ITU - Telecommunication Standardization Sector Temporary Document **2012-11-4A-022**

STUDY GROUP 15 Original: English

Chengdu, China, 5 – 9 November 2012

Question: 4a/15

SOURCE[1]: TNO

TITLE: G.fast: Release of interpolated TNO cable measurements

ABSTRACT

This contribution contains the two TNO papers regarding cable measurements that have been uploaded earlier to the directory of the October 4th, 2012 teleconference. The second of these papers has not yet been discussed by the group. For ease of reference, those two papers and associated data files are submitted as a single contribution for the Chengdu meeting. This contribution is for information only.

1. Introduction

TNO has performed transmission and crosstalk measurements on various cables. A number of these measurements have been released for the benefit of Q4a in order to perform simulations on channel estimation and vectoring.

The original measurements and accompanying description [2012-11-4A-TC-TNO.zip] have been discussed by Q4a at the conference call of 4 Oct 2012. TNO was requested during that conference call to provide similar datasets but now interpolated at a linear frequency grid (at the centre frequencies of the carriers of G.fast). The requested interpolated data and accompanying description has been uploaded to the FTP directory of the 4 Oct conference call as well [2012-11-4A-TC-TNO2.zip]. However, this second contribution has not yet been discussed by Q4a, and should be discussed during the Chengdu meeting.

For ease of reference, this contribution combines those two conference call papers and the associated data files in a single zip-file.

2. Summary

This paper should be presented under the G.fast agenda item. This contribution is for information only. It is related to the agreed goal described in issue 6.2.10.3.4:

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.

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ITU - Telecommunication Standardization Sector TD **2012-11-4A-TC-TNO**

STUDY GROUP 15 Original: English

Conference call, 4 October, 2012

Question: 4a/15

SOURCE[1]: TNO

TITLE: G.fast: Release of TNO cable measurements for use in simulations

ABSTRACT

TNO has performed transmission and crosstalk measurements on various cables. A number of these measurements are released for the benefit of Q4a in order to perform simulations on channel estimation and vectoring. This contribution describes these measurements. This contribution is for information only.

1. Introduction

At the September 2012 meeting, the following goal was agreed by the group:

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.

In order to progress this work, TNO provides to Q4a a number of the crosstalk measurements that it has performed. Interested parties can use this data for simulations regarding channel estimation and vectoring performance.

2. Description of the cables

The measurements are taken in the 100 m long KPN access cable (see Figure 1) that has been described in chapter 7 of report [1]. This cabling is typically used within the Netherlands by KPN in the access network, and the cable can be found underground as well as in buildings. The transmission properties of this cable are described by the cable model "T05u" described in Appendix I of the current draft of the G.fast standard [2].

This is a "(6×4×0.5)"cable: it consists of six quads, each quad consisting of two twisted wire pairs of 0.5 mm PE-insulated wire. The four wires in the quad are twisted together as a whole, which means that the two wire pairs in a quad have the same twist length. Wire pairs in different quads may have different twist length, to reduce crosstalk even further. The cable has a common metallic shielding.

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Figure 1: The 6x4x0.5 KPN Access cable that was used in the measurements. This cable corresponds to the "T05u" cable model described in the Appendix I of the draft G.fast standard.

More information regarding the transmission and the FEXT in this cable can be found in [1]. Details about the measurement method can be found in [3]. A discussion about the dual-slope effect of the FEXT in this cable (and in other cables) can be found in [4].

3. Motivation for selecting these measurements

The following arguments explain why this cable is relevant for G.fast simulations:

- It is a common access cable in the Netherlands.
- The length of around 100 meter is in the middle of the length range for which G.fast should be optimized.
- There is strong FEXT in the in-quad measurements. As KPN intends to use G.fast in bonded scenarios, it is relevant for KPN to know whether G.fast can operate properly in such a high-FEXT environment.

There is no reason to assume that the used sample of this cable has particular bad or good characteristics.

It should be remarked that paper-insulated cable is also still in wide use in the Dutch network. Measurements in the past suggested this older type of cable to have worse transmission and crosstalk properties, at least in the VDSL frequency bands. It is subject of speculation whether this is due to the paper insulation or to e.g. less tight twisting during manufacturing.

4. The provided measurements

The provided data is taken from three measurements: One in-quad measurement, a reproducibility check of this measurement, and one out-of-quad measurement. Each of these measurements consists of a complete multi-port measurement of two wire pairs. Two DataSets are provided per measurement, one for each of the two wire pairs (see Figure 2):

1. The transmission of the first wire pair, S_t (1 **à** 2), and the FEXT to this wire pair, S_{xf} (3 **à** 2)
2. The transmission of the second wire pair, S_t (3 **à** 4), and the FEXT to this wire pair, S_{xf} (1 **à** 4)

This means that each DataSet consists of:

- the transmission S_t : this is the transfer function, from transmitter to receiver,
- the FEXT coupling S_{xf} : this is the far-end crosstalk coupling, from disturber to receiver.

All measurements represent s-parameters, normalized to a reference impedance of 100 Ω.

Overall, the following six DataSets are provided:

1. TNO_DataSet01 and TNO_DataSet02: for the two wire pairs in the same quad
2. TNO_DataSet03 and TNO_DataSet04: for the two wire pairs in the same quad (reproducibility check)
3. TNO_DataSet05 and TNO_DataSet06: for two wire pairs in different quads

NOTE: DataSet 03 and 04 were obtained from a reproducibility check, and are provided for completeness. DataSet03 is almost identical to DataSet01, and DataSet04 is almost identical to DataSet02.

For vectoring simulations it would be desirable to have measurements of all the FEXT couplings within a cable. However, this exhaustive set of measurements has not been performed yet. The measurements provided to the ITU that are described in this contribution constitute all currently available data on differential mode transmission and FEXT in this cable in one direction[2].

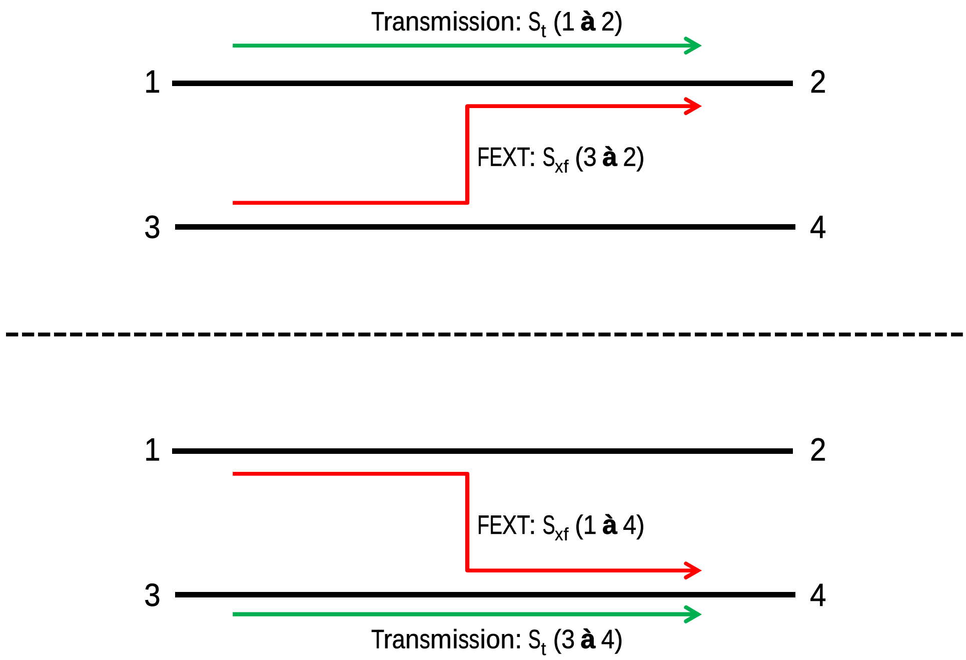

Figure 2: Each measurement consists of two DataSets. The first DataSet is shown at the top of the figure, the second DataSet is shown at the bottom. The plot shows the naming convention for the ports.

[2] The FEXT and transmission in the reverse direction were also measured. Because of reciprocity, these measurements are highly comparable to the measurements in forward direction, and are therefore not provided.

5. Format of the measurement data

The six DataSets are provided in the form of as many MATLAB files, named "TNO_DataSet01_FEXT.m" to "TNO_DataSet06_FEXT.m". The files are in ASCII-format, in order that also parties who do not use MATLAB may use the data. The tabular data within these files describe the transfer function S_t and the FEXT coupling S_{xf} in polar form, i.e. the magnitude in dB and the phase in degrees. This data is provided for 2403 frequencies between 10 kHz and 500 MHz.

Upon execution, these MATLAB files return a struct variable with fields that contains the frequency grid (in Hz), the transfer function and the FEXT coupling (both as complex transfer values).

A separate program "TNO_show.m" is also provided that generates plots for each of these six DataSets. The plots are similar to the plots shown in the Appendix of this contribution. More information can be found in the comments fields and in the source code in the provided set of MATLAB files.

6. Some observations on the measurements

A number of observations regarding these measurements can be made:

- There is some resonant behaviour visible near 27, 54 and 81.5MHz. These notches are currently not well understood (see also [1]).
- When the Equal-Level FEXT (EL-FEXT, i.e. the FEXT divided by the transmission) is calculated for these measurements, the 'dual-slope' effect is clearly visible in the 'in-quad' measurements. See [4] for the plots and for more discussion on this.
- The FEXT for the in-quad measurements is considerably higher than for the out-of-quad measurement. The explanation for this may not be (just) in the proximity of the wire pairs in the quad, but in the fact that the twist length of the two wire pairs in a quad is the same (allowing for 'constructive interference'). For the out-of-quad combinations of wire pairs, the twist length may be different.[3]
- Above 100 MHz, the transmission and in-quad FEXT transfer curves are "resonating" around each other. It means that the crosstalk signal is sometimes higher than the transmitted signal for a few distinct frequency bands. This behaviour is typical for frequencies where transmission and crosstalk are of the same order of magnitude, and seen in other cables as well. Although the initial profile for G.fast will only go up to 100 MHz, an extension up to 200 MHz is foreseen. It would be very interesting to see how channel estimation and vectoring are capable of dealing with the harsh FEXT conditions above 100 MHz.

7. Summary

This paper should be presented under the G.fast agenda item, and is for information only. It is related to the agreed goal described in issue 6.2.10.3.4. The provided measurements are intended to be used by Q4a members for simulations of channel estimation and vectoring.

References

[1] TNO: *"G.fast: Wideband modeling of twisted pair cables as two-ports"*, Contribution ITU-T SG15/Q4a 11GS3-028, Geneva, Switzerland, Sept 2011

[2] Editor G.fast: "*Updated draft text for G.fast – version 2.1*", Contribution ITU-T SG15/Q4a 2012-09-4A-R20R3 / TD-759R1, Geneva, Switzerland, Sept 2012

[3] TNO: *"G.fast: Wideband transfer and crosstalk measurements on twisted pair cables"*, Contribution ITU-T SG15/Q4a 11BM-021, Conference Call, 18 April 2011

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

[3] Typically, different twist length are used in these cables. It has not been determined whether or not the twist lengths of the two pairs in the out-of-quad measurements are different.

Appendix

In-Quad #1

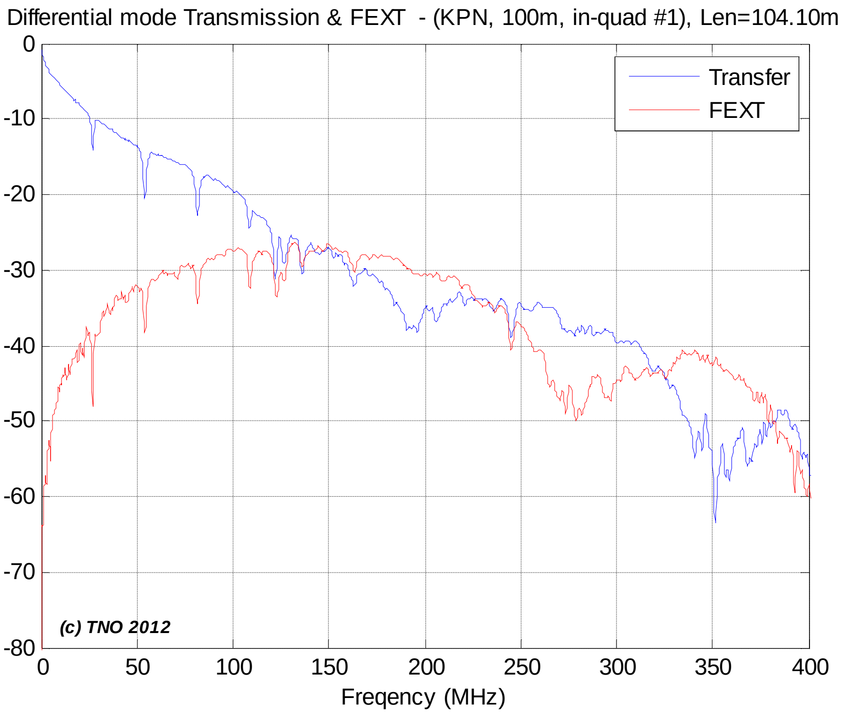

Figure 3: TNO_DataSet01. Transmission and FEXT on the first wire pair in measurement "in-quad".

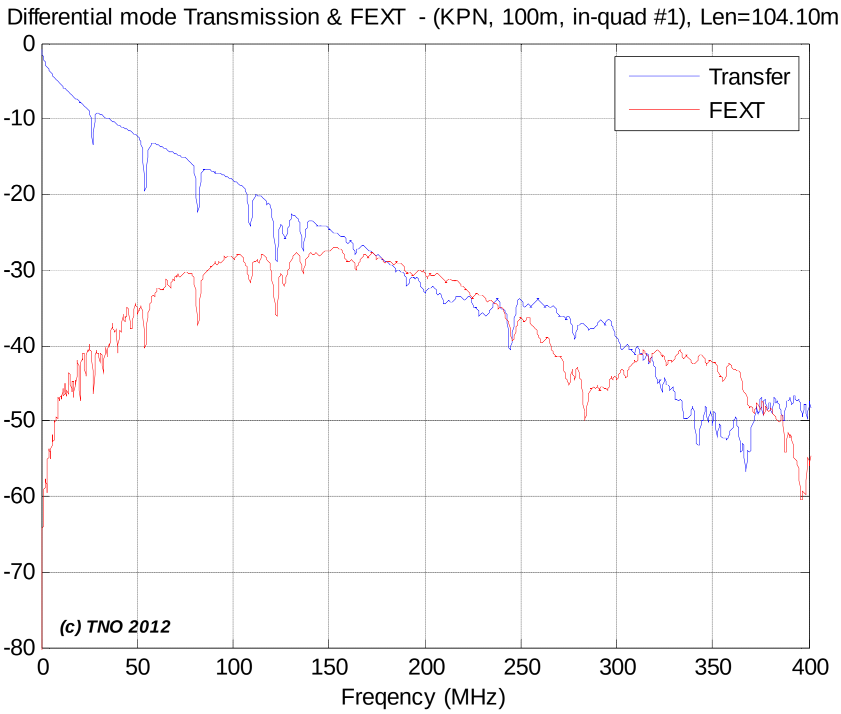

Figure 4: TNO_DataSet02. Transmission and FEXT on the second wire pair in measurement "in-quad".

In-Quad #2

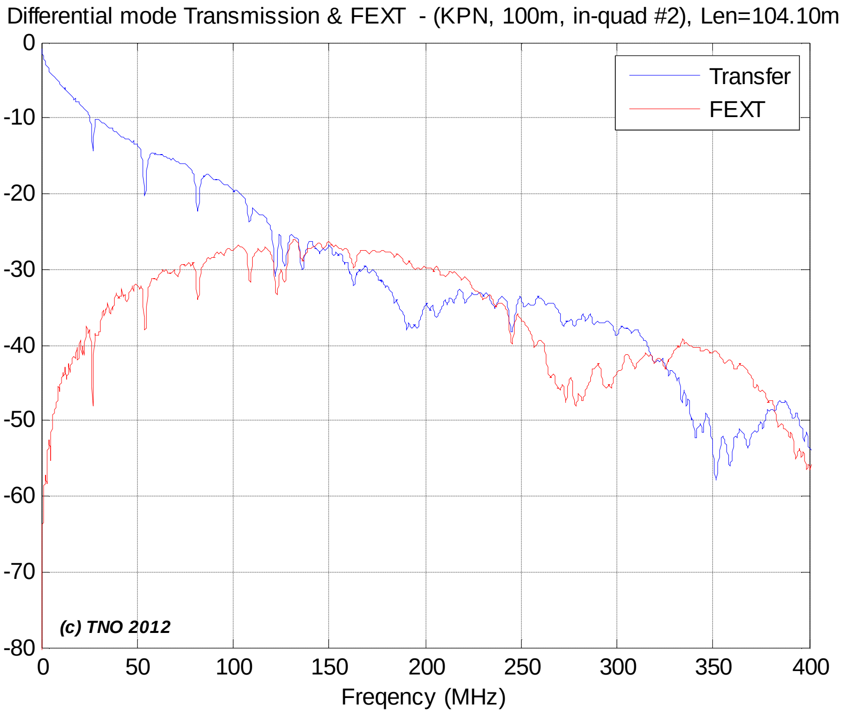

Figure 5: TNO_DataSet03. Transmission and FEXT on the first wire pair in the repetition of the “in-quad” measurement.

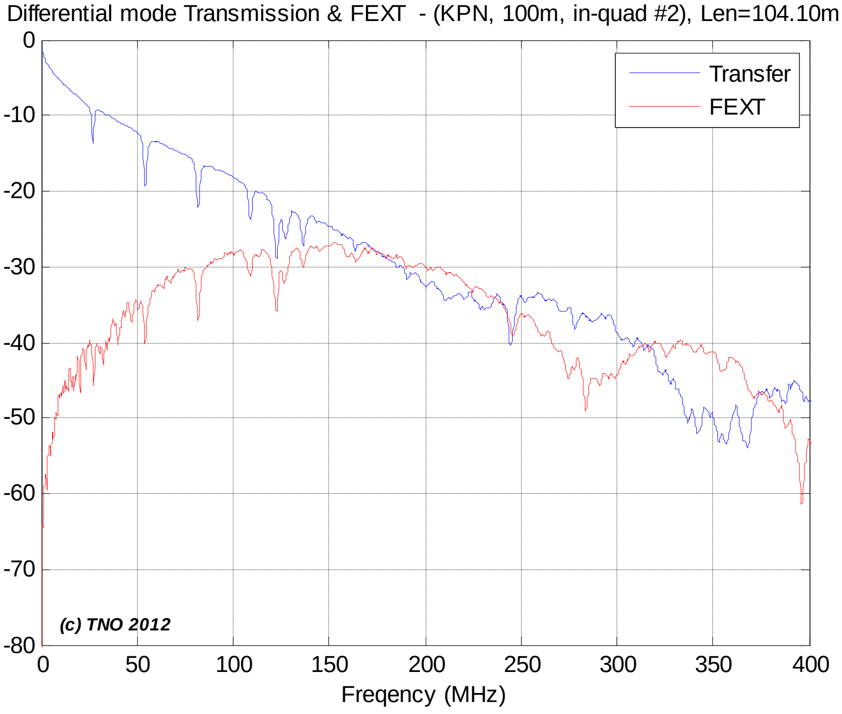

Figure 6: TNO_DataSet04. Transmission and FEXT on the second wire pair in the repetition of the “in-quad” measurement.

Out-of-quad

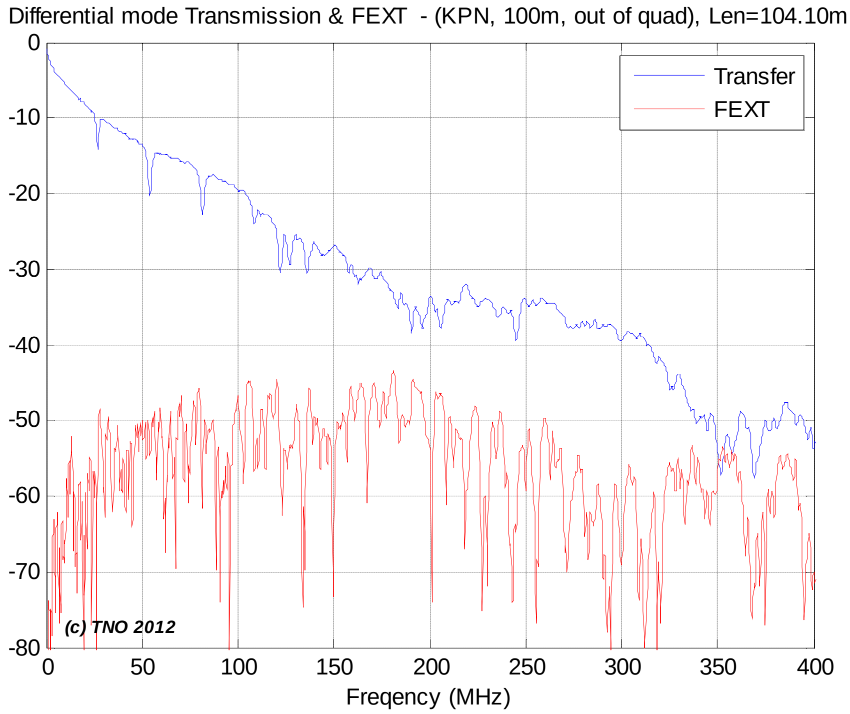

Figure 7: TNO_DataSet05. Transmission and FEXT on the first wire pair in measurement "out-of-quad".

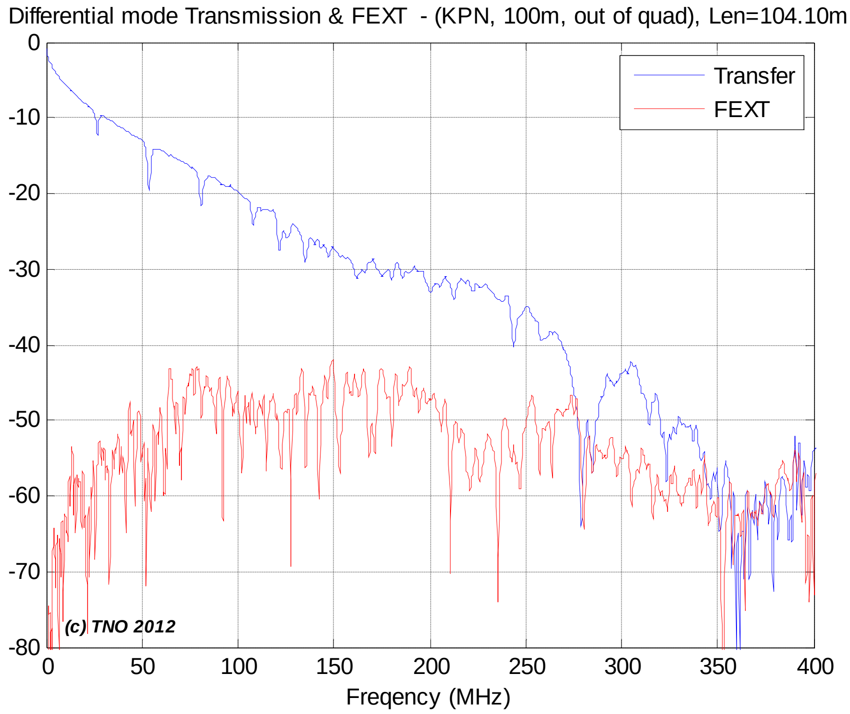

Figure 8: TNO_DataSet06. Transmission and FEXT on the second wire pair in measurement "out-of-quad".

ITU - Telecommunication Standardization Sector TD **2012-11-4A-TC-TNO2**

STUDY GROUP 15 Original: English

Conference call, 4 October, 2012 (Follow up)

Question: 4a/15

SOURCE[1]: TNO

TITLE: G.fast: Release of TNO cable measurements, interpolated at a linear frequency grid

ABSTRACT

TNO has performed transmission and crosstalk measurements on various cables. A number of these measurements are released at the conference call of 4 Oct 2012 for the benefit of Q4a in order to perform simulations on channel estimation and vectoring. TNO was requested during that conference call to provide similar datasets but now interpolated at a linear frequency grid (at the centre frequencies of the carriers of G.fast). This contribution is therefore an addition to TD2012-11-4A-TC-TNO and provides the requested interpolated data. This contribution is for information only.

| 1. Introduction | 2. Format of the measurement data | 3. Summary |

1. Introduction

At the September 2012 meeting, the following goal was agreed by the group:

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.

In order to progress this work, TNO has recently provided Q4a with a number of the crosstalk measurements in a tabular electronic format [5]. Relevant details of the released data sets are provided in the associated TNO contribution [5], and they were based on TNO measurements contributed before [1, 2, 3, 4].
During the conference call of 4 oct 2012, TNO was asked to provide similar datasets but now interpolated at a linear frequency grid, at multiples of 12×4.3125kHz = 51.75kHz. These frequencies are aimed for as the centre frequencies of the G.fast carriers.
The present contribution is an addition to [5], to provide the requested data. The complex values are all obtained via a cubic spline interpolation from the original measurements at the requested frequency grid. This interpolation was done directly on the original measured complex values (linear).

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2. Format of the interpolated data

The data sets in the associated zip-file are provided as tabular data in an ascii format that can be handled directly within Matlab. The format is such that you can easily convert it into another tabular ascii format via a plain text editor when Matlab is not available for you.

- The files **TNO_DataSet01_FEXT.m** to **TNO_DataSet06_FEXT.m** contain the measured data at their original frequencies. They are identical to what has been provided in contribution TD2012-11-4A-TC-TNO.
- The files **TNO_DataSet01_FEXT_IPOL.m** to **TNO_DataSet06_FEXT_IPOL.m** contain the interpolated data at 8192 frequencies up to about 400 MHz. Each frequency is a multiple of 12×4.3125kHz = 51.75kHz, which are the centre frequencies of the carriers that are aimed for G.fast.
- The file **TNO_Show.m** is a Matlab script to show how to read this data in Matlab and to plot several relevant curves.

These data files are all recognized by Matlab as functions, and return a single structured variable containing the data in different fields. It has several expressions on board to instruct Matlab how to convert the values into the complex numbers of interest, and to pack them into a single structured varable. For instance:

Data=TNO_DataSet01_FEXT_IPOL;

- Data.freq table with real values representing the frequencies in [Hz]
- Data.St table with complex values representing the transmission (linear)
- Data.Sxf table with complex values representing the FEXT (linear)
- Data.Rn real value representing the reference impedance used to normalize the measurements [ohm]
- Data.Length real value representing the length of the loop in [m]
- Data.Label string describing the measured loop

Figure 1 shows the interpolated results of the first measurement representing the transmission and FEXT. It consist of 8192 frequencies and the plot has a linear frequency axis. This figure illustrates that the resolution of the grid (Δf = 51.75kHz) is fine enough to prevent that relevant details get lost.

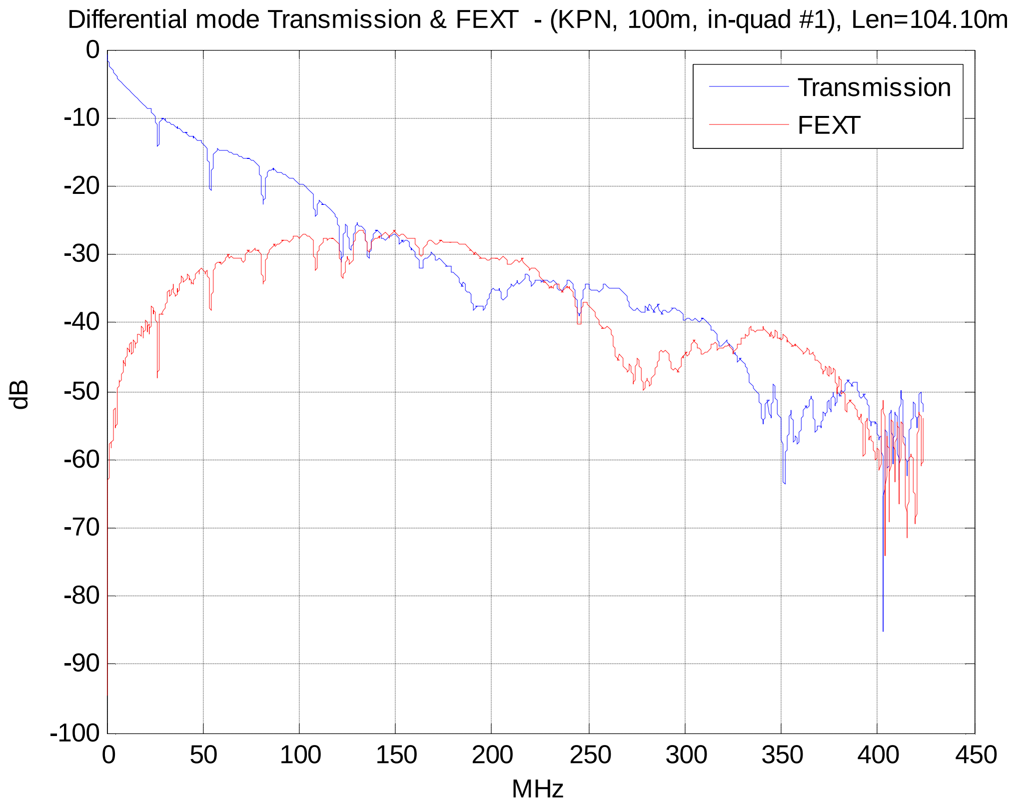

Figure 1: Magnitude of transmission and FEXT, interpolated at a linear frequency grid.

The use of interpolation will always bring the risk that interpolated values are unrealistic at some of its frequencies. This is because both the magnitude and phase of each complex values are to be realistic. Figure 2 illustrates that our interpolation is realistic, even for very high frequencies where the magnitude of the FEXT changes rapidly within a small frequency band. It compares a polar representation of the interpolated and the measured FEXT curve (the one shown in figure 1) within in a narrow frequency band between 402 and 408 MHz. This example was selected since the magnitude of the FEXT changes rapidly within this band (see figure 1). The polar curve also shows how rapidly the magnitude and phase changes within this band, but the interpolated polar curve nicely follows the measured points in a very plausible manner. This is because the frequency grid used during the measurements was tight enough to enable the "cubic spline" interpolation.

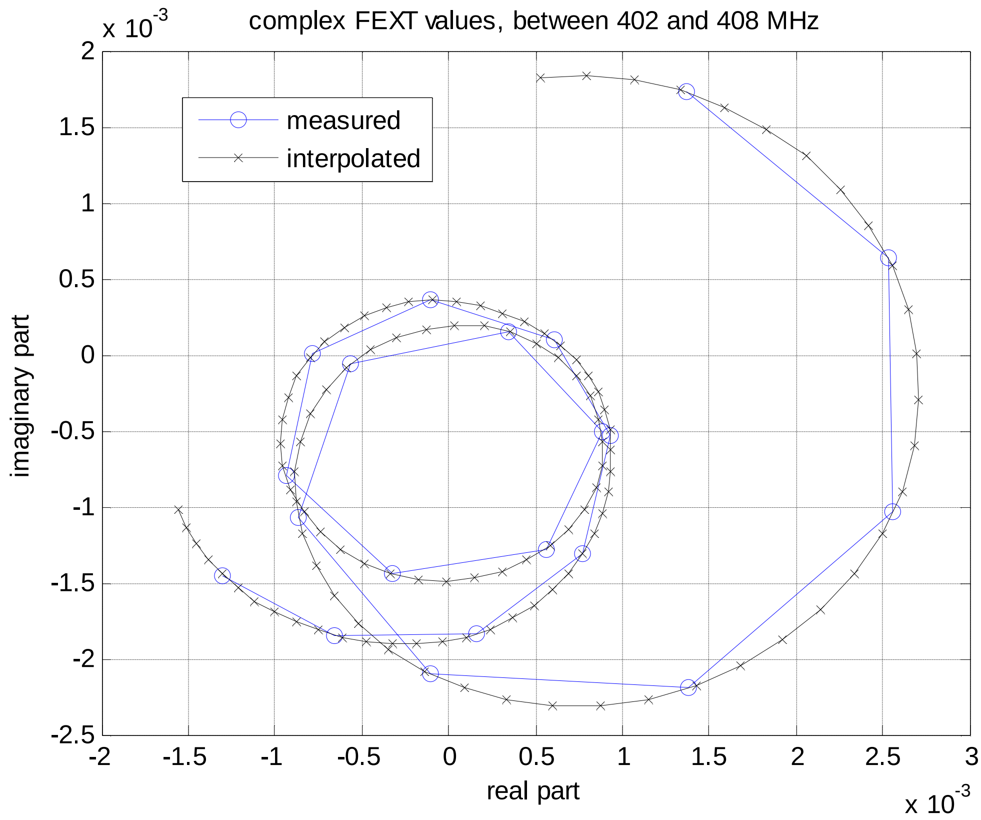

Figure 2: Polar representation of the FEXT within in a narrow frequency band around 404 MHz

3. Summary

This paper should be presented under the G.fast agenda item, is an addition to [5] and is for information only. It is related to the agreed goal described in issue 6.2.10.3.4. The provided measurements are intended to be used by Q4a members for simulations of channel estimation and vectoring.

References

[1] TNO: *"G.fast: Wideband modeling of twisted pair cables as two-ports"*, Contribution ITU-T SG15/Q4a 11GS3-028, Geneva, Switzerland, Sept 2011

[2] Editor G.fast: "*Updated draft text for G.fast – version 2.1*", Contribution ITU-T SG15/Q4a 2012-09-4A-R20R3 / TD-759R1, Geneva, Switzerland, Sept 2012

[3] TNO: *"G.fast: Wideband transfer and crosstalk measurements on twisted pair cables"*, Contribution ITU-T SG15/Q4a 11BM-021, Conference Call, 18 April 2011

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

[5] TNO: *"G.fast: Release of TNO cable measurements for use in simulations",* Contribution ITU-T SG15/Q4a, TD2012-11-4A-TC-TNO, Conference call 4 oct 2012.