ITU - Telecommunication Standardization Sector Temporary Document 2012-02-4A-038

STUDY GROUP 15 Original: English

Paris, France - February 2012

Question: 4/15

SOURCE[1]: TNO

TITLE: G.fast: Dual slope behaviour of EL-FEXT

ABSTRACT

Several previous contributions have confirmed that the simple first order model for EL-FEXT is inadequate for predicting the performance of G.fast. This contribution analyses the higher order effects in EL-FEXT crosstalk coupling in further detail, shows that it can be ignored in some cases, and shows that it is clearly visible in other cases.
These effects have been ignored for DSL performance calculations in the past but one set of measurements show that they can even hit the VDSL performance significantly.

1. Introduction:

The estimation of channel capacity for G.fast requires adequate models for crosstalk. Legacy models for FEXT [5] are pretty simple and based on the cascade of a transmission model and a first order (capacitive) coupling function for EL-FEXT. This approach is too simple for G.fast.
The need for using higher order models for FEXT was raised by TNO in [1] and was reconfirmed by Ericsson [3] and Huawei [4]. Several measurements have shown that the EL-FEXT factor within FEXT has not only a first-order slope of 20 dB/decade, but has also a second order slope of 40 dB/decade above a certain frequency. However this second order effect is not visible in all cables.
This contribution analyses this effect in further detail, organizes its measurement in good and bad examples, and illustrates at the end how good a second order transfer function can represent EL-FEXT over a wide frequency interval. We propose the use of dual slope models for FEXT, but further study is required to understand how the second order slope scales with the length of the cable.

2. Coupling mechanism between the far ends of a copper cable

The far end crosstalk coupling function (FEXT) is a transfer function that is build-up from at least three physical mechanisms:

- The transmission of source and crosstalk signals via a wire pair
- The dielectric (capacitive) coupling between different wire pairs
- The magnetic (inductive) coupling between different wire pairs

Many measurement in the past have demonstrated that the first two of these mechanisms are dominating the FEXT at lower frequencies. Therefore the legacy model [5] of a pure capacitive transfer function (proportional with the frequency) in combination with a model of the transmission has proven to be very useful for many DSL applications. And since this capacitance is a differential one (most of it is annihilated by good cable construction), its residue is random in nature and varies between positive and negative. This random behavior makes that the expected capacitance increases with the root of the loop length instead of a proportional increase.
However when FEXT is to be modeled over a wider frequency interval one should not be surprised that the first order capacitive approach is too simple. Higher order effects should also be taken into account. The surprise may come from

[1]

Author:	Rob van den Brink TNO	Tel:+31 88 86 67059 Email: rob.vandenbrink@tno.nl
Contact:	Bas van den Heuvel TNO	Tel: +31 88 86 67126 Email: bas.vandenheuvel@tno.nl

the observation that the use of a simple two-slope approach is good enough to model the combination of dielectric and magnetic coupling for G.fast applications. This effect of a second slope was first observed by TNO in [1] and reconfirmed by measurements from Ericsson [3] and Huawei [4].

This contribution gives more emphasizes to this phenomenon and analyses EL-FEXT measurements on different cables. Some of them have convincing second order slopes and where others have second order slopes that are moderate or even hardly visible. We also have found a cable where this effect is very prominent and starts from about 1 MHz. So this dual slope issue is also highly relevant for VDSL performance estimations in certain cases.

Although the mechanism behind this second order slope is not fully understood (especially how it scales with the loop length) we believe that these second order slopes are only visible in cables where the magnetic coupling is “sufficiently” high and their dielectric coupling is “sufficiently” low. Our measurements give the impression that this “criterion” can easily be met for FEXT coupling between in-quad wire-pairs with good geometric symmetry. We assume that it may also hold for crosstalk between out-of-quad wire pairs with equal twist lengths.
Our measurements give also the impression that this “criterion” will often not hold for cables with low FEXT (ingenious twist length combinations may reduce magnetic coupling as well) or for coupling between wire pairs with poor geometric symmetry (dielectric coupling will then dominate everything).

3. <u>EL-FEXT measurements with signifiant second order effects</u>

This chapter shows EL-FEXT measurements on twisted pair cabling, where the slopes are highlighted via asymptotic lines, representing a slope of respectively 20dB/decade and 40 dB/decade, or a ceiling value at 0dB. The associated plots with transmission ***<u>and</u>*** FEXT curves illustrate to what extend the noise floor of the measurement setup has deteriorated the involved EL-FEXT measurement. They show that this noise floor is only limiting for the highest frequencies, and that the second order slopes (40 dB/decade) are not caused by the measurement setup itself.
The involved cables were described in great detail in previous contributions [6] and [7].

3.1 KPN access cabling for telephony – in quad EL-FEXT measurements

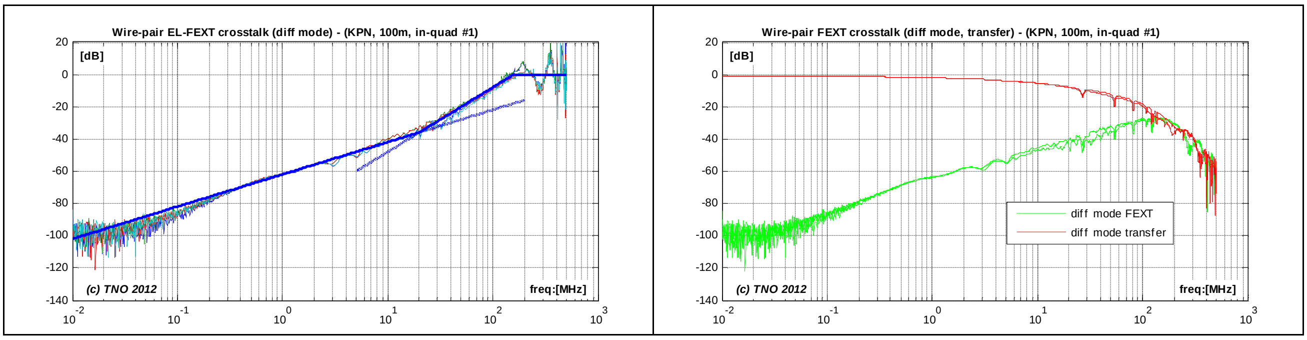

Fig 1. KPN Access cable, 100m, in-quad, group 1

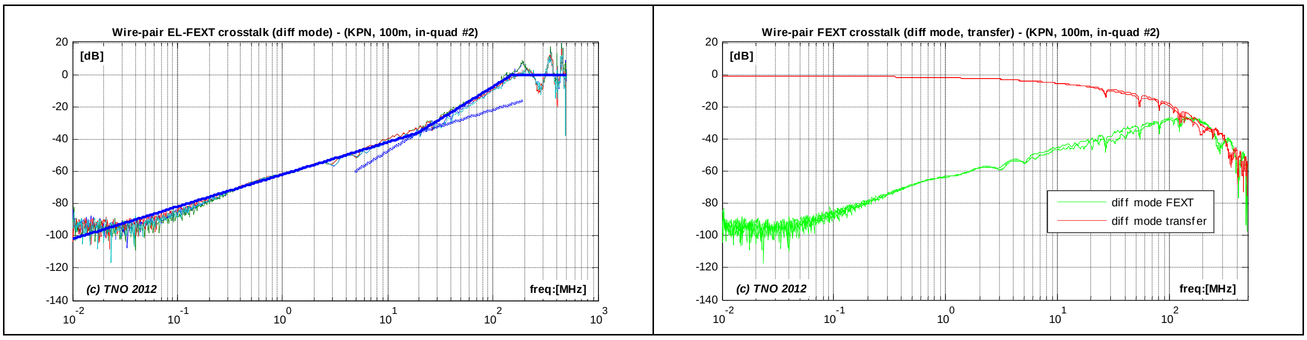

Fig 2. KPN Access cable, 100m, in-quad, group 2

3.2 Medium quality cabling for telephony – in quad EL-FEXT measurements

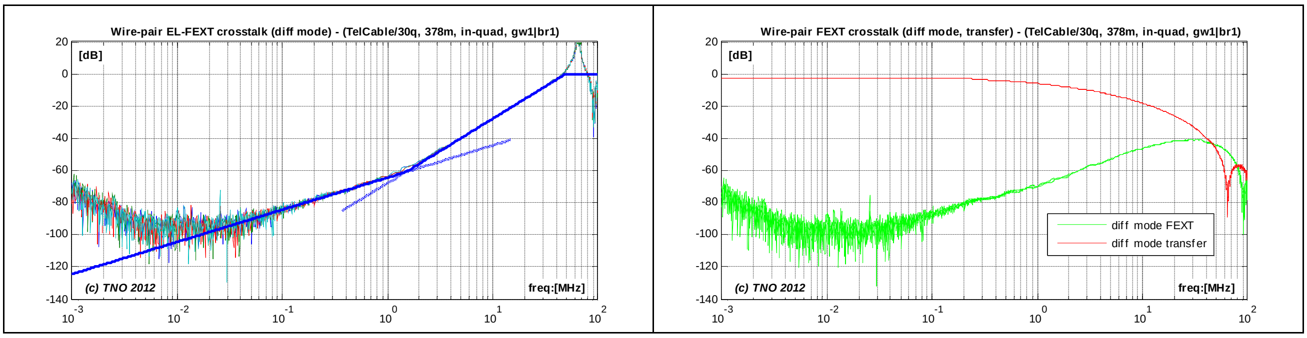

Fig 3. Multi quad telephony cabling, 378m, in-quad, group 1

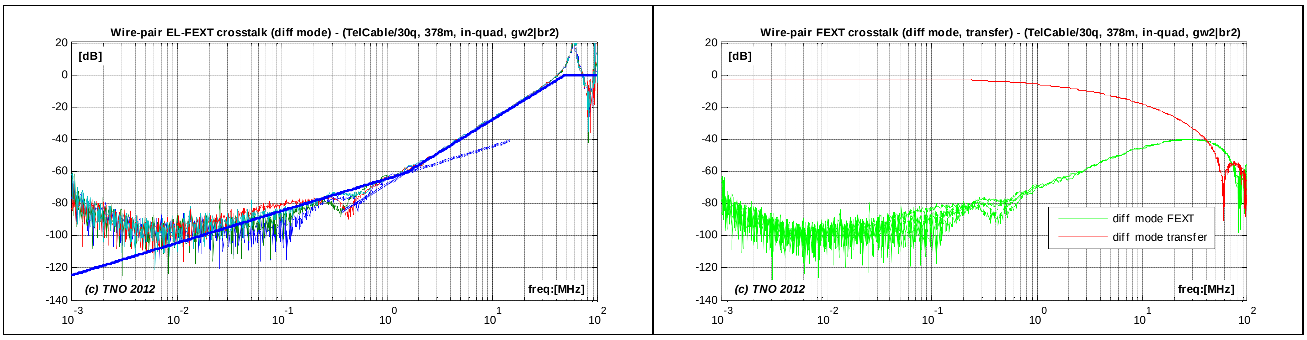

Fig 4. Multi quad telephony cabling, 378m, in-quad, group 2

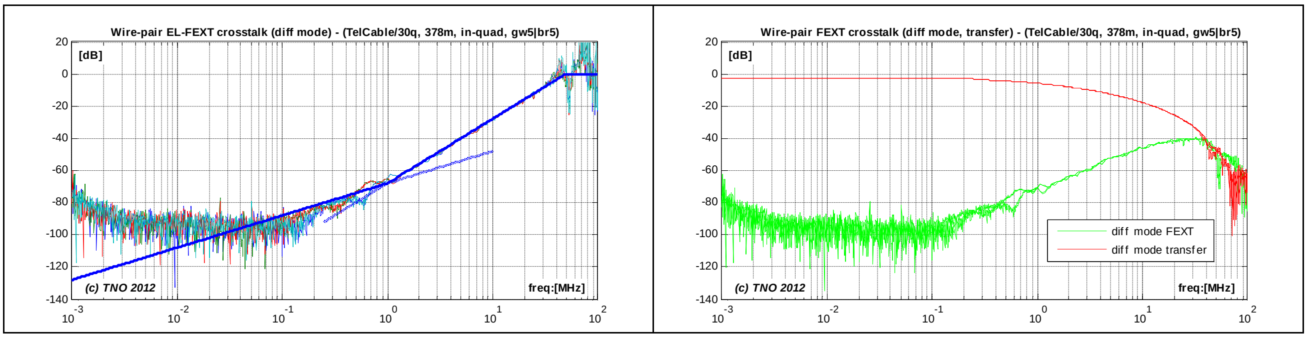

Fig 5. Multi quad telephony cabling, 378m, in-quad, group 5

4. EL-FEXT measurements with weak second order effects

This chapter also shows EL-FEXT measurements on twisted pair cabling, similar to the previous chapter, but now for cases where the dual slope effects are weak. The associated plots with transmission ***and*** FEXT curves illustrate that this is not caused by noise floor limitation in the measurement setup.
The involved cables were described in great detail in previous contributions [6] and [7].

4.1 KPN access cabling for telephony – out of quad EL-FEXT measurements

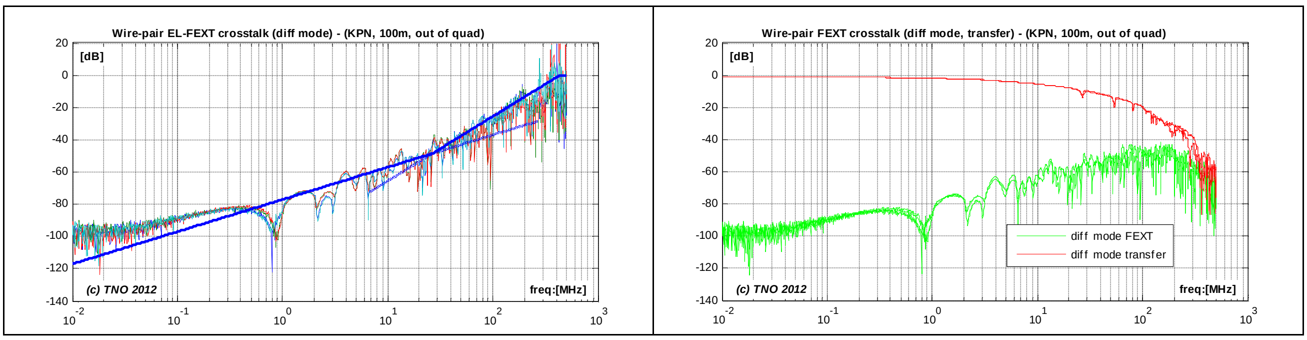

Fig 6. KPN Access cable, 100m, out-of-quad

4.2 Medium quality cabling for telephony – out of quad EL-FEXT measurements

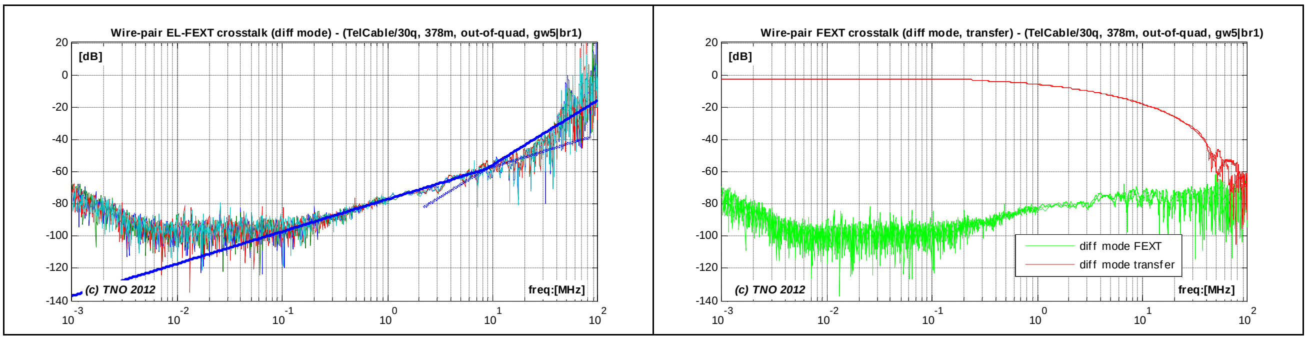

Fig 7. Multi quad telephony cabling, 378m, out of quad (group 5, group 1)

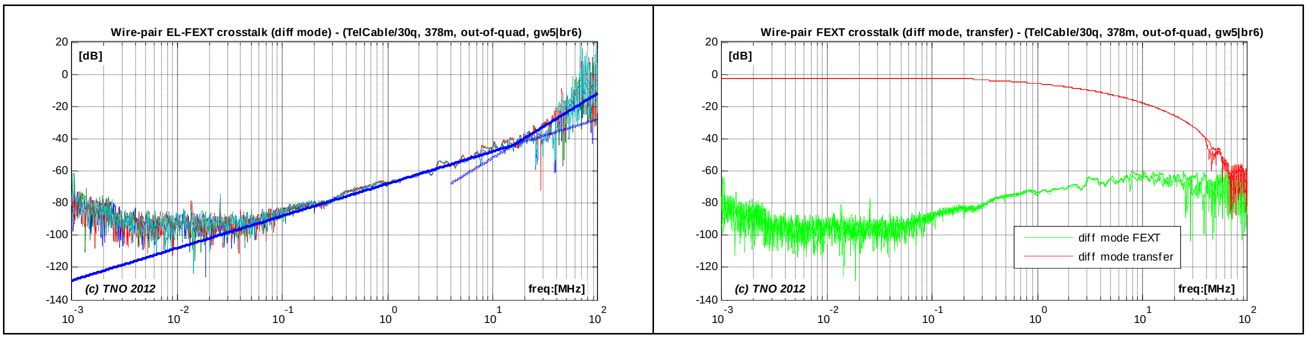

Fig 8. Multi quad telephony cabling, 378m, out of quad (group 5, group 6)

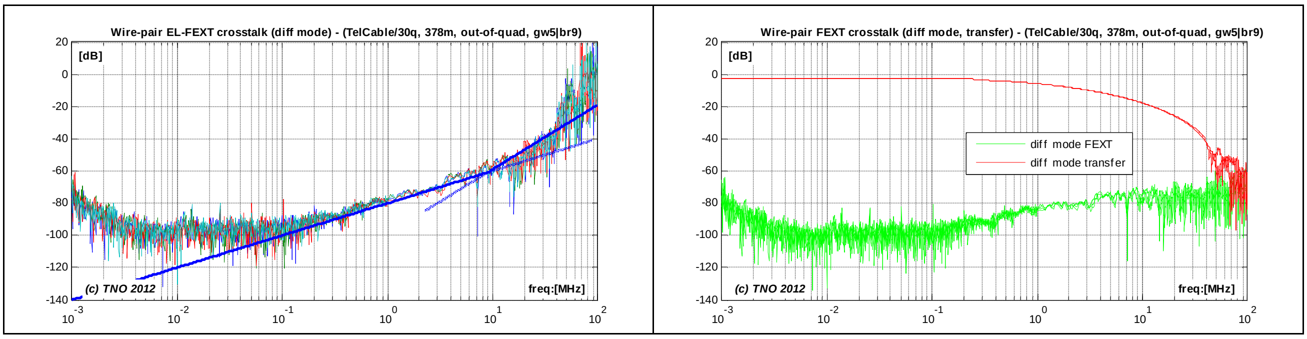

Fig 9. Multi quad telephony cabling, 378m, out of quad (group 5, group 9)

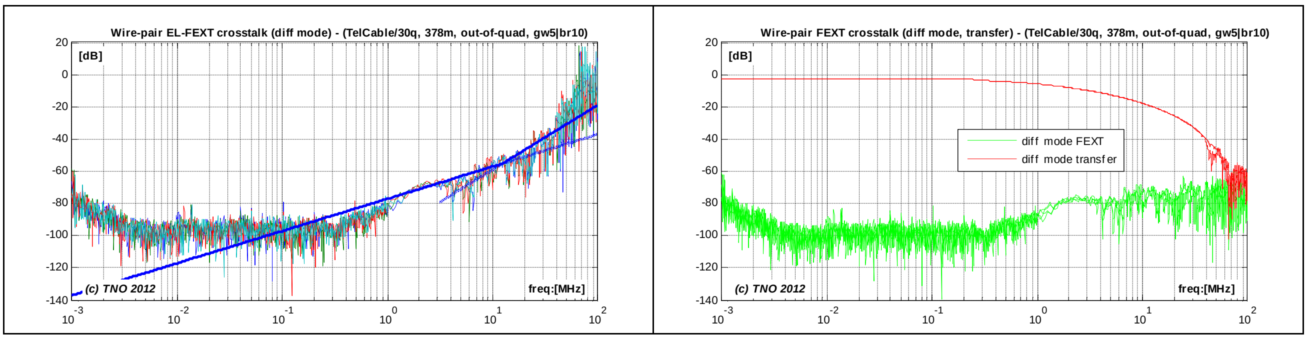

Fig 10. Multi quad telephony cabling, 378m, out of quad (group 5, group 10)

4.3 High quality CAT5 Cabling – out of quad EL-FEXT measurements

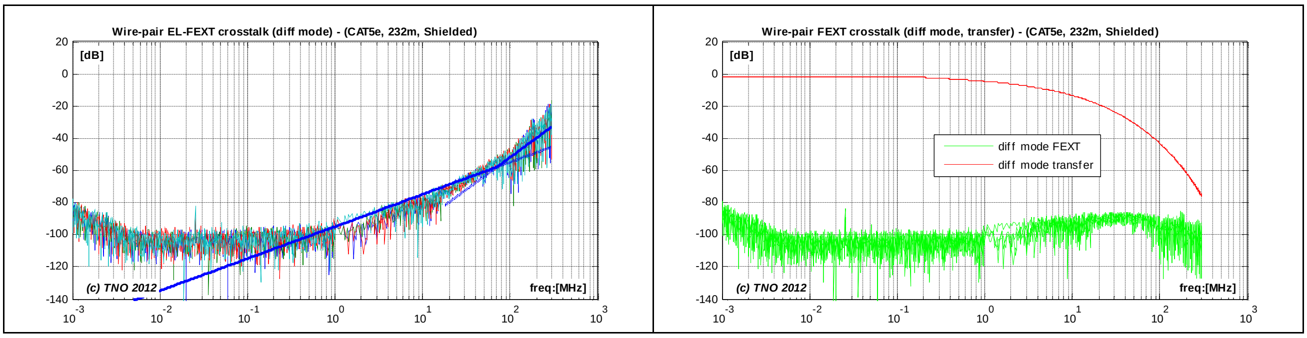

Fig 11. CAT5 quality cabling for Ethernet networks, 232m

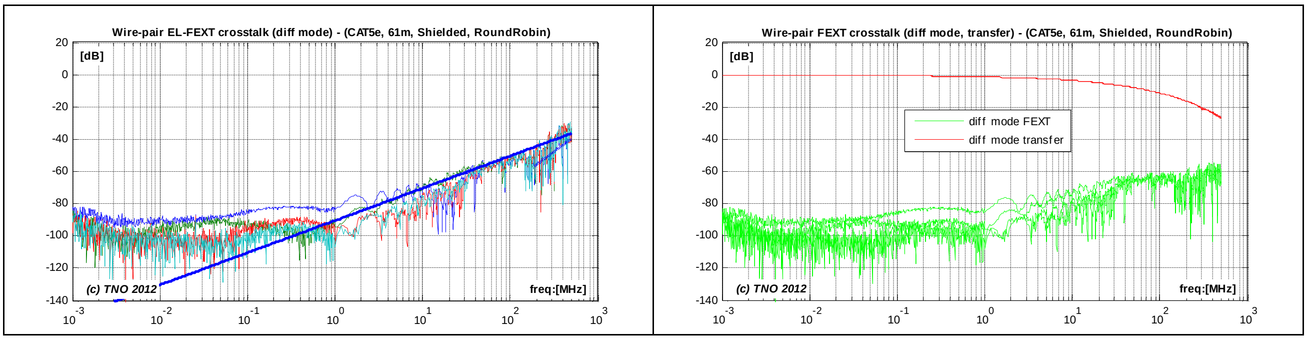

Fig 12. CAT5 quality cabling for Ethernet networks, 61m

4.4 Low quality cabling for telephony – EL-FEXT measurements

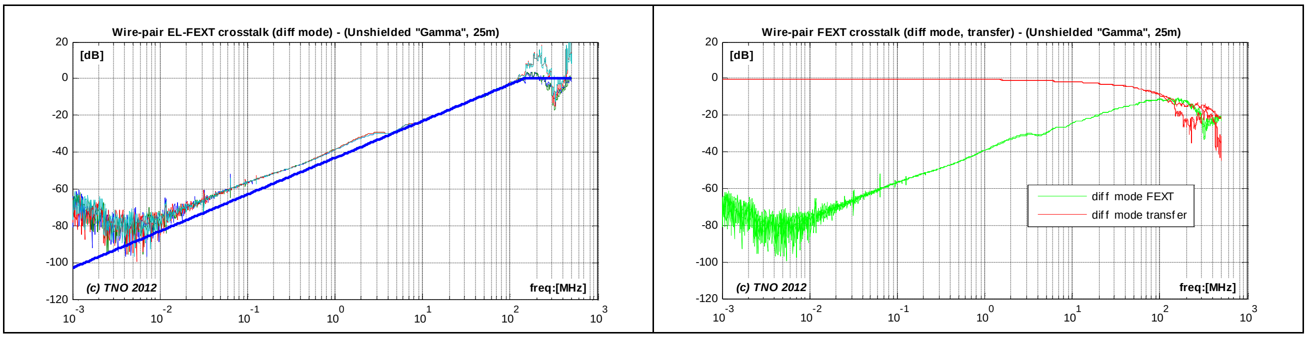

Fig 13. Low quality telephony cable found in consumer shop (Gamma), 25m

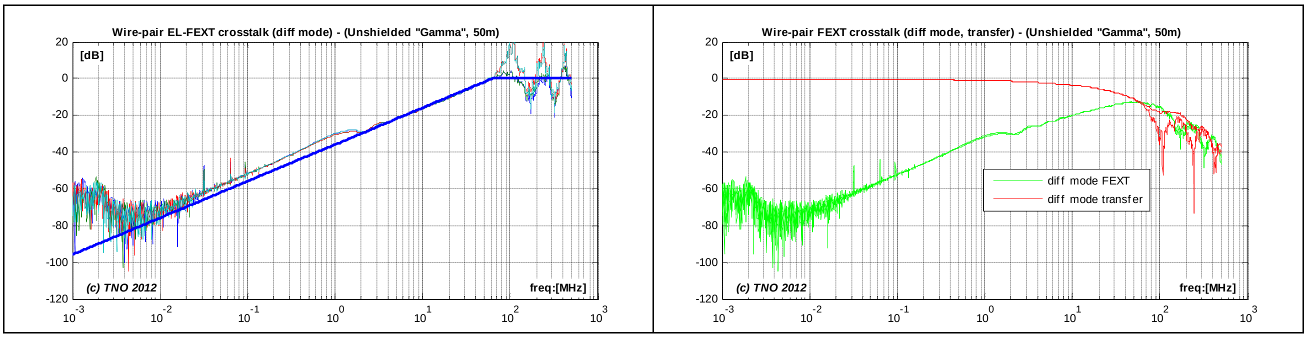

Fig 14. Low quality telephony cable found in consumer shop (Gamma), 50m

5. EL-FEXT modeling via second order coupling functions

The asymptotic curves in chapter 3 have demonstrated that the dual slope approach of EL-FEXT modeling is capable of a significant extension of the usable frequency band. The involved coupling should therefore be described with a second order high-pass transfer function with two poles and two zeros, with one zero in the origin. It can be expressed in many ways, but a normalized form is shown in expression 1 and requires only two break frequencies and a quality factor *q*. The associated parameters change with the loop length, and that dependency is currently not fully understood.

$$H_{EL-fext}(jw) = \left(\frac{(jw/w_1)\times\left(1+ jw \cdot \frac{w_1}{w_2 \cdot w_2}\right)}{1+2/q\cdot(jw/w_2)+(jw/w_2)^2} \right)$$

Expr 1. A simple second order high pass function is capable of describing the EL-FEXT over a much wider frequency interval than its legacy model.

The EL-FEXT curves in figure 15 to 17 illustrate how close the model (red curves) can follow the two-slopes, and provide with parameter *q* even an effective means to model the resonation peaks at the highest frequencies.

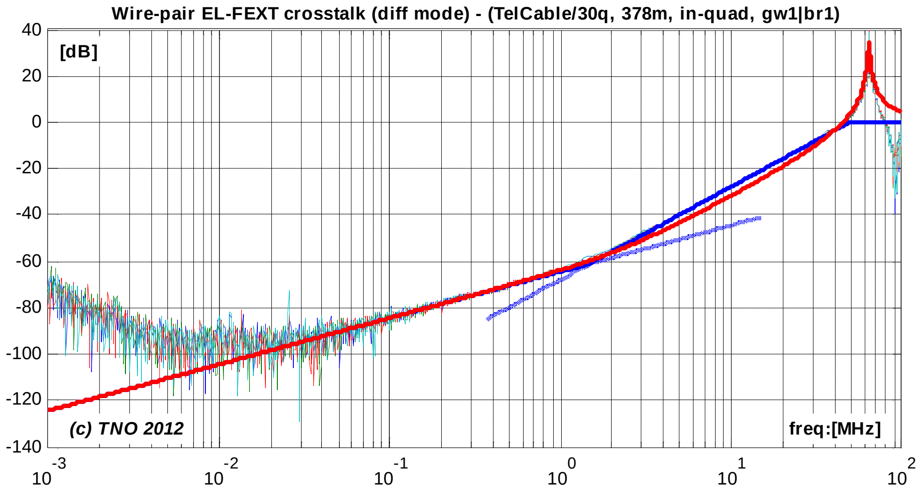

Fig 15. Multi quad telephony cabling, 378m, in-quad, group 1

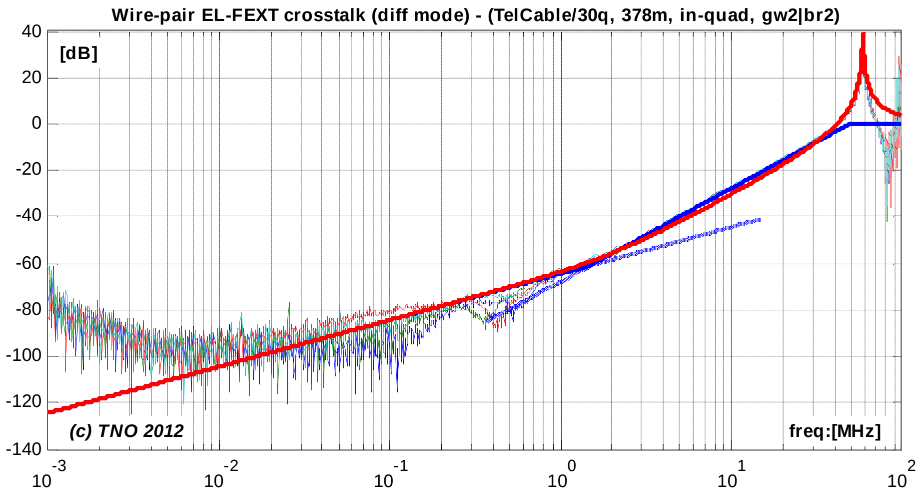

Fig 16. Multi quad telephony cabling, 378m, in-quad, group 2

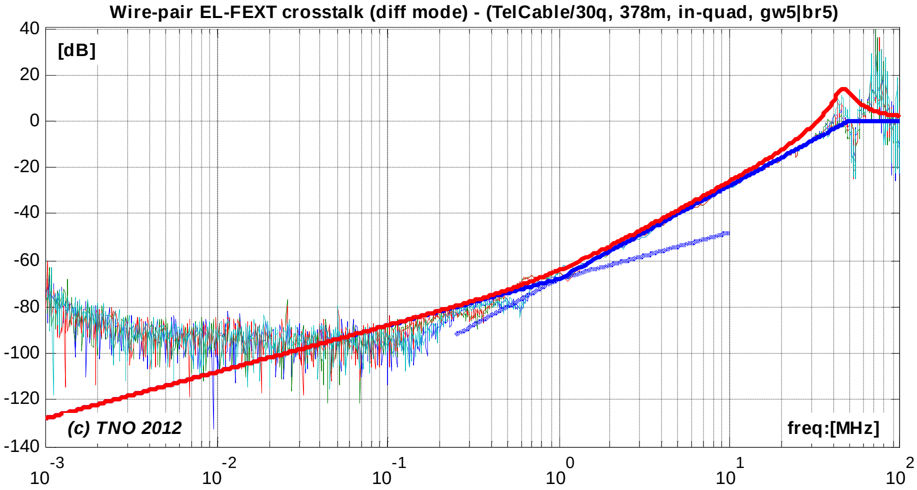

Fig 17. Multi quad telephony cabling, 378m, in-quad, group 5

6. Summary

This paper should be presented under the G.fast agenda item, and addresses issue 5.2.1

The paper illustrates how good a two slope model for far-end crosstalk can solve the short comings of the legacy model for FEXT [5]. The proposed dual slope approach is capable of extending the usable frequency band significantly, and such an extension is needed since the legacy model for EL-FEXT has proven to be very inadequate for G.fast studies [1, 3, 4]. The curves in this contribution show how effective that approach can solve that problem in cables where the second slope is prominent. It is even applicable for cables where a single slope is adequate: simple define the added parameters in such a manner that it simplifies into a first order transfer function. Therefore we propose to use the dual slope model as the preferred one for G.fast studies.

It is proposed to add the following new issue to the G.fast issues list and agree to it.

5.2.1.x	Open	Should parametric models for FEXT include dual slope behavior of the EL-FEXT factor, by means of a second order transfer function	2012-02-4A-038

7. References

[1] TNO, "G.fast: Far-end crosstalk in twisted pair cabling: measurements and modeling," ITU-T Q4/15 Contribution 11RV-022, Nov 2011.

[2] TNO (Rob van den Brink, Bas van den Heuvel), "*G.fast: Enhanced model for FEXT*" , ITU contribution 11RV-023, Richmond, Nov 2011.

[3] Ericsson AB, "G.fast: Equal Length FEXT measurements on PE05 cable" ITU-T Q4/15 Contribution 11RV-054R1, Nov 2011.

[4] Huawei, G.fast: Equal-Length FEXT Measurements on PE05 Cable. ITU-T Q4/15 Contribution , COM 15 - C 1864 Rev. 1 – E, nov 2011.

[5] ETSI TR 101 830-2, Transmission and Multiplexing (TM); Access networks; "*Spectral management on metallic access networks; Part 2: Technical methods for performance evaluations*." 2008.

[6] TNO (Rob van den Brink, Bas van den Heuvel), *"G.fast: Wideband transfer and crosstalk measurements on twisted pair cables"*, ITU contribution 11BM-021, April 18, 2011.

[7] TNO (Rob van den Brink, Bas van den Heuvel), "*G.fast: Wideband modeling of twisted pair cables as two-ports*" , ITU contribution 11GS3-028, Geneva Sept 2011.