A Methodology for Measurements of Basic Parameters in a xDSL System

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ABSTRACT

In order to qualify a subscriber loops for xDSL transmission, basic parameters like transfer function, scattering parameter S_{11} and characteristic impedance should be known. The aim of this paper is to present a test methodology for measurements of these basic parameters. The characteristic impedance is measured by open/short method and it is compared with the terminated measurement method defined in IEC (International Electrotechnical Commission) 611156-1. Transfer function and scattering parameter S_{11} of DSL loop are also measured on a real cable. The methodology is based on measurements of a 0.4 mm, 10 pairs, balanced twisted-pair cable of 1400 m of length. In order to improve the analysis of results, we compared the measurements from real cable with results from wireline simulators. The measurement of parameters of xDSL copper loop is done in an infrastructure set up in the LABIT (Technological Innovation in Telecommunications Lab) at UFPA (Federal University of Pará), that consist of a wireline simulators, a precision impedance analyzer, and a network analyzer. The results show a difference between the measurements performed with real cables and wireline simulators for transfer function parameter. Characteristic impedance obtained by both methods presented quite similar results.

Keywords: xDSL, broadband communication, DSL test methodology, characteristic impedance, transfer function, scattering parameter.

1. INTRODUCTION

DIGITAL Subscriber Line (DSL) technology is a technology that provides transport of high-bit-rate digital information over telephone subscriber lines. The term xDSL covers a number of similar yet competing forms of DSL, including ADSL, SDSL, HDSL, RADSL, and VDSL [1]. xDSL is drawing significant attention from vendors, technology and service providers because it promises to deliver high data rates to dispersed locations with relatively small changes to the existing telecommunication infrastructure.

ADSL (Asymmetric Digital Subscriber Line) is an enabling technology for high data rate communication and fast internet access over ordinary telephone lines. ADSL modems can transfer data at up to 8 Mbps for downstream and 640 kbps for upstream. Future technologies, such as VDSL, will increase this rate to 52 Mbps. This is many times faster than current high speed modems. ADSL shares the copper wires with POTS (Plain Old Telephone Service) and ISDN (Integrated Service Digital Network). One important criterion for deploying ADSL service is to ensure that there is not interference to the existing services [1].

Since the copper infrastructure was not designed for high frequency use, measuring the physical layer is required to ensure successful deployment of ADSL services. Because one end of the loop is in the central office (CO) and the other end is in the subscriber premises, only one end of the loop is typically available for testing.

ADSL technology is asymmetric. It allows more downstream bandwidth — from a central office to the customer site — than upstream from the subscriber to the central office. This asymmetrical traffic profile, combined with always-on access (which eliminates call setup), makes ADSL ideal for Internet/intranet web browsing, video-on-demand, and remote LAN access. Users of these applications typically download much more information than they send [1], [2].

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ADSL downstream data rates depend on a number of factors, including the length of the copper line, wire gauge, presence of bridged taps, cross-coupled interference cross-coupled interference as well as the attenuation mechanism. Line attenuation increases with line length and frequency and decreases as wire diameter increases.

Verification and testing of ADSL technology involves performance measurements over a predefined set of conditions that represent scenarios in the loop plant. These scenarios include specific sets of measures of copper loops. Electrical characteristics of the twisted pair cables are defined using the classical transmission line model. Such model incorporates a set of parameters per unit length. In this paper three parameters are utilized for characterization of the ADSL copper loops. The parameters are derived from model two-port network twisted pair cable of the telephone lines.

Measurement of the performance of ADSL devices during test bed was done using the instruments in the LaBIT that consisted of a wireline simulator, a precision impedance analyzer, a network analyzer and a GPIB interface. The performance evaluation of ADSL copper loop was done by measuring parameters such as: characteristic impedance, transfer function and scattering parameter S_{11} of a real cable of 1.400 m length and 0.4 mm gauge (cable CTP-APL from Furukawa). The measured results were compared with the measures obtained by the wireline simulators.

In order to describe such methodology, the remainder of the paper is organized as follows. In Section 2, the basic parameters and the two-port network for twisted-pair cable are demonstrated. Section 3 contains the descriptions of the measurements of characteristic impedance, transfer function and scattering parameter S_{11}. The results are discussed in Section 4, and conclusions are drawn in the final section.

2. BASIC PARAMETERS

2.1 The Copper Loop

Thorough these 100 years of evolution of the telephone network, one factor has remained constant: telephone is still connected to the network by a twisted pair of copper wires. The reason for this is simple economics: attempts to replace it with more modern technology cost more than the revenue form basic phone bill could support. Copper wire is relatively inexpensive, it is in place, and it does the job [3].

Age and quality of the cable also have a great deal to do with how much noise is present. If we are reused the existing twisted pair local loop for high speed service distribution, then we have to deal with line attenuation (cable loss) which increases with line length and frequency and decreases as wire diameter increases [3].

Loop is divided into two parts: the feeder and the distribution segments. Feeder cables are large, high pair count cables that leave the CO and head down major corridors. Periodically, a certain number of pairs are dropped to a distribution frame and connected to distribution cables, which actually deliver service to the subscriber (see Fig. 1).

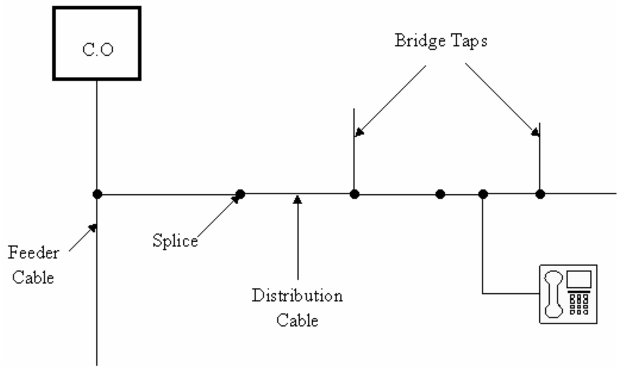

Fig. 1. Typical copper feeder/distribution loop.

2.2 Characteristic Impedance

This subsection is a review of the relationships between the characteristic impedance, propagation constant and the primary parameters R, L, G and C. Characteristic impedance is associated to with propagation constant and it is readily viewed as being complex, consisting of the real attenuation and imaginary phase coefficient components. The two secondary components are related to the primary components. Frequency dependence of these parameters is also developed.

Frequency domain of the complex characteristic impedance Zc and the propagation constant γ relates the primary parameters as [4]:

$$Zc = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{1}$$

Relationship between propagation constant and the primary parameters by [4]:

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{2}$$

by separately (2) in its real and imaginary parts, we can obtain the attenuation coefficient α and phase coefficient β respectively. These two parameters are defined according to [4] as:

$$\alpha = \sqrt{-\frac{1}{2}\left(\omega^2 LC - RG\right) + \frac{1}{2}\sqrt{\left(R^2 + \omega^2 L^2\right)\left(G^2 + \omega^2 C^2\right)}} \tag{3}$$

$$\beta = \sqrt{\frac{1}{2}\left(\omega^2 LC - RG\right) + \frac{1}{2}\sqrt{\left(R^2 + \omega^2 L^2\right)\left(G^2 + \omega^2 C^2\right)}} \tag{4}$$

where:

R is the resistance of the twisted-pair (Ohms/meters);

L is the inductance of the twisted-pair (Henry/meters);

C is the capacitance of the twisted-pair (Faraday/meters);

G is the conductance of the twisted-pair (Siemens/meters);

ω is the radian frequency (rad/s).

Characteristic impedance of a cable can be obtained by:

$$Z_0 = \sqrt{Z_{SC} \times Z_{OC}} \tag{5}$$

where:

– Input impedance of a loop terminated by a short-circuit;

– Input impedance of a loop terminated by an open end.

Whenever there is a mismatch between the loop and the load, reflections will occur. When a loop is terminated by an open end, the reflection coefficient at the load is $\Gamma = 1$ which means the reflected wave has the same amplitude and is in phase with the wave from the source. When a loop is terminated by a short circuit, the reflection coefficient at the load is $\Gamma = -1$, which means the reflected wave has the same amplitude but is out of phase with the wave from the source. As the reflections in these two cases differ from 180°, their influence will cease if these impedances are multiplied with each other, since:

$$Z_{OC} \times Z_{SC} \Rightarrow \angle Z_{OC} + \angle Z_{SC} \tag{6}$$

Although (5) represents the characteristic impedance, this expression does not give us the effects of reflections.

2.3 The Twisted-Pair Cable as a two-port Network

Every twisted-pair cable can be accurately modeled as a two-port network (2PN). In transmission line theory, a common way to represent a 2PN is to use the transmission matrix, also known as the ABCD matrix [5]. Fig. 2 shows a model of a telephone subscriber loop.

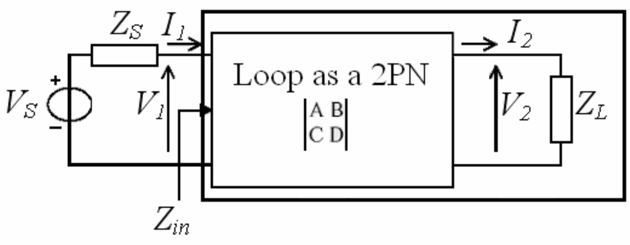

Fig. 2. 2PN (Two-Port Network) representation of the subscriber loop.

2.4 Input Impedance

Input impedance of a subscriber loop is defined as the ratio between the voltages applied to the input of such circuit and its resulting current [1]. The relationships between the input and output variables of the two-port network are:

$$V_1 = AV_2 + BI_2 \tag{7}$$

$$I_1 = CV_2 + DI_2 \tag{8}$$

According to Fig. 2, it is possible to notice that $V_2 = Z_L I_2$. Thus, the ratio between the current and the voltage over the load can be expressed by

$$\frac{I_2}{V_2} = \frac{1}{Z_L} \tag{9}$$

Dividing (7) by (8) we have

$$\frac{V_1}{I_1} = \frac{AV_2 + BI_2}{CV_2 + DI_2} \tag{10}$$

Thus, assuming Zin $= \frac{V_1}{I_1}$ and applying (9) in (10), we obtain

$$Z_{in} = \frac{AZ_L + B}{CZ_L + D} \tag{11}$$

2.5 Transfer Function

In a general way, the transfer function of a system can be defined as a mathematical statement that describes its transfer characteristics, i.e., the relationship between the input and the output of a system in terms of the transfer characteristics. Transfer function is a frequency dependent quantity and it rolls off with frequency. This is a consequence of the greater interaction between the propagating signals and the material comprising the transmission medium. For a perfectly terminated loop with length *l*, the transfer function is given by $H(l, f) = e^{-l\gamma(f)}$, where γ is the propagation constant of the loop. However, such a simplified twisted-pair cable transfer function based on the propagation constant is only good for a single gauge twisted-pair with perfect terminations at both ends. A subscriber loop, however, usually consists of many sections of different gauges, with bridged taps, and terminated with resistive impedance [1], [5].

Transfer function of a telephone subscriber loop is not a simple product of transfer functions of these twisted-pair cable sections because of impedance mismatches. To accurately represent a subscriber loop channel, the concept of a two-port network and its ABCD parameter representation is normally used for the analysis of DSL systems.

Transfer Function is an important parameter used for defining the maximum allowable cable length and the frequency response of the cable. The attenuation is defined as the forward transmission S-parameter called S_{21}. According to Fig. 2, it is possible to notice that [1]:

$$\frac{V_1}{V_S} = \frac{AZ_L + B}{AZ_L + B + CZ_L Z_S + DZ_S} \tag{12}$$

Finally, we have

$$\frac{V_2}{V_S} = H_f(f) = \frac{Z_L}{AZ_L + B + CZ_L Z_S + DZ_S} \tag{13}$$

2.6 Scattering Parameter S_{11}

S-Parameters are relatively easy to obtain at high frequencies. These parameters relate the main familiar measurements (gain, loss, reflection and transmission coefficient …). We can compute H, Y or Z parameters from S-parameters if desired [6]. In this paper, the one-port scattering parameter S_{11}, which is ratio of the reflected wave and the incident wave, is measured by means of a network analyzer (NA) directly in the frequency-domain. As only the CO end of the network may be considered as a one-port. All the information that can be acquired about the network through port 1 is contained in the S_{11} scattering parameter.

3. MEASUREMENT METHODOLOGY

Measurements consisted of tests using a real cable and wireline simulators. The wireline simulators were an ADSL2++ 414E model and an ADSL 400E3 from Spirent. These wirelines can simulate loops between 50 m to 7000 m (414E model) and 50 m to 3700 m (400E3 model), with a characteristic impedance of 100 Ω.

It was used the 4395A Network Analyzer and the 4294A Precision Impedance Analyzer, both from Agilent. Almost all measurement instruments have unbalanced input and output ports [7]. Thus, a balun (balanced unbalanced) transformer is necessary to convert balanced signal to unbalanced signal. Two wideband transformers (baluns) North Hills model 0301BB, 10 kHz – 60 MHz, 50 Ω (unbalanced) 100 Ω (balanced) were used for the measurements.

Frequency range used for the measurements was 4.3125 kHz to 1.104 MHz, (ADSL range). The initial frequency of balun is higher than the ADSL initial frequency, so the results will have a cut in initial frequencies. This will be discussed in details in Section 4.

3.1 Measurement of Characteristic Impedance

Tests for measurement of characteristic impedance consist in a single ended testing method, and in an open/short circuit method using a balun but excluding the balun performance [4]. The steps for the measurement of characteristic of the copper loop are [4]:

a. Primarily is done the measure $\mathbf{Z_{itf}}$ (input impedance measured by leaving the balanced output of the balun open (Ω));

b. Measure $\mathbf{Z_{its}}$ (input impedance measured by shorting the balanced output of the balun (Ω));

c. Measure $\mathbf{Z_{itr}}$ (input impedance measured by terminating the balanced output of the balun in a non-inductive, resistive load (ZR Ω) which value is balanced to ± 1% (Ω));

d. Measure $\mathbf{Z_{itcf}}$ (input impedance measured by connecting the balanced output of the balun in a twisted pair with far end of the pair open (Ω));

e. Measure $\mathbf{Z_{itcs}}$ (input impedance measured by connecting the balanced output of the balun in a twisted pair with far end of the pair shorted (Ω));

Equation (14) was utilized for determine the characteristic impedance (Z_C) through of the input impedance measurements above [4].

$$Zc=\sqrt{Z_R{}^2\left(\frac{Z_{itr}-Z_{itf}}{Z_{itr}-Z_{its}}\right)^2\left(\frac{Z_{itcf}-Z_{its}}{Z_{itcf}-Z_{itf}}\right)\left(\frac{Z_{itcs}-Z_{its}}{Z_{itcs}-Z_{itf}}\right)} \qquad (14)$$

where

Z_R is the terminating resistance 100 ± 1%(Ω).

3.2 Measurement of Transfers Function and Scattering Parameter S_{11}

Measurements of transfer function and scattering parameter S_{11} were done using the setup shown in Fig. 3. The DUT (Device Under Test) can be the real cable or the wireline simulator.

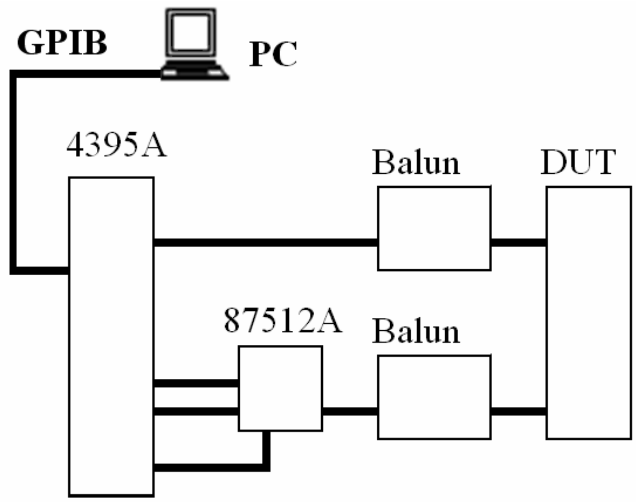

Fig. 3. Setup for transfer function and S_{11} measurements using the 87512A transmission/reflection set.

Besides of Network Analyzer 4395A, it was also used the 87512A Transmission/Reflection Set from Agilent to make the measurements [7]. The advantage of this setup is that it is possible with only a single setup, make two different measurements (transfer function and scattering parameters).

4. RESULTS

Results for the characteristic impedance using (5) and (14) are shown in Fig. 4. The error between the traditional measurement (open/short method) and the method described in [4] is around 0.2 dB, except to initial frequency range, where it can be noted the influence of the baluns in the measurements for the traditional method.

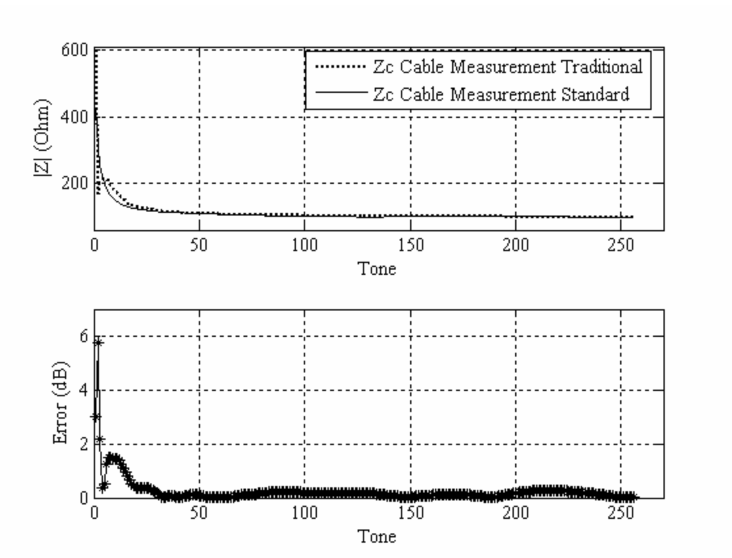

Fig. 4. Characteristic impedance.

Results for scattering parameter S_{11} are shown in Fig. 5. The error between the measurements from real cable and wireline simulators is smaller than 0.3 dB. The strange values in the initial frequencies are due to frequency of cut of the baluns (10 kHz).

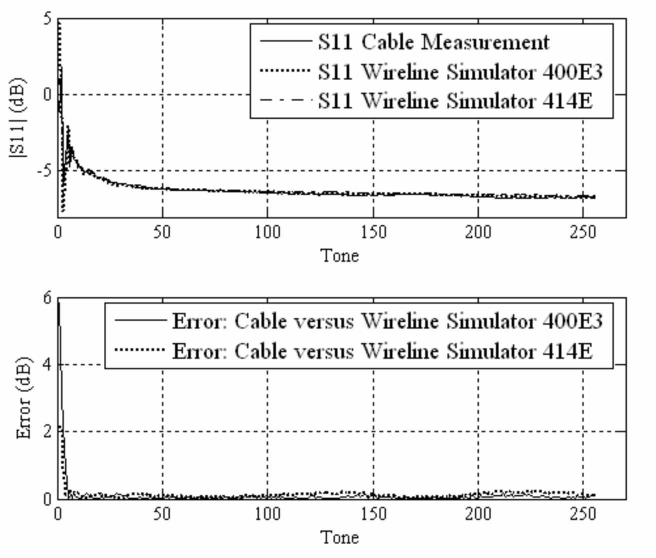

Fig. 5. Scattering parameter (S_{11}) results from real cable and wireline simulators, with an error smaller than 1 dB.

Results for forward transfer function measurements are shown in Fig. 6. The wireline simulator used reproduce the AC and DC characteristics of twisted pair copper telephony cable using passive circuitry (R, L & C), which means that attenuation, complex impedance and velocity (propagation delay) of the wireline is properly simulated. However, in a real cable, the electric components depend on the physical characteristics of each cable. When it increases the operation frequency, parasitic components (unwanted inductance in resistors, unwanted resistance in capacitors, unwanted capacitance in inductors, etc.) of the cable tend to assume values every time larger, what will influence in the response in frequency for the cable.

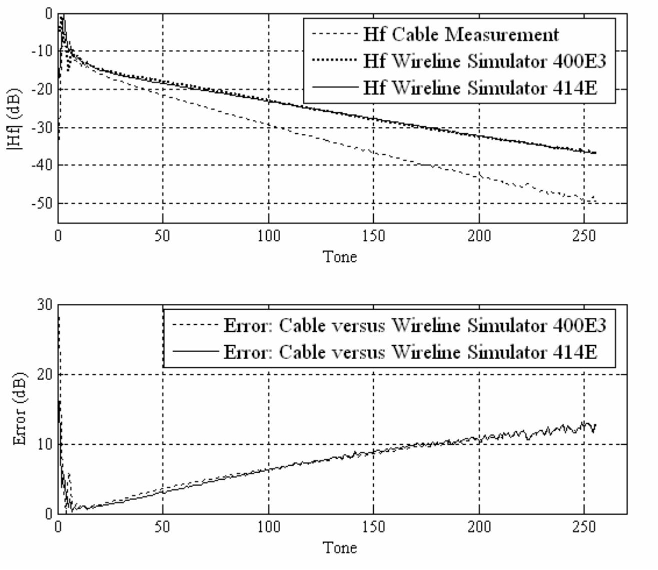

Fig. 6. Transfer function results from real cable and wireline simulators.

Measurements of the basic parameters in real cables can have influences of the environment like temperature change and noise. Additionally, reels of cable can introduce unrealistic coupling effects. Thus, the results obtained for transfer function are coherent with the expected.

Uncertainties of measurements were estimated and they are shown in Table 1. The coverage probability is 95.45 %, and three repetitions were done for each measurement.

Table 1 – Uncertainties of measurements

Parameter	**Cable/Wireline Simulator**	**Uncertainty**
Z_{in}	Real Cable	*2.08 Ohms*
Transfer Function	Real Cable	*0.63 dB*
Transfer Function	Wireline Simulator 400E3	*0.74 dB*
Transfer Function	Wireline Simulator 414E	*0.60 dB*
S_{11}	Real Cable	*0.29 dB*
S_{11}	Wireline Simulator 400E3	*0.95 dB*
S_{11}	Wireline Simulator 414E	*0.59 dB*

Largest standard deviation was used for the calculation of the uncertainty. The obtained uncertainties have acceptable values, once such uncertainties do not have negative impact on the final conclusions. Additionally, tests of Dixon [8] were accomplished in measurements obtained to verify the existence of outlying data. Such tests presented satisfactory results.

5. CONCLUSION

This paper has presented a methodology for measurements of the ADSL copper loop parameters. The results of the measurements for a real cable are compared with the results for wireline simulators. The error for the S_{11} measurement is around 0.2 dB and the error for the characteristic impedance is around 0.5 dB. The measurements of transfer function presented sensitive differences between the simulators and the real cable, possibly due to the increase of the parasitic components in high frequencies for the real cable. For the transfer function measurement, physical characteristics and environmental conditions has great influence in final results. Additionally, the wireline simulators meet the requirements of international DSL standards [9], resulting in a natural difference between real cable and wireline simulator measurements for transfer function parameter.

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