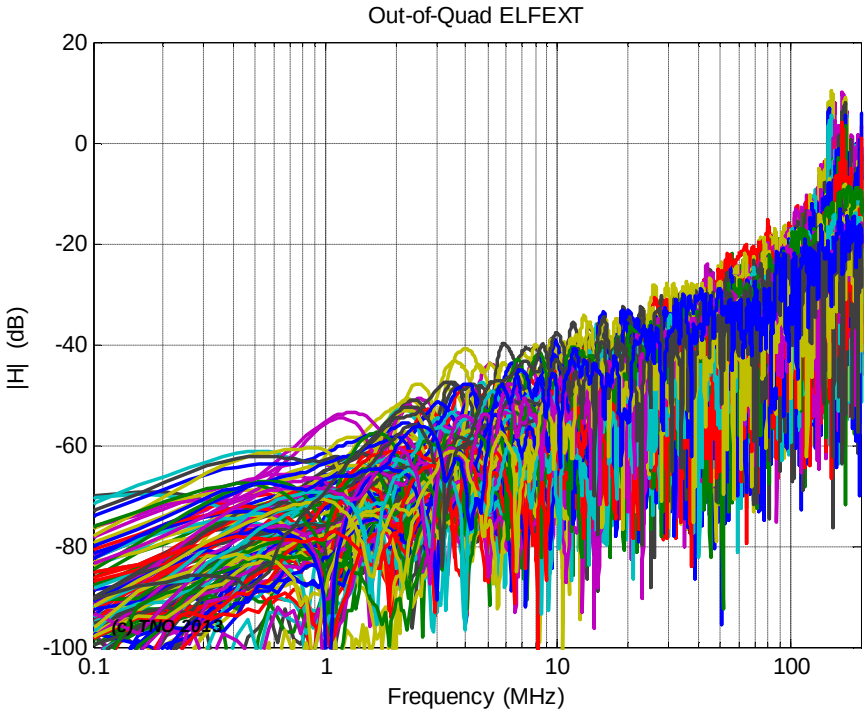

Figure 8: The 120 out-of-quad EL-FEXT couplings.

The out-of-quad disturbers show quick and large fluctuations as function of frequency. Calculating for each victim wire pair the power sum of all the ten out-of-quad disturbers results in much smoother curves. Figure 9 shows these 12 out-of-quad power sums.

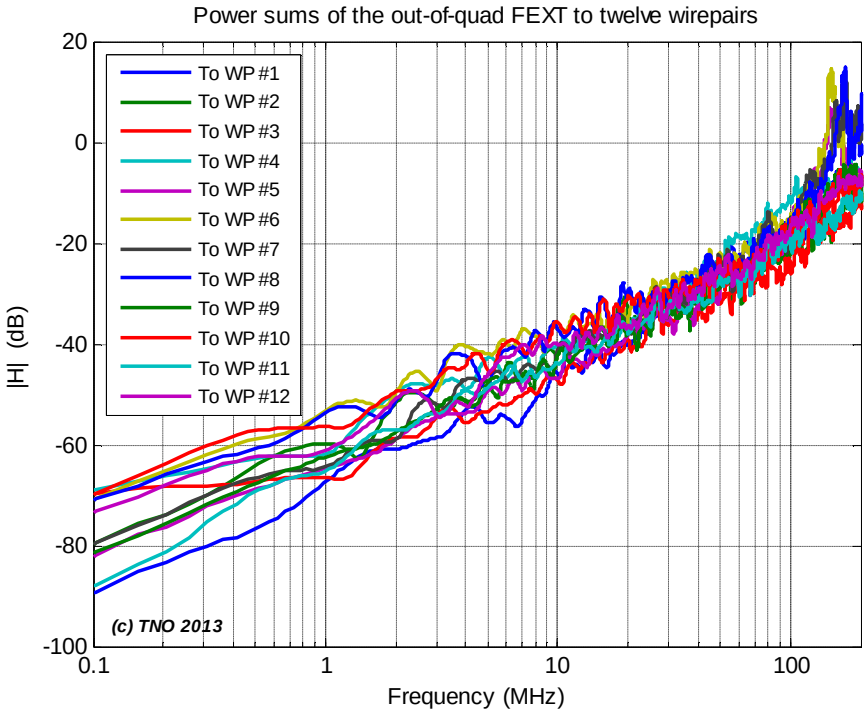

Figure 9: The twelve power sums of the ten out-of-quad disturbers for each victim line.

To investigate further the trend of the EL-FEXT as function of frequency, two average curves are calculated:

- The average (on the dB-scale) of the twelve measured in-quad EL-FEXT curves shown in Figure 7.
- The average (on the dB-scale) of the twelve powersums of the out-of-quad EL-FEXT shown in Figure 9.

Figure 10 shows the two resulting curves. Roughly speaking, above 20 MHz the average in-quad crosstalk exceeds the averaged power sum of the out-of-quad disturbers.

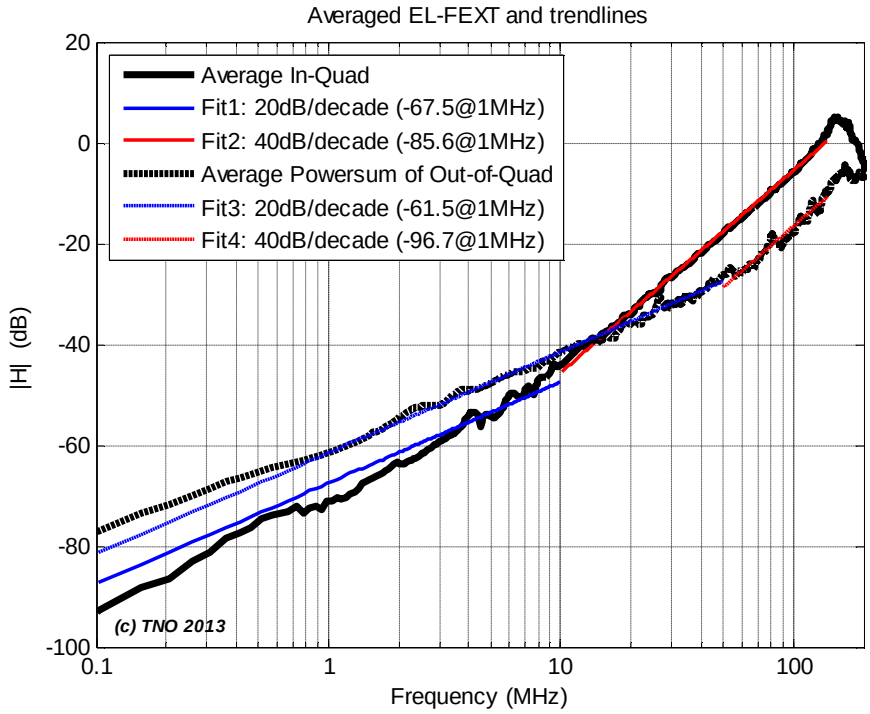

Figure 10: The averaged EL-FEXT curves and some trendlines.

For reference, Figure 10 also shows a couple of possible fits as trendlines. Especially the averaged in-quad EL-FEXT curve displays the "double-slope" phenomenon: a 40 dB/decade slope is applicable for a wide range of frequencies (more than a decade). A "double-slope" is also visible for the out-of-quad EL-FEXT, but over a smaller range of frequencies. Close to the "resonance" around 150 MHz, even higher slopes are present. But as the frequency range over which this is apparent is rather small, an ad-hoc piecewise linear approach with multiple values (such as 60 and 80 dB/decade, or even non-integer multiples of 20dB/decade) for the slope does not seem the right way forward.

Contribution [3] has argued that a second order transfer function gives a good fit to curves such as shown in Figure 10. Such a transfer function does not only account for the 20 and 40 dB/decade slopes, but also captures the "resonance" peak. Details of the modelling of the EL-FEXT are left for further study.

7. Distribution of the EL-FEXT

As a preliminary investigation into the statistical distribution of the EL-FEXT, the so-called "1 MHz fit values" were calculated for each EL-FEXT curve. To this end, the magnitude of each individual EL-FEXT coupling was fitted over the frequency range from 2 to 106 MHz with a traditional 20 dB/decade straight line, even though this slope is known to be incorrect for higher frequencies. Despite this obvious incorrect slope, the reduction of curves to single numbers is a useful method to obtain a first idea about the statistical properties of the crosstalk.

Figure 11 shows the obtained values as a crosstalk "heatmap". The figure shows once more that the in-quad EL-FEXT is very strong. The plot also illustrates the fact that the EL-FEXT is approximately symmetrical in this cable. Figure 12 shows the cumulative distributions of the obtained 1 MHz fit values, together with normal approximations.

The average of the twelve 1 MHz fit values for the (strong) in-quad EL-FEXT is around -53 dB. This appears small compared to the common ETSI/ANSI assumption of the EL-FEXT of -45 dB. However, it must be remembered that this common assumption corresponds to a cable length of 1 km, whereas the investigated KPN Access cable is only 104 meters long. This length difference combined with the customary $^{10}\log(L)$ dependence of the EL-FEXT explains a difference of around 10 dB[3].

[3] It must also be noted that the ETSI/ANSI value is taken from a formulae describing the crosstalk sum of *n* disturbers, which should not be expected to match directly with a direct average of fitted pair-pair couplings.

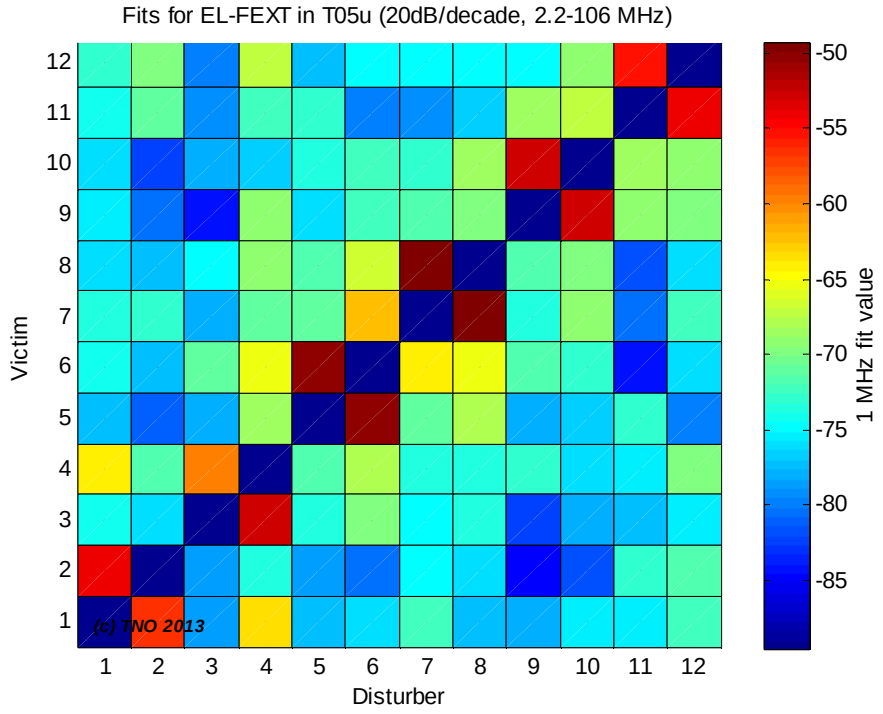

Figure 11: The EL-FEXT matrix. The colours denote the 1 MHz fit values, using a traditional 20 dB/decade fit.

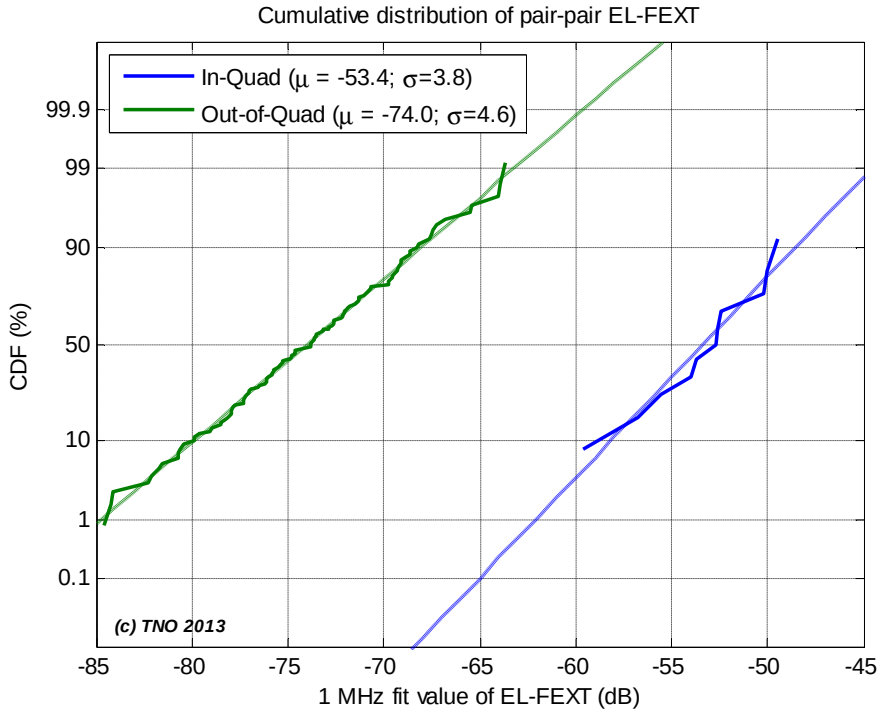

Figure 12: The cumulative distribution of the 1 MHz fit values to the EL-FEXT, plotted on 'normal' paper. The percentage on the y-axis denotes the fraction of 1 MHz fit values below the value on the x-axis.

8. Conclusions

This paper discusses various properties of the measured transmission and crosstalk characteristics of the 104 m KPN access cable. The following summarising observations can be made:

- Once the transmission becomes comparable to the crosstalk, the transmission starts to show spread and fluctuations.
- At low frequencies, the match between the "T05u" two-port cable model and the measured transmission is very good; once the FEXT becomes comparable to the transmission, the two-port cable model no longer applies.
- The notches at 27, 54 and 81 MHz in the transmission are probably caused by waterplugs in the cable at regular 4m intervals.
- In the investigated cable, the in-quad crosstalk dominates the out-of-quad crosstalk.
- It is strongly suspected that the root cause of the in-quad dominance is not proximity, but the fact that the twist length of the wire pairs in the quad is necessarily the same; the twist length of wire pairs in different quads in the investigated cable is suspected to be different.
- In-quad and out-of-quad EL-FEXT both show a double-slope effect; this effect is more pronounced in the in-quad case.

1. Introduction | 2. Transmission | 3. FEXT | 4. The cause of strong crosstalk | 5. Modelling the transmission | 6. Equal-Level FEXT | 7. Distribution of the EL-FEXT | 8. Conclusions | 9. Summary

9. Summary

This paper should be presented under the G.fast agenda item. It discusses various properties of the measured transmission and crosstalk characteristics of the 104 m KPN access cable. This contribution proposes no new issues for the issue list. It is related to various existing issues dealing with channel characteristics and reference loops (examples below). This contribution is for information only.

5.1.1.1	Agreed 12-Sept-11	To adopt the parametric models proposed in section 2 of 11GS3-029 for CAT5 and T05u wiring types.	
5.2.1.2	Agreed 28-Feb-12	that a parametric model for FEXT shall include dual slope behaviour of the EL-FEXT factor, by means of either a second order transfer function or a piecewise linear function.	
5.2.1.x	Open	Various issues relating to FEXT modelling.	
6.2.10.3.4	Agreed 20-Sept-12	that simulation conditions and environment to conclude on performance advantages/disadvantages for any proposed channel estimation scheme and its relationship to vectoring should be provided by the November 2012 Q4a/15 meeting, and that simulations should be provided no later than the January 2013 Q4a/15 meeting, with a goal to make a decision at that meeting.	

References

[1] TNO: *"G.fast: Release of measured transfer characteristics of the 104m KPN access cable"*, ITU-T Contribution 2013-03-Q4-025, Red Bank, New Jersey, March 2013.

[2] Editor G.fast: "*Updated draft text for G.fast – version 4.0*", Contribution ITU-T SG15/Q4a 2013-03-Q4-R20, Red Bank, USA, March 2013

[3] TNO: *"G.fast: Dual slope behaviour of EL-FEXT"*, Contribution ITU-T SG15/Q4a 2012-02-4A-038, Paris, France, February 2011