ETSI STC TM6 **TD 09**
Sophia-Antipolis, France **033t09**
September 29 – October 3, 2003

Project:	SpM
Title:	A model for an Austrian PE04 cable
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Abstract:	This paper presents a parametric cable model for an Austrian 0.4 mm cable.
Distribution:	ETSI STC TM6 working group members
Status:	For information

Introduction

This paper presents the measurements and analysis from measurements conducted in April 2003 on cables used in Telekom Austria's testlab. The object under test was a 50 pair copper cable of the type F-02YHJA2Y (50x2x0.4). The length of the cable was 333m.

This paper has the following organization: first we give some information on the cable we measured and the measurement equipment used for these measurements. Then, we describe the cable model we have used (MAR) and the model parameters resulting from our measurements. We end this paper with an assessment on how well this model matches the measurements and how it relates to other PE04 models.

1 Cable Structure

The cable is a 50 pair copper cable of the type F-02YHJA2Y (50x2x0.4). The length of the cable was 333m. The internal layout of this cable is shown in Fig.1 below. It is a layered cable with star-quads (two pairs twisted together) as the basic building block.

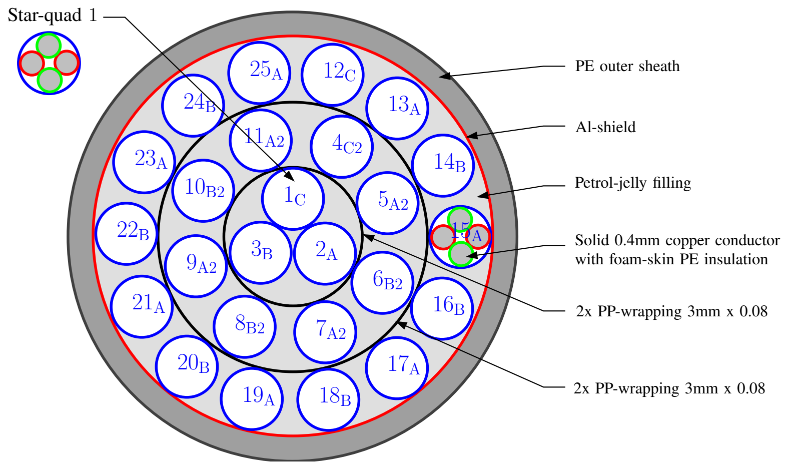


Figure 1: Cable structure

The following tables shows the twist lengths of each pair (quad) in [mm]:

First (core) layer		
Star quad	Twisting [mm]	Code
1	125	C
2	71	A
3	100	B

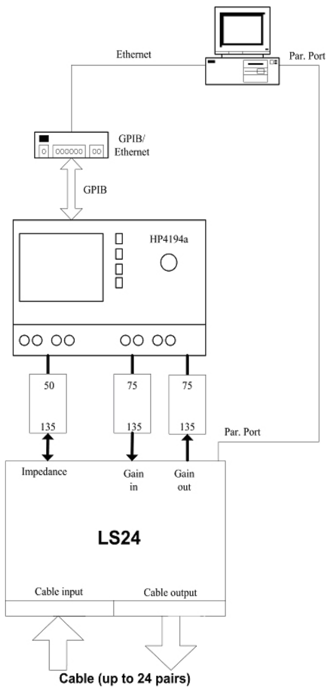
Second layer		
Star quad	Twisting [mm]	Code
4	90	C2
5	112	A2
6	140	B2
7	112	A2
8	140	B2
9	112	A2
10	140	B2
11	112	A2

Third layer		
Star quad	Twisting [mm]	Code
12	125	C
13	71	A
14	100	B
15	71	A
16	100	B
17	71	A
18	100	B
19	71	A
20	100	B
21	71	A
22	100	B
23	71	A
24	100	B
25	71	A

Figure 2: Pair twisting lengths

We see that there are always three different twisting lengths in each layer. The first quad of each layer has a special twisting length 125, 90, and 125 mm for respectively layer 1, 2, and 3. The twist lengths from the first layer (71 and 100 mm) are then reused in the third layer. There is no reuse of twist lengths between the second and third layer.

All our measurement was performed using our automated impedance and gain measurement equipment. Using this equipment the complex short and open impedance (Z_{SC}, Z_{OC}) and the FEXT and NEXT coupling function of up to 24 pairs can be measured fully automated. Fig. 3 shows the measurement setup.



Measurement Equipment:

gain/phase analyzer Hewlett Packard, HP4194A, 10 Hz – 100 MHz, 0 – 100 dB ± 0.5 dB, $\pm 2.5°$
longitudinal measurement balun North Hills, 0409BF, 10 kHz – 30 MHz, 135 Ω balanced, 50 Ω unbalanced
wideband balun transformer North Hills, 0312BB, 10 kH – 60 MHz, 135 Ω balanced, 50 Ω unbalanced
wideband balun transformer North Hills, 1315BB, 10 kHz – 60 MHz, 135 Ω balanced, 50 Ω unbalanced
loop selector ftw. LS24

Figure 3: Measurement setup with LS24

To cover most of the interesting FEXT and NEXT functions (not reported here) 6 separate measurements sessions was used. For the current analysis we have used pair 1-24 from the first measurement seesion, pair 25-37 from the second, and pair 38-50 from the third measurement session.

2 Modeling

Cable Modeling

The MAR model was introduced by Mossun in [1] and was further analyzed in [2]. Being the only model that by design adheres to the Hilbert relation between real and imaginary parts of the parameters it guarantees to give a reasonable time-domain behavior. Therefore we have selected to use this model when modelling our cable measurements.

The series impedance and shunt-admittance for the MAR1 model is given by:

$$Z_s(f) = j2\pi f L_\infty + R_o \left(\frac{1}{4} + \frac{3}{4}\sqrt{1 + \frac{as(f)(s(f)+b)}{(s(f)+c)}} \right), \quad (1)$$

$$Y_p(f) = 2\pi f C_f (j + \tan(\delta)) = j2\pi f C_{1MHz} \cdot (jf/10^6)^{-\frac{2\delta}{\pi}}, \quad (2)$$

where

$$s(f) = \frac{\mu_0 jf}{0.75^2 R_0} \approx \frac{jf}{447.6 R_0},$$

for $\mu_0 = 4\pi 10^{-4}$ [H/km] and using the relation $C_f = C_{1MHz}(f/10^6)^{\frac{-2\delta}{\pi}} \cdot \cos\delta$ (assuming constant δ).

The seven MAR1 model parameters are then:

R_0	the DC resistance per km [Ω/km]
L_∞	the high frequency inductance per km [H/km]
a	a proximity factor (by which the effective skin effect frequency is increased)
b and c	skin effect shape coefficients
δ	the shunt capacity loss angle (constant)
C_{1MHz}	the capacitance per km at 1 MHz [F/km]

Table 1: MAR cable model parameters

The secondary cable parameters:

$$\begin{array}{ll} Z_0 & \text{Characteristic impedance } [\Omega] \\ \gamma & \text{Propagation constant } [\text{km}^{-1}] \end{array}$$

can be calculated from the MAR1 model as:

$$\begin{aligned} Z_0 &= \sqrt{Z_s/Y_p}\,, \\ \gamma &= \sqrt{Z_s \cdot Y_p}\,. \end{aligned}$$

The primary cable parameters (RLCG), if needed, can then be found from the following relations:

$$\begin{aligned} R &= \Re\{\gamma Z_0\}\,, \\ L &= \tfrac{1}{\omega}\Im\{\gamma Z_0\}\,, \\ C &= \tfrac{1}{\omega}\Im\left\{\tfrac{\gamma}{Z_0}\right\}, \\ G &= \Re\left\{\tfrac{\gamma}{Z_0}\right\}. \end{aligned}$$

3 The Austrian PE04 Model

By fitting the data from 50 cable measurements to a 7 parameter MAR model (MAR1) we get the following cable model:

Parameter	Value
R_0	286.321
L_∞	0.000644875
Proximity factor a	1.33944
Proximity factor b	$5.63424 \cdot 10^{-23}$
Proximity factor c	0.145707
C_{1MHz}	$3.31668 \cdot 10^{-08}$
δ	0.00668243

Table 2: MAR cable model parameters for the PE 0.4 mm cable, AT_40x

The attenuations per kilometer at 300 kHz is then:

Diameter	0.4 mm
Attenuation	10.956 dB/km

Table 3: Cable attenuation for for the PE 0.4 mm cable, AT_40x

If we then round these numbers we get:

Parameter	Value
R_0	286
L_∞	0.000645
Proximity factor a	1.34
Proximity factor b	0
Proximity factor c	0.146
C_{1MHz}	$3.32 \cdot 10^{-08}$
δ	0.00668

Table 4: Rounded MAR cable model parameters for the PE 0.4 mm cable, AT_40

The attenuations per kilometer at 300 kHz is then:

Diameter	0.4 mm
Attenuation	10.953 dB/km

Table 5: Cable attenuation for for the PE 0.4 mm cable, AT_40

The maximum difference in attenuation between the exact and the rounded model is below 0.01 dB.

4 Analysis

The graphs below show how well the cable model matches the cable measurements. Both the characteristic impedance Z_0 and the propagation constant γ has been divided into their amplitude and phase components (thus, $\gamma = \alpha e^{j\beta}$). We note that α directly corresponds to the attenuation of the cable.

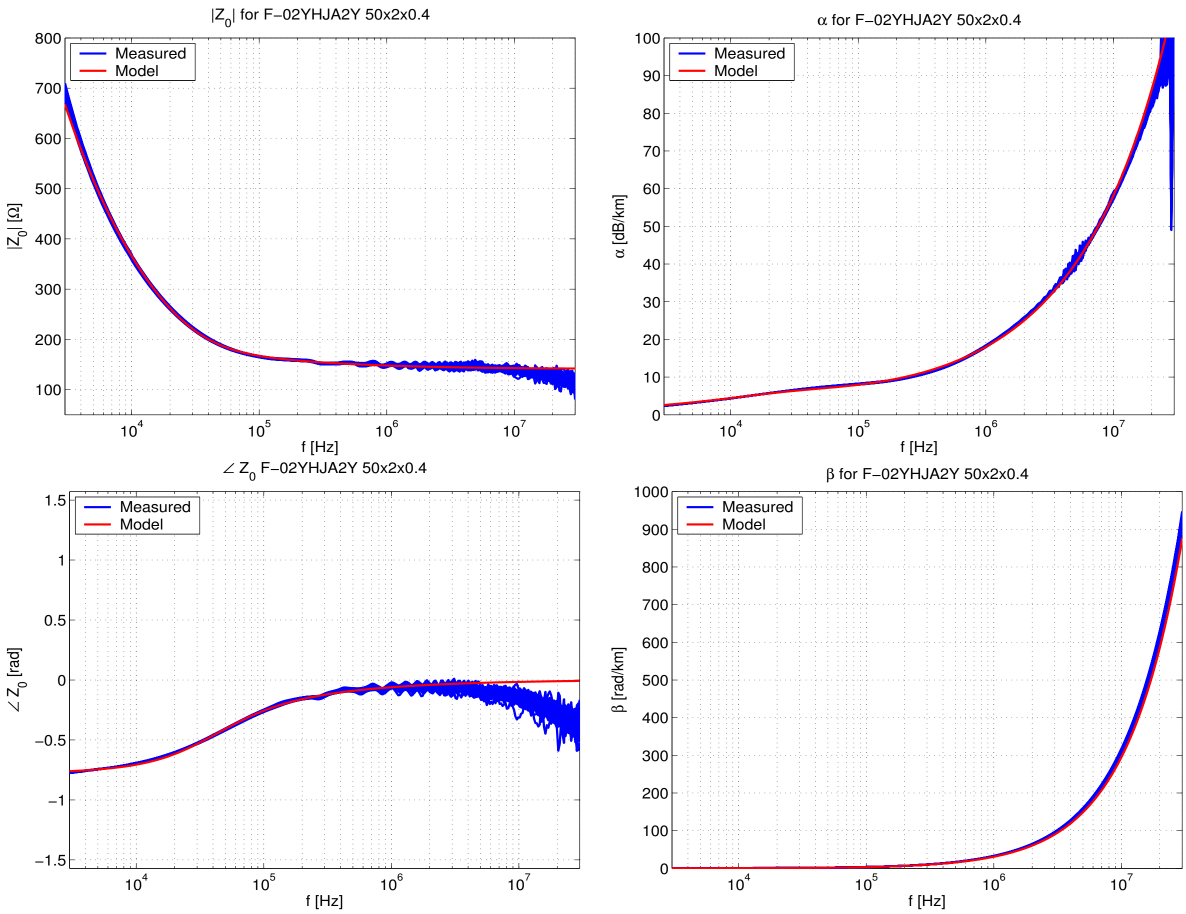


Figure 4: Showing the $|Z_0|$, $\angle Z_0$, α, β measurements for the TA cable together with the established MAR model (AT_40x).

The difference between our model and the measured data is shown in the Figure below:

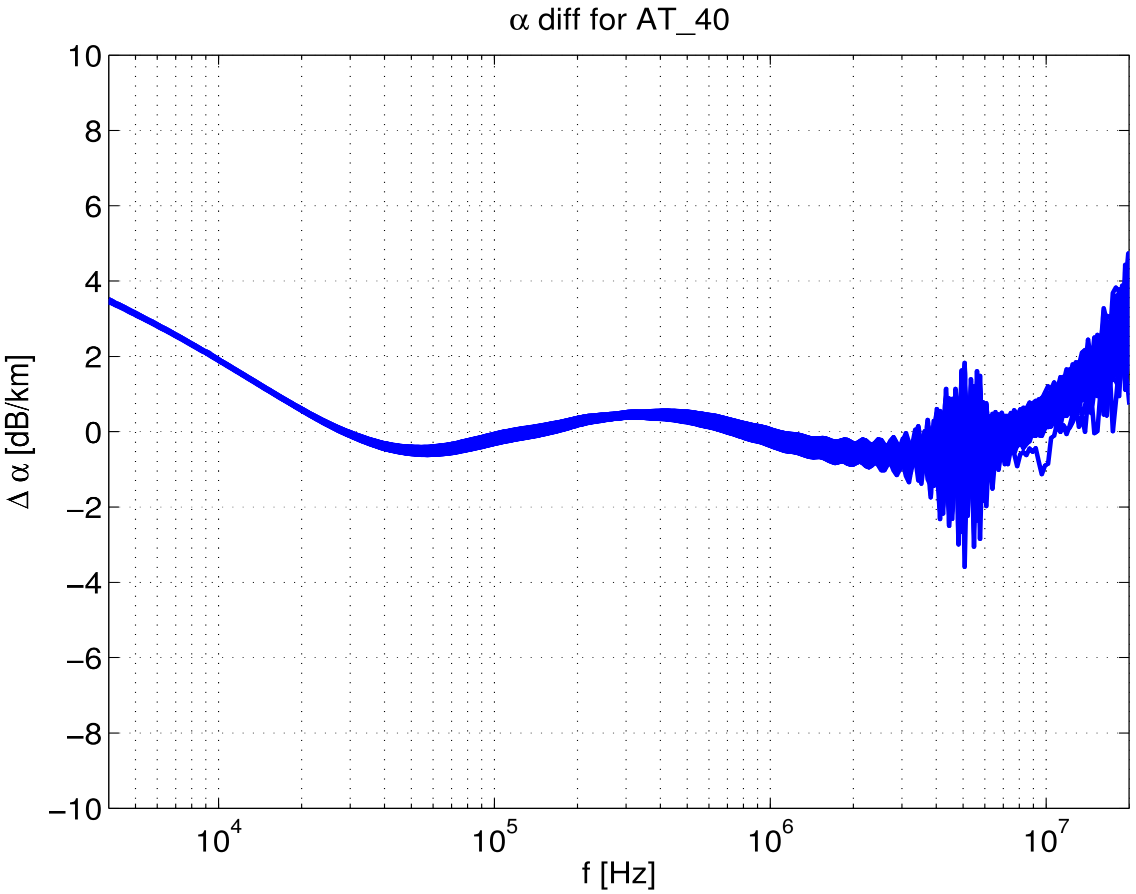


Figure 5: Comparing the difference beween the insertion loss of the AT_40 model (i.e., rounded) and the measured insertion loss

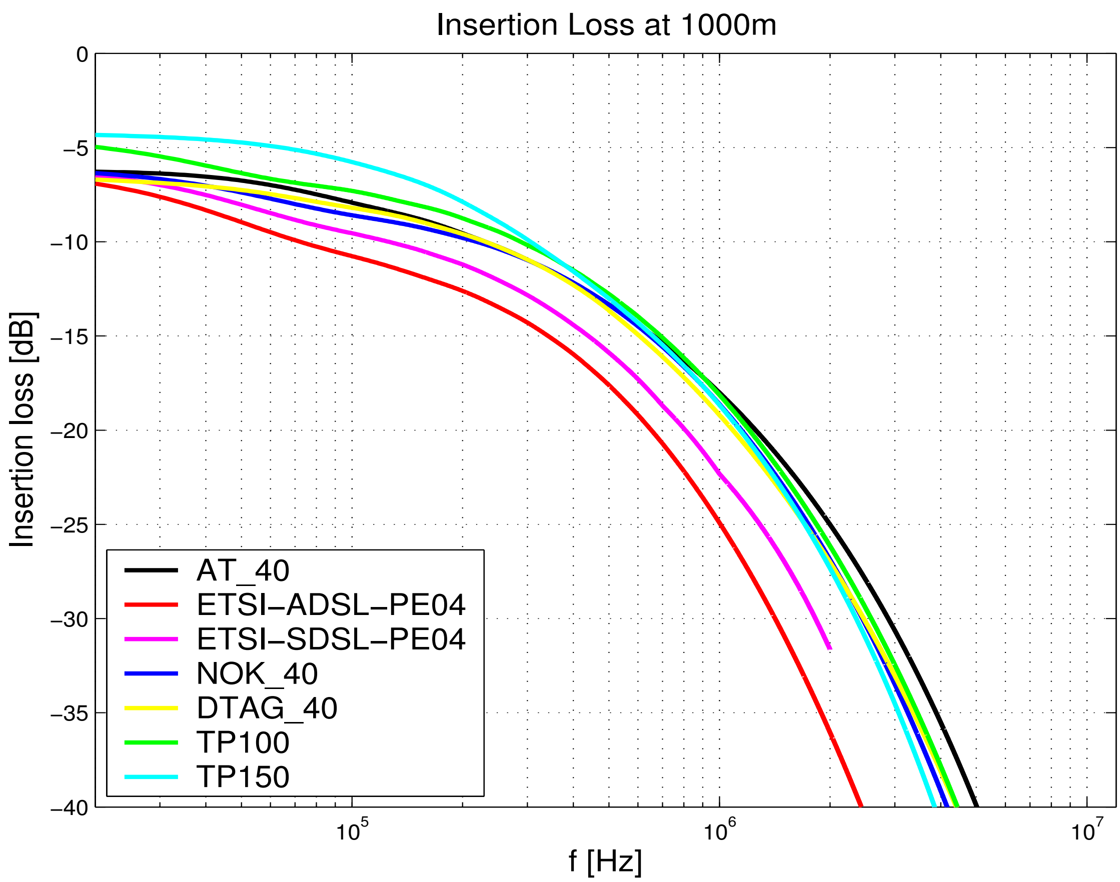


Figure 6: Comparing insertion loss for various 0.4mm cable models

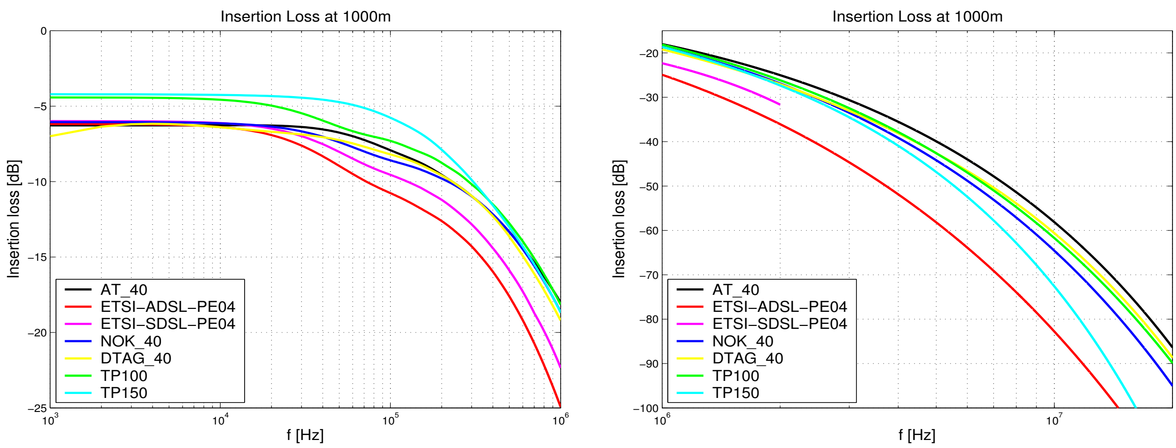


Figure 7: Zooming in on the insertion loss curves for various 0.4mm cable models

5 Conclusions

Using our measurement equipment LS24 we have measured all pairs on a 50-pair cable. A parametric MAR1 model AT_40 was matched to this data and the resulting parameters are shown in Table 6 below. In addition, this paper compares this model with our measured data as well as other 0.4 mm cable models.

Parameter	Value
R_0	286
L_∞	0.000645
Proximity factor a	1.34
Proximity factor b	0
Proximity factor c	0.146
C_{1MHz}	$3.32 \cdot 10^{-08}$
δ	0.00668

Table 6: The suggested MAR cable model parameters for the PE 0.4 mm cable, AT_40

References

[1] J. Musson, “Maximum likelihood estimation of the primary parameters of twisted pair cables,” *ETSI/STC TM6 981t08a0*, Jan. 1998.

[2] J. Musson L. Heylen, “Cable models predict phyically impossible behaviour in time domain,” *ETSI/STC TM6 994t53a0*, Nov. 1999.

6 Acknowledgments

This work was partially financed by the Austrian K-plus program.