Measurement and Modeling of Short Copper Cables for Ultra-Wideband Communication

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Outline

- Background and motivation
- Cable models: state of the art
- Wideband measurements: challenge and setup
- Measurement results
- Conclusions and outlook
Background

- Wireline communications: data transmission over telephone wires
- Breakdown\(^1\) of broadband access technologies:

\(^1\)Average over OECD countries, December 2005
Digital Subscriber Line (DSL) achieves high rates by exploiting wide bands of the copper cable channel.

- Current DSL standards foresee the use of bands up to 30MHz.
- Cable properties have been studied by means of measurements, characterization and modeling up to frequencies of 30MHz.
- Very short cables (up to 200m) can be exploited even more.
- Prerequisite for further evaluation: cable models for higher frequencies.
Motivation

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State-of-the-art cable models

- Primary parameters (*RLCG*)
- Secondary parameters (characteristic impedance $Z_0$ and propagation constant $\gamma$)
- $ABCD$ model (based on secondary parameters)
- Multiconductor model
- None of current models deals with frequency bands above 30MHz
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**Reference models**

- **Insertion loss [Chen98]:**

  \[ H_{IL}(f, L) = e^{-L/L_{mile}}k_1 \sqrt{f} + k_2 f - jL/L_{mile}k_3 f \]  
  with \( L_{mile} = 1609.344 \text{m} \), \( k_1 = 4.8 \times 10^{-3} \), \( k_2 = -1.709 \times 10^{-8} \), \( k_3 = 4.907 \times 10^{-5} \)  

- **FEXT [ETSI01]:**

  \[ H_{FEXT}(f, L) = k_{XF} f/ f_0 \sqrt{L/L_0} |H_{IL}(f, L)| \]  
  with \( f_0 = 1 \text{MHz} \), \( L_0 = 1 \text{km} \), \( k_{XF} = 10^{-45/20} \)  

- **NEXT [ETSI01]:**

  \[ H_{NEXT}(f, L) = k_{XN} (f/f_0)^{3/4} \sqrt{1 - |H_{IL}(f, L)|^4} \]  
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\( f \) ... frequency in Hz, \( L \) ... length of the loop in m
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Measurement setup

Insertion loss: \( H_{\text{ins}} = \frac{V'_1}{V_1} \)

NEXT: \( H_{\text{NEXT}} = \frac{(V_3 - V_2)}{V_1} \)

FEXT: \( H_{\text{FEXT}} = \frac{(V'_3 - V'_2)}{V_1} \)
Measurement setup

- Insertion loss: \( H_{\text{ins}} = \frac{V'_1}{V_1} \)
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- FEXT: \( H_{\text{FEXT}} = \frac{(V'_3 - V'_2)}{V_1} \)
Measurement setup

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Measurement setup

- Cables:
  - Cable No. 1: 200m EULEV 10x2x0.4 TEH 240 1402/010 on drum
  - Cable No. 2: 50m EULEV 10x2x0.4 TEH 240 1402/010 wrapped to a ring with a mean diameter of 0.55m

- Gain/phase-analyzer parameters:

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<tr>
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Stability and reproducibility of UWB measurements

50m-cable: mean insertion loss and 95% confidence interval

-20  -15  -10  -5  0

-20  -15  -10  -5  0

1  20  40  60  80  100  120  140  160  180  200

1  20  40  60  80  100  120  140  160  180  200

magnitude (dB)

phase (rad)
Stability and reproducibility of UWB measurements

50m-cable: mean FEXT and 95% confidence interval
Stability and reproducibility of UWB measurements

50m-cable: mean NEXT and 95% confidence interval

![Graph showing NEXT measurements and confidence intervals over frequency range from 1 MHz to 200 MHz. The graph displays magnitude in dB and phase in radians.]
50m-cable, long-term measurements: FEXT coupling function ensemble mean (corresponds to mean over time) and minimum/maximum range (gray-shaded fields)
200m-cable, long-term measurements: FEXT coupling function ensemble mean (corresponds to mean over time) and minimum/maximum range (gray-shaded fields)
Comparison with extrapolated 30MHz-models

50m-cable, insertion loss: ensemble mean and extrapolated Chen-model (1)
Comparison with extrapolated 30MHz-models

50m-cable, FEXT: ensemble mean and extrapolated ETSI-model (2)

![Graph showing comparison between measured data and extrapolated ETSI-model for 50m-cable FEXT. The graph displays magnitude and phase across different frequencies.]
Comparison with extrapolated 30MHz-models

50m-cable, NEXT: ensemble mean and extrapolated ETSI-model (3)
Comparison with extrapolated 30MHz-models

200m-cable, insertion loss: ensemble mean and extrapolated Chen-model (1)

![Graph showing comparison between measured and extrapolated Chen-model](image)

- **Magnitude (dB)**
  - **measured**
  - $|H_{IL}(f, 200)|$

- **Phase (rad)**
  - **measured**
  - $\arg(H_{IL}(f, 200))$
Comparison with extrapolated 30MHz-models

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Conclusion

- Measurement results of insertion loss and crosstalk coupling properties of short copper cables for frequencies beyond 30MHz
- Good match between the measured insertion loss results and the extrapolated 30MHz models
- Extrapolated ETSI models are
  - reasonable worst-case models for crosstalk over 50m
  - a bit too pessimistic for crosstalk over 200m
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Cumulative Shannon rate versus frequency
'Usable' bandwidth versus length
Outlook

Shannon rate versus length

- Shannon rate in Mbit/s
- Loop length in m

Graph showing the relationship between Shannon rate and loop length.
Thank you!