EMC AND CO-EXISTENCE ISSUES OF BROADBAND COMMUNICATIONS OVER COPPER

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Abstract: In this paper, we give an overview of EMC issues of ADSL, VDSL and PLC systems. We focus successively on a statistical impulse noise characterization, a determination of xDSL radiated emission by a theoretical approach and a PLC and VDSL co-existence study.

1. Introduction

In the recent few years, Internet access over Digital Subscriber Loop (DSL) has been experiencing a constantly growing popularity. Recent technological advances have increased the potential capacity of telephone operators access networks, which were originally intended to provide plain old telephone service (POTS). Thanks to the availability of high-speed digital processing and the use of bandwidth-efficient modulation schemes such as Discrete Mutli-Tone (DMT), xDSL technologies are able to transmit very high bit-rates that reach several tens of Mbps downstream and upstream for VDSL (Very-high speed DSL). Beside the Telco Local Loop infrastructure, Low Voltage Electricity Distribution Networks have also become potential fruitful media in order to offer Power Line Communication (PLC). The introduction of PLC is based on the fact that in-house electric-power line can function as high-speed transmission lines for home networking.

Nevertheless, because of the imperfect unbalance of the twisted pairs and electrical lines, not intended to broadband communications, there are EMC and co-existence issues.

This paper is organized as follows. Section 2 gives a description of the main broadband technologies –ADSL, VDSL and PLC. In section 3, we present EMC issues of broadband transmission systems carried out by France Telecom. This section focuses on a statistical impulse noise characterization and on a determination of xDSL radiated emission by a theoretical approach. Section 4 deals with the co-existence of VDSL and PLC systems. Conclusions are given in Section 5.

2. xDSL and PLC technologies

2.1 Presentation

The Asymmetric DSL (ADSL) technology is intended to convey asymmetric bit-rates between the subscriber side modem and the central office side modem. The downstream link can reach 10 Mbps, whereas the upstream one guarantees few hundreds of Kbps. It uses a Discrete MultiTone (DMT) modulation scheme as specified in [1]. Regarding the Very high bit-rate DSL (VDSL), it allows throughputs that reach 60 Mbps downstream and 6.4 Mbps upstream and it is intended for residential service. Symmetric VDSL applications provide up to two-way 25 Mbps mainly to business service. Power Line Communications systems can also transmit tens of Mbit/s. They use frequency bands that overlap: the ADSL frequency band is comprised between 30 kHz and 1.1 MHz, the VDSL frequency band is comprised between 138 KHz and 12 MHz [2] and the PLC frequency band is comprised between 4 MHz and 21 MHz [3].

3. EMC studies

This section presents EMC issues of broadband transmission systems. It focuses on a statistical impulse noise characterization and on a determination of xDSL radiated emission by a theoretical approach.

3.1 Characterization of impulse noises

Different noise types appear on phone and electric-power lines. These noises are well summarized in [4]. The most common of them are crosstalk noise, radio-frequency interference (RFI) and impulse noise. Crosstalk noise is caused by electromagnetic radiation of other adjacent wires, in practice, in the same cable. RFI is the remnant of wireless transmission signals coupling into phone lines. Impulse noise bursts that appear on the copper lines, are caused by coupling from different electromagnetic interferers such as home appliances, electrical switches or motors. Impulse noise is the most corrupting of these noises in terms of errors because of its very random characteristics that render its prediction difficult and its high amplitudes compared to the transmitted DSL signal.

In order to determine by simulation [5,6] the impact of impulse noise on xDSL systems, statistical study of impulse noises parameters (amplitude, duration, interarrival and spectral characteristics) has been launched.

Impulse noise recordings have been realized on residential and professional customer installations. These customers have been chosen in order to be the most representative with various architectures (underground and aerial branching cable, house, building…), different electromagnetic environments (isolated area, near industrial zone …). For each customer, recordings duration are several days to consider the different activity periods.

These different recordings constitute a data base, which continue to be alimented by other measurements campaign.

A first data analyze shows two types of behavior for impulse noises: impulse noise organized with burst (several impulsions separated by a small duration, cf. figure 1) and impulse noise constituted by an isolated impulsion (cf. figure 2).

A statistical analyze has been realized considering this two behavior. The analyzed parameters are:

- Temporal parameters: peak to peak amplitude, duration, interarrival (of isolated impulsions, of bursts and of small impulsions constituting a burst).
- Frequential parameters: power spectral density.

Table 1 and 2 indicate the main statistical results corresponding to these parameters.

Table 1 : burst results.

	Mean	Standard deviation	Law
Amplitude	64 mV	58 mV	Log-Normal
Duration	640 µs	0.96 ms	Log-Normal
Interarrival	20 ms	*	Exponential
Interarrival in the burst	75 µs	140µs	Log-Normal
Number of impulsions in a burst	8	9	*

Table 2 : isolated impulse results.

	Mean	Standard deviation	Law
Amplitude	77 mV	73 mV	Log-Normale
Duration	490 µs	3.7 ms	Log-Normale
Interarrival	10 ms	*	Exponential

In addition, the PSD average of all the burst and all the isolated impulsions has been calculated.
From mean values of the amplitude, the duration and PSD, two mean models of impulse noise have been established: one for the isolated impulsion and the second for the burst. These models are represented on figures 1 and 2 in the time domain and in the frequential domain.

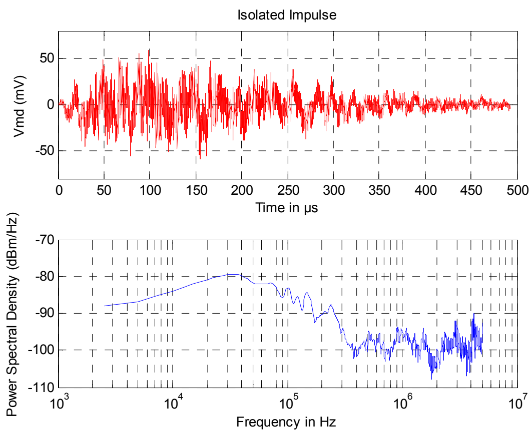

Figure 1: burst model in the time domain and frequency domain.

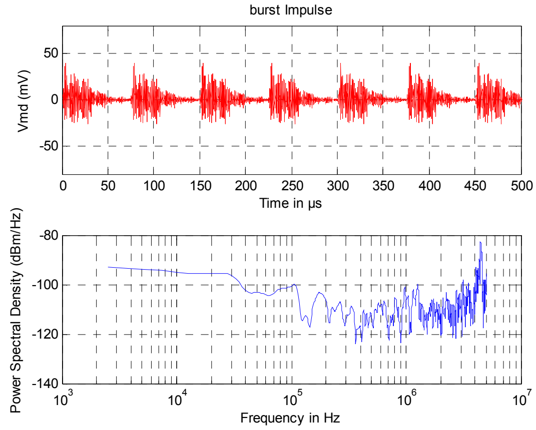

Figure 2: isolated impulsion model in the time domain and frequency domain.

3.2 xDSL radiated emission

3.2.1 Theory of cable radiation problems

The goal of this work is to establish a theory to determine the electromagnetic field radiated by UTP or STP cables. Calculating the distribution of the electromagnetic field radiated by the telecom cables requires basic knowledge of the relationship between current - charge distributions and the electromagnetic field. This study is covered by Maxwell's theory, and it is based on the theory of the multi-conductor transmissions lines associated with a topological approach.

3.2.2 Measurement configuration

The development of the numerical code permitted the simulation of fields radiated by telecom cable networks. Later, the results were validated by a comparison with experimental measurements.
The measurements are carried out in a semi-anechoic chamber for the 10 kHz - 30 MHz frequency band. The load impedance of 120 Ω represents the modem's impedance. The network analyser associated with a linear amplifier generates a signal of +27 dBm in the 10kHz-30MHz frequency band. Using this power, the limits of all electronic components used for these measurements were respected.
Finally, a loop antenna was used to measure the magnetic field and a dipole antenna allowed the measurement of the electric field.

3.2.3 Validation of theoretical results

In order to validate the simulation results, experimentation was carried out to measure the fields radiated by shielded cables. The electric and magnetic fields were measured at 1 meter from the cable and then these results were compared with the calculated fields.
Figure 3 shows an example of results of the magnetic field measured when the shield of the cable was not connected to the ground at the extremities (blue curve). Finally, the magenta curve shows the calculated field which shield is not connected to ground.

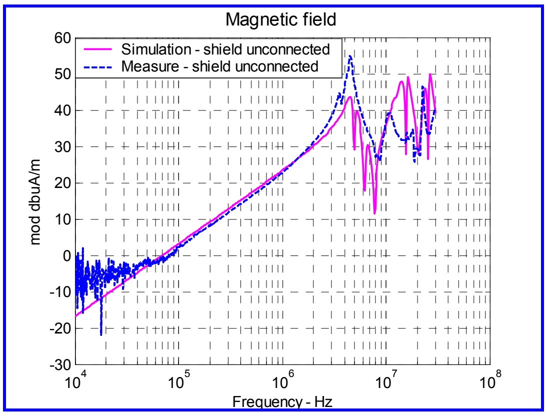

Figure 3 : Magnetic field.

We can notice a good agreement between the two curves. However, the difference between simulations and experimental results is due to:
- The inaccuracy of measurement and the difficulty of field measurement,
- The assumptions made in the theoretical approach.

The developed numerical tool can then be used to evaluate the radiated emission for any xDSL systems.
As an example, figure 4 shows the electric field results for the ADSL technology. The M313 mandate project standard limit was respected for this cable, with connected and unconnected shield to the ground.

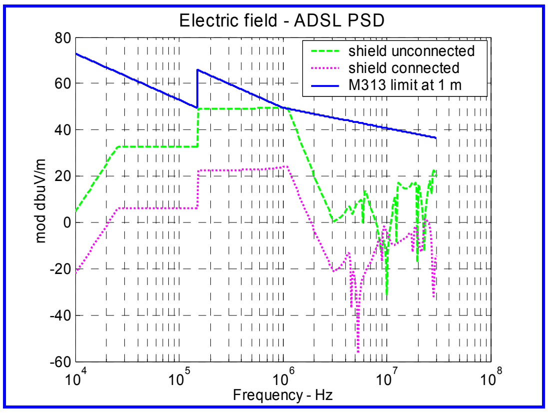

Figure 4 : Electric field, ADSL - PSD.

Such tool is very useful for France Telecom to verify whether the radiated emission of an xDSL system transmitted through a twisted copper pair respects the standards limits.

4. VDSL and PLC coexistence

The VDSL and PLT systems will coexist in collective environment such as buildings, student campuses, hotels…
In this section, we show the resulting stationary noise from PLC link on the telephone cable placed in the vicinity and we present the performance reduction of VDSL transmissions due to the stationary rise computed by simulation.

4.1 Coupling between power lines and copper pairs

For our study, the experimental device includes a PLC link- whose modems are certified using the CE label- set at a distance d from a telephone cable.

Figure 5 shows the stationary noise measured on the telephone cable, on the one hand when no PLC signal is carried by the power line and on the other hand when a PLC signal is transmitted on a power line situated either close to the copper pair (with d = 0 the distance separating the two lines), or at respectively d = 10 cm and d = 30 cm. The two downstream standardized VDSL frequency bands (information transmitted towards the customer) are also represented.

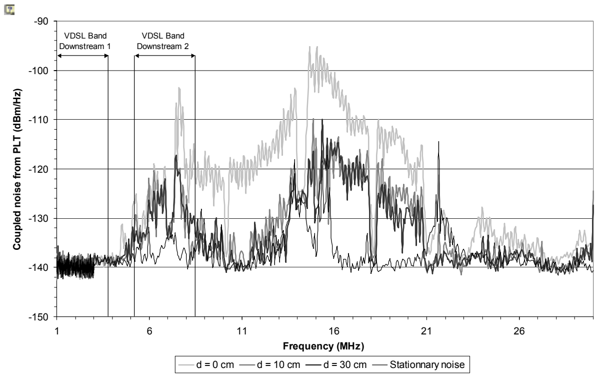

Figure 5 : Coupled noise from PLC signal on telephone cable.

We notice an increase in the stationary noise on the copper pair in presence of a PLC signal on the adjacent power line. The levels are approximately the same when the distances separating the two cables are equal to respectively 10 and 30 cm. On the other hand, the stationary noise level is much higher for the configuration of stuck copper and power cables. The maximum level of coupled noise is 25 dB for d = 10 cm or d = 30 cm and reaches 40 dB for d = 0 cm.
We can observe that the first downstream band is not affected by the proximity of the PLC signal transmission. Indeed, the PLC signal spectral occupation starts at 4 MHz, which is beyond this first VDSL downstream band.
As for the second VDSL downstream band, the levels of coupled noise are identical in the first half for the three distances d that separate the two cables. On the other hand, the stationary noise level in the second half of the frequency band is higher for the distance configuration d = 0 cm. The noise coupling in the second VDSL frequency band is less important in comparison with the coupling in other parts of the measured spectrum.

We should note that resonances occurrence in the spectrum depends directly on the lengths of the power transmission lines. For other configurations, the resonance located around 16 MHz as shown in Figure 5, and that presents a maximum at -95 dBm/Hz, could occur in the VDSL band.

4.2 Impact on VDSL performances

In the previous section, we measured the increase in stationary noise related to the proximity of the telephone cable to a PLC power line. We will determine now its impact on the performance of a VDSL transmission. The results are obtained by simulating a VDSL transmission chain. This simulation considers the downstream channels. For a given length, it makes it possible to determine the maximum capacity supported in this transmission direction, or, for a fixed rate, it calculates the cable range according to the line attenuation and the stationary noise [5]. Note that the cohabitation of PLC/VDSL systems is done in the customer environment, thus, taking into account only this direction of transmission is relevant.

Our simulated VDSL system respects the 998 frequency band plan. For this plan, the spectral occupation of the two downstream bands is as follows:

- 138 kHz - 3.75 MHz for the first band;
- 5.2 MHz - 8.5 MHz for the second band.

Note that the transmission of the information in the second band depends on the line attenuation and, thus, on the length of the line. For instance, for a length of 1000 m, only the first band is occupied.

4.2.1 Configuration 1

Let us consider now a line length equal to 300 m and a pair diameter equal to 4/10 mm.

The results of table 3 represent the maximum rates obtained on this channel in the downstream direction in the presence of the different stationary noises represented on figure 5: noise of the environment when no PLC signal is transmitted, and the noises generated by coupling of the PLC signal when the telephone cable is distant from the power-line by respectively 0, 10 and 30 cm.

Table 3 : Impact of the proximity of a PLC connection on the maximum rates transmissible on a VDSL liaison - L = 300 m

Noise	Maximum rate
Stationnary	68.74 Mps
D = 30 cm	68 Mps
D = 10 cm	67.8 Mps
D = 0 cm	65.12 Mps

The results of table 3 show that when the power line is stuck to the telephone cable, the rate reduction is of 5.3% in comparison to the transmissible rate in the absence of thePLC signal.

Similarly, rates are calculated for a length of 1000 m. The results are presented in table 4.

Table 4 : Impact of the proximity of a PLC link on the maximum rates transmissible on a VDSL chain - L = 1000 m

Noise	Maximum rate
Stationnary	27.8 Mps
D = 30 cm	27.48 Mps
D = 10 cm	27.24 Mps
D = 0 cm	27.34 Mps

For this line length, no reduction of rate is observed. Indeed, for 1000 m, the transmission is done only in the first downstream band, *i.e.* outside the PLC band. Thus, no stationary noise is generated by coupling in this band.

Consequently, the impact of a PLC system on a VDSL one is not significant for the 20 m configuration when the power-line and the telephone cable cohabit. Indeed, for this length, the stationary noise generated in the downstream VDSL bands is undeniably below the levels of the stationary noise measured in the remaining of the bands.

However, for other lengths configurations, the maximum levels of the stationary noise are likely to occur in the second downstream VDSL band.

4.2.2 Configuration 2

For this second configuration, we will thus compute the reduction of the rate when the levels of noises maxima, located around 16 MHz, are in the second VDSL downstream band.

The results are shown in table 5 for a length of a copper pair equal to 300 m.

Table 5 : Impact of the proximity of a PLC link on the transmissible maximum rates on the VDSL chain- L = 300 m

Noise	Maximum rate
Stationnary	27.8 Mps
d = 30 cm	27.48 Mps
d = 10 cm	27.24 Mps
d = 0 cm	27.34 Mps

The reductions of the rates caused by the vicinity of the PLC link are then of 25.2 % when the two transmission media are not separated and of 8.2 % when they are 10 cm or 30 cm away from each other.

5. Conclusion

In this paper, the approach to determine impulse noise models has been presented. Using these models, impulse noise impact on xDSL systems can be studied for different configurations.

Regarding xDSL radiated emission, a theoretical approach based on Maxwell's equations associated to the theory of multi-conductor transmission lines has been validated by experimental results.

Results concerning VDSL and PLC co-existence show that, near a PLC transmission, the maximum stationary noise increase generated by coupling on the close telephone cable is 40 dB if the two transmission lines are stuck and 25 dB if their spacing is of 10 or 30 cm. Only the stationary noise included in the second downstream VDSL band - 5.2 MHz up to 8.5 MHz - will have an impact on the performance of VDSL transmissions. Therefore, if the length of a VDSL link is such that only the first downstream band is occupied, the proximity of a PLC link will not have any impact on the VDSL transmission. Reversely, if the second VDSL frequency band is used, the reductions in terms of rate can reach 25%.

6. References

[1] ITU-T, "Draft new Recommendation G.992.21 : Asymmetrical Digital Subscriber Line (ADSL) Transceivers", March 1999.

[2] ETSI TS 101 270-1 v2.0.6 (2002-11), Transmission and Multiplexing, "Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1 : Functional requirements.

[3] Home Plug Power line Alliance, Home Plug 1.0.1 Specification, December 2001.

[4] J.J. Werner, "The HDSL environment," in IEEE J. Select. Areas Commun., vol. 9, August 1991, pp. 785-800.

[5] M. Ouzzif, "Etude comparative des performances des liaisons SCM-VDSL et DMT-VDSL en présence de bruits impulsifs", Ph. D. Thesis, 2004, Institut National des Sciences Appliquées de Rennes, Rennes, France.

[6] F. Moulin, "Etude de l'impact des bruits impulsifs sur la qualité de transmission d'une liaison ADSL", Ph. D. Thesis, 2000, Institut National des Sciences Appliquées de Rennes, Rennes, France.