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TITLE **VDSL - A round robin test on cable measurements**

STATUS for information and invitation.

ABSTRACT KPN, Bell Labs / Lucent Technologies, Swiss Telecom, Telia and British Telecom have recently started a round robin test on cable measurements. Our aim is to validate and improve the measurement methods of the participants by sharing and discussing the results. This paper shows the KPN results on this testbox and invites all operators and manufacturers to join this experiment.

1. Objective

The VDSL standardisation process will at first be focussed on the specification of functional requirements. These requirements include the definition of usefull testloops and noise environment. Publishing the characteristics of various European copper cables plays an important role in this process [5]. A lack for measurements and models on European cables may result in too optimistic predictions of the VDSL range, and may lead to functional requirements that do not serve the interests of operators. Therefore, reliable cable measurements are desired to enable the extraction of usefull simulation models.

KPN, Bell Labs / Lucent Technologies, Swiss Telecom, Telia and British Telecom have recently started a round robin test on cable measurements. The aim is to validate and improve the measurement methods of the participants by sharing and discussing the results. We hope that this will result in fruitfull technical discussions and that it will stimulate cooperation on measuring and modelling the copper access networks in various countries. All ETSI participants (operators as well as manufacturers) are invited to join this experiment.
This paper gives a description of the testbox, and presents the measurement results of KPN.

2. The round robin test: characterize the KPN Testbox #1

KPN has constructed a box, containing a long cable. This testbox construction enables reproducable measurements on (differential mode) transfer, reflection and crosstalk characteristics. It is a metalic box of 34*34*32 cm, it weights 15.5 kg, and is filled with nearly 400m indoor cabling. In combination with the 45*45*45 cm wooden transport container, it weights 25kg.
the cable itself is unshielded and has two 0.5mm pairs in a twisted quad. The overall construction is very stable and robust, because all free space in the box has been filled-up with foam. This enables reproducable measurements.

Our invitation is to measure the four-port (differential mode) s-parameters of this testbox, normalized to 135 ohm, and to share them in an electronic format. This reference impedance has recently been adopted in the ETSI technical report on VDSL as design impedance, and is also used for HDSL.

The advantage of specifying *s-parameters* is that they describe directly the signal behavior for xDSL modems in a 135 ohm operational environment. Large errors in intrinsic cable parameters (γ,Z_0), or primairy parameters (R_s,L_s,G_p,C_p) are irrelevant when they cause no more than minor errors[1] in the s-parameters. Another advantage of s-parameters is that they enable a full four-port description of the testbox, without any assumptions[2] on (lateral) unbalance or (reversal) asymmetry of the cable.
When a measurement method is used that measures intrinsic cable parameters rather than s-parameters, this data can easily be transformed into the 135 ohm s-parameter format to enable a realistic comparison.

Different aspects play a role when characterizing cables. On one hand, different measurement methods are commonly in use:

- The well-known impedance/reflection measurements on one cable end, while the other end is left open or in short, are explicitly mentioned as method in the ANSI report on ADSL.
- The two-port (vector) network analyzer method, that measures s-parameters directly, is another method. (We use this method at KPN.)
- The modal decomposition method, that uses an eight-port network analyzer to eliminate the need for balanced transformers, is another method that recently has been introduced by Hewlett-Packard.
- Time domain reflection measurements are applicable too when the measured impulse response is transformed into the frequency domain.
- Maybe other measurement principles do exist.

On the other hand, different strategies are in use to characterize a cable:

- measurements on relatively short cables, in the order of 100 meter [1], 10 meter [2] or even 1 meter [3], to meet certain measurements requirements.
- measurements on relatively long cables in the order of 1 kilometer [4] to average random errors due to spread in cable characteristics per unit length.

Each measurement method and strategy has its advantages and disadvantages. Comparing reproducable measurements on the KPN testbox enable the participants to validate their favorite method. Discussions on differences between measured results are valuable to improve methods.

At this moment, three participants have characterized the box (KPN, Lucent Techn., Swiss Telecom), and the box is sent to number four (Telia). KPN has characterized it from 1kHz to 30MHz in 801 logaritmic steps, and Lucent Technologies from 100kHz to 40MHz in 400 linear steps. Above 1MHz there was good agreement between the two datasets, and this exercize helped to eliminate bugs in conversion software.
Please contact me if you want to join us; on request I will email the measured data (in a binary Matlab form as well as in Ascii). Each lab may keep the testbox for about two weeks, and shipment to the next lab will cost approximately one week. If you feel the need to measure and share the common mode behavior too, please do so. When possible, make a model of this cable, and publish the results.

3. Measurements

Figure 1 shows the magnitude of the measured four-port s-parameters on the 400 meter cable in the testbox. The numbering of the four ports follows the conventions as described in [5].
These four-port (differential mode) s-parameters, normalized to R_N=135Ω, were combined from four independent two-port s-parameter measurements, while all unused ports were terminated by resistors having R_N as value.
All linear systematic errors of the network analyzer and balanced transformers have been eliminated from the measurements, by using a dedicated calibration method.

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[1] An example is a 20% error below 10kHz in the characteristic cable impedance Z_0. From the intrinsic parameter point of view, this is a 'large' error, but it will hardly affect the s-parameters in that frequency range. Errors in the series resistance R_s should always be analyzed with respect to the other primary cable parameters; especially above 1MHz.

[2] The use of intrinsic parameters γ and Z_0 assume that the crosstalk between the (two) wire-pairs is zero, and tends to assume that the cable is (reversal) symmetric.

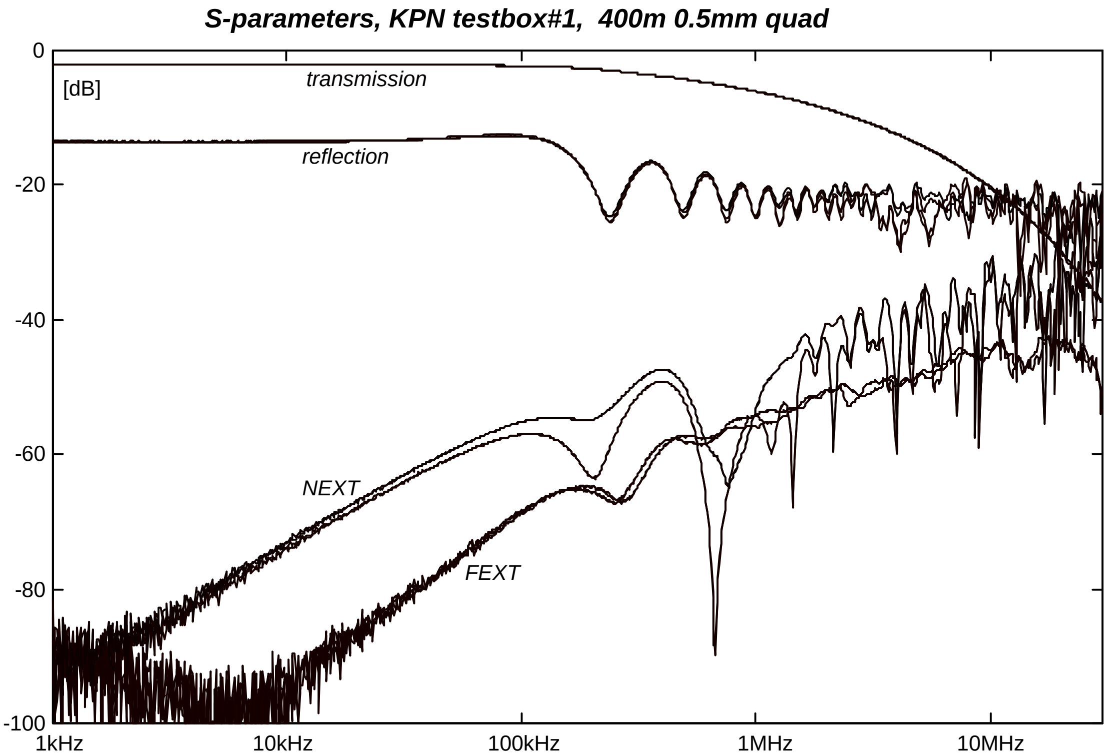

Figure 1 *Measured four-port s-parameters on the KPN Testbox #1, normalized to* R_N*= 135W.*

Description of the measurement setup

The measurement setup is schematically shown in figure 2. NWA refers to a two-port Network Analyzer (HP8751a) and a 50Ω multi-port testset (HP4380, used in two-port mode). Each port has been extended with a 50Ω coaxial cable (40cm), a balanced transformer (North Hills 0415LB) that transforms 50Ω into 150Ω, and a shielded twisted pair measurement cable (1.70m). This shield is connected with transformer cabinet and (via the coaxial cable) with the analyzer. The center tap of the transformer is not grounded. Connecting the shield of the twisted pair connection cable to the cabinet of the testbox did not result in noticable differences.

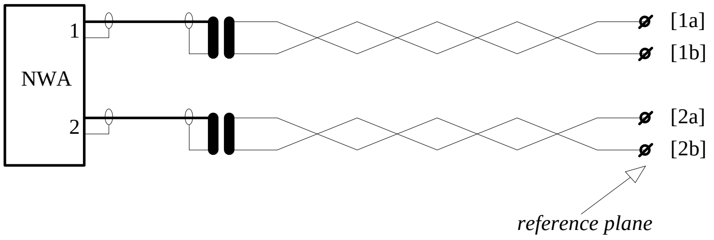

Figure 2 *Measurement setup. Transformers and connection cables are part of the setup, and their influence have been eliminated from the cable measurements by calibrating the setup at the reference planes.*

The reference plane is the ‘interface’ beween measurement setup and cable under test. Seen from the measurement side, it was positioned at the end of the shielded twisted pair cables. Seen from the testbox side, it was positioned directly at the input of the cable; this is where the wires are soldered on the (green) connector blocks of the testbox.

Description of the calibration method

All linear systematic errors of analyzer and transformers (up to the reference plane) were eliminated from the measurements, by using a dedicated calibration method. As a result, the connection cables and transformers are ***no*** part of the cable under test. We estimate that the callibration has positioned the reference plane at a location that is accurately known within ±2mm.
Callibration was carried out by means of a symmetric (floating) callibration[3] set, which is nothing more than (1) a small sized resistor R_N as *load*, (2) a wire as *short*, (3) a 'nothing' as *open* and (4) a connection as *thru*. This approach results in accurate s-parameters, normalized to R_N, without any change of the build-in calibration software of the network analyzer.
We have chosen $R_N=150\ \Omega$, so we had to do a mathematical transformation afterward from 150 Ω s-parameters into 135 Ω s-parameters. If a value of $R_N=135\ \Omega$ was chosen, then the right s-parameters could be obtained directly from the network analyzer.
Since this approach yields very accurate results, it is noticed that saturation (in the transformer) could be the remaining limitation. For that reason the source power of our network analyzer was a few dB reduced at 'transmission' two-port measurements.

4. Two-port modelling

Two-port modelling of the individual wire pairs, while ignoring the crosstalk between them, has been performed on the basis of the KPN#1 model [4,5]. The line constants are summarized in table 1. Line "KPN_d1x" refers to the two-port between port 1 and 2 (see labels on the testbox), and line "KPN_d1y" refers to port 3 and 4. These model have been extracted to fit the s-parameters.

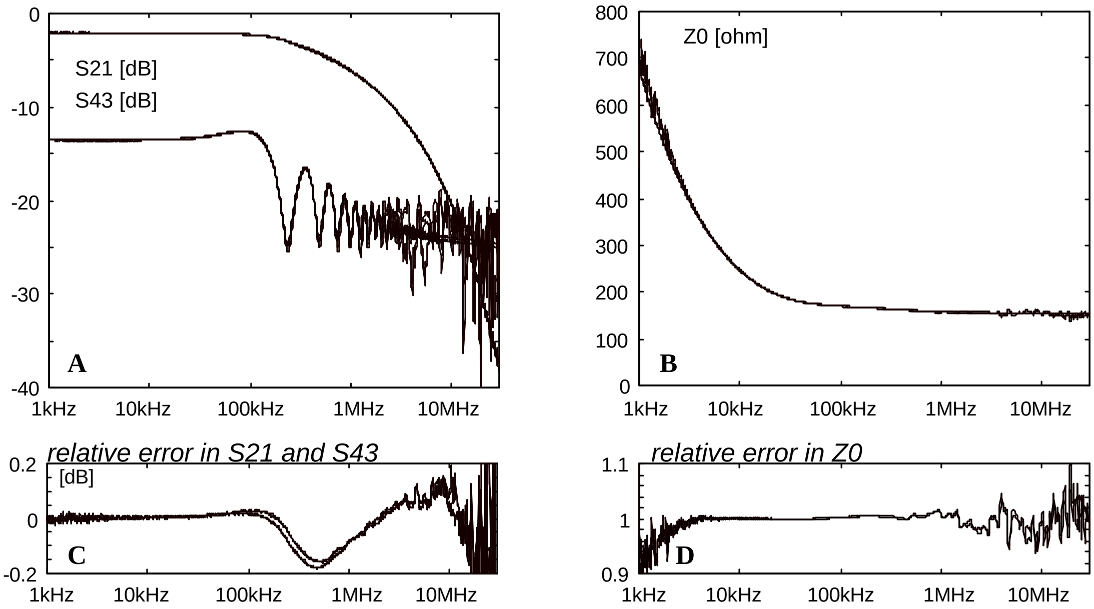

Figure 3 *Measured transmission and characteristic impedance of the two wire pairs of 400m. The measured curves in plots A and B are overlayed with the modeled curves. The difference between measurents and models are shown in plot C and D.*

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[3] Connect a resistor R_N between terminal "1a" and "1b", and a second resistor R_N between terminal "2a" and "2b", when a "full 2-port" calibration procedure requires *loads*. Connect terminal "1a" with "1b", and "2a" with "2b" when the procedure requires a *short*. Leave all terminals unconnected when an *open* is required. Connect terminal "1a" with "2a", and "1b" with "2b" using the shortest possible wires when *thru's* are required. The ultimate precision will be achieved when the callibration resistors are mounted in indentical connector blocks that are used for connecting the cable under test with the measurement setup. Verify that the cal-kit constants (e.g. offset) in the analyzer match with the layout of the *short* , *load*, *open*, and *thru*. This method can be made reliable up to hundreds of MHz, because it is mainly limited by the construction layout rather than the frequency response of the resistor itself.

	$Z_{0¥}$	c/c_0	R_{ss00}	2p·tan(f)	K_f	K_l	K_n	K_c	N	f_{c0}	M
KPN_d1x	149.673	0.70664	0.178969	0.0312794	0.82	1.1	1	1.02764	1	100000	1
KPN_d1y	150.593	0.70265	0.180989	0.0338506	0.78	1.1	1	1.02999	1	167076	1

Table 1: *Line constants for the wire pairs in the testbox 1 cable, using the KPN#1 model [4,5] KPN_d1x refers to the two-port between port 1 and 2; KPN_d1y refers to port 3 and 4.*

Figure 3A compares this model with the transmission (s_{21}, s_{43}) and figure 3B the extracted characteristic impedances of the two wirepairs. The relative errors between modelled and measured data are shown in figure 3C and 3D.

Figure 4 shows the extracted primairy parameters $\{R_s,L_s,G_p,C_p\}$ of the 400m cable, based on the measurements as well as the model. Twisted pair cables are a little bit inhomogeneous in nature, which causes small differences between 'identical' sections. Especially when cables are long, this effect gives parameters such as R_s and G_p a very random appearance as the frequency increases. This is because very small differences in s-parameters of long cables are 'exploded' to large differences in parameters such as R_s and G_p.
As a result, the individual value of one primary parameter is not particularly meaningful when it is not observed in connection with the other primairy parameters. Therefore, the modelled parameters are not *individual* fits to these primary parameters, but a *combined* fit to the two-port parameters.

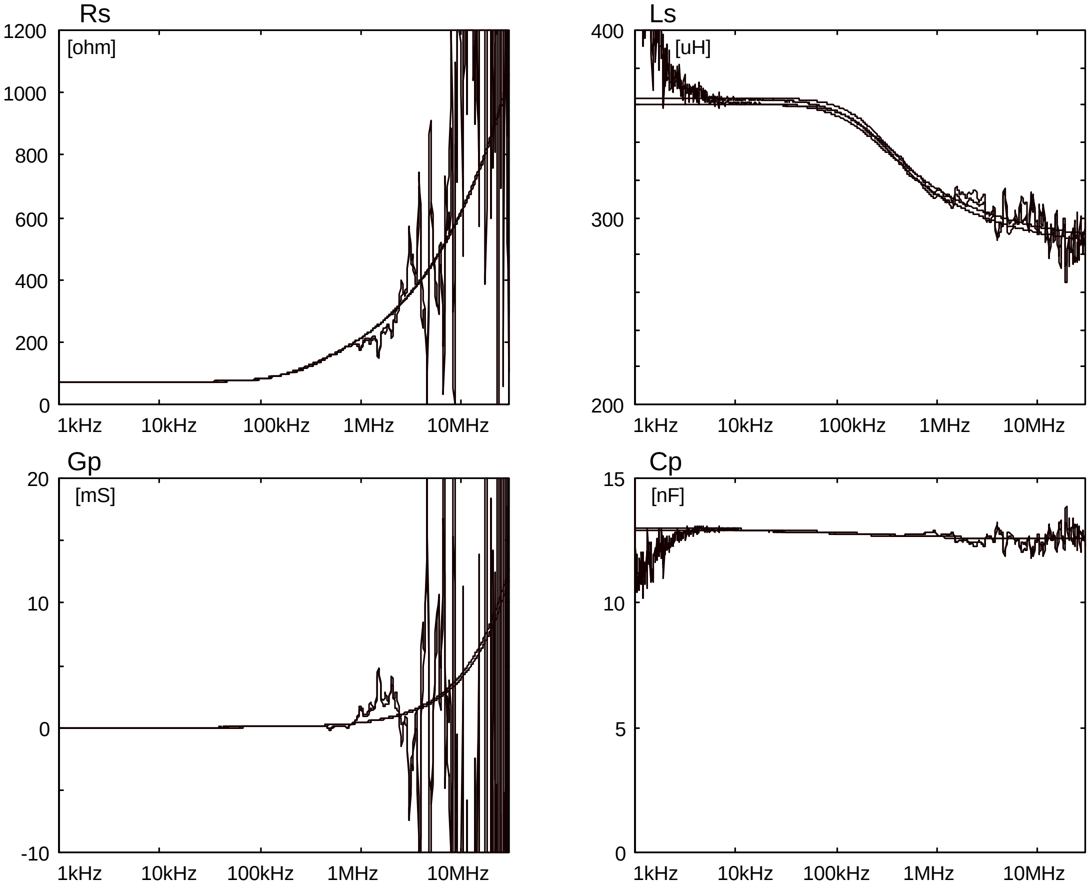

Figure 4 *Extracted primairy cable parameters of the 400m test cable, overlayed by curves generated from the cable model of table 1. The plots show that R_s and G_p become very random in nature as the frequency increases. As a result, their actual value, extracted from real measurements, is not particularly meaningful.*

5. Crosstalk modelling

Crosstalk can be approximated by straight lines on a log-log plot. Figure 5 illustrates this for NEXT (s_{xn}), and for Equal Level FEXT which is the average FEXT (s_{xf}) scaled by the average transmission (s_T). See [5] for a definition of these quantities. The associated line-equations can be expressed in various ways, for instance as summarized in table 2. The advantage of this representation is that the constants C_{xn} and C_{xf} can be interpreted as a ‘differential crosstalk capacitance’ between the two wire pairs. The sign of C_{xf} is dependend on the (arbitrary) choice of the ‘+’ wire and the ‘–‘ wire of a pair.

NEXT:	$\lvert s_{xn} \rvert \approx (½·\omega·R_N·C_{xn})^{M_{xn}}$	$R_N = 135\Omega$
FEXT:	$s_{xf} \approx (½·j\omega·R_N·C_{xf} ·\sqrt{x}) · s_T$	$C_{xn} = 2pF$
EL-FEXT:	$s_{xf} / s_T \approx (½·j\omega·R_N·C_{xf} ·\sqrt{x})$	$C_{xf} = –0.5pF/\sqrt{m}$
		$M_{xn} = 0.75.$

Table 2 *Constant and equations for a simple modeling of the crosstalk shown in figure 5. Note that it has not been verified if scaling of FEXT is proportional with Öx or not.*

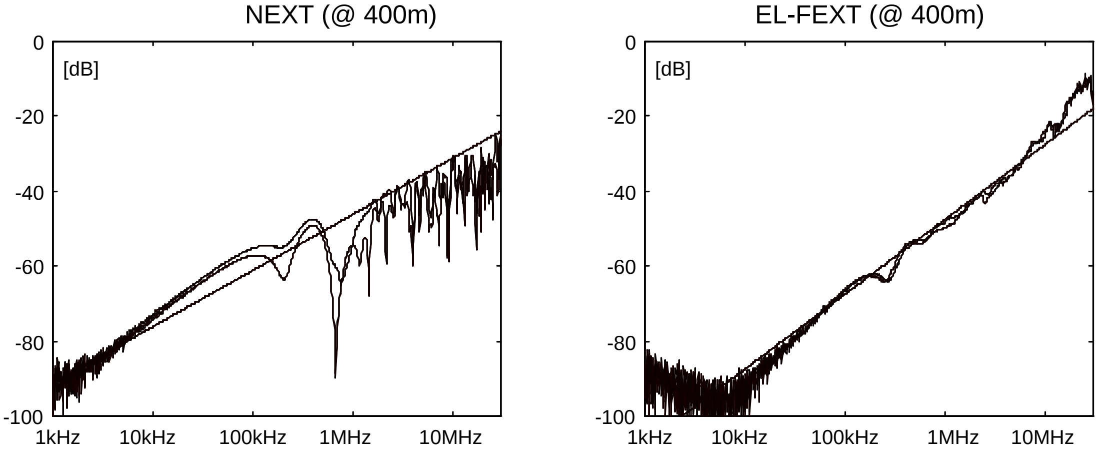

Figure 5 *Plots of near end crosstalk, and equal-level far end crosstalk. The curves are overlayed with straight lines, following the equations of table 2.*

6. Bibliography

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