

# INNOVATION OF METHODS FOR MEASUREMENT AND MODELLING OF TWISTED PAIR PARAMETERS

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**Abstract.** The goal of this paper is to optimize a measurement methodology for the most accurate broadband modelling of characteristic impedance and other parameters for twisted pairs. Measured values and their comparison is presented in this article. Automated measurement facility was implemented at the Department of telecommunication of Faculty of electrical engineering of Czech technical university in Prague. Measurement facility contains RF switches allowing measurements up to 300 MHz or 1 GHz. Measured twisted pair's parameters can be obtained by measurement but for purposes of fundamental characteristics modelling is useful to define functions that model the properties of the twisted pair. Its primary and secondary parameters depend mostly on the frequency. For twisted pair deployment, we are interested in a frequency band range from 0,1 to 100 MHz.

## Keywords

*Twisted pair, British telecom model, measurement method.*

## 1. Introduction

The secondary parameters of a twisted pair may be modeled directly, as implements the Deutsche Telekom, or it can model primary parameters of a twisted pair. This way of modelling has chosen British Telecom (BT). Primary parameters, which are frequency dependent, can be designed for a limited frequency range and limited accuracy. There are several empirical models based on the frequency band [2]. 9-parameters BT model [1] can be used as model of primary parameters up to 100 MHz. 9-parameters BT model is given by following equations:

$$R(f) = \sqrt[4]{r_0^2 + a \cdot f^2}, \quad (1)$$

where  $r_0$  is the DC resistance,  $a$  is a parameter which characterizes the slope of the frequency response.

$$L(f) = \frac{l_0 + l_\infty \cdot \left(\frac{f}{f_m}\right)^b}{1 + \left(\frac{f}{f_m}\right)^b}, \quad (2)$$

where  $l_0$  is inductance at zero frequency limiting,  $l_\infty$  is inductance at the highest frequencies of the band,  $f_m$  and  $b$  are parameters that characterize the threshold between low and high frequencies.

$$C(f) = c_\infty + c_0 \cdot f^{-c_g}, \quad (3)$$

where  $c_0$  is capacity at the highest frequencies in the band,  $c_\infty$  is capacity at zero frequency limiting and  $c_g$  is parameter characterizing the shape of frequency-dependent waveform.

$$G(f) = g_0 \cdot f^{g_e}, \quad (4)$$

where  $g_0$  is conduction at low frequency and  $g_e$  is coefficient increasing towards to high frequency.

A certain problem at high frequencies the impedance inhomogeneity of transmission line that cause partial reflections and then ripple on attenuation frequency dependence of twisted pair [5].

## 2. Measurement Methods

The twisted pair was chosen in order of measurement methods comparison. Method with internal and external bridge was chosen.

### 2.1. Internal Bridge Method

The internal bridge method uses North Hill 032BF balun

(transformer for conversion from balance to unbalance port and vice versa) which acts as an internal measuring bridge between unbalance port with termination 50 Ω and balance port with termination 100 Ω. The balun works with frequencies from 100 kHz to 100 MHz. Block diagram is depicted in Fig. 1.

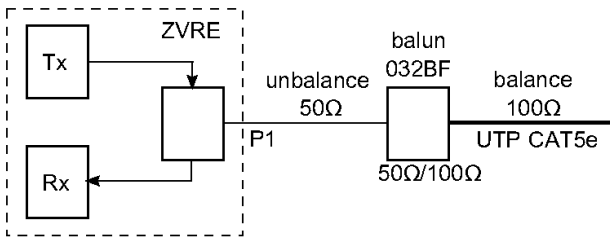


Fig. 1: Block diagram for measurement method with internal bridge North Hill 032BF.

The internal method is based on obtaining of return loss (RL, S11 parameter) at the input of Vector Network Analyzer ZVRE. Measured twisted pair is terminated by short, open and matched impedance. The input impedance of the twisted pair is given by equations:

$$Z_c(f) = Z_0 \cdot \frac{1 + \Gamma}{1 - \Gamma}, \tag{5}$$

where  $Z_{ref}$  is reference 100 Ω impedance of the twisted pair and  $\Gamma$  is reflection coefficient of the twisted pair terminated by short, open or matched impedance.

The characteristic impedance of the twisted pair  $Z_0$  is given by equations:

$$Z_0(f) = \sqrt{Z_{x,open}(f) \cdot Z_{x,short}(f)}, \tag{6}$$

where  $Z_{x,open}$  and  $Z_{x,short}$  are measured impedances obtained from (5), where open and short termination was considered.

### 2.2. External Bridge Method

The external bridge method uses North Hill 0319NA which acts as an external measuring bridge between unbalance ports with termination 50 Ω and balance port with termination 100 Ω for twisted pair. Measuring bridge works with frequencies from 100 kHz to 100 MHz. Block diagram is depicted in Fig. 2.

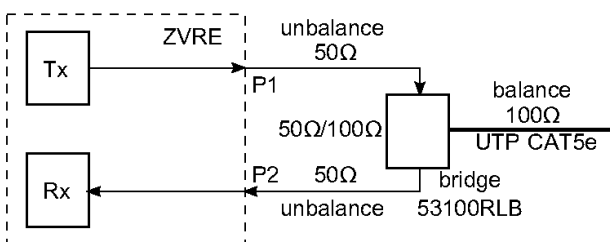


Fig. 2: Block diagram with external measuring bridge North Hill 53100RLB.

The external bridge method is based on obtaining of the forward transmission coefficient (S21 parameter). The external measuring bridge is used in the frequency range from 1 MHz to 100 MHz. Measured twisted pair is terminated by short, open and matched impedance. In order of proper results all measured values from Vector Network Analyzer ZVRE have to be corrected. Correction coefficient is obtained after removing of the twisted pair and leaving the port open. Revised value of return loss is given by:

$$\Gamma_{cor} = \frac{\Gamma}{\Gamma_{open}}, \tag{7}$$

where  $\Gamma$  is the reflection coefficient of the twisted pair terminated by short, open or matched impedance and  $\Gamma_{open}$  is reflection coefficient of an external measuring bridge terminated by open.

Regarding of manual correction the return loss is obtained (S11 parameter) instead of forward transmission coefficient (S21 parameter). It is also necessary to determine the standardized characteristic impedance of the twisted pair, because of the transformation from 50 Ω to 100 Ω twisted pair according to the equation:

$$Z'_{norm}(f) = Z_0 \cdot \frac{1 + \Gamma_{ref}}{1 - \Gamma_{ref}}, \tag{8}$$

where  $\Gamma_{ref}$  is reflection coefficient of the external measuring bridge terminated by the reference resistor (100 Ω).

The input impedance of the twisted pair  $Z_x$  is given by the Eq. (9). The characteristic impedance of the twisted pair  $Z_0$  is given by the Eq. (10).

$$Z(f) = Z'_{norm} \cdot \frac{1 + \Gamma_{cor}}{1 - \Gamma_{cor}}, \tag{9}$$

$$Z_0(f) = \sqrt{Z_{x,open}(f) \cdot Z_{x,short}(f)}, \tag{10}$$

where  $Z_{x,open}$  and  $Z_{x,short}$  are measured impedances obtained from (9), where open and short termination is considered.

### 3. Measurement Workplace

At the Department of Telecommunications Technology of Faculty of Electrical Engineering of CTU in Prague was implemented measurement facility which allows automatic measurement. This facility is depicted in Fig. 3.

The facility consists of:

- Vector Network Analyzer ZVRE firm ROHDE SCHWARZ,

- Agilent 3499B 2-Slot Switch/Control Mainframe,
- 2x Agilent 44478A Dual 1x4 RF Multiplexer Module (1,3 GHz, 50 Ω). Dual 1-to-4 multiplexers provide bidirectional switching of signals from DC to 1,3 GHz,
- Baluns 0319NA firm North Hill, with the frequency,
- bandwidth from 100 kHz to 300 MHz,
- 50 Ω cables,
- Measured UTP cable.

The goal of a measuring facility is a faster and more accurate measurement of the secondary parameters, input impedance and crosstalk at the far end FEXT (Far End Cross-talk). Switching of RF (Radio Frequency) switches and processing of values is controlled by computer. Switching matrix also performs termination of unused pairs.

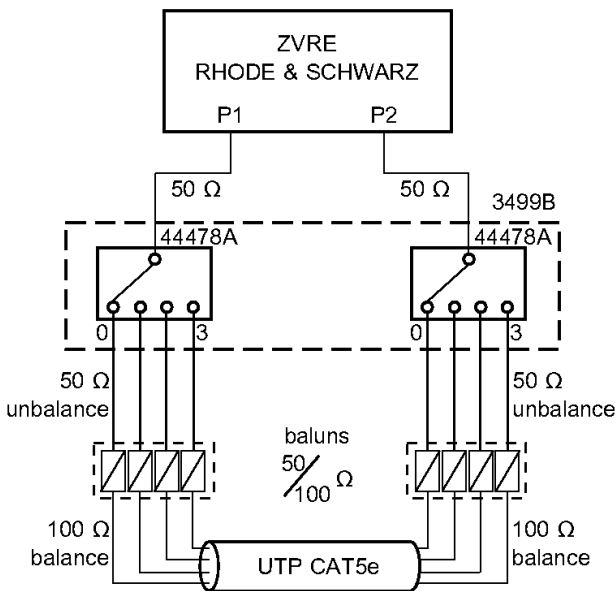


Fig. 3: Block diagram of measuring facility of the Department of Telecommunications Technology.

The detailed diagram of measuring facility is on Fig. 4 (for attenuation, FEXT and RL measurement) and Fig. 5 (for NEXT measurement).

Measuring facility contains additionally network analyzer ZVRE Rohde & Schwarz connected to port CH00 and CH10 of RF switches. Ports are equipped by internal termination resistors which are important for FEXT measurements. Red dashed lines depicted on Fig. 4 are states of switches for NEXT (Near End Cross-talk) measurements which are executed between port CH00 and CH10. All four channels of measuring facility are connected to near and far end of tested cable using adaptor for termination and balancing (coaxial interface of 50 Ω to 100 Ω for symmetrical cable).

Measuring facility setup for NEXT measurement is depicted on Fig. 5. This setup is special because allows to change channels for generator and receiver at the same end of tested cable. This operation is carried out thanks to internal ports of the switch (CH00-03), which is primary designed for termination of the cable. The connection is made by four cables to second switch (at CH10-13). The crosstalk modelling is presented in detail in [4].

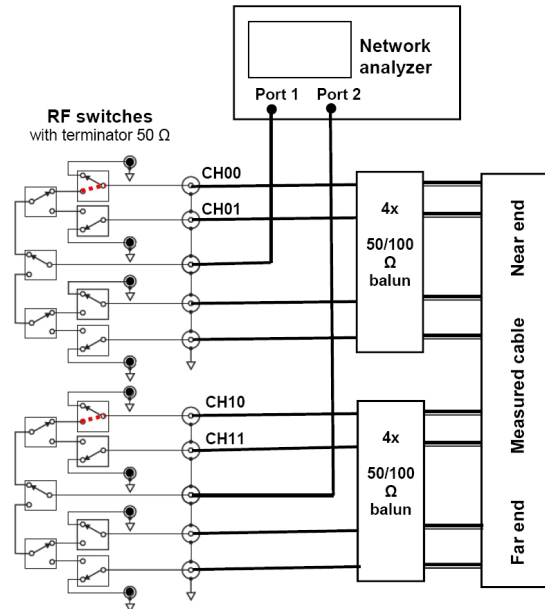


Fig. 4: Detailed block diagram of measuring facility setup for attenuation, FEXT and RL measurements.

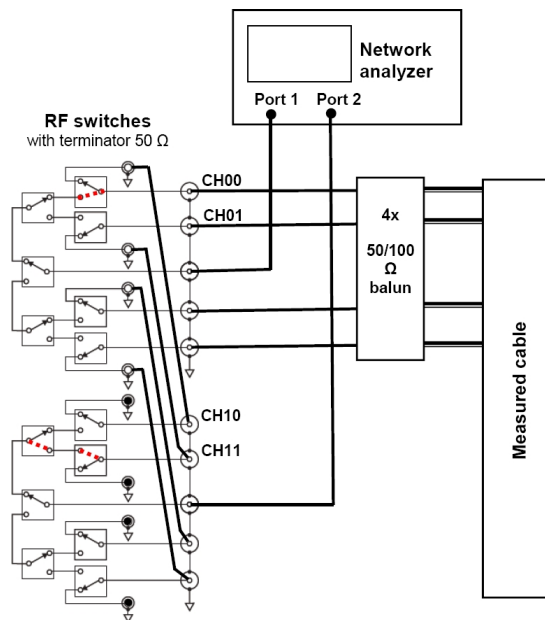


Fig. 5: Detailed block diagram of measuring facility setup for NEXT measurement.

### 4. Measurement Results

The measured secondary parameters of each pair (transformed at 1 km cable length) are depicted in Fig. 6.

Figure 7 depicts a difference between waveforms of  $|Z_0|$  measured using the methods above. Method with an external bridge has more stable waveform of the values  $|Z_0|$  that is probably caused by attenuation reflection coefficient between ZVRE and external measuring bridge.

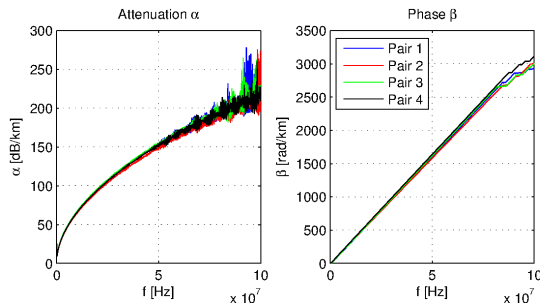


Fig. 6: Waveforms of the secondary parameters of each pair CAT5 UTP cable.

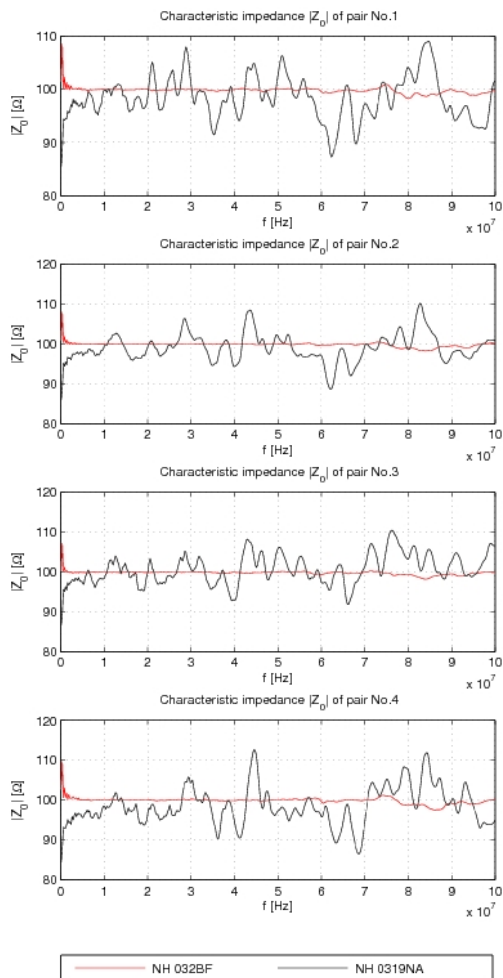


Fig. 7: Waveforms of  $|Z_0|$  for pair in UTP cable.

The primary parameters (Fig. 8) were obtained using Eq. (11), (12), (13), (14) from secondary parameters.

$$R = \alpha \cdot \Re(Z_0) - \beta \cdot \Im(Z_0), \tag{11}$$

$$G = \frac{\alpha \cdot \Re(Z_0) + \beta \cdot \Im(Z_0)}{\Re(Z_0^2) + \Im(Z_0^2)}, \tag{12}$$

$$\omega \cdot L = \beta \cdot \Re(Z_0) + \alpha \cdot \Im(Z_0), \tag{13}$$

$$\omega \cdot C = \frac{\beta \cdot \Re(Z_0) - \alpha \cdot \Im(Z_0)}{\Re(Z_0^2) + \Im(Z_0^2)}. \tag{14}$$

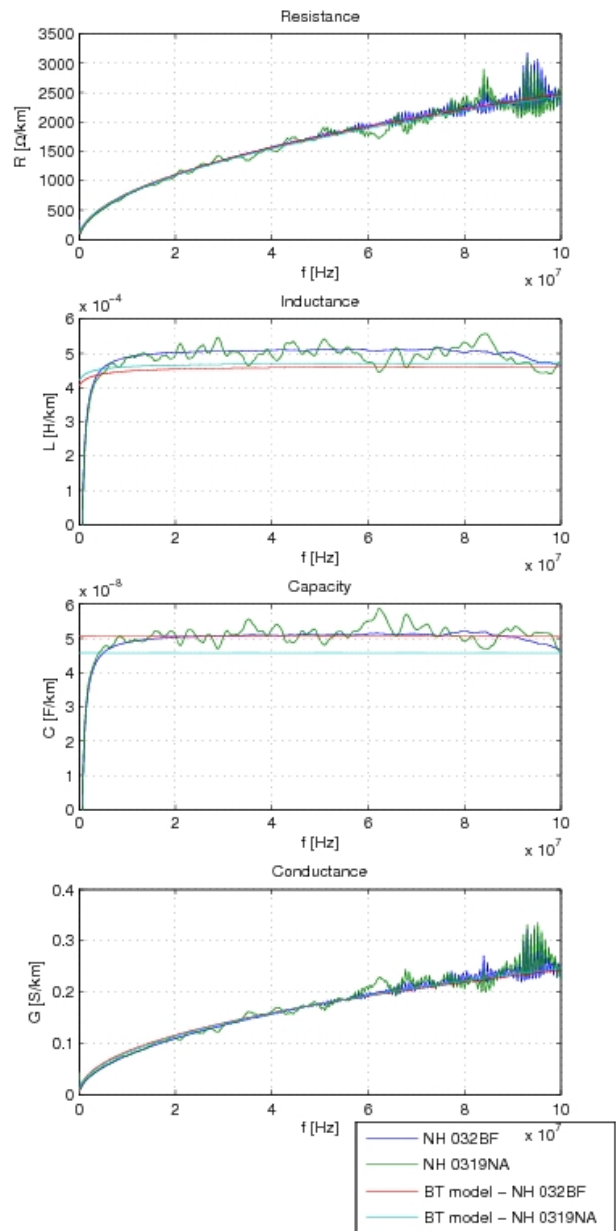


Fig. 8: Waveforms of the primary parameters of pair No. 1.

## 5. Modelling Parameters

The BT model parameters were identified by Matlab from waveforms of Fig. 8. Tab. 1 contains a summary of identified BT model parameters for the two measurement methods; see Eq. (1) to (4).

**Tab.1:** Summarized parameters of BT model of two methods.

Parameters	NH 032BF	NH 53100RLB
$a$	$3,758 \cdot 10^{-3}$	$3,542 \cdot 10^{-3}$
$r_o$	90,655 $\Omega$ /km	90,655 $\Omega$ /km
$l_o$	$404,434 \cdot 10^{-6}$ H/km	$415,632 \cdot 10^{-6}$ H/km
$l_\infty$	$464,784 \cdot 10^{-6}$ H/km	$473,367 \cdot 10^{-6}$ H/km
$b$	0,831	0,816
$f_m$	3 247 986,503 Hz	2 076 121,279 Hz
$c_\infty$	$4,666 \cdot 10^{-8}$ F/km	$4,581 \cdot 10^{-8}$ F/km
$c_0$	$4,239 \cdot 10^{-9}$ F/km	$7,941 \cdot 10^{-11}$ F/km
$c_g$	$-2,344 \cdot 10^{-5}$	$-0,239 \cdot 10^{-5}$
$g_e$	0,459	0,482
$g_o$	$5,169 \cdot 10^{-5}$ S/km	$3,472 \cdot 10^{-5}$ S/km

## 6. Conclusion

This article describes methods for measuring of the characteristic impedance  $|Z_0|$  using internal and external bridge, combined with automatic measurement facility controlled by computer in frequency range from 0,1 MHz to 100 MHz with the possibility to use up to 300 MHz. Facility can be used for attenuation, reflection and crosstalk measurement of twisted pairs. Such measuring facility can provide a measured waveforms and subsequent mathematical analysis. The measured values of secondary parameters UTP CAT5e cable will be used to refine the existing secondary parameters in the program used to evaluate the fundamental characteristics of metallic cables on Matlab server [3] and xDSL transmission rate estimation.

## Acknowledgements

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