Progressing G.fast

contributions from 4GBB consortium to standards

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1. Progressing G.fast – how did it originate?

MUSE Consortium

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	

1. Progressing G.fast – how did it originate?

MUSE | **CELTIC 4GBB Consortium**

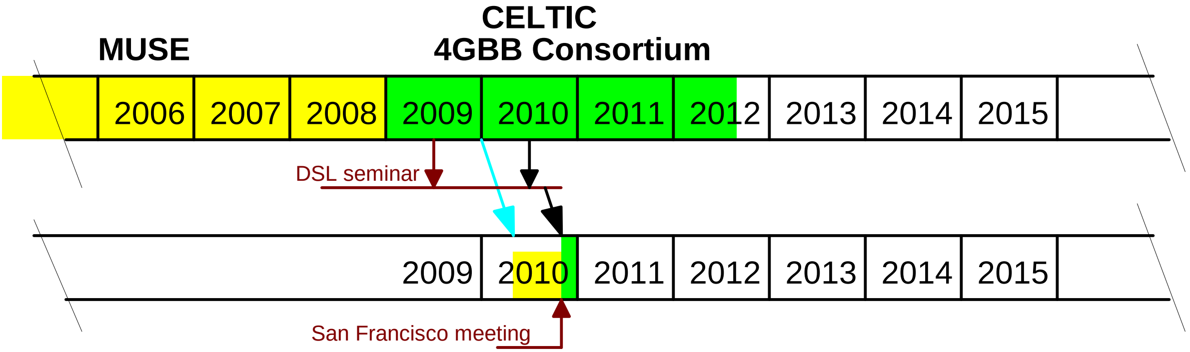
2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

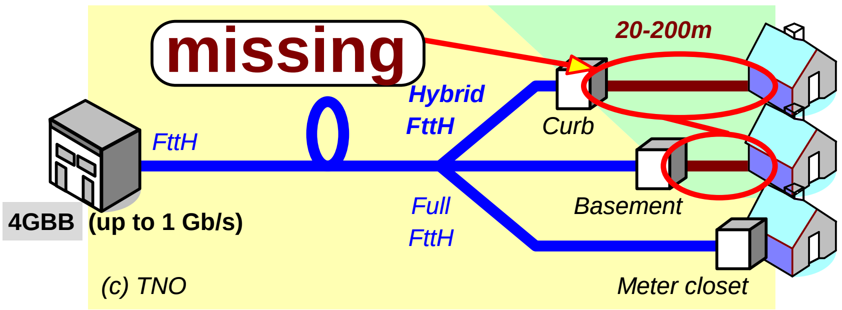
4GBB everywhere

Aims:
- **show feasibility**
- **initiate a standard**
- **bring the industry into motion**

TNO innovation for life · Telefónica Investigación y Desarrollo · Ericsson · Lund University · Telnet Redes Inteligentes · Marvell · BT · France Telecom · Politécnica "Ingeniamos el futuro" · 4GBB everywhere

1. Progressing G.fast – how did it originate?





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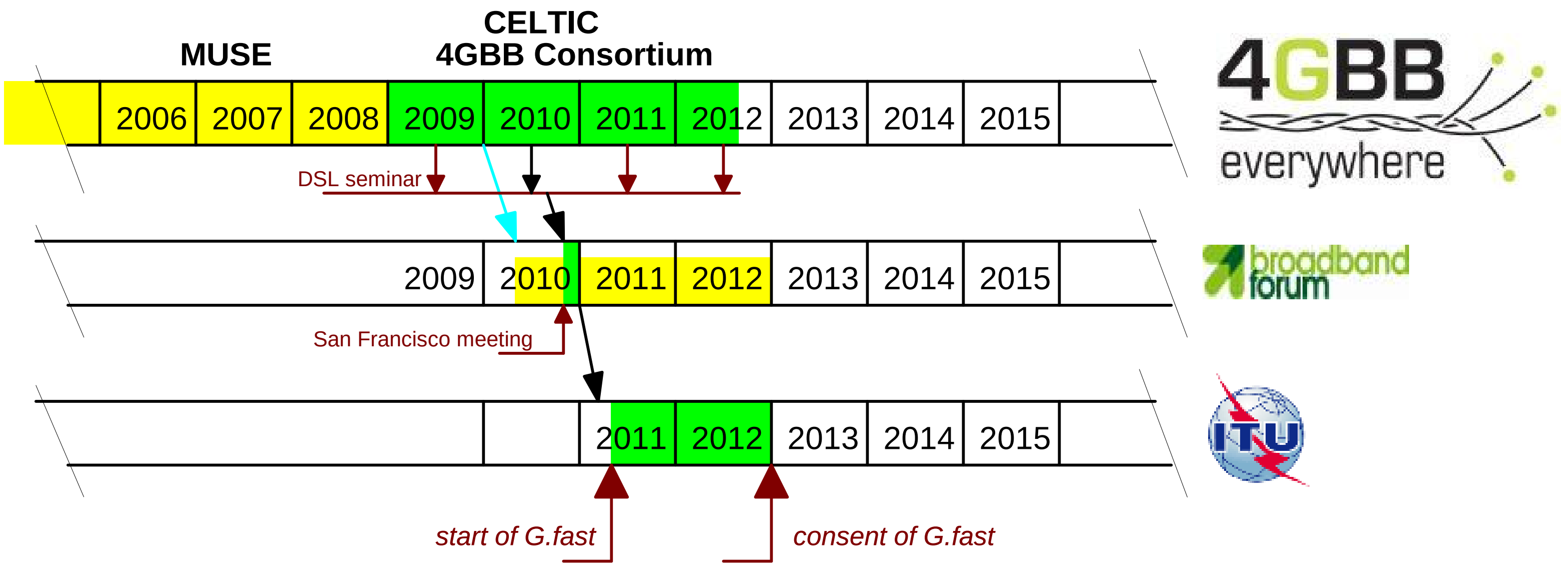
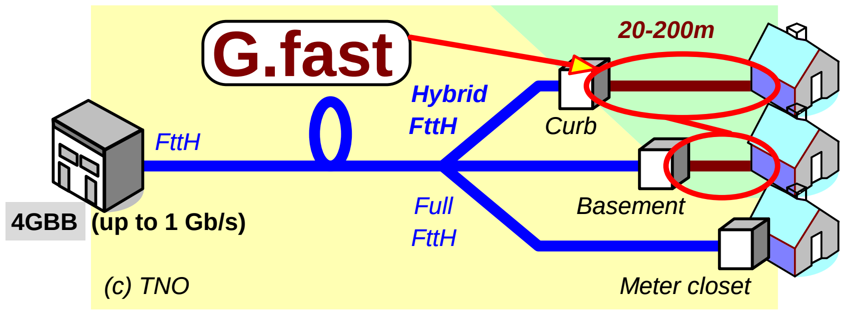
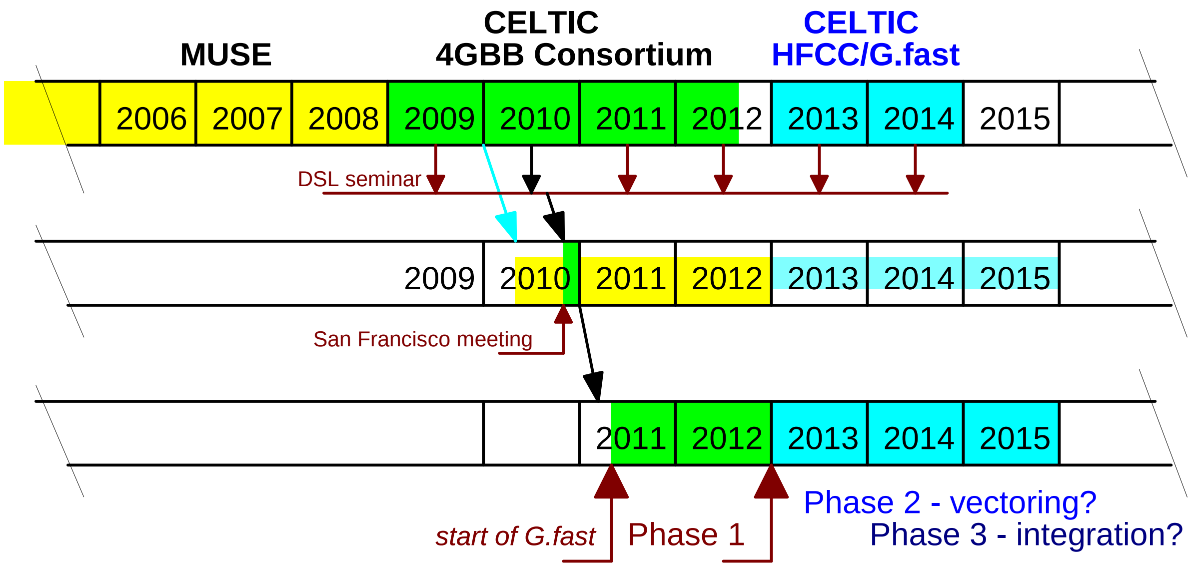
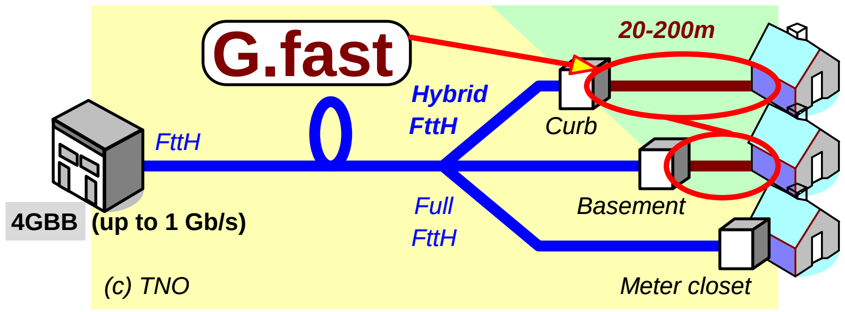




1. Progressing G.fast – how will it continue?





1. Progressing G.fast – on what topics?

e.g. by developing knowledge on cable modelling & simulations

- Chapter 1 – Progressing G.fast
- Chapter 2 – Progress on cable transmission modeling
- Chapter 3 – Progress on crosstalk modeling
- Chapter 4 – Progress on performance studies

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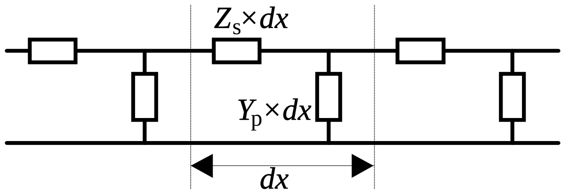
Bitrate targets for G.fast, as agreed within ITU

aimed service rates (US+DS rates) under noisy conditions from 8 disturbers

note: different service rate definitions are under discussion

- agreed: at least 10Mb/s when deployed on loops with exceptional length and noise
- agreed: 150 Mb/s @ 250m
- agreed: 200 Mb/s @ 200m
- agreed: **500 Mb/s** @ 100m (typically a FTTB deployment) **à** *2×500 Mb/s with bonding*
- agreed: **500 Mb/s** @ 50m when **above 17.7MHz**, and not too bad noise
- agreed: **up to 1Gb/s** on shorter loops (protocol should not prevent 1Gb/s)

2. Progress on cable transmission modeling



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R_s(jw) &= real\big(Z_s(jw)\big) \\
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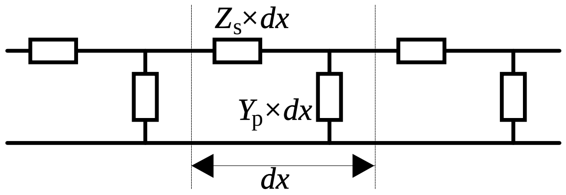

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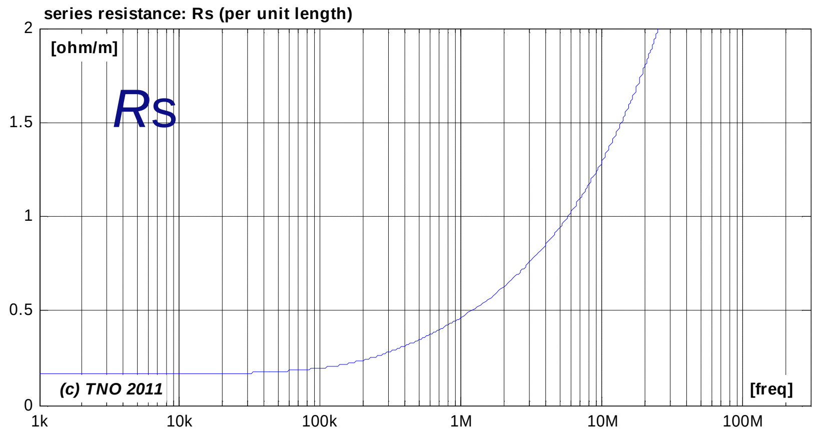

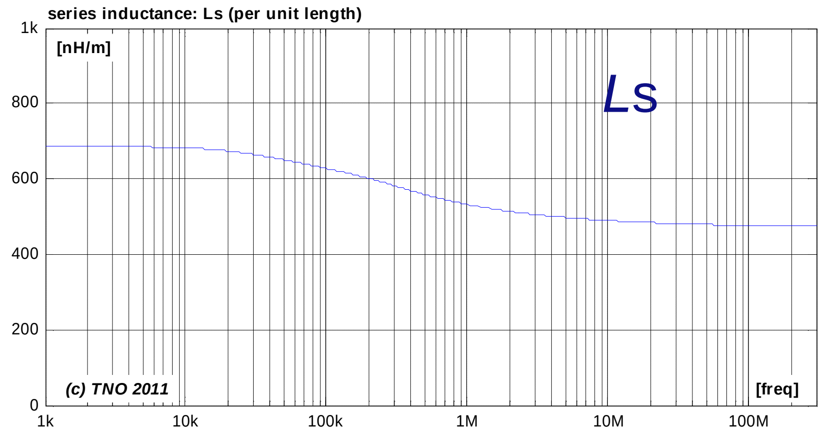

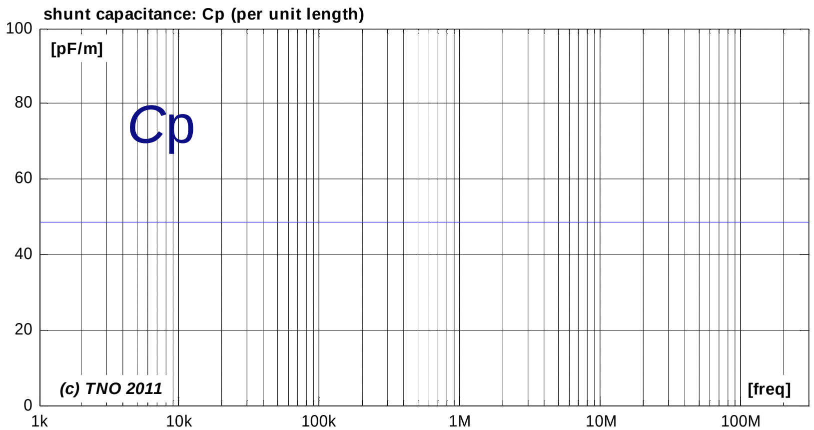

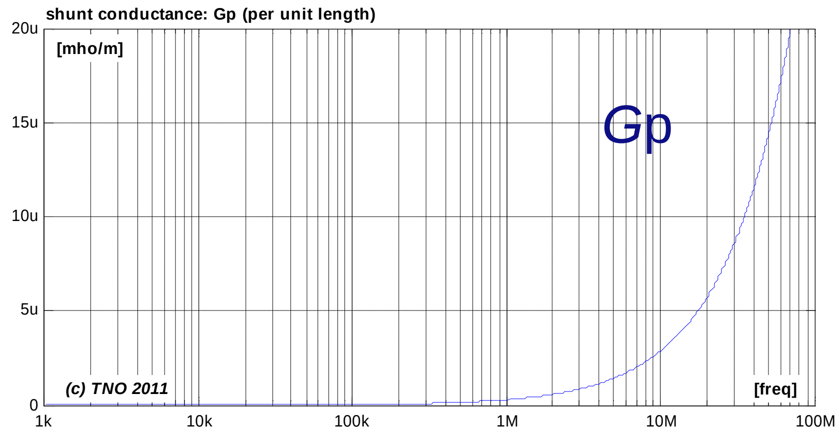

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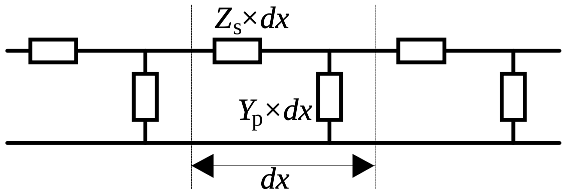

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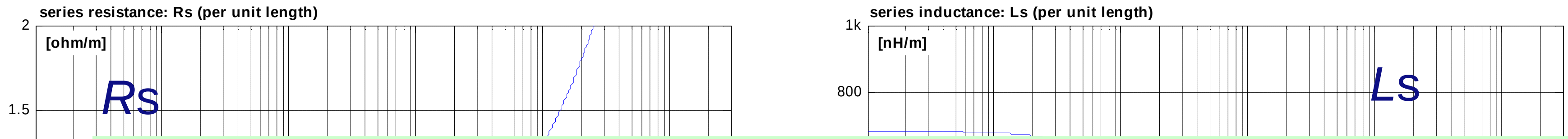
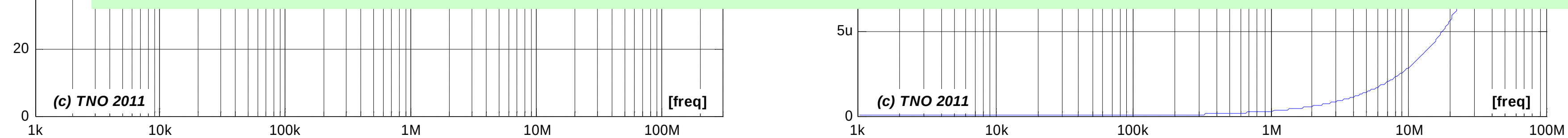


Legacy approach (*see VDSL2 standard*)

- Model Rs, Ls, Cp, Gp independently, using 4 functions of “w”
- (BT Model (1996): 13 parameters, KPN Model (1997), etc)
- modification needed to make impulse response **causal**
- ***problem:*** this troubles time-domain simulations

Improved approach (TNO model, 2009/2011):

- Model (Rs+jw.Ls) and (Gp+jw.Cp), using 2 functions of “jw”
- (7+1 parameters)
- you get causality almost for “free” (*if done in a clever way*)



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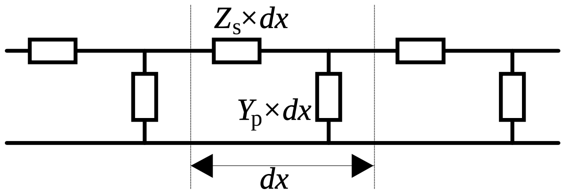

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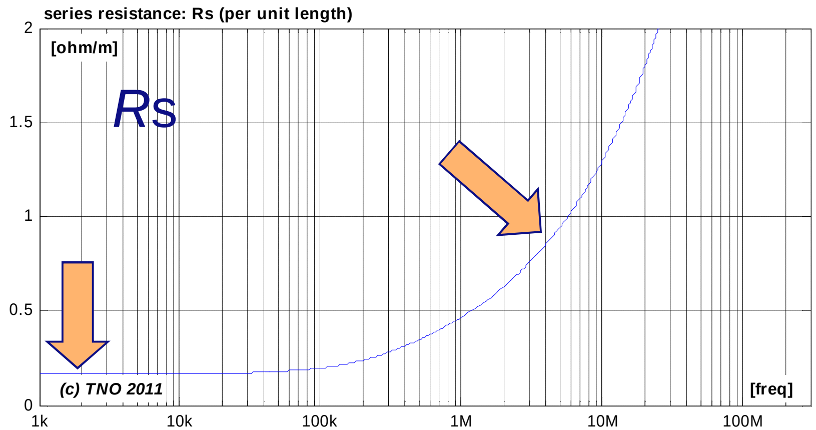
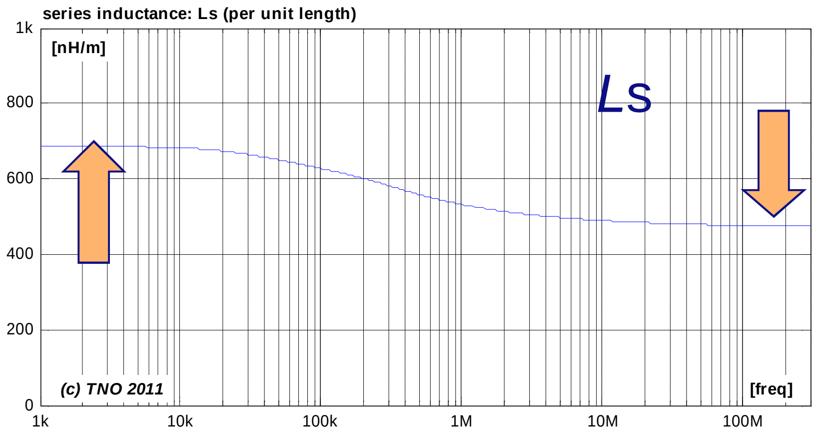
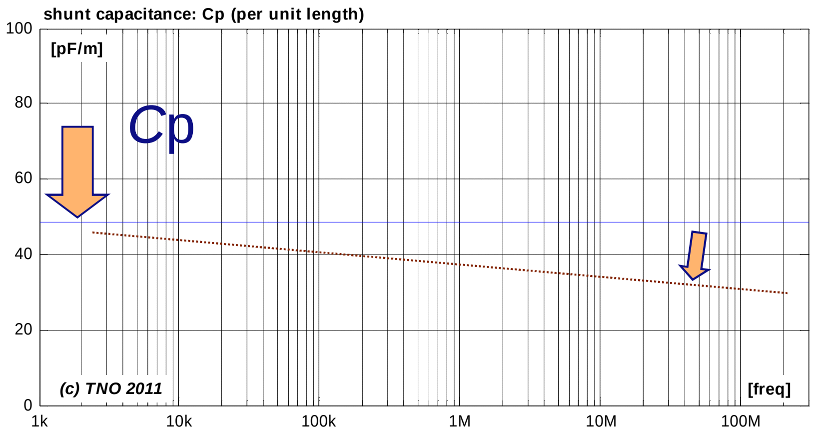
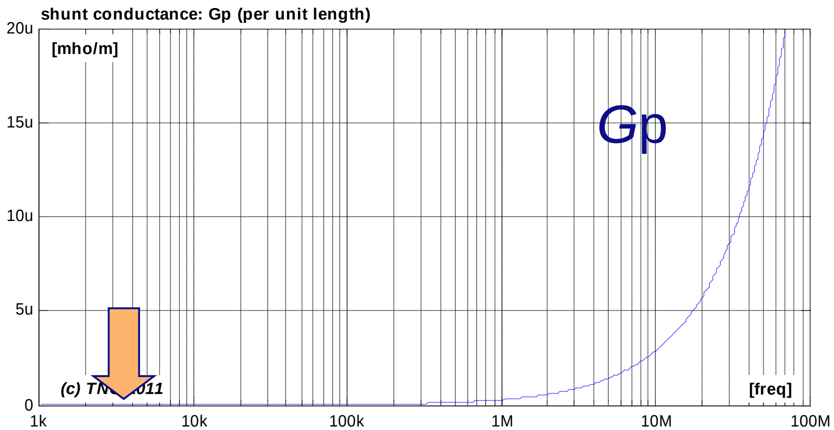
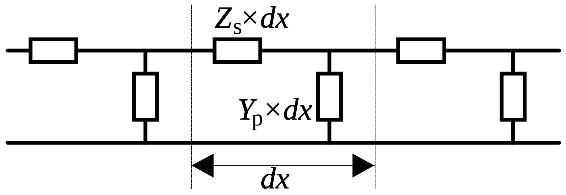








2. Progress on cable transmission modeling - expressions for impedance Zs



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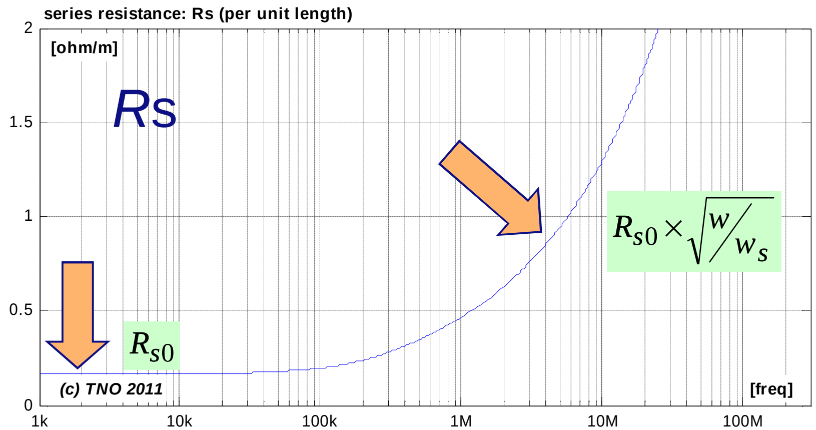

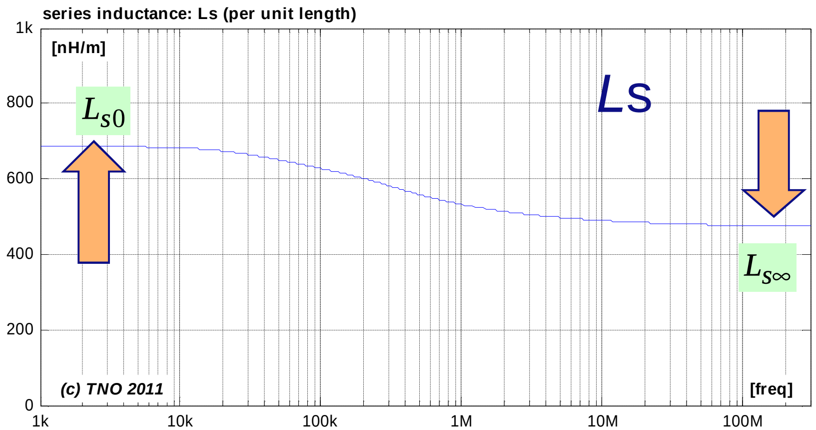

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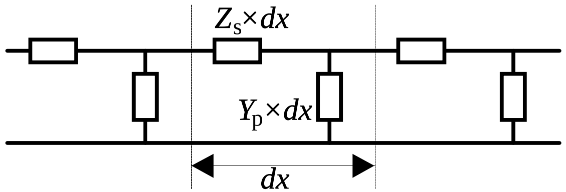

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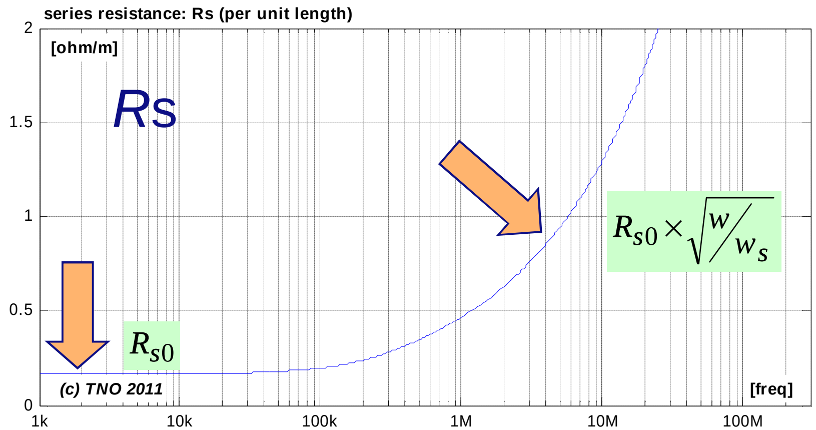

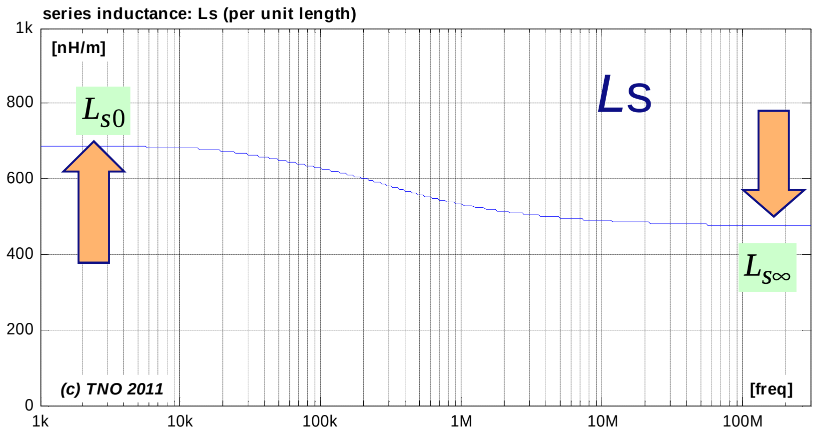

Approach: *take observations as parameters*

$L_{s\infty}, R_{s0}, w_s, q_s$ parameters

$L_{s0} = L_{s\infty} + (R_{s0}/w_s)/q_s$ substitution

$Q_Z(j\Omega)$ glue (shaping function)

→

$$Z_s(jw) = jw \cdot L_{s\infty} + R_{s0} \times \left(1 - q_s + q_s \cdot Q_Z\left(\frac{jw}{q_s^2 \cdot w_s}\right)\right)$$

Qz is restricted by certain analytical properties

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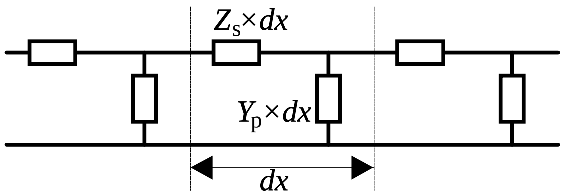

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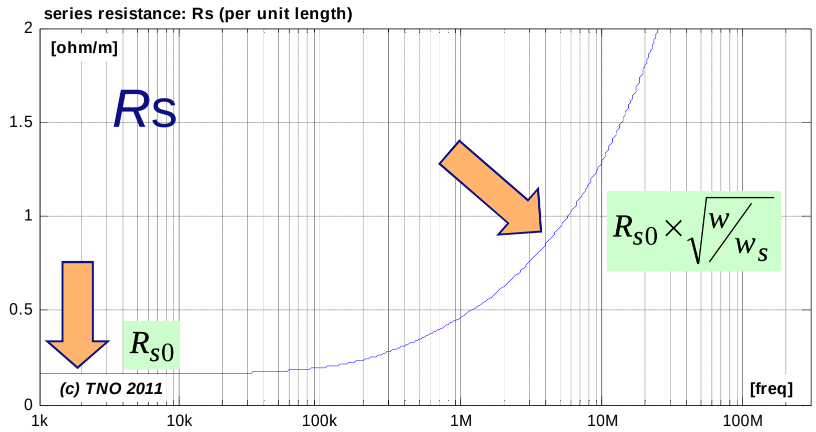

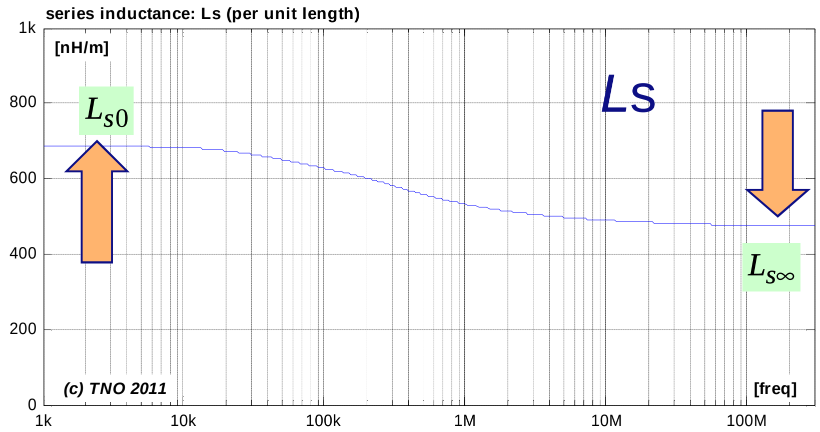

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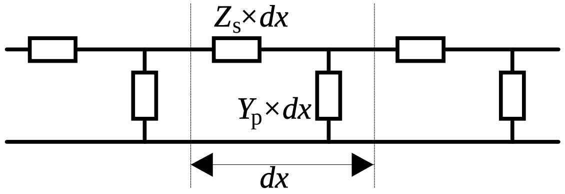
Qz is restricted by certain analytical properties

The simplest form of Qz is already very good

$$Z_s(jw) = jw \cdot L_{s\infty} + R_{s0} \times \left(1 - q_s + sqrt\left(q_s^2 + 2 \cdot \frac{jw}{w_s}\right)\right)$$

2. Progress on cable transmission modeling - expressions for admittance Yp



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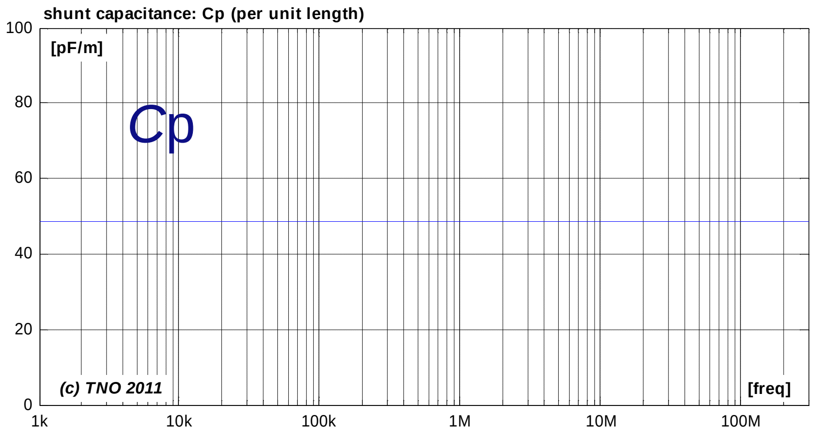

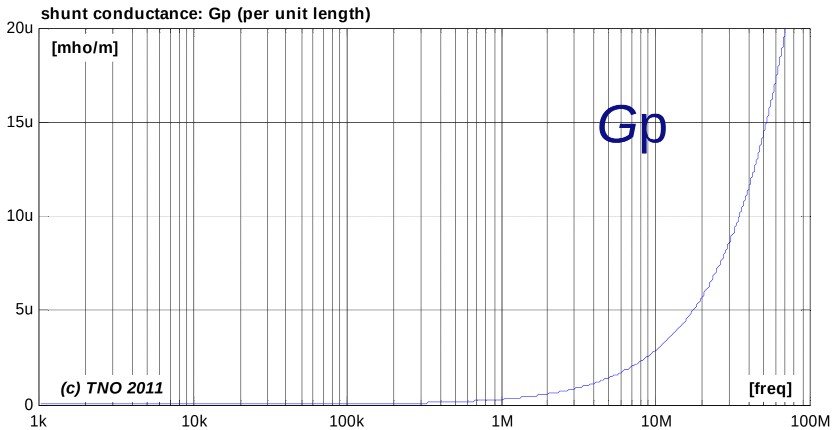

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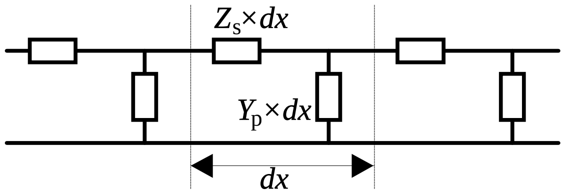

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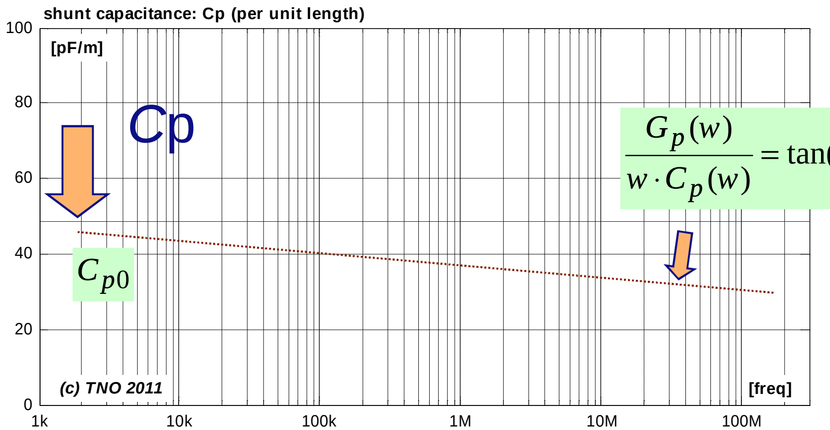
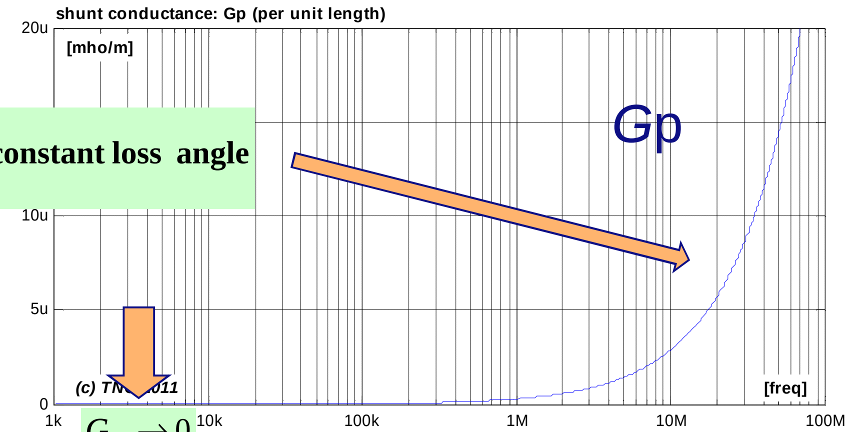


$$\frac{G_p(w)}{w \cdot C_p(w)} = \tan(f) \approx \textbf{constant loss angle}$$



$$G_p \rightarrow 0$$

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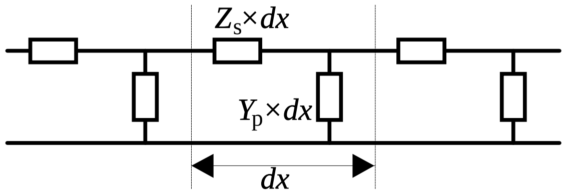

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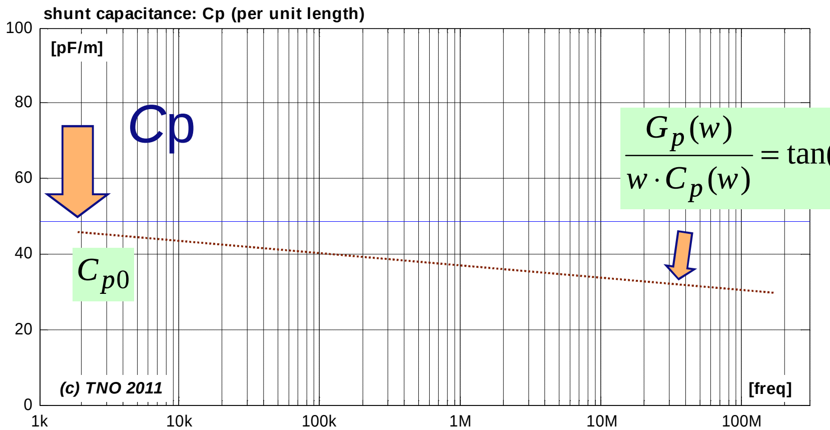

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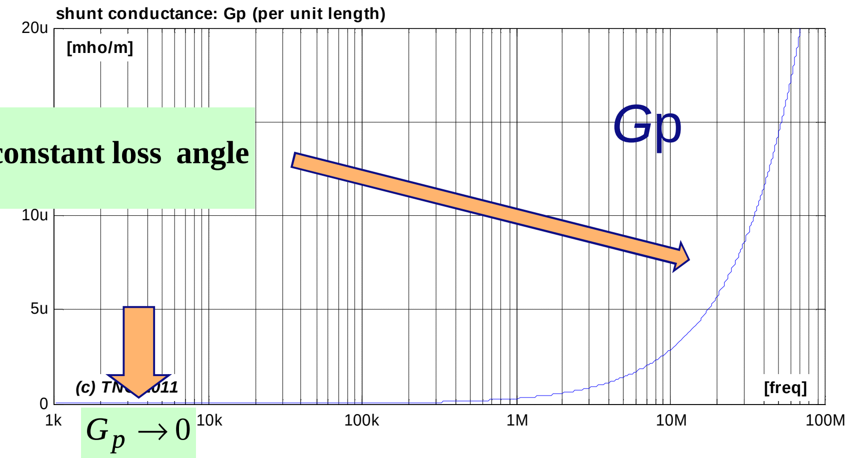

Approach: *take observations as parameters*

$C_{p0},\ f,\ w_d$ parameters

$Q_Y(jw)$ glue (shaping function)

$$\rightarrow \quad Y_p(jw) = jw \cdot C_{p0} \times \left[Q_Y\left(\frac{jw}{w_d}\right)\right]^f$$

Qy is restricted by certain analytical properties

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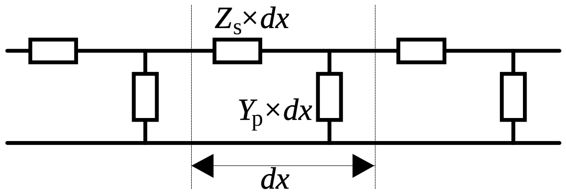

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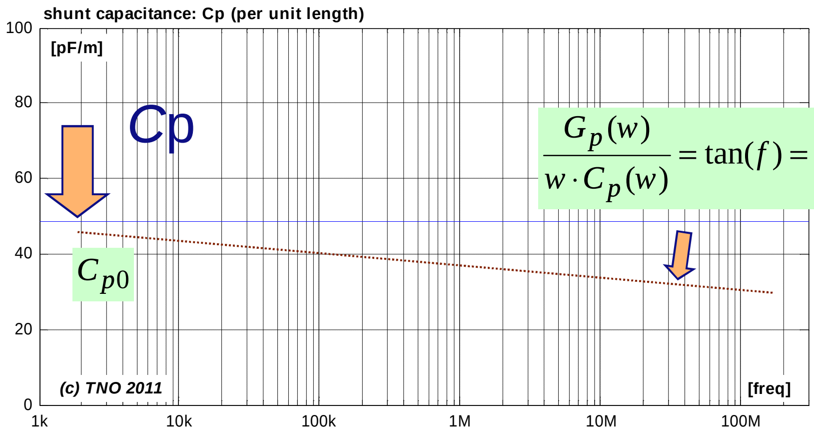
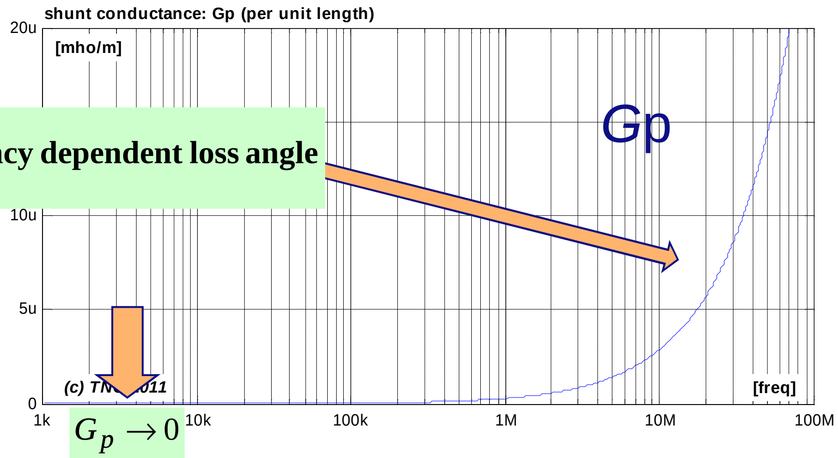


$$\frac{G_p(w)}{w \cdot C_p(w)} = \tan(f) = \textbf{frequency dependent loss angle}$$



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Refinement from Ericsson+LTH contributed to last ITU meeting

ERICSSON

Relevant when dielectric loss becomes significant

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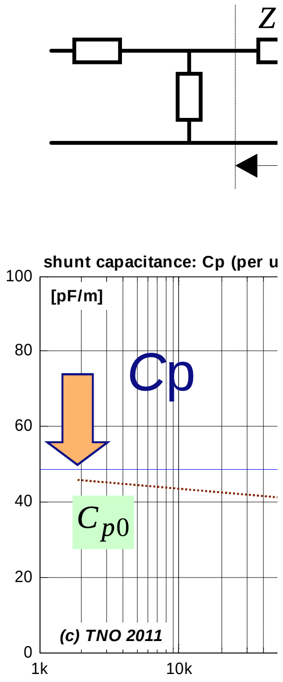

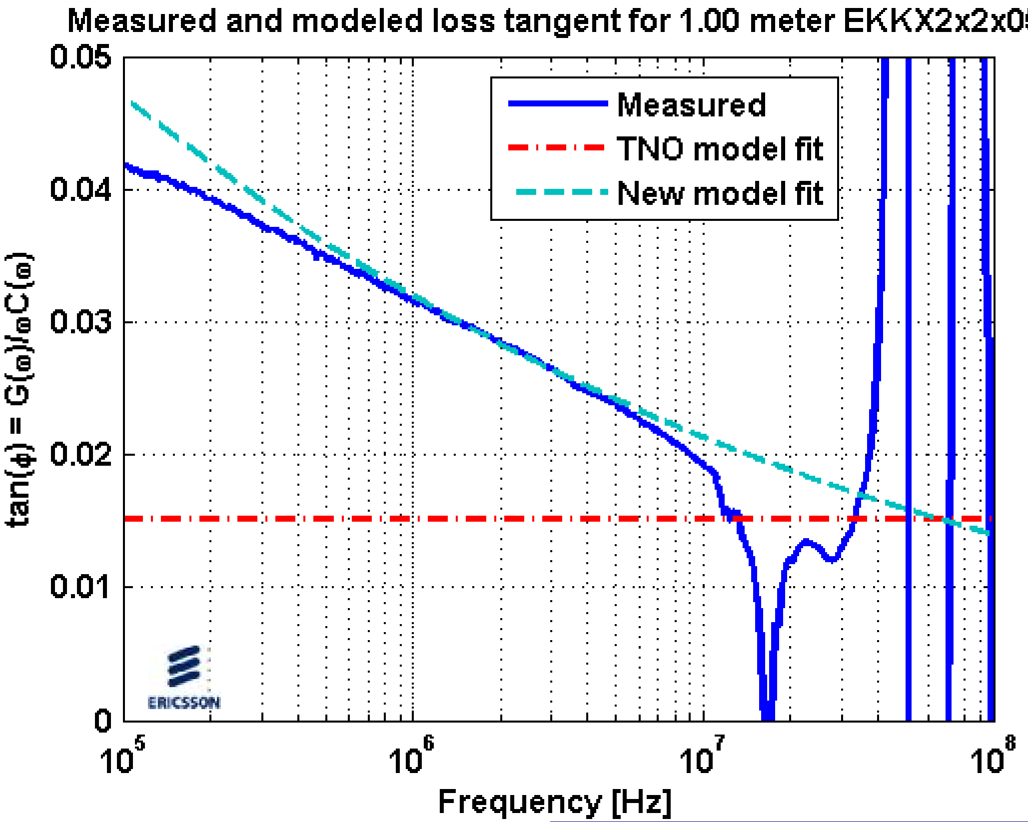

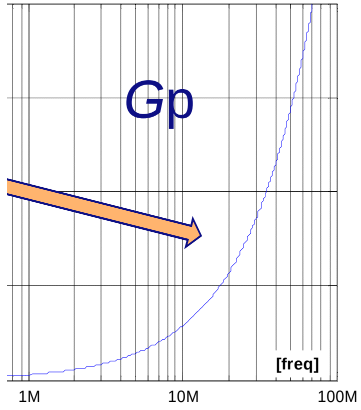

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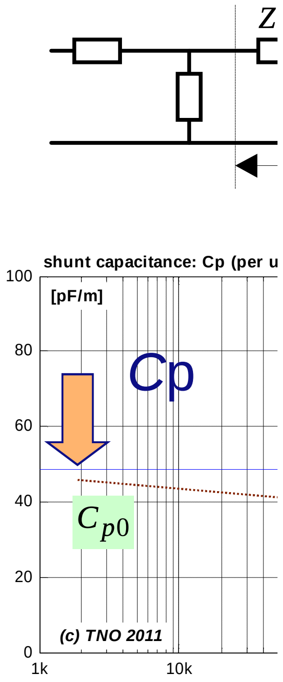

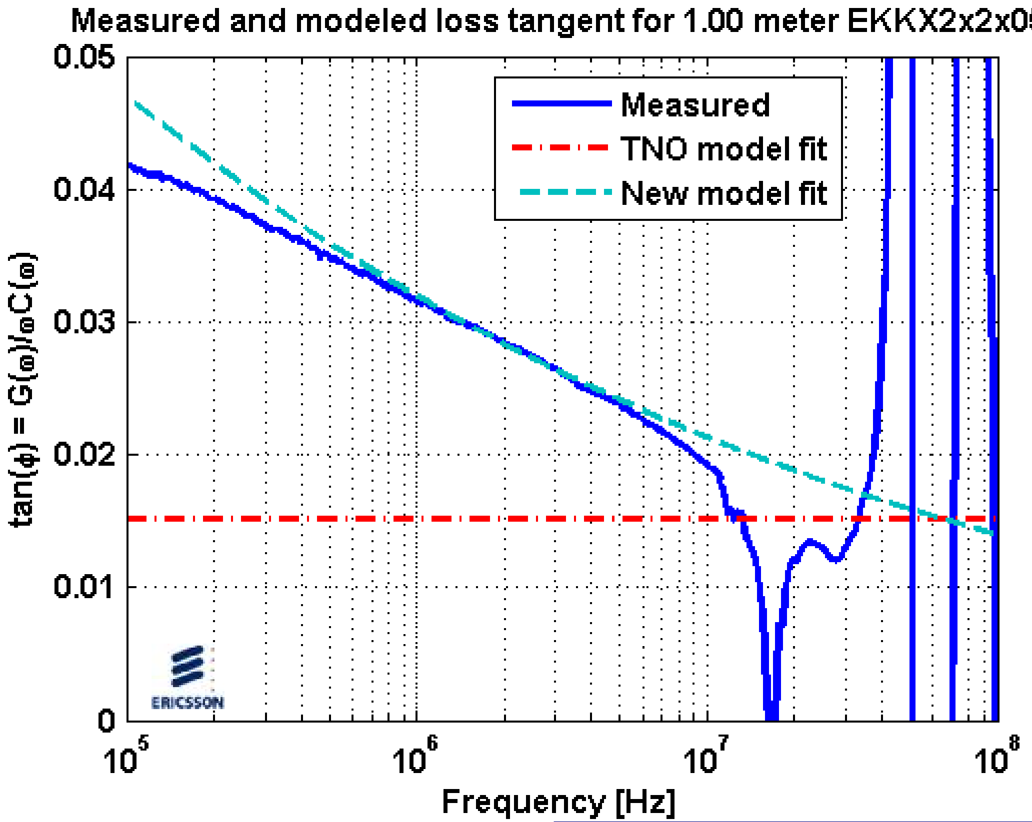

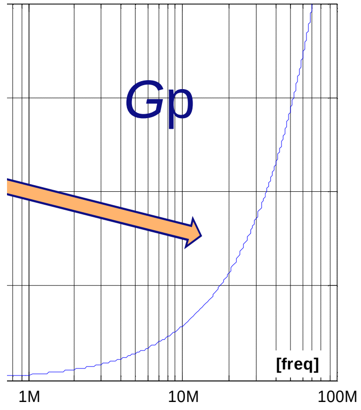

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The simplest form of Qy is already very good

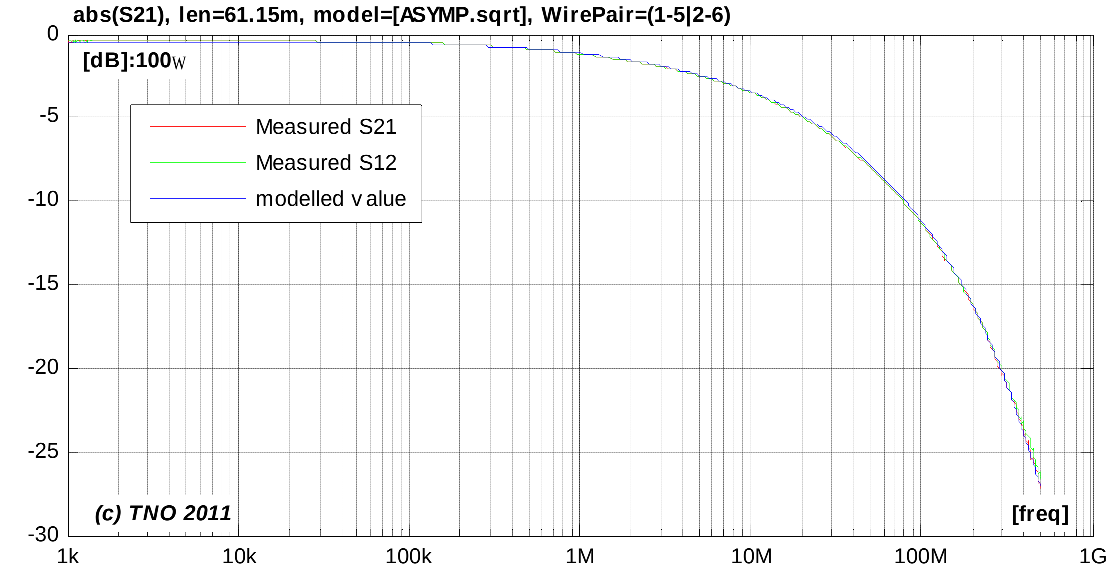
$$Y_p(jw) = jw \cdot C_{p0} \times \left(1 + \frac{jw}{w_d}\right)^{-2 \cdot f/p} \times (1-q_c) + jw \cdot C_{p0} \times q_c$$

Relevant when dielectric loss becomes significant

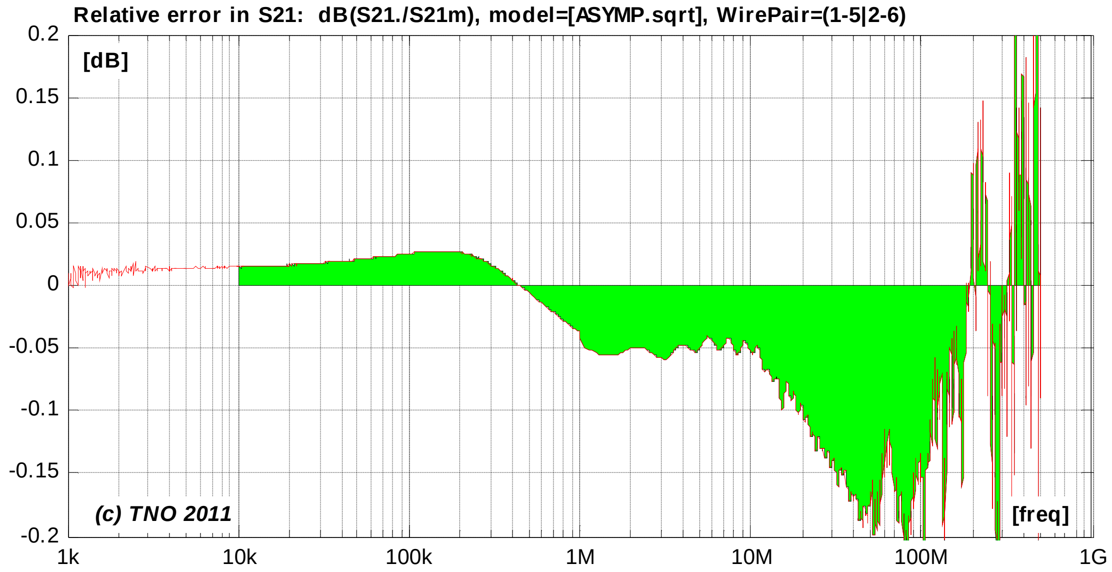
2. Progress on cable transmission modeling - results

CAT5e cabling

61m



232m



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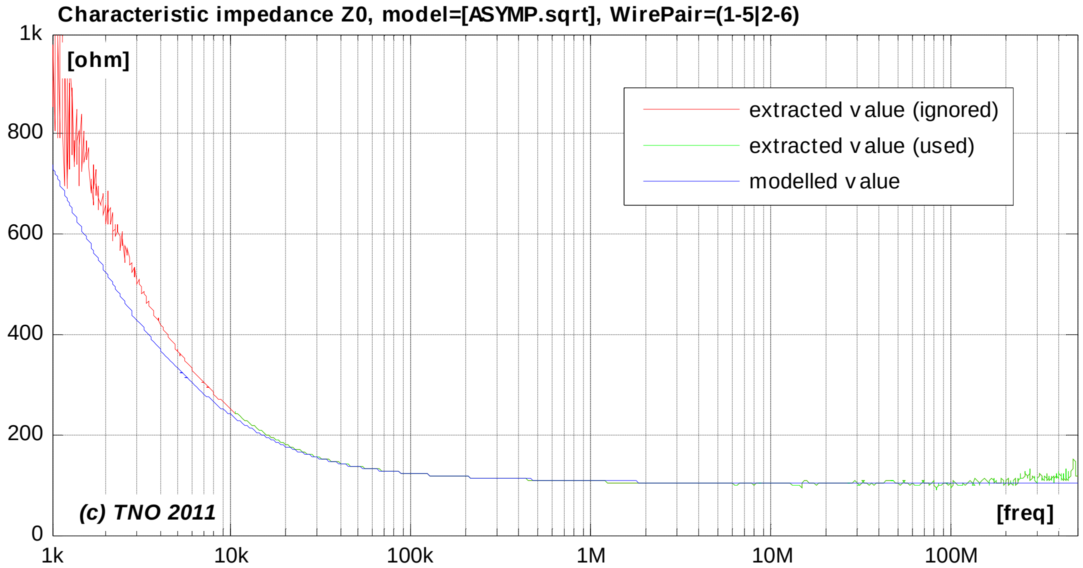
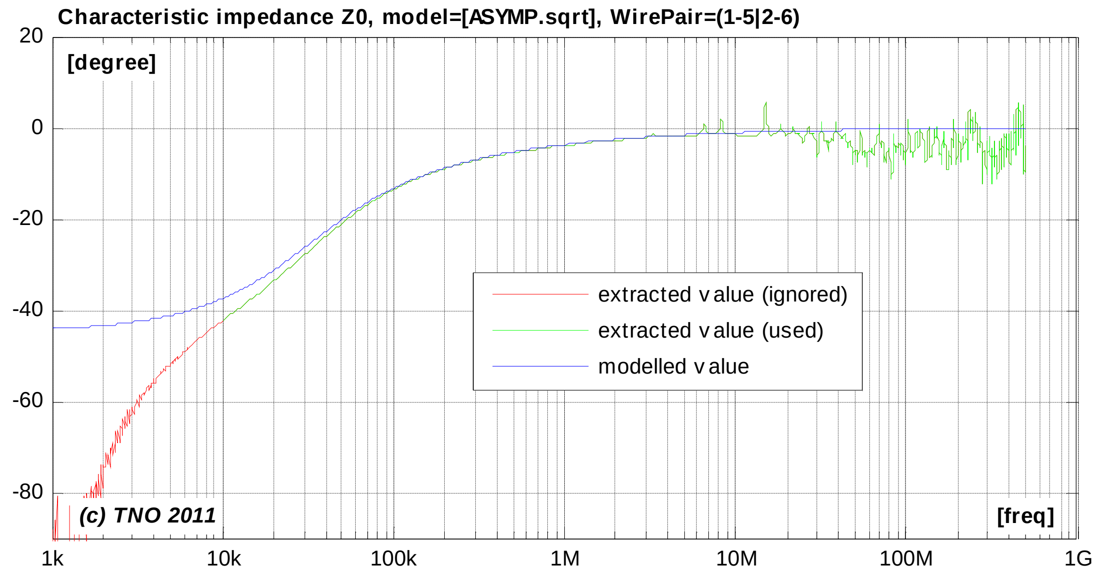


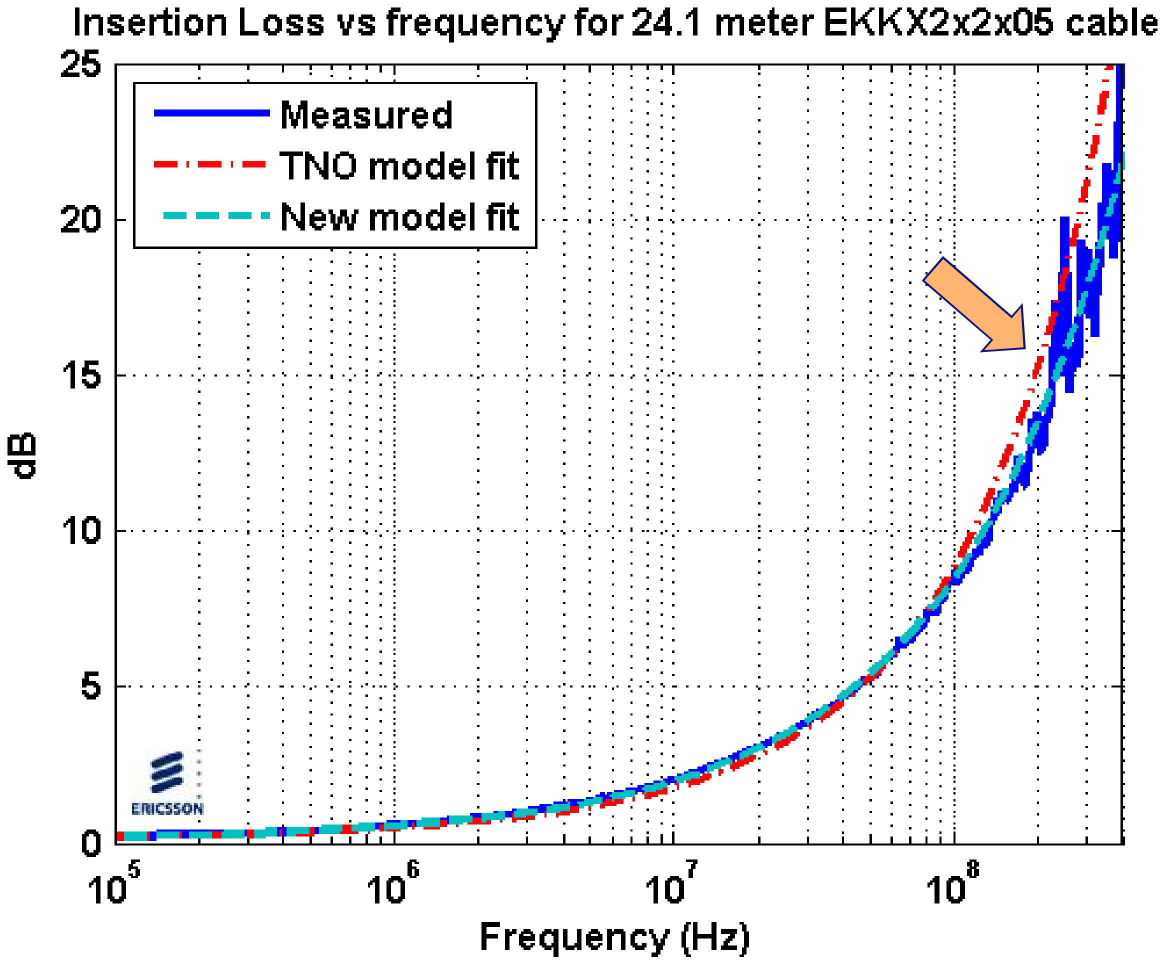


2. Progress on cable transmission modeling - results

PVC insulated drop cable

Dielectric losses become significant;

Use of proposed refinement from Ericsson and LTH offer valuable improvements

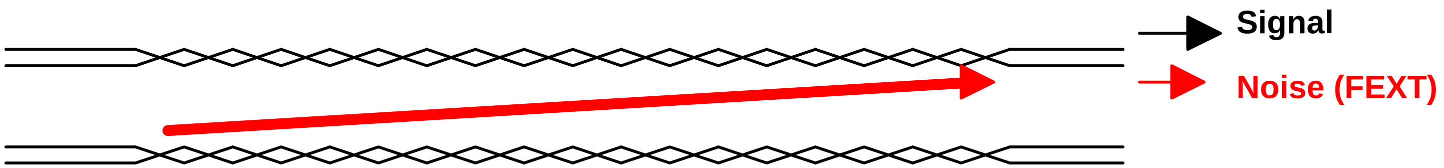


24m

New approach

has gained acceptance in ITU

3. Progress on crosstalk modeling - EL-FEXT, legacy approach



$$\text{EL - FEXT} = \frac{\text{Noise (FEXT)}}{\text{Signal}} = \frac{1}{\text{S/N ratio}}$$

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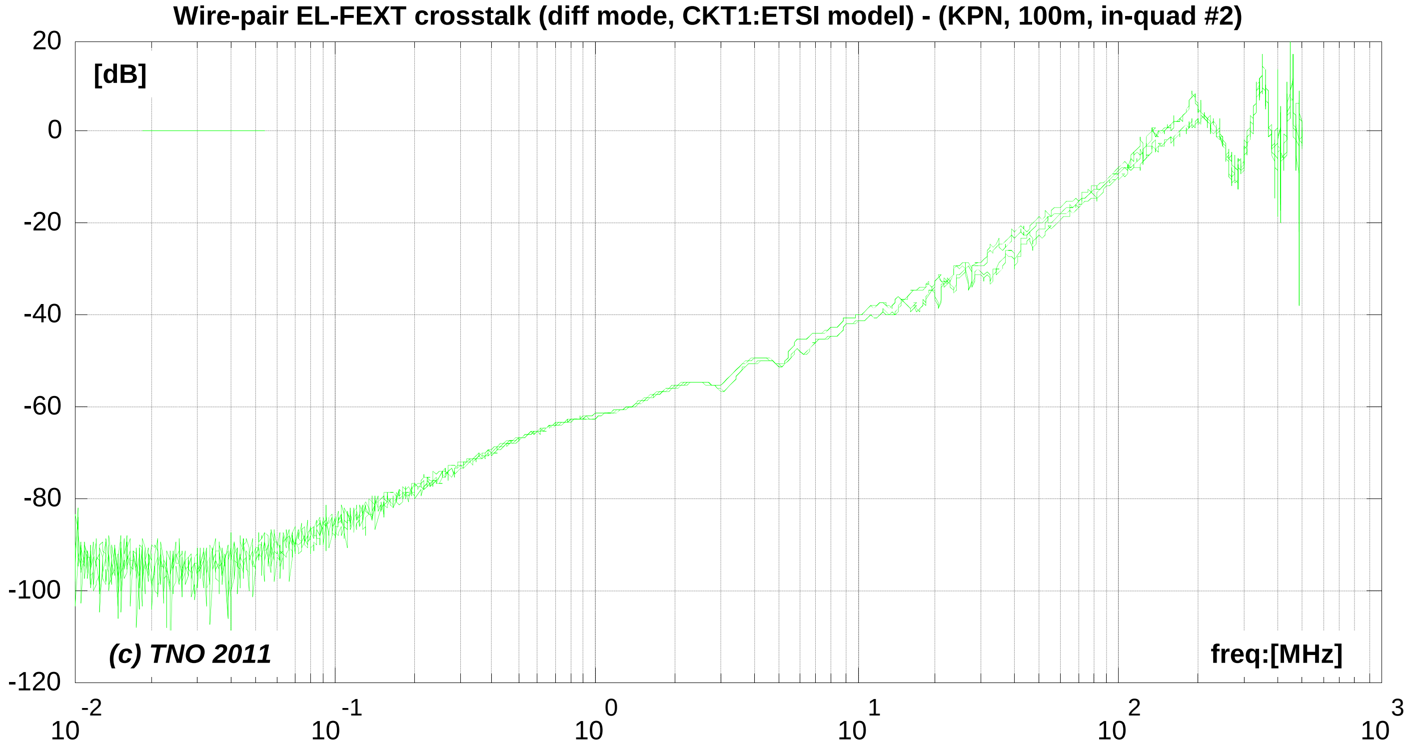

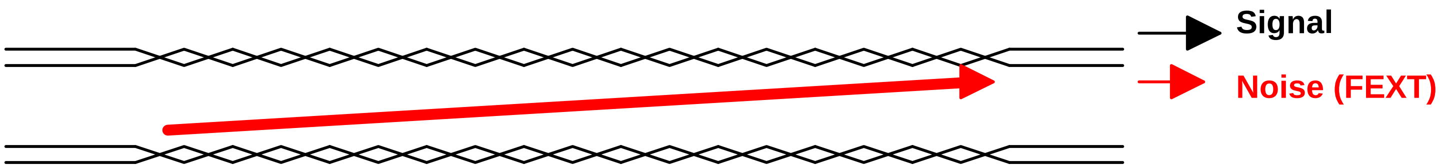

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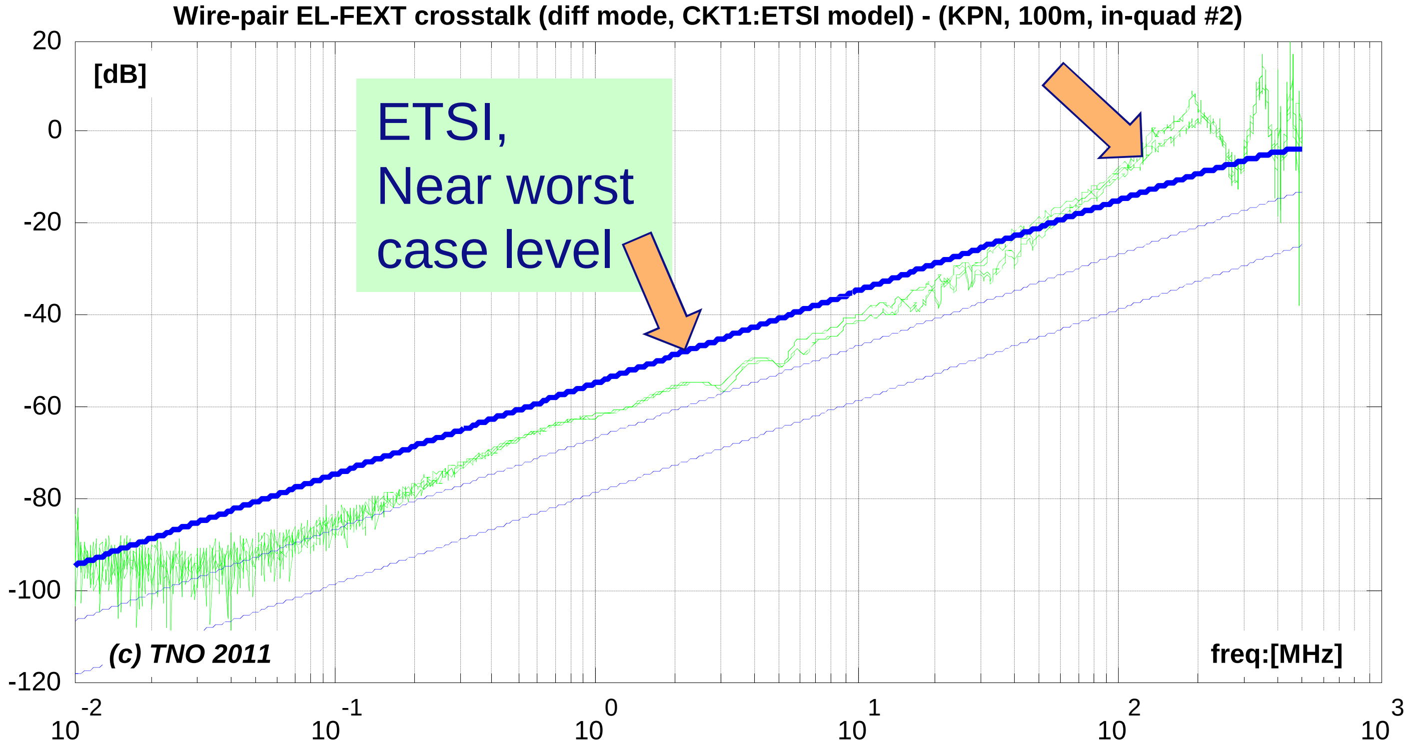


Legacy model: (FSAN)
EL-FEXT is linear proportional with the frequency.

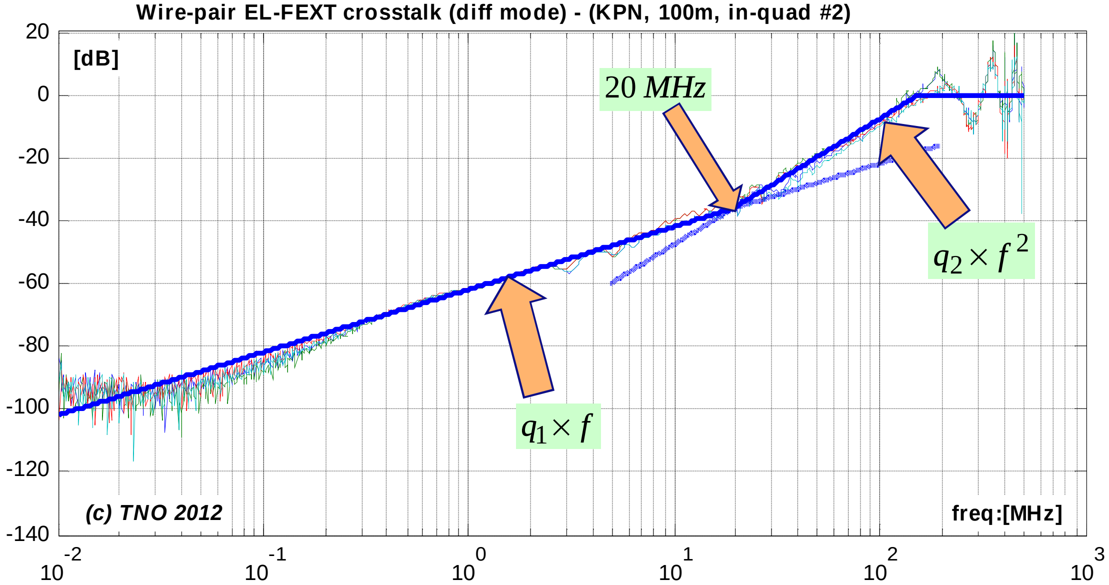
Too low for higher frequencies

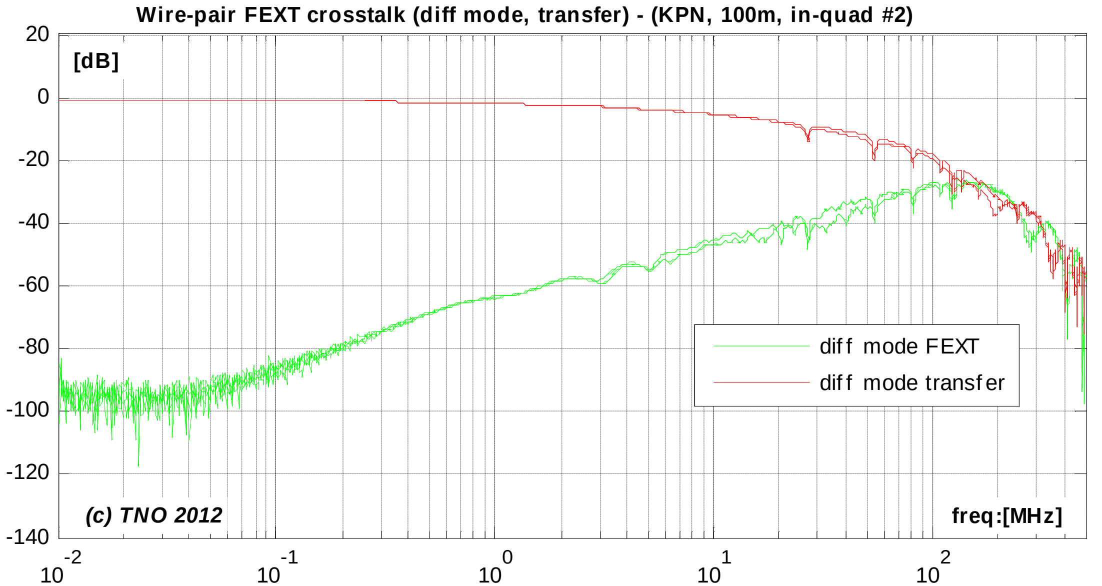
Performance studies for G.fast will be too optimistic when this is ignored

3. Progress on crosstalk modeling - EL-FEXT with dual slope

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

104m

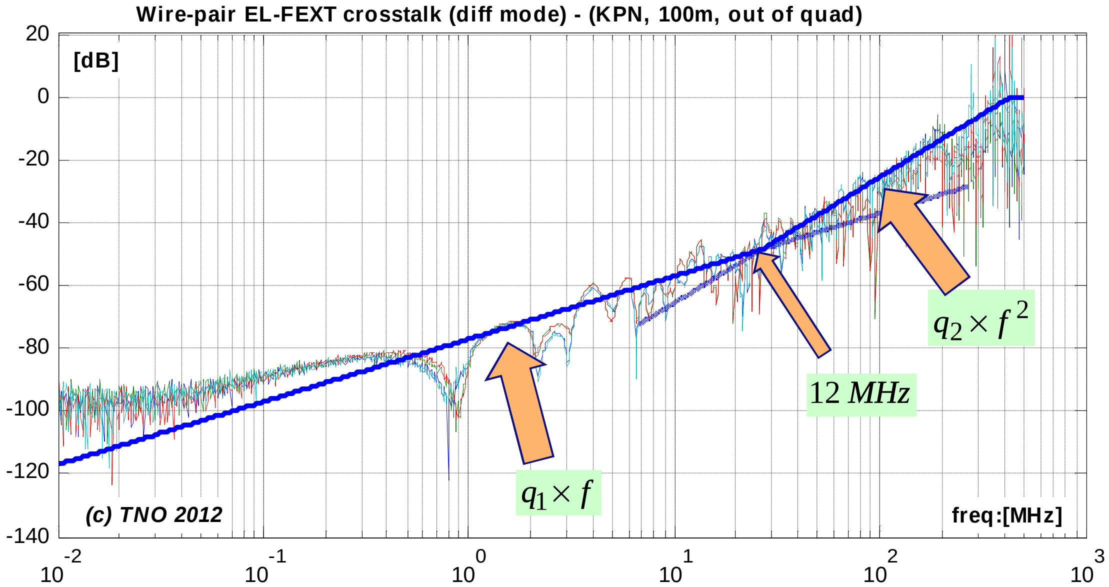


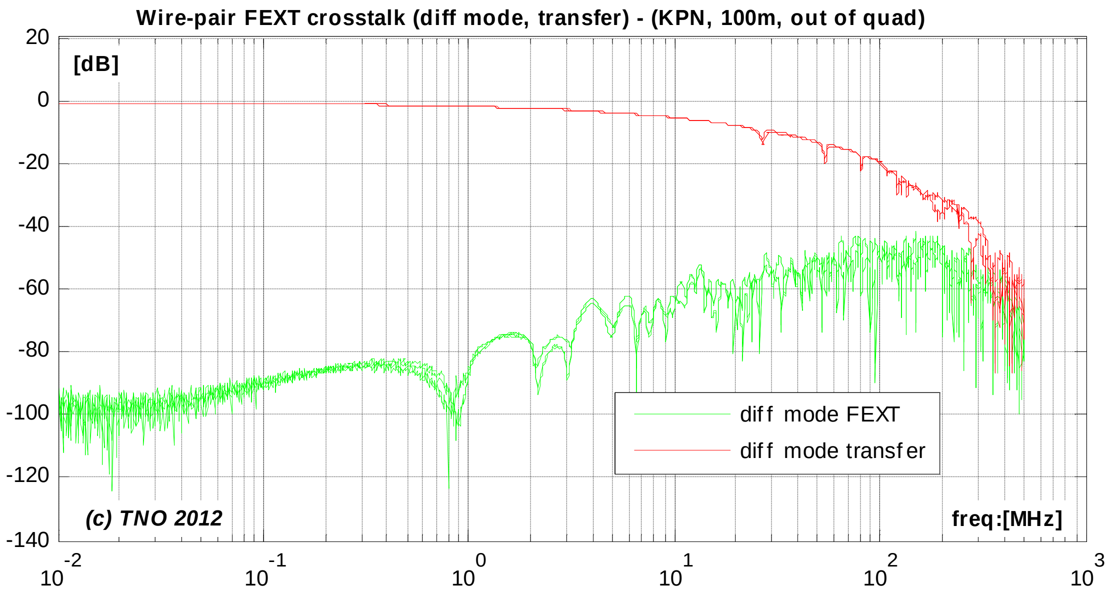


3. Progress on crosstalk modeling - EL-FEXT with dual slope

KPN Access cable, 100m, out-of-quad

104m



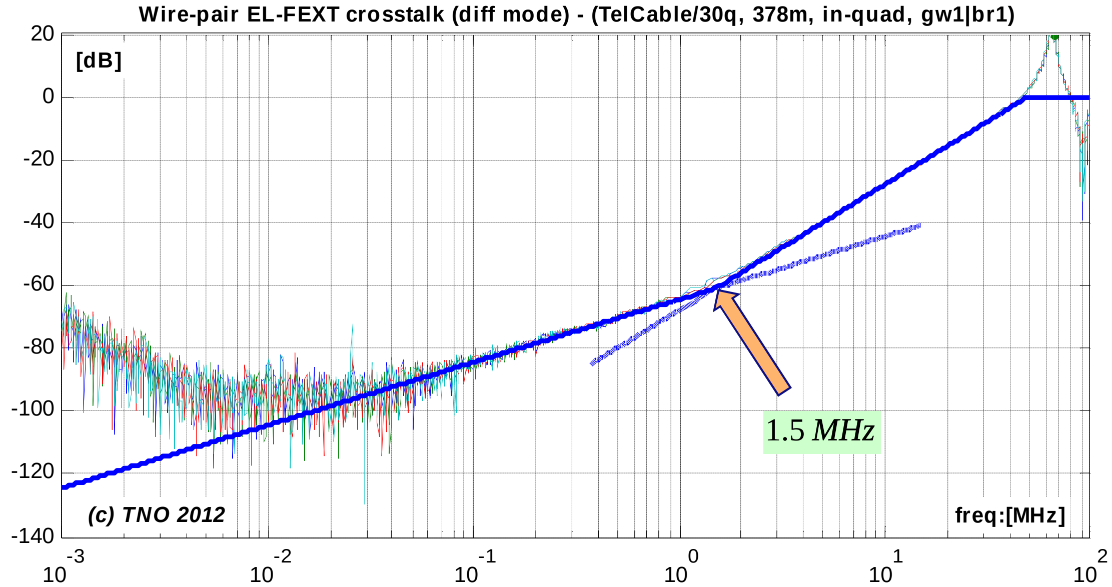


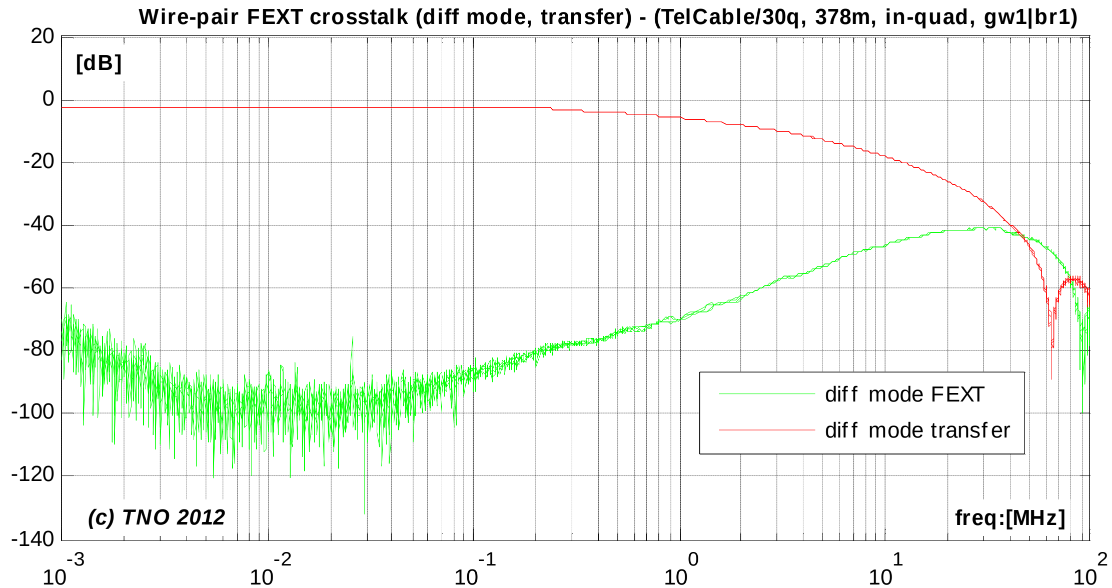
3. Progress on crosstalk modeling - EL-FEXT with dual slope

Multi quad telephony cabling, 378m, in-quad, group 1

378 m

This cannot be ignored for even VDSL frequencies! (roughly 1.5 MHz)

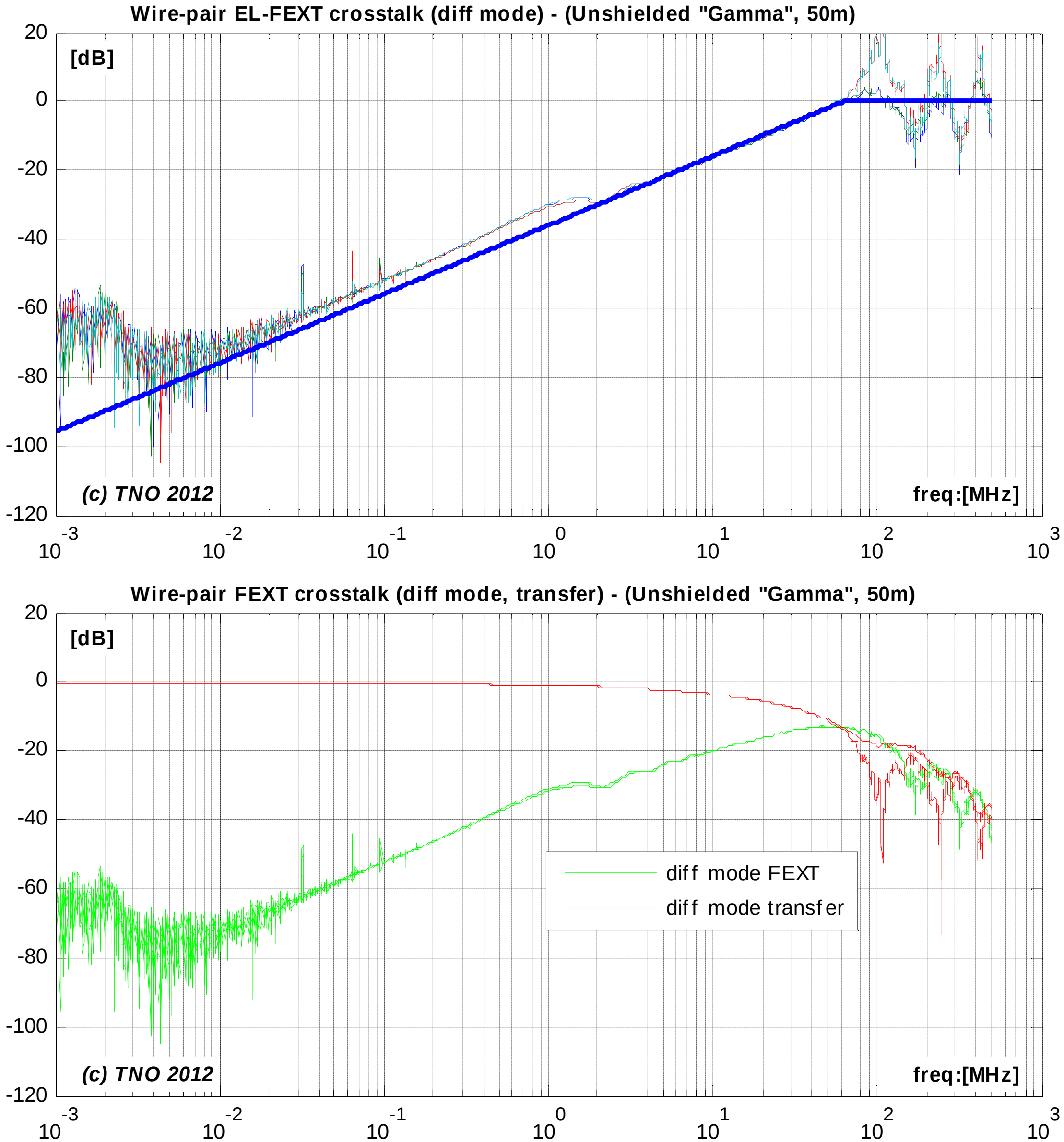




3. Progress on crosstalk modeling - EL-FEXT with dual slope

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

51m



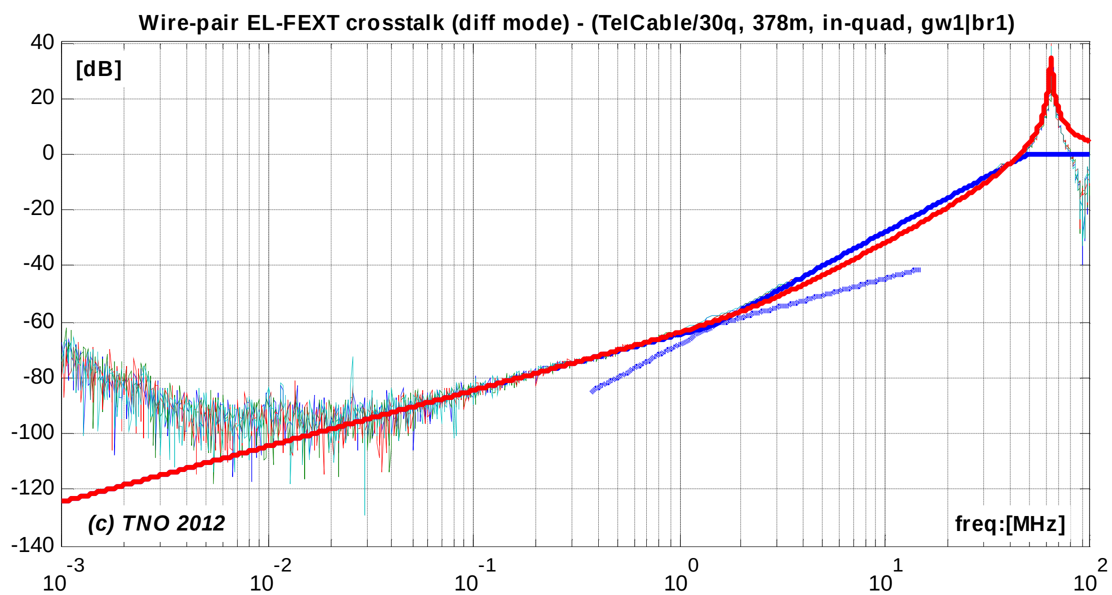
Crosstalk is soo high, dual slope effect not present

How to model this?

à Dual slope = 2nd order transfer function

Models dual-slope effect very well, …

… models even the resonation peak, …

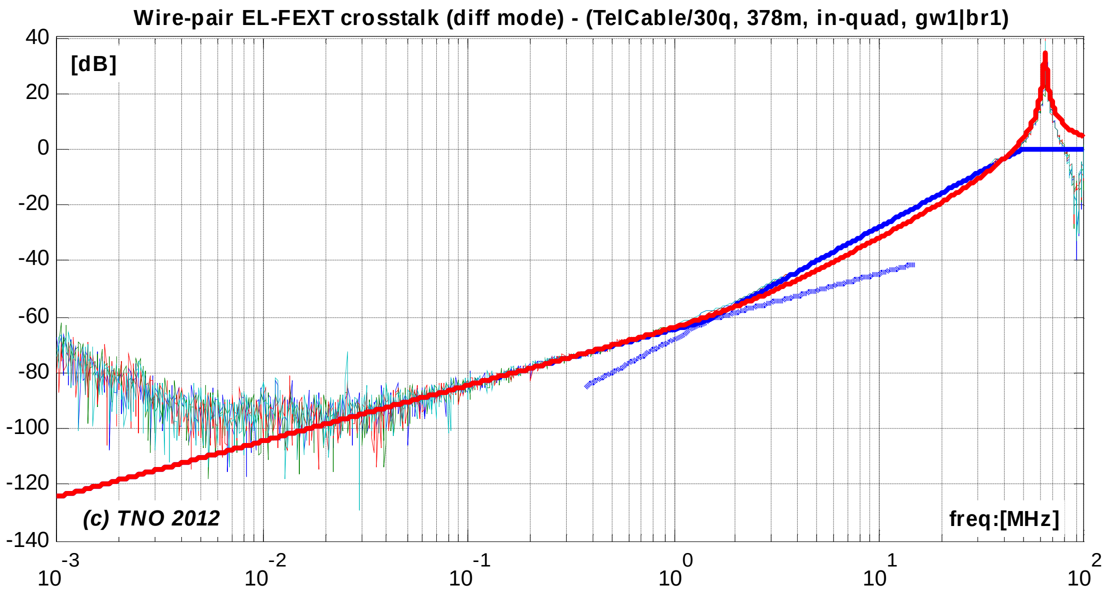


3. Progress on crosstalk modeling - EL-FEXT via 2nd-order transfer

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

Models dual-slope effect very well, …

… models even the resonation peak, …



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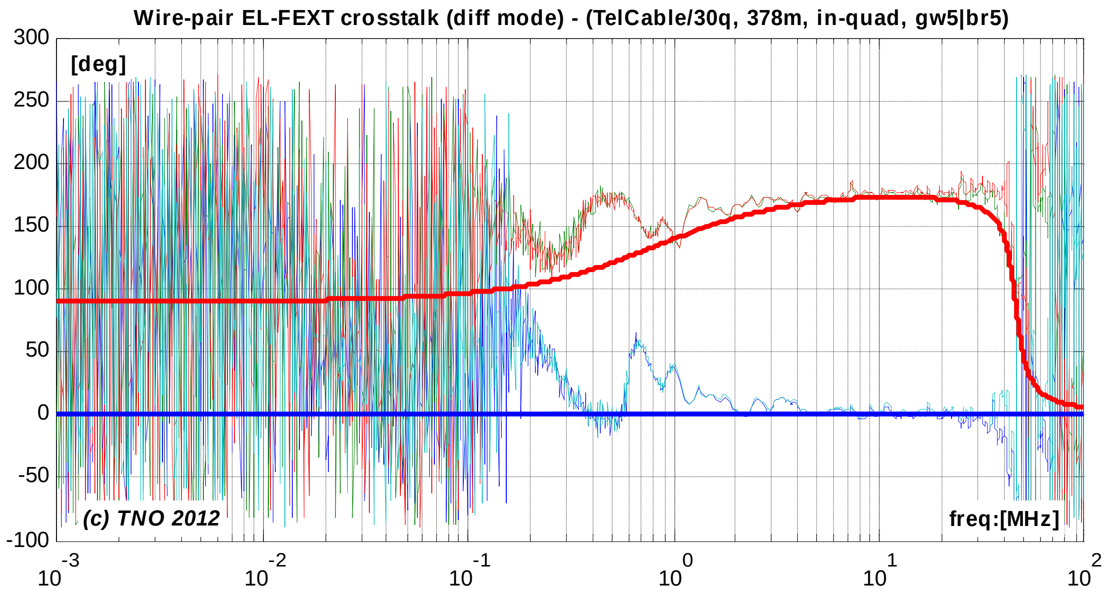
$$H_{EL-FEXT}(jw) = \left(\frac{\left(\frac{jw}{w_1}\right) \times \left(1 + \frac{jw \times w_1}{w_2 \cdot w_2}\right)}{1 + 2/q \cdot \left(\frac{jw}{w_2}\right) + \left(\frac{jw}{w_2}\right)^2} \right)$$

Models dual-slope effect sometimes very well, …

… and also the phase (in quad cables)



New approach

is gaining acceptance in ITU

GOAL: Predict attainable bitrates within a given scenario
(Important in system design phase)

Traditional approach: Frequency domain calculations

- How:
  - Calculate SNR from cable models and noise assumptions (*from frequency domain calculations*)
  - Run bit loading algorithm with the SNR
  - Remove overhead of Cyclic Extension (prefix + suffix) and coding.
- Advantages
  - Simple
  - Adequate for channels dominated with additive white Gaussian noise (AWGN)

GOAL: Predict attainable bitrates within a given scenario

(Important in system design phase)

Advanced approach: Time domain calculations

› Why: G.fast channel can be more ISI limited, especially with short cyclic prefix,

- High tone spacing -> short symbol period
- Long dispersion due to bridge taps
- CP may not cover the whole channel dispersion.

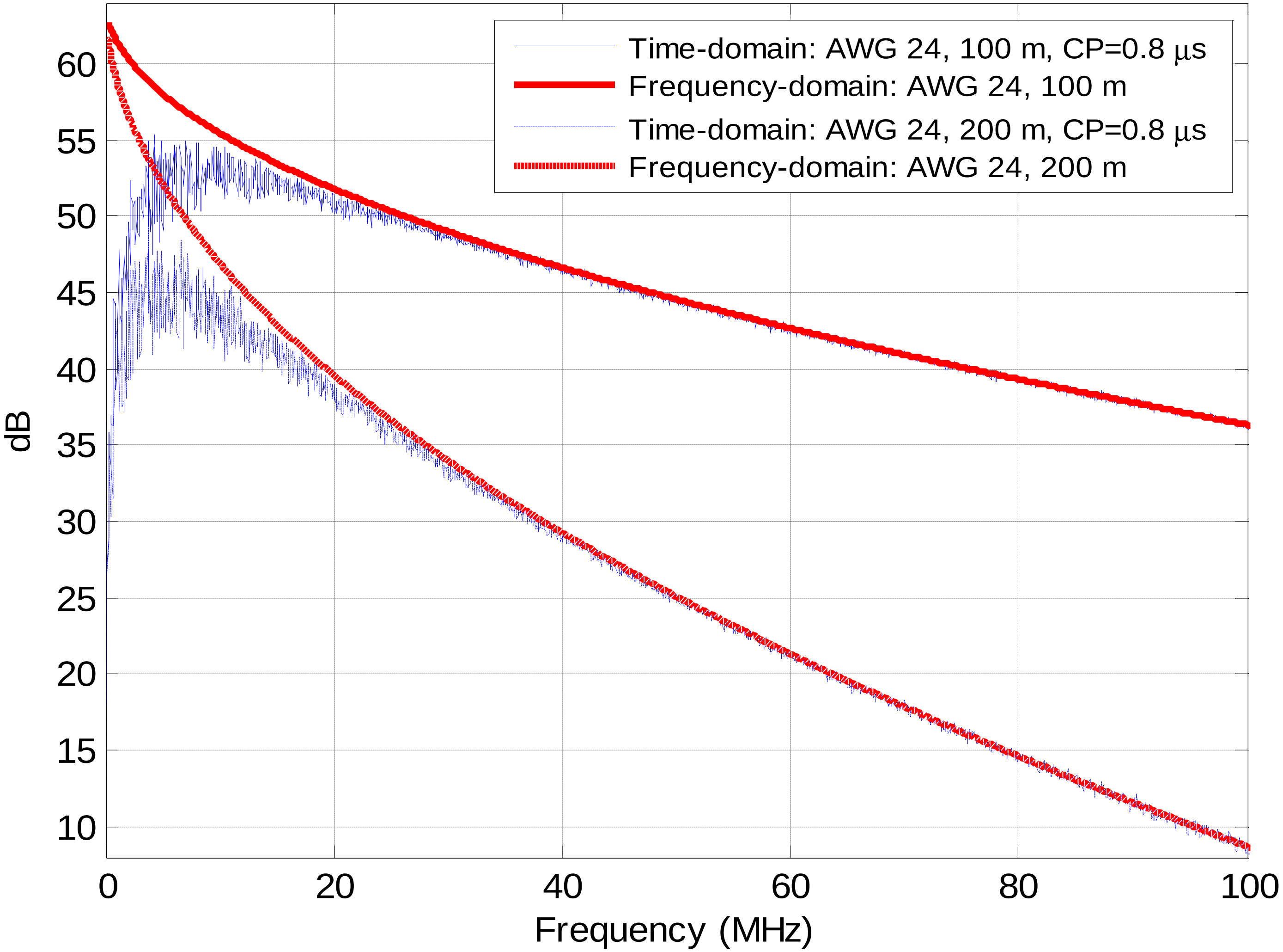
› How: Take inter-symbol interference (ISI) into consideration for estimating Signal to Noise and Interference Ratio estimation (SINR)

– Calculate that via impulse response of (improved) cable model

- Estimate SINR from a time domain simulation from training symbols
  Implementation of symbol timing detection (or frame detection) and Frequency domain equalizer (FEQ) are needed.
- Upsampling is needed to reduce windowing effects of Inverse Discrete Fourier Transform (IDFT) when generating impulse noise

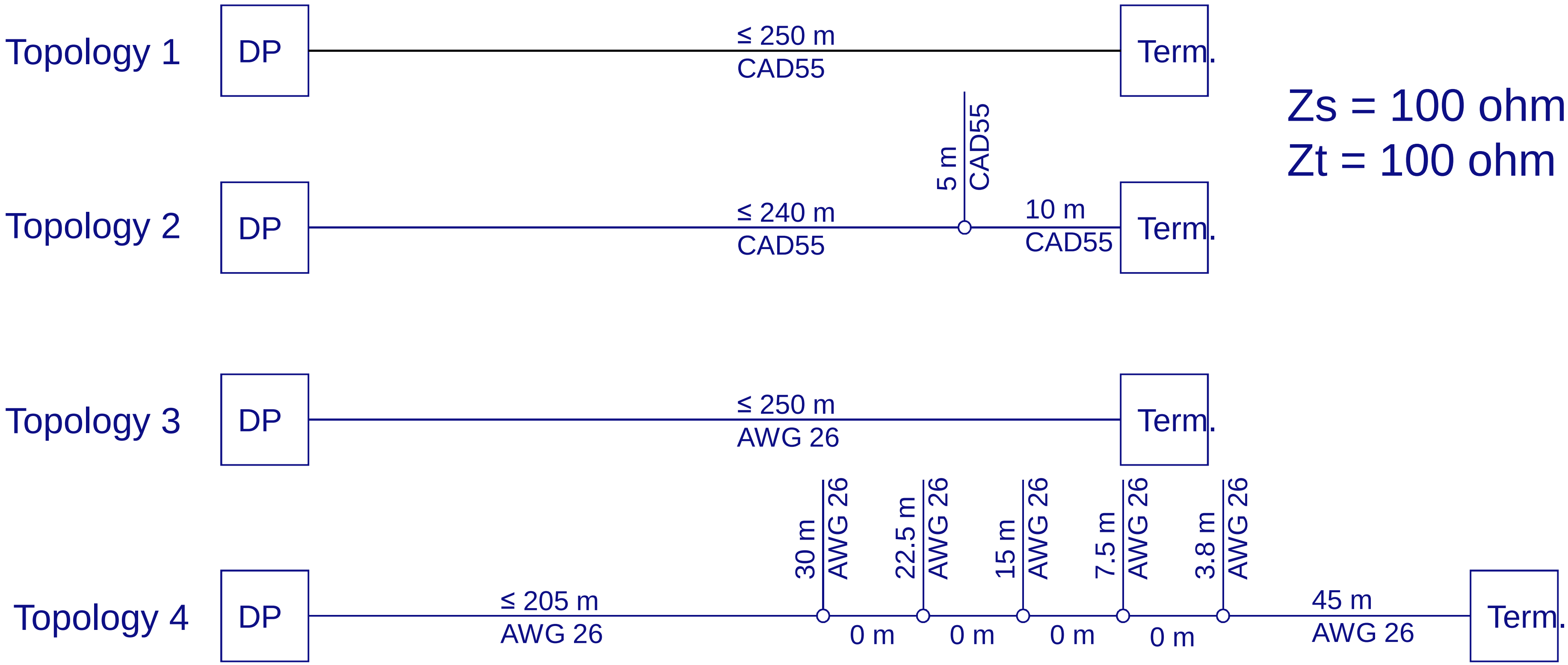
4. Progress on performance studies – approach

SNR comparison: time vs. frequency domain approach



4. Progress on performance studies – initial studies

Initial studies: Selected loop topologies



Zs = 100 ohm

Zt = 100 ohm

References:

- Loop topology: "G.fast: Wiring topologies and reference loops", (ITU 11GS3-100)
- CAD55 model: BT, "G.Fast: Cable Models ", (ITU 11RV-026)
- AWG 26 model: ANSI TP1 (ANSI T1.417-2003)

4. Progress on performance studies – initial studies

Initial studies: Simulation assumptions

- Channel bandwidth: 200 MHz
  - Channel is filtered with 53-tap FIR filter to reduce ringing from windowing effects of IDFT.
- Tone spacing: 48.84 KHz
- Data Bandwidth: 3.5 - 100 MHz
- Number of tones: 2048
  - Tone 0 is DC. Tones below 3.5 MHz are not loaded.
  - FFT size: 8192. FFT oversampling is used for fitting channel bandwidth.
- Signal PSD: -76 dBm/Hz
- AWGN noise: -140 dBm/Hz
- Coding: RS + Trellis
  - RS: N/R = 255/16.
  - Trellis: 0.5 bit/tone overhead.
  - Total coding gain = 5 dB.
- SNR gap: 9.75 dB
- SNR margin: 6 dB
- Bit loading: 1-12 bits
- Cyclic Extension: (Prefix+Suffix) 0.4 µs, 0.8 µs, 1.2 µs, 1.6 µs, 2.0 µs, 2.4 µs
- Loop length (DP to terminal): 50 m, 100 m, 150 m, 200 m

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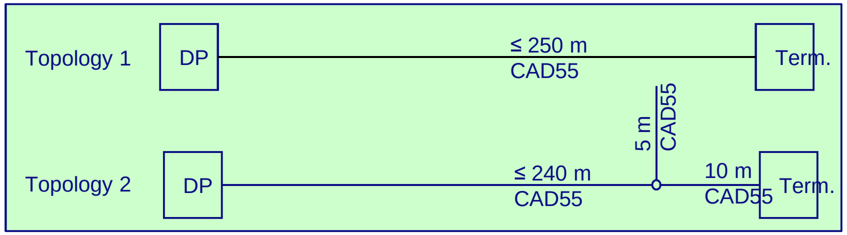
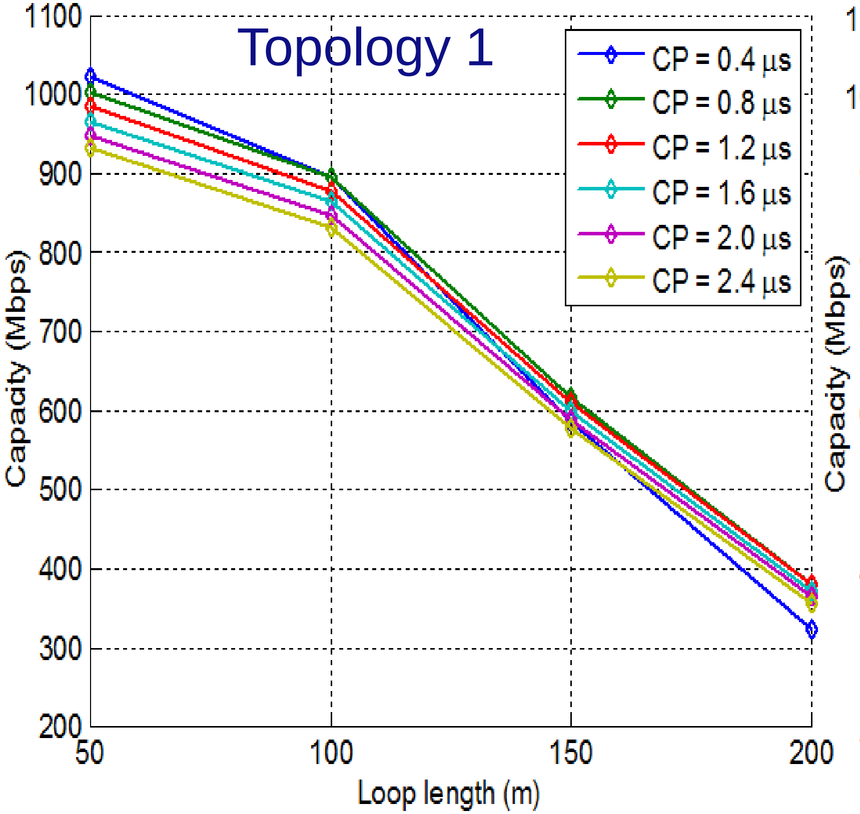
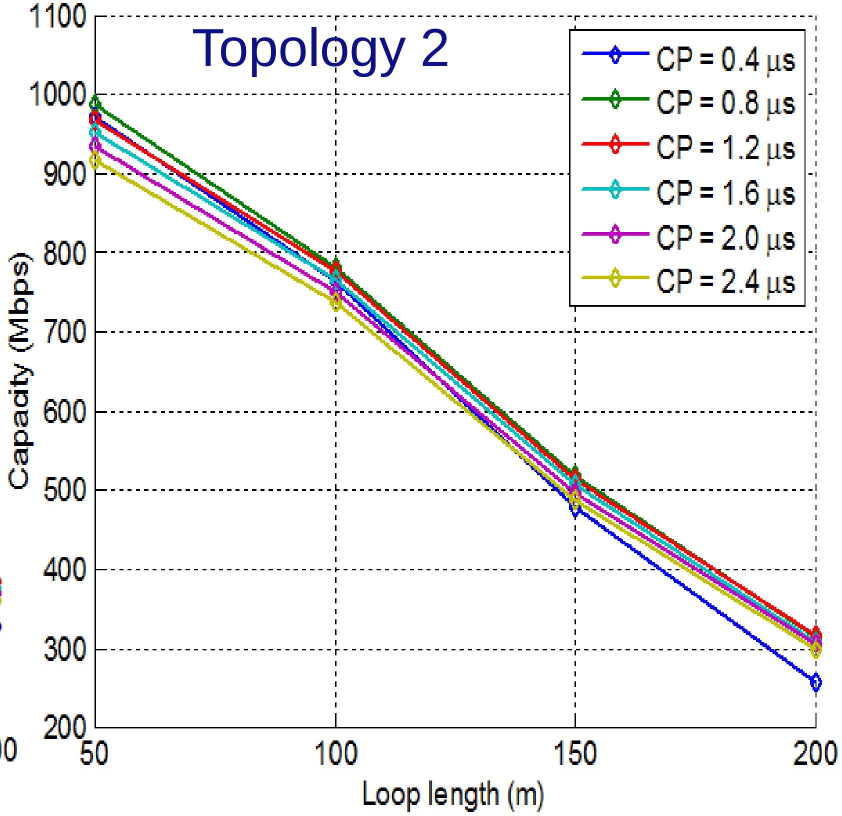
4. Progress on performance studies – initial studies

Initial studies: Bitrate results







- Topology 1&2: Optimal CP = 0.8 µs, CP overhead = 3.76%
- Up to about 100 Mbps decrease due to a 5-meter bridge tap.

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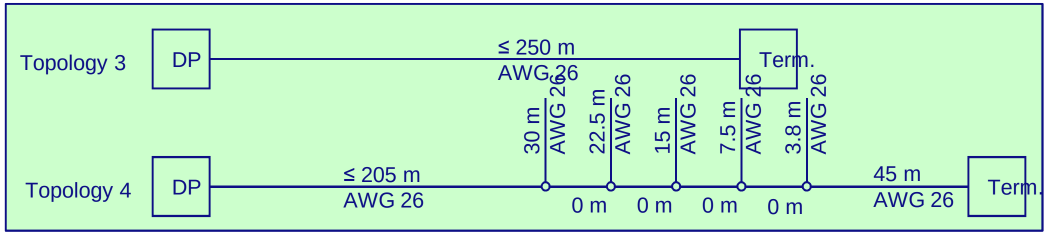
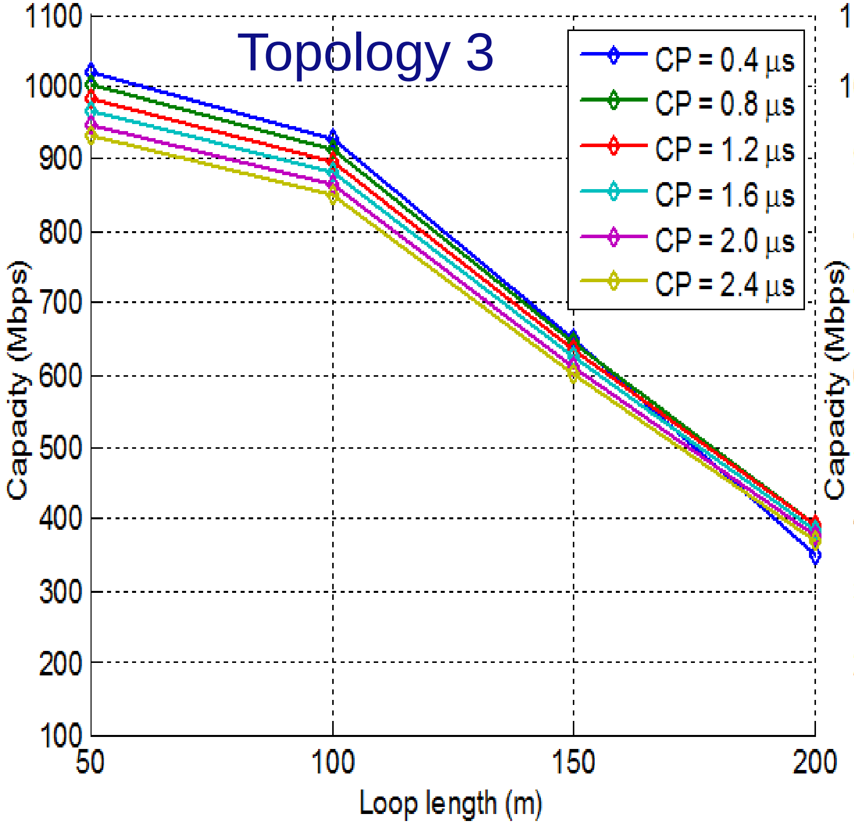
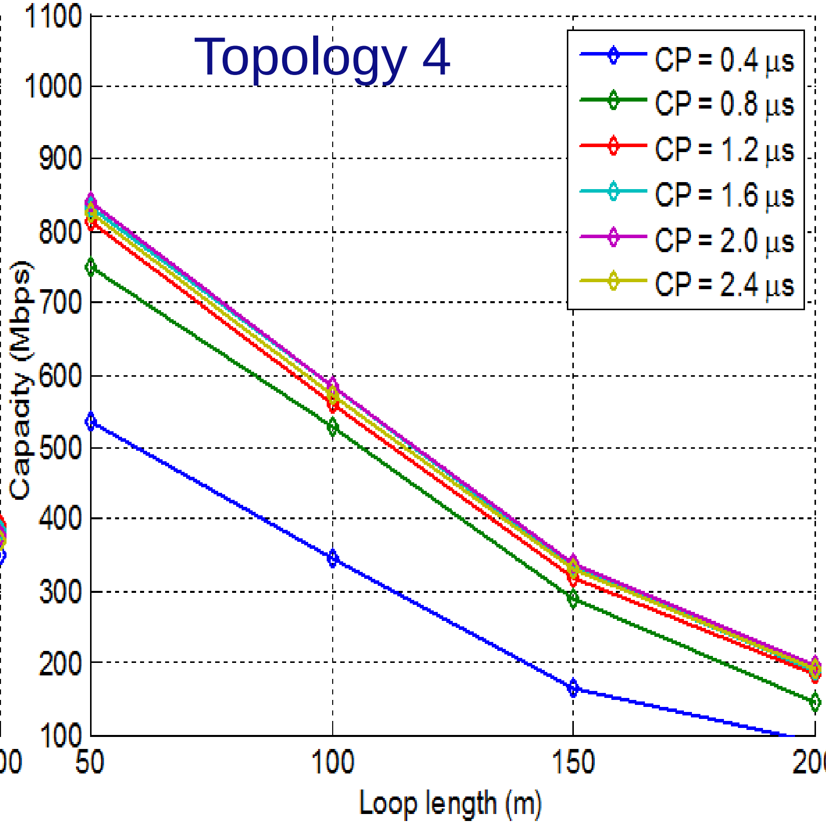
4. Progress on performance studies – initial studies

Initial studies: Bitrate results







- Topology 3: optimal CP = 0.4 or 0.8 µs, CP overhead = 1.88% or 3.76%.
- Topology 4: optimal CP = 2 µs, CP overhead = 8.9%.
- More than 300 Mbps rate loss can be seen due to multiple bridge taps of star topology.

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5. Conclusions

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G.fast standardization is progressing very well

- Concept of Hybrid FttH via G.fast Initiated by 4GBB consortium
- global industry is now active in ITU to develop G.fast
- Aimed ITU deadline (dec 2012: consent on G.fast) is just a first phase

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Cable models have been developed for hundreds of MHz, so use them to describe your cable plant