

PowerLine Telecommunications (PLT); Study on signal processing improving the coexistence of VDSL2 and PLT



Reference

DTR/PLT-00030

Keywords

emission, powerline

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

Individual copies of the present document can be downloaded from:

<http://www.etsi.org>

The present document may be made available in more than one electronic version or in print. In any case of existing or perceived difference in contents between such versions, the reference version is the Portable Document Format (PDF). In case of dispute, the reference shall be the printing on ETSI printers of the PDF version kept on a specific network drive within ETSI Secretariat.

Users of the present document should be aware that the document may be subject to revision or change of status. Information on the current status of this and other ETSI documents is available at

<http://portal.etsi.org/tb/status/status.asp>

If you find errors in the present document, please send your comment to one of the following services:

http://portal.etsi.org/chaicor/ETSI_support.asp

Copyright Notification

No part may be reproduced except as authorized by written permission.
The copyright and the foregoing restriction extend to reproduction in all media.

© European Telecommunications Standards Institute 2010.
All rights reserved.

DECT™, **PLUGTESTS™**, **UMTS™**, **TIPHON™**, the TIPHON logo and the ETSI logo are Trade Marks of ETSI registered for the benefit of its Members.

3GPP™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners.

LTE™ is a Trade Mark of ETSI currently being registered

for the benefit of its Members and of the 3GPP Organizational Partners.

GSM® and the GSM logo are Trade Marks registered and owned by the GSM Association.

Contents

Intellectual Property Rights	4
Foreword.....	4
Introduction	4
1 Scope	5
2 References	5
2.1 Normative references	5
2.2 Informative references.....	5
3 Abbreviations	6
4 Analysis of the electromagnetic coupling between PLC and VDSL2 links.....	6
4.1 Executive summary about the analysis.....	6
4.2 First consideration	7
4.3 Reference configuration	7
4.4 Power Injected between two PLT modems	7
4.5 Theoretical approach	8
4.5.1 Coupling to aerial cables.....	8
4.5.2 Synthesis processing	10
4.6 Summary of the results.....	10
4.6.1 Untwisted Telecom wires	10
4.6.2 Twisted wires (CAT3).....	11
4.6.3 Twisted wires (CAT5).....	12
4.7 Examples of theoretical results.....	12
5 Algorithms to allow the coexistence of PLT with VDSL2	15
5.1 Executive summary about the algorithms	15
5.2 Problem statement	15
5.3 Analysis of the PHY layers of PLT and VDSL2.....	15
5.4 Channel Coupling Model for Signal Processing	16
5.5 Method 1: Adaptive interference cancelling filter.....	17
5.6 Method 2: Spectral management.....	18
6 PLT implementation of coexistence algorithms.....	19
6.1 Executive summary	19
6.2 Operating Principle.....	20
6.3 End-user Coexistence Tool.....	20
6.4 Installer Tool	21
6.5 Service Provider Tool.....	23
7 Crosstalk measurements in real houses	24
7.1 Executive summary	24
7.2 Measurements.....	24
8 Effect of the mitigation on a VDSL2 system	28
8.1 Executive summary	28
8.2 Measurements.....	28
9 Conclusions	30
Annex A: Bibliography	32
History	35

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: "*Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards*", which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (<http://webapp.etsi.org/IPR/home.asp>).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

Introduction

The current solution for the IPTV market is based on ADSL link from the TELCO office to the customer premises, an ADSL gateway at the customer premise to decode the signal, and a home network to distribute the signal within the house. The next generation of broadband access, currently being deployed by European TELCOs, is based on VDSL2 technology. On the other hand, powerline technology is becoming the preferred solution for home networking when applications, such as IPTV, requiring high throughput and QoS are provided. However, both technologies, VDSL2 and PLT, use the same frequency band (2 MHz to 30 MHz), and several studies ([i.6] and [i.7]) predict the interference of PLT modems over VDSL2 systems. To confirm these predictions the ETSI PLT group conducted a Plugtest where the level of interference between both technologies was measured, and set up a Specialist Task Force with the following assignments:

- 1) to analyze the severity of the interference; and
- 2) to propose solutions to mitigate it.

The present document presents the result of the STF.

1 Scope

The present document presents the result of the work of the STF and suggests the methods and practices to reduce or mitigate the crosstalk between electricity and telephone cables. The present document also includes the results of a small measurement campaign in real houses aimed at confirming the results of the Plugtest and validating the mitigation methods.

The work was organised in three phases assigned to different STF members:

- Phase 1: Modelling the coupling channel between VDSL2 and PLT (clause 4).
- Phase 2: Simulations of signal processing algorithms for coexistence (clause 5).
- Phase 3: Implementation of the algorithms in PLT devices (clause 6); field measurements (clause 7) and laboratory validation (clause 8).

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at <http://docbox.etsi.org/Reference>.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] "Analysis of Multiconductor Transmission Lines", C.R. Paul. John Wiley & Sons, 1994.
- [i.2] "Coupling of External Electromagnetic Fields to transmission Lines", A.A Smith John. Wiley & Sons, 1977.
- [i.3] "Principes and applications of EM field coupling to transmission lines", F.M. Tesch. Proc. Int'l Symp. Electromagn. Compat. (EMC'95), Zurich, Switzerland, pp.21-31 (Supplement), 1995.
- [i.4] "Compatibilité Electromagnétique 1 - des concepts de base aux applications", P. Degauque, A. Zeddani. Hermes Science. Get et Lavoisier, Paris 2007.
- [i.5] "Coupling to Shielded Cables", E.F. Vance. John Wiley & Sons, 1977.
- [i.6] "Analyse du rayonnement et des couplages électromagnétiques provoqués par des signaux hautes fréquences interférant avec des câbles d'énergie basse tension", R.Razafferson. Thèse de doctorat, Université des sciences et Technologies de Lille, 31 October 2002.
- [i.7] "PowerLine effects over VDL2 performances", A.Bergaglio, U.Eula, M.Giunta, A.Gnazzo. IEEE international Symposium on Power Line, ISPLC 2008.

- [i.8] ETSI TR Plugtest Report on Coexistence VDSL2 and PLT (LANPARK).
- [i.9] PLC-VDSL Crosstalk Measurements (DS2). Description of the test kit, installer tool and measurement procedure for field and laboratory test.
- [i.10] Broadband Forum TR-069. CPE WAN Management Protocol v1.1.
- NOTE: See http://www.broadband-forum.org/technical/download/TR-069_Amendment-2.pdf.

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACS	Auto Configuration Server
AFE	Analog Front-End
AGC	Automatic Gain Control
CAT3	Category-3 twisted-pair cable
CAT5	Category-5 twisted-pair cable
CPE	Customer Premises Equipment

NOTE: DSL modem installed in the customer premises.

CSV	Comma-Separated Value
DMT	Discrete Multi Tone modulation
DSL	Differential Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
FDD	Frequency Division Diplexing
MTL	Multiconductor Transmission Lines
OFDM	Orthogonal Frequency Division Multiplex
PHY	Physical Layer
PLC	Power Line Communications
PLT	Power Line Telecommunications
POTS	Plain Old Telephone Service (legacy telephone network)
PSD	Power Spectral Density
RPC	Remote Procedure Call
TEM	Transversal Electromagnetic Mode
TLT	Transmission Line Theory
UPA	Universal Powerline Association
VDSL2	Very High-speed DSL 2

4 Analysis of the electromagnetic coupling between PLC and VDSL2 links

4.1 Executive summary about the analysis

VDSL2 access technology will be used in Next generation networks as final drop for residential customer. Within customer premises and in certain circumstances we can have coexistence between VDSL2 and Powerline technology (PLT or PLC). The problem of coexistence between Powerline and VDSL2 depends on the fact that these technologies share the same frequency band up to 30 MHz, and sometimes the power line can be located near the VDSL2 cable. It is well known that cables constituting the power line network are not balanced and consequently at these frequencies some radiated emissions may occur. The aim of this paper is to theoretically study the coupling between Powerline and VDSL2 links. In order to validate the proposed model a comparison with experimental results is also given.

The simulation tool based on the transmission line theory allows us to have a good knowledge about the mechanisms of coupling between a VDSL2 cable and PLT link located both in the customer premises. The differences observed between theoretical and experimental results are mainly due to the difficulties to define with enough precision the per unit length parameters of the lines and the parallelism between the wires. However we can consider as sufficient the agreement between the theoretical results and the measurements obtained by LANPark Lab or given in [1.7] in order to carry out a complementary study taking into account all the main parameters involved in the coupling.

4.2 First consideration

VDSL2 access technology will be used in next generation networks as final drop for residential customer. Within customer premises and in certain circumstances we can have coexistence between VDSL2 and Powerline technology (PLT or PLC). As both technologies use the same frequency bandwidth we are thus interested in this paper in the theoretical study of the coupling between Powerline and VDSL2 links. In order to validate the proposed model a comparison with experimental results is also given.

4.3 Reference configuration

Figure 1 shows a uniform multiconductor transmission line (unshielded VDSL2 multipair cable and unshielded 3-wires powerline) above an ideal ground-plane. The conductors are assumed to be infinitely long and the ground-plane is infinitely extended.

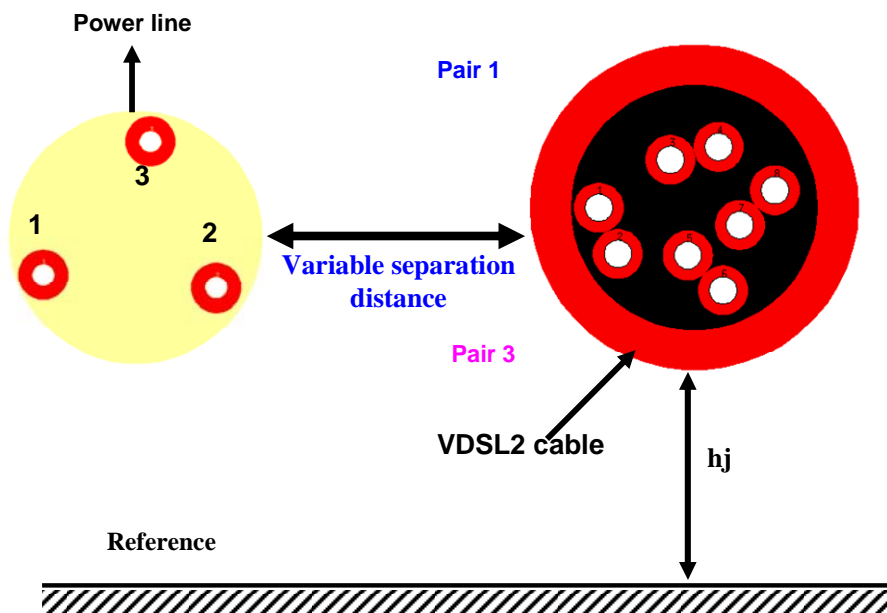


Figure 1: Reference configuration

4.4 Power Injected between two PLT modems

Figure 2 shows a wanted signal differential Power Spectral Density (PSD) measured between the two PLT modems using different coupling network. The obtained mean value is around -55 dBm/Hz (QuasiPeak). This value has been used during the simulation.

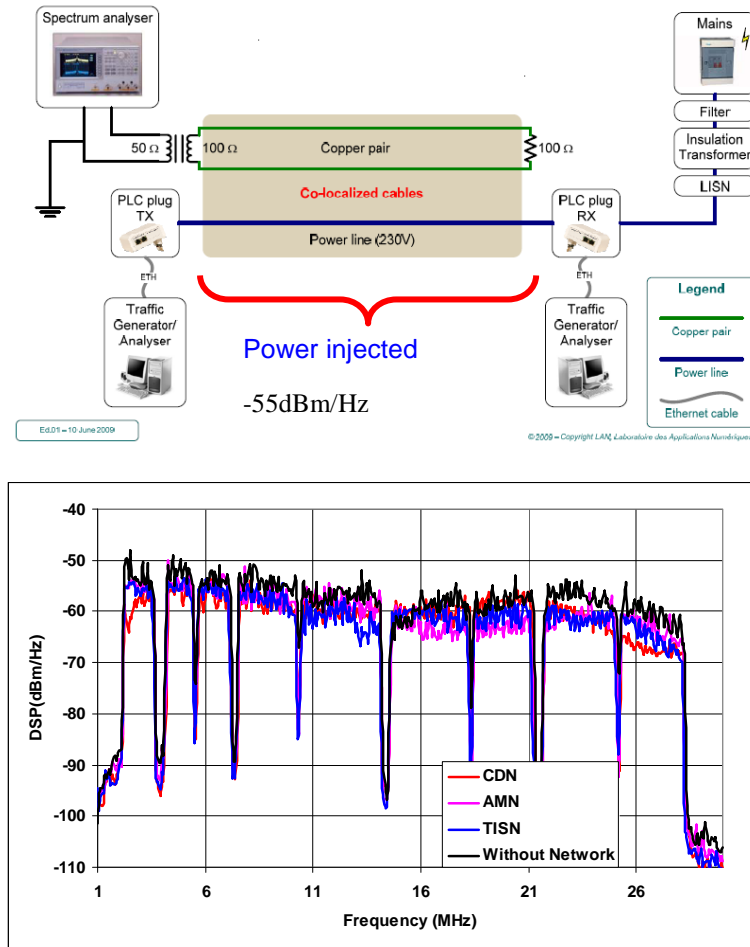


Figure 2: PSD measured between 2 PLT modems

4.5 Theoretical approach

To resolve this problem, we have chosen to use modelling tools based on the transmission-line theory (TLT). This choice is basically justified by the mathematical and computational simplicity of the model, together with the good accuracy it has proven over more than one hundred years of extensive validations in many different contexts [i.1], [i.2], [i.3], [i.4] and [i.5].

The formulation and analysis method employed is the quasi-TEM (transverse electromagnetic) approach, i.e. the principal propagation mode of the line is TEM. Taylor and al. applied this approach to study the field coupling to a two-wire line and later generalized to Multiconductor Transmission Lines (MTL), and the line is considered a uniform line in that the $(n+1)$ conductors are parallel to each other and the axis of a rectangular coordinate system.

4.5.1 Coupling to aerial cables

The process is first to consider the incident electric field in the absence of the cable then to transform this incident field like an equivalent source term (Figure 3) in the model of the transmission-line theory (TLT). In practice, it is the approach known as of Agrawal which primarily has the most advantages because the incident field useful for the model is limited to the component of the incident electric field tangential to the cable [i.4].

$$[E_T(x, z)]_i = \int_{C_i} \mathcal{E}^{incident} \cdot d\vec{l} \quad \text{Equation (1)}$$

The quantity $[E_T(x, z)]_i$ is the integral of the component of the incident electric field vector line that is in the transverse plane and tangent to the contour C_i along that contour.

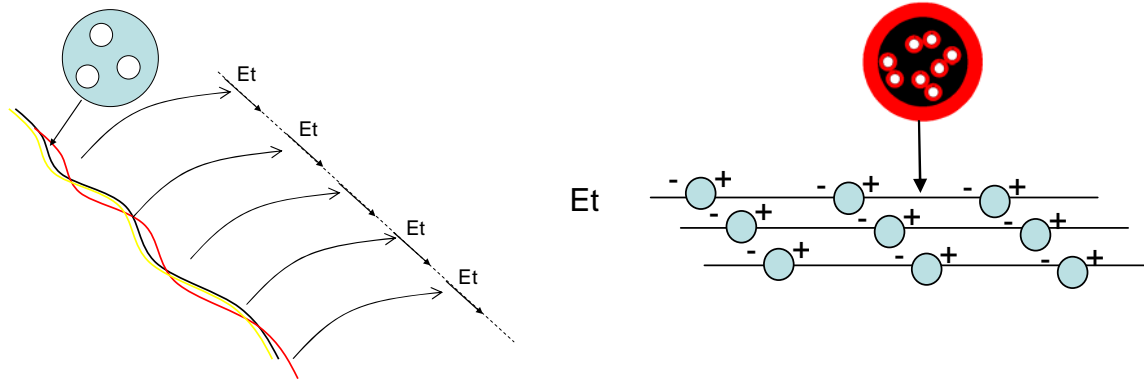


Figure 3: Equivalent source term

The differential equations for the voltage and current along the transmission line in the presence of distributed excitations are:

$$\begin{cases} \left(-\frac{dV}{dz} \right) = (Z) \cdot (I) - E_x^i(x) - j \cdot w \cdot \left(\int_0^h B_y^i(x, z) \cdot dz \right) \\ \left(-\frac{dI}{dz} \right) = (Y) \cdot (V) + j \cdot (C) \cdot w \cdot \left(\int_0^h E_z^i(x, z) \cdot dz \right) \end{cases} \quad \text{Equation (2)}$$

Where :

Z = impedance per unit length.

Y = admittance per unit length.

$E_x^i(x)$ = tangential electric field at the surface of the ground and in the absence of the cable.

$B_y^i(x, z)$ = the y -component of the magnetic field in the absence of the cable.

$E_z^i(x, z)$ = the z -component of the electric field in the absence of the cable.

The right hand terms $E_x^i(x)$, $j \cdot w \cdot \left(\int_0^h B_y^i(x, z) \cdot dz \right)$ and $j \cdot (C) \cdot w \cdot \left(\int_0^h E_z^i(x, z) \cdot dz \right)$ represent the distributed line excitations of the common impedance, inductance and capacitive coupling modes, respectively. The impedance and admittance per unit length (Z) and (Y) are defined as:

$$\begin{aligned} (Z) &= R + j \cdot (L) \cdot \omega \\ (Y) &= G + j \cdot (C) \cdot \omega \end{aligned} \quad \text{Equation (3)}$$

In this section, we will consider an MTL line with perfect conductors surrounded by a homogeneous and lossless medium. In this case matrices R and G are equal to zero. Due to the TEM assumption, the matrices of inductance and capacitance are related to the static solution of Laplace's equation.

In particular, (C) and (L) are related by:

$$(C) = \mu \cdot \varepsilon \cdot (L)^{-1} \quad \text{Equation (3a)}$$

where μ and ε are respectively the magnetic permeability and the dielectric permittivity of the surrounding medium.

The differential equation current (4) of the 2nd order is obtained by the combination of the equations (2) and (2) in which (S) is a term related to excitation.

$$\left(\frac{d^2 I}{dz^2}\right) - (Z) \cdot (Y) \cdot (I) = (S) \quad \text{Equation (4)}$$

The voltages and currents are virtual quantities, related to the physical ones by equation (1). Actually, the propagation along each line corresponds to the N TEM modes allowed by a MTL, as introduced in clause 4.5. For this reason, this solution of equation (4) is referred to as a modal approach. Hereafter, the quantities voltages and currents will be referred to, respectively, as modal voltages, currents and excitation terms.

4.5.2 Synthesis processing

Data processing and calculations were done using Fortran 90 Software™ (already developed in [i.6] for similar studies). Of course, we envisaged using the CRIPTE software™ for simulation, but it is not currently available. Since the calculation process is the same. We think that the results will lively be the same.

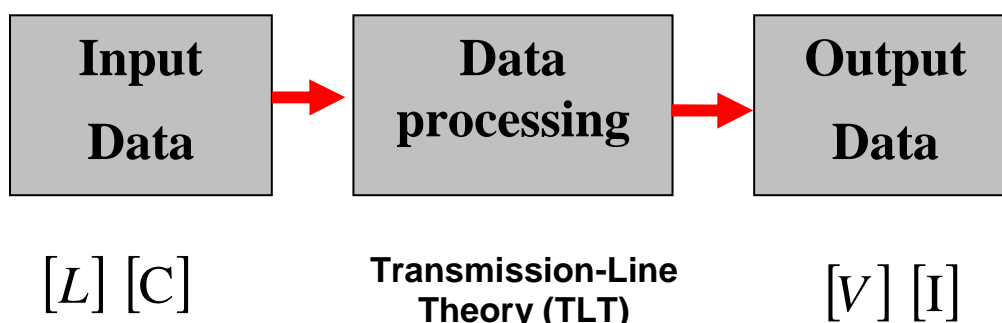


Figure 4: Calculation process

4.6 Summary of the results

4.6.1 Untwisted Telecom wires

Table 2 shows the coupling noise PSD (dBm/Hz) on the telephone wires positioned at different distance according to the simulation (Wire diameter, $d_w = 0,5$ mm).

Table 1: Experimental results for untwisted telecom wires

		Untwisted Length			
		1 m	5 m	20 m	40 m
Distance	20 cm	-140,5	-140,5	-135,7	-134,6
	6 cm	-138,3	-127,1	-125,8	-126,2
	1 cm	-136,2	-124,6	-122,9	-123,4
	0 cm	-126,1	-123,1	-121,3	-121,1

The experimental results indicated in Table 1 (obtained by LanPark) show the variation of the level of coupling noise between -121 dBm/Hz and -140,5 dBm/Hz.

Table 2: Summary of theoretical results for untwisted telecom wires

		Length			
		1 m	5 m	20 m	40 m
Spacing	20 cm	-147,1	-145,3	-144,7	-143,5
	6 cm	-137,2	-132,4	-132,6	-131,3
	1 cm	-130,2	-127,6	-127,4	-127,1
	0 cm	-127,8	-126,2	-126,1	-125,7

The simulation results are shown in Table 2. These results show that the level of the coupled noise on the telephone wires in presence of the PLC can reach -125,7 dBm/Hz to -147,1 dBm/Hz.

4.6.2 Twisted wires (CAT3)

Table 3 shows the coupling noise PSD (dBm/Hz) on the twisted telephone wires positioned at different distance according to the simulation.

Table 3: Experimental results for twisted telecom wires (CAT 3)

CAT 3

		Length			
		1 m	5 m	20 m	40 m
Space	20 cm	-140,7	-139,1	-137,5	-135,6
	6 cm	-139,9	-138,9	-137,9	-136,2
	1 cm	-139,0	-135,1	-129,8	-129,8
	0 cm	-138,0	-130,2	-124,7	-121,2

The experimental results for the same cable are indicated in Table 3 (obtained by LanPark). They show the variation of the level of coupling noise between -121 dBm/Hz and -140,7 dBm/Hz.

Table 4: Summary of theoretical results for twisted telecom wires (CAT3)

		Length			
		1 m	5 m	20 m	40 m
Spacing	20 cm	-147,8	-147,3	-145,7	-144,7
	6 cm	-141,1	-139,7	-138,5	-137,6
	1 cm	-134,6	-133,3	-133,1	-132,7
	0 cm	-131,6	-130,3	-129,8	-129,2

The simulation results are presented in Table 4. These results show that the level of the coupled noise on the telephone wires (CAT3) in presence of the PLC can reach -129 dBm/Hz to -147,8 dBm/Hz.

4.6.3 Twisted wires (CAT5)

Table 5 shows the coupling noise PSD (dBm/Hz) on the twisted telephone wires positioned at different distance according to the simulation.

Table 5: Experimental results for twisted telecom wires (CAT 5)

		Length			
		1 m	5 m	20 m	40 m
Space	20 cm	-140,4	-140,4	-140,6	-140,6
	6 cm	-140,3	-140,2	-140,3	-139,9
	1 cm	-139,4	-139,0	-138,7	-139,1
	0 cm	-138,5	-138,7	-137,1	-136,8

The experimental results for the same cable are indicated in Table 5 (obtained by LanPark). They show that the variation of the level of coupling noise is between -136,8 dBm/Hz and -140,4 dBm/Hz.

Table 6: Summary of theoretical results for twisted telecom wires (cat5)

		Length			
		1 m	5 m	20 m	40 m
Spacing	20 cm	-149,2	-147,3	-147,2	-146,8
	6 cm	-142,3	-140,3	-140,1	-140,1
	1 cm	-135,6	-134,4	-134,5	-134,3
	0 cm	-132,5	-130,8	-130,9	-130,6

The simulation results are presented in Table 6. These results show that the level of the coupled noise on the telephone wires (CAT5) in presence of the PLC can reach from -130,6 dBm/Hz to -149,2 dBm/Hz.

Remark: According to other results given in [i.7], the level of coupling noise PSD on the telephone lines positioned at different distance can reach from -95 dBm/Hz to -110 dBm/Hz in the presence of PLC.

4.7 Examples of theoretical results

Figure 5, Figure 6 and Figure 7 show the examples of theoretical results of the coupling noise PSD on the VDSL2 lines at three different cables and different lengths, as the PLC signals is carried by the power line situated at a separating distance of 0 cm.

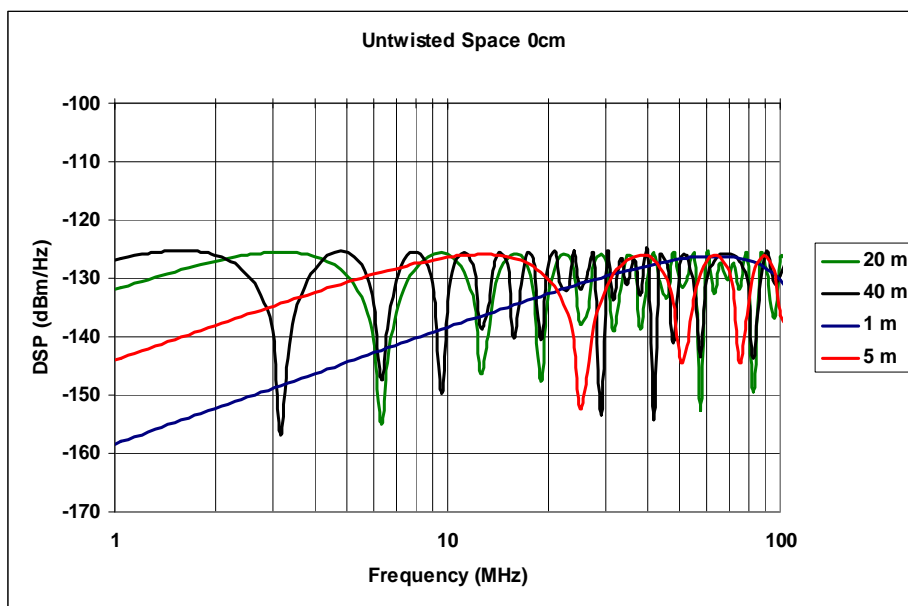


Figure 5: Coupling noise PSD on the VDSL2 lines positioned at different distance (Untwisted, space = 0 cm and wire diameter (dw) = 0,5 mm)

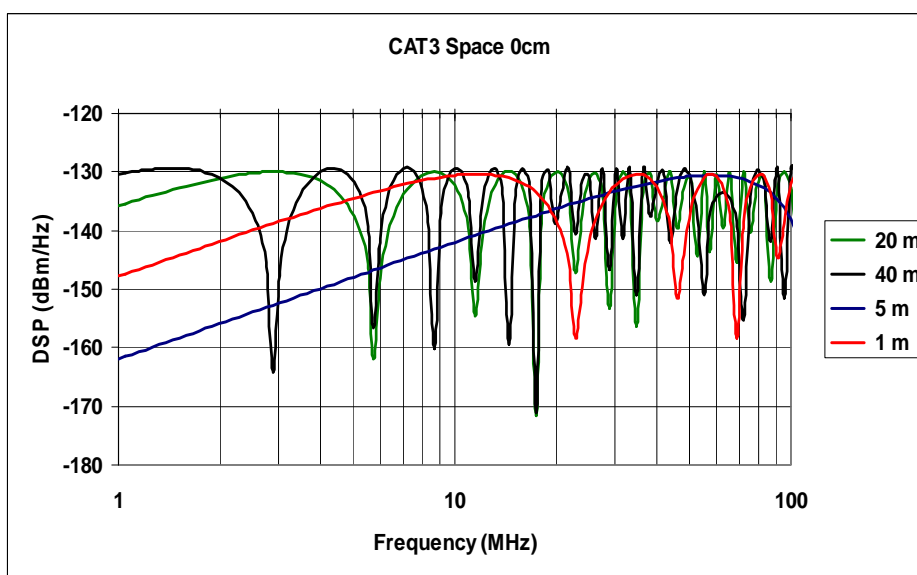


Figure 6: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cat3, space = 0 cm and wire diameter (dw) = 0,5 mm)

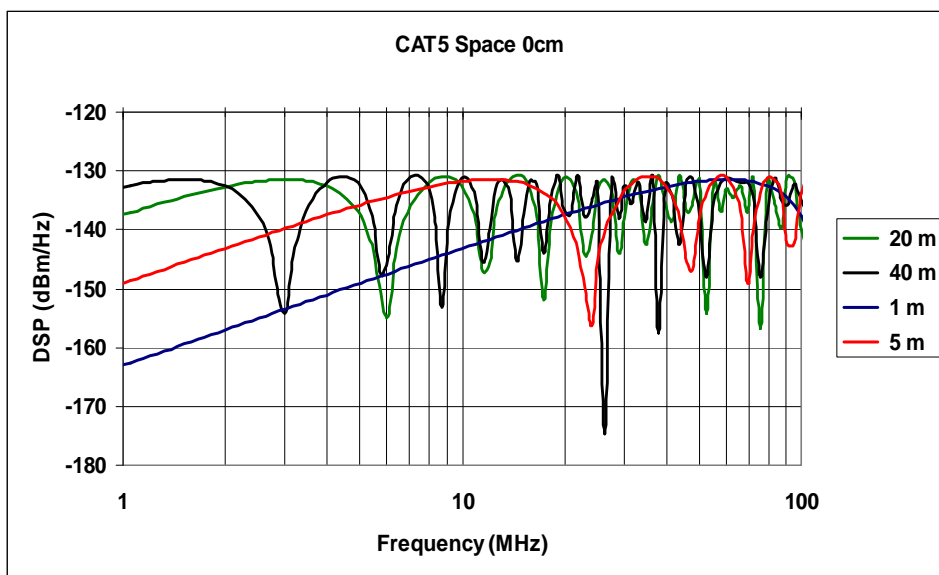


Figure 7: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cat 5, space = 0 cm and wire diameter (d_w) = 0,5 mm)

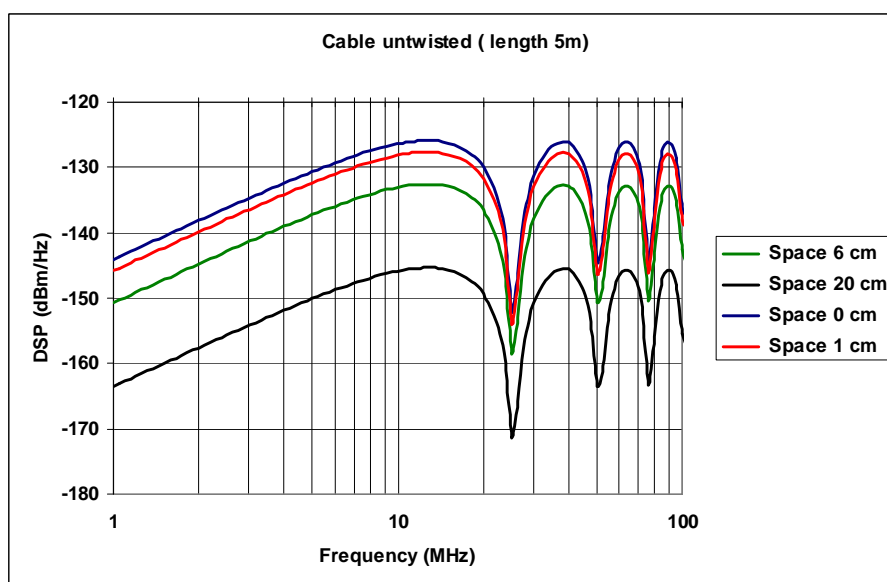
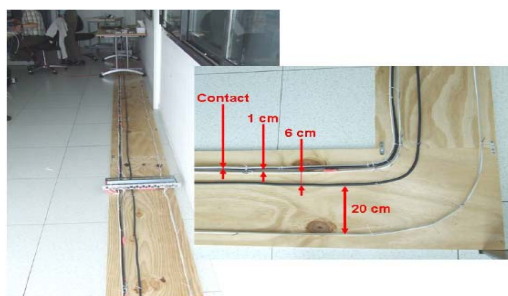


Figure 8: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cable untwisted length = 5m, space (variable) and wire diameter (d_w) = 0,5 mm)

Figure 8 shows the impact of the space for cable untwisted (length 5 m). We can see that we obtained a variation about 19 dB.



© 2009 – Copyright Laboratoire des Applications Numériques pour ETCI/CTI

Figure 9: Experimental set up

The differences between the theoretical and the experiments results are mainly due to the non-respect of parallelism between the wires (see the picture in Figure 9).

5 Algorithms to allow the coexistence of PLT with VDSL2

5.1 Executive summary about the algorithms

We focus our effort on the spectral management as the occupation of each carrier . To ensure a better coexistence of PLT and VDSL2 services, we propose two solutions for this purpose: an approach based on detection and an approach based on avoidance.

- 1) In case of mild interference of PLT on VDSL2, an adaptive filter at the input of the VDSL2 transceiver is a mitigation solution.
- 2) In case of severe interference of PLT on VDSL2, a spectral management based on listing PLT carriers close to VDSL2 carriers and reducing their power level and modifying the bit loading should be implemented in PLT modem.

5.2 Problem statement

A recent survey of literature on this coexistence problem shows the interest of other members not involved in this STF384 and other publications motivating to solve this problem of coexistence.

This motivation is aiming our investigation on signal processing solutions by examining in detail both the VDSL2 and PLT signals on the telephone and electrical channels.

The coupling of PLT on VDSL2 is a wide band signal and therefore traditional methods of coexistence (such as notching) are not applicable.

The data exchange between the PHY layers of existing VDSL2 CPE and PLT modems is not possible, therefore the DSM methods applied to DSL are not exploitable. The only feature we can exploit is the fact that the residential gateway based on VDSL2 technology is connected to at least one PLT modem in the same outlet.

The constraint on this investigation is related to present PLT and VDSL2 equipments and not forthcoming products. The solutions to be implemented should be simple and viable with existing technology.

VDSL2 and PLT technologies are based on ITU and ETSI standards respectively, both operating with OFDM transmission on different wires at home.

Both PLT and VDSL2 modems operate in the frequency range from 2 MHz to 30 MHz, although on different cables. The ETSI PLUGTEST on PLT-VDSL2 coexistence confirms the risk of potential interferences when the cables are very close to each other.

The work of the PLUGTEST was followed by a modelling performed by France Telecom in phase 1 of this STF384. The findings can be summarized as follows:

- 1) The dominating part of the interference above certain frequency is due to electromagnetic emission (radiation).
- 2) The interference (or the coupling) will increase with frequency up to a certain cut-off frequency.
- 3) The conducted field interference is not so strong as would generally be perceived.

5.3 Analysis of the PHY layers of PLT and VDSL2

The physical layer of PLT modem (PHY) is based on windowed Orthogonal Frequency Division Multiplexing (OFDM) as the basic modulation technique. The physical layer of VDSL1/VDSL2 modem (PHY) is based on windowed Orthogonal Frequency Division Multiplexing (OFDM) as the basic modulation technique, also called DMT (Discrete Multitone Transmission).

VDSL2 transceivers use frequency division duplexing (FDD) to separate upstream and downstream transmissions. The overlapping of the upstream and downstream passbands is not allowed. The allocation of the upstream and downstream frequency bands is defined by the band plan, which is specified by band-separating frequencies.

The VDSL2 signal can potentially use the frequency range up to 30 MHz, although the maximum frequency used by a modem to transmit data depends on the selected band plan and the conditions of telephone line.

The VDSL2 transceiver may select one or more sub-carriers to use for timing recovery, called Pilot Tones. Pilot tones are selected separately for initialization and showtime.

For VDSL2 two sub-carrier spacing are available: 4,3125 kHz and 8,625 kHz.

Table 7: PHY parameters of the VDSL2 profiles

Profile	Bandwidth (MHz)	Number of carriers	Carrier bandwidth (kHz)	Power (dBm)	Max. Throughput (Mbit/s, downstream)
8a	8,832	2 048	4,3125	+17,5	50
8b	8,832	2 048	4,3125	+20,5	50
8c	8,5	1 972	4,3125	+11,5	50
8d	8,832	2 048	4,3125	+14,5	50
12a	12	2 783	4,3125	+14,5	68
12b	12	2 783	4,3125	+14,5	68
17a	17,664	4 096	4,3125	+14,5	100
30a	60	3 479	8,625	+14,5	100

5.4 Channel Coupling Model for Signal Processing

For the purpose of signal processing to improve the coexistence of PLT with VDSL2, we consider the following model. Let $h_{1,1}$ be the channel model for VDSL2 and $h_{2,2}$ the model for the PLT channel. Let $h_{2,1}$ be the coupling model from PLT to VDSL2 and $h_{1,2}$ the coupling model from VDSL2 to PLT. This complete model is described in Figure 10 as an additive model of the coupling.

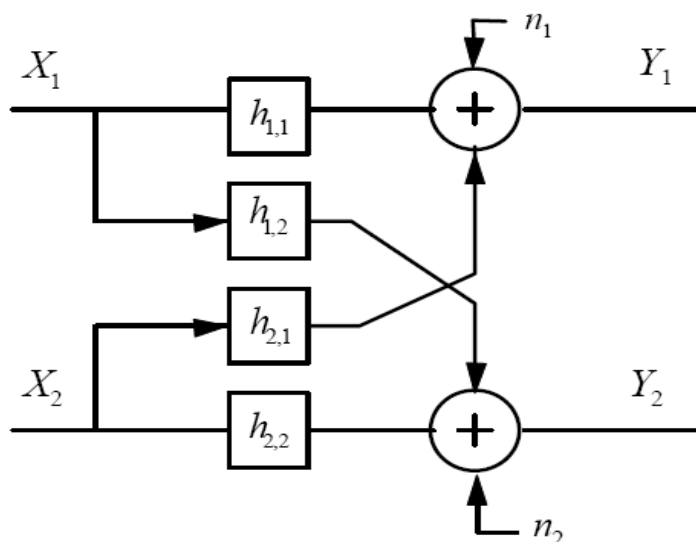


Figure 10: Channel coupling model

Following the simulation results produced by France Telecom (see clause 4), we consider only the baseband signals up to 30 MHz and focus on the coupling in the range of 1MHz to 30 MHz.

The cross-channel coupling depends on the type of cables (twisted or untwisted) used for VDSL2 transmission as well as the space between cables and their length.

We observe that the coupling factor is increasing as a function of frequency; this observation is correlated to the coupling factor between DSL lines in a same cable.

In the following clause 5.5, $H(f)$ is the transfer function, based on the PLT and VDSL2 channel coupling model (Figure 10), expressed as a matrix.

The following equations describe the coupling process between VDSL2 signal X_1 and PLT signal X_2 as linear mixing of signals with additive gaussian noise:

$$\begin{aligned} Y_1 &= h_{11}X_1 + h_{12}X_2 + n_1 \\ Y_2 &= h_{21}X_1 + h_{22}X_2 + n_2 \end{aligned} \quad \text{Equation (5)}$$

The input signals are X_1 for VDSL2 and X_2 for PLT and output signals (the ones actually received by the modems) are Y_1 for VDSL2 modem and Y_2 for PLT modem.

5.5 Method 1: Adaptive interference cancelling filter

The present method relates to a cancellation filter to suppress the interference of a PLT signal carried by a power distribution network in the user premises to the VDSL signal carried by a telephone system that is located close to some power cable.

The method is based on feeding the signal carried by the power network to the adaptive filter in order to obtain an estimate of the PLT signal that couples on the telephone line. The estimated signal is then subtracted from the signal carried by the telephone line.

This estimation is based on minimization of mean square error and following equation are classical for estimation of original signals (X_1, X_2) from linear combination of corrupted data (Y_1, Y_2).

$$\begin{pmatrix} \hat{X}_1 \\ \hat{X}_2 \end{pmatrix} = (H^T H)^{-1} H^T \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} \quad \text{Equation (6)}$$

The implementation of this system involves a VDSL gateway fed by a splitter filter modified in order to reject the interference of the PLT signal. The interference cancelling device includes an adaptive filter with a differential input and one output.

The adaptive filter receives the signal from the VDSL splitter and from an outlet of the electrical network where the PLT modem is connected. The device includes a capacitive coupler that is connected to an electrical outlet preferably located near the gateway integrating the VDSL2 modem to retrieve the signal carried by the power line.

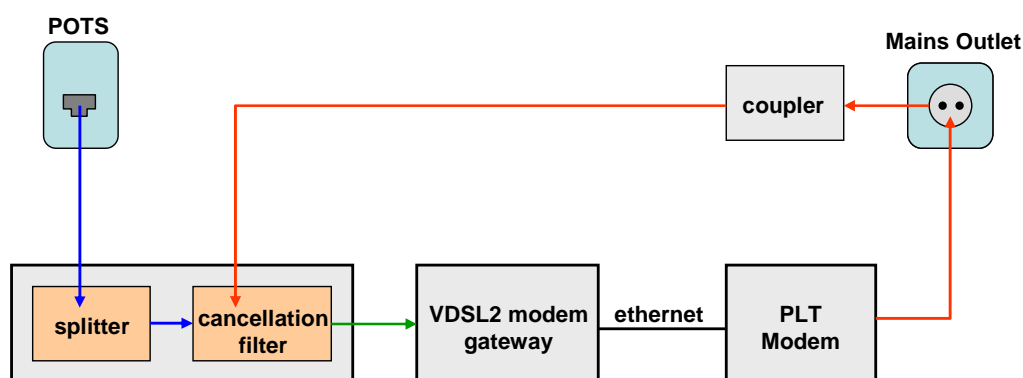


Figure 11: Block diagram of the interference cancellation system.

The process to cancel the interference involves picking-up the signal carried on the power line so that the adaptive filter obtains an estimate of the signal that disrupts the VDSL communication and subtracts the estimated signal from that carried by telephone line.

$$Y_1 - h_{12}\hat{X}_2 \quad \text{Equation (7)}$$

We proceed in two steps: first we use the zero forcing method to determine the complex coefficients of channel parameters:

$$\begin{pmatrix} Y_1 - h_{12} \dot{X}_2 \\ Y_2 - h_{22} \dot{X}_2 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad \text{Equation (8)}$$

Secondly, we estimate the original signals by solving the following equations:

$$\begin{pmatrix} Y_1 - h_{12} \dot{X}_2 \\ Y_2 - h_{22} \dot{X}_2 \end{pmatrix} = \begin{pmatrix} h_{11} \dot{X}_1 \\ h_{21} \dot{X}_1 \end{pmatrix} \quad \text{Equation (9)}$$

These two steps are repeated within a time interval to take into account the time variations of the PLT channel.

5.6 Method 2: Spectral management

We describe a method to reduce the interference from the PLT signal to the VDSL signal transmitted over a telephone line located at near the power line.

Both signals convey data in bits which are assigned to many carriers distributed over the same frequency band. The frequency plan for the VDSL2 upstream and downstream bands varies depending on the region.

A spectral management method to reduce the interference between a PLT signal and a VDSL2 signal transmitted on a phone line that is located near the power line is described.

In a first step, we determine at least one carrier frequency, called VDSL frequency, of a frequency plan used for the transmission whose level of spectral power density exceeds a predetermined threshold.

In a second step we determine at least one carrier frequency, called PLT frequency, of another frequency plan used for signal transmission on powerline, which is shared with at least one VDSL frequency.

And in a third step we reduce the power and therefore the number of bits assigned to each PLT frequency determined thereby.

The proposed method is based on the fact that a PLT carrier and a VDSL2 carrier overlap or they are separated by a distance smaller than a predetermined maximum distance.

The method is also based on the fact that the maximum distance is either zero, strictly greater than zero or greater than or equal to zero. This distance is defined as the magnitude of the difference between the VDSL2 windowed OFDM carrier and the PLT windowed OFDM carrier. This distance measures how close are the carriers between VDSL and PLT signals.

In Figure 12, the first graphs shows roughly the N VDSL carriers with frequencies F_k in the range and a threshold relative to the maximum PSD level. The second graph shows the N PLT carriers in the same band but the carrier spacing has a ratio of 1 to 4 from VDSL to PLT. According to the distance D, one VDSL carrier may be affected by 3 PLT carriers. For instance, VDSL carrier at F_k ($k = 11$) is interfered by PLT carriers at F_k ($k = 10, k = 11, k = 12$).

The third graph shows the result of the iterative bit loading algorithm decreasing the power level of these 2 PLT carriers and the redistribution of their payload on carriers 14 and 15.

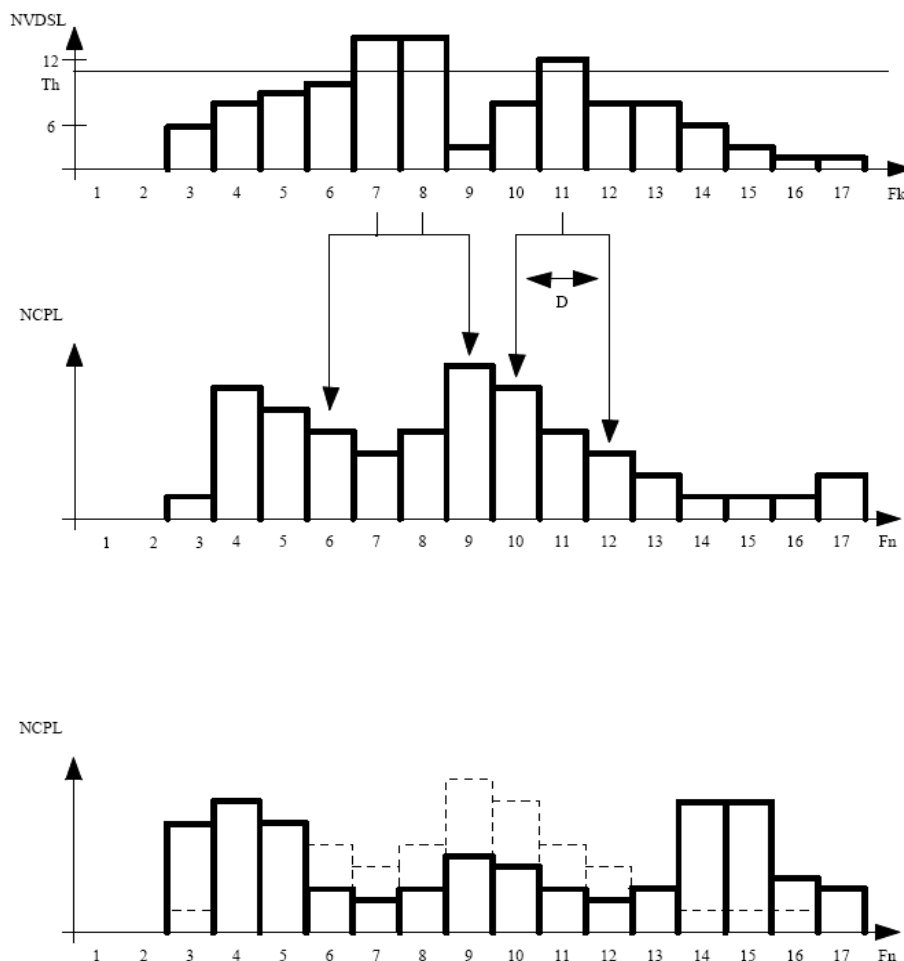


Figure 12: Spectral management and redistribution of the bit loading in a PLT signal

We make additional iterations according to steps 1 to 3, where the number of bits assigned to PLT carriers is decreased until the interference on the VDSL signal is compensated by the error correcting codes.

The Powerline Modem should be modified so as to detect the VDSL signal in silent periods of the PLT transmission by using an amplifier of VDSL signal when this signal is too weak to be detected by PLT modem.

6 PLT implementation of coexistence algorithms

6.1 Executive summary

The main requirement of this STF is to produce algorithms that can be implemented with the existing technologies. At present there is no standardized way to exchange information between the VDSL2 and PLT systems that would allow a coordinated action to detect and mitigate the interference. Therefore, it has been chosen to work exclusively on the PLT technology as it is the expertise of the concerned experts.

From the algorithms presented in clause 5, the one that is suitable for implementation on PLT devices is the spectral management (adjustment of the amplitude of the OFDM carriers). This clause presents three methods to manage the PLT spectrum: one for End Users, one for Installers and one for Service Providers. Although the implementation has been done for UPA modems, the methods described in this document are applicable to other power line technologies.

In addition to the tools, DS2 has developed a kit for installers that allows an easy measurement of the crosstalk in real scenarios. This kit has been used to measure the crosstalk level in several locations in order to complement the results obtained in the Plugtest. The results obtained in Spain and in France confirm that the coupling levels in real houses are in line with the experimental values, and they are low enough to allow the simultaneous use of VDSL2 and PLT.

6.2 Operating Principle

The spectral management consists in modifying the amplitude of the OFDM carriers of the PLT modem in the frequencies where the VDSL2 communication is affected.

Being the interference level very low as demonstrated in [i.8], it is likely that it will affect only the downstream bands of the VDSL2 signal. Therefore, only these bands are regarded when it comes to analyzing the interference and applying the spectral management.

The PLT system is tolerant to any variation in the PSD of the transmitted signal. If the spectrum is modified, the modems negotiate a new bit-loading scheme and the communication continues with a lower physical speed. A reduction of 10 dB to 20 dB in some parts of the PLT signal will still leave enough bandwidth to provide the required services while protecting the VDSL2 communication.

Figure 13 explains how the spectrum management is used to mitigate the interference. The red line represents the crosstalk of the PLT signal measured on the telephone line. Applying a different attenuation to each carrier that falls within a downstream band will set the crosstalk level to a predefined value (blue line) that is low enough to allow the correct demodulation of these bands in the CPE.

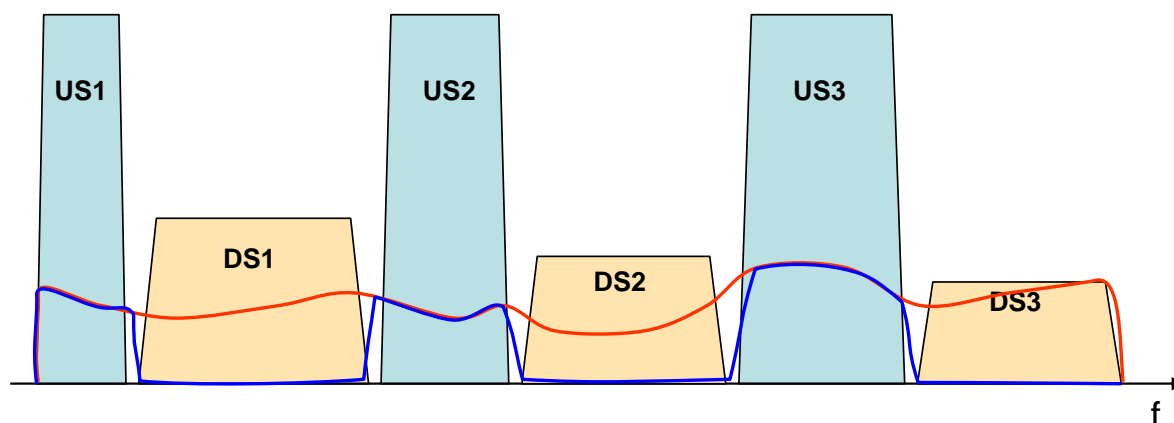


Figure 13: PSD of the PLT crosstalk signal before (red) and after (blue) the modification of the spectrum

6.3 End-user Coexistence Tool

This tool is designed for users that have bought a set of PLT modems in the retail market and have found that they interfere with their VDSL2 communication. In this case the Service Provider may be able to diagnose the problem on the VDSL2 system but he will not have the means to configure the PLT modems.

Knowing the VDSL2 profile being used, the end user can configure the PLT modems to reduce the power in the downstream bands. The tool allows setting a variable attenuation of the PLT signal in these bands between 0 dB and 25 dB. If the Service Provider is not able to give a clue of the attenuation required on the PLT signal, the end user should try out, through trial and error different values until the VDSL2 communication works smoothly.

A snapshot of the tool is presented in Figure 14. There are two controls that need to be configured by the user: the VDSL2 profile and the percentage of the mitigation. Once the level is selected, it can be applied individually to each of the modems shown in the list. There is an indicator that turns green if the operation has been successful.

The information regarding the frequencies of the upstream and downstream bands is contained in a configuration file located in the same directory as the application.

This tool has one major shortcoming. The lack of information about the real coupling level and the frequencies where this coupling is more intense does not allow an optimal adjustment of the PLT spectrum. The mitigation is applied blindly on all the downstream bands and with the same intensity. Therefore, when the level is adjusted for the band where the interference is strongest it might be excessive for the other bands, resulting in an unnecessary deterioration of the PLT speed.

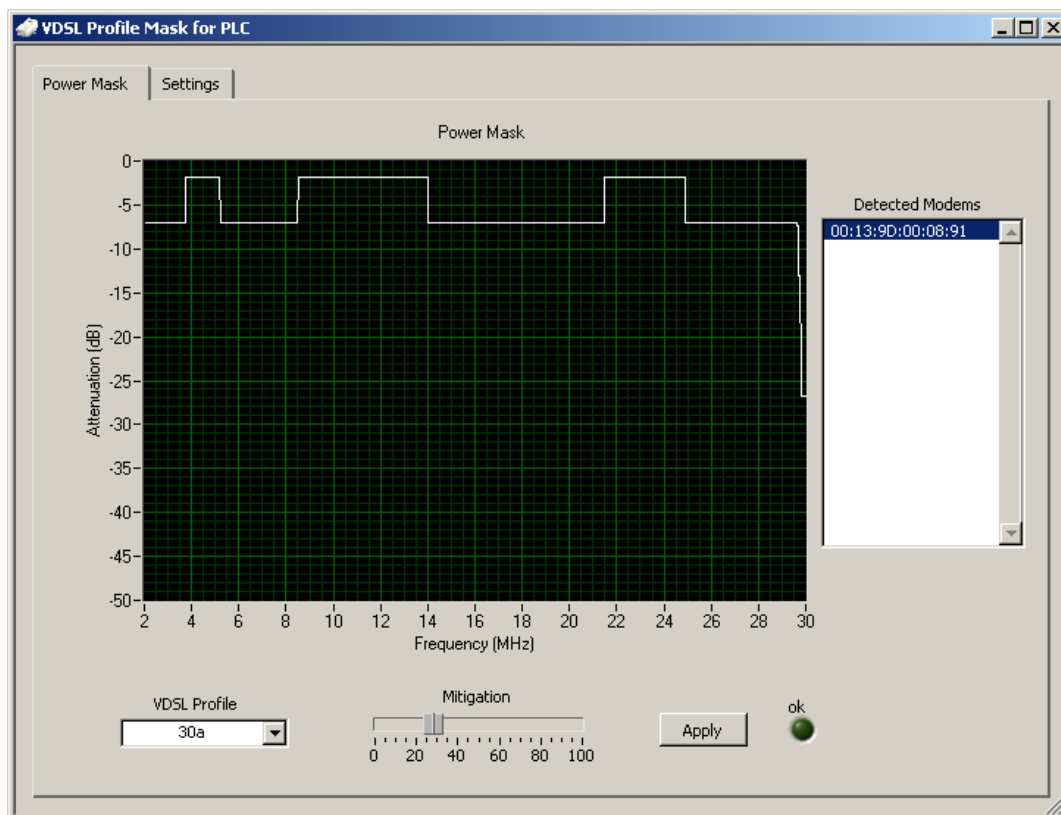


Figure 14: End-user tool for PLT spectral management

6.4 Installer Tool

This tool is designed for the crew in charge of installing the VDSL2 and PLT modems provided by the Service Provider. The software application is complemented with a special PLT modem that connects to the telephone outlet in order to measure the interference seen by the VDSL2 CPE. This PLT modem has a modified analog front-end that resembles the impedance and sensitivity of the CPE. This modem can detect crosstalk levels as low as -140 dBm/Hz.

The installer should plug the PLT modems in the locations selected by the customer. The coupling pattern depends on the location of the PLT modem, therefore it needs to be adjusted separately for each device.

A snapshot of the Installer Tool is shown in Figure 15. The tool is slightly more complicated than the end-user tool, but it is intended to be used by a technician. The detailed explanation of the use of this tool is explained in [i.9].

Once the installer has acquired the crosstalk profile from the PLT modem to the VDSL2 CPE (blue line in Figure 15) the tool calculates the amount of mitigation required for every carrier, taking into account the VDSL2 profile and desired level after mitigation (yellow line). The tool highlights the portions of the PLT spectrum to be trimmed with a thicker red line. On the right side of the window there is a level indicator that reports the average crosstalk PSD in dBm/Hz. In case there are dynamic variations of the average coupling level, the indicator will report the maximum value with a yellow bar stacked on the red bar.

The tool records the measured crosstalk levels in a file that can be processed at a later time. This feature has been used to collect statistics of the coupling levels in real houses.

The spectral configuration calculated with this tool is transferred and stored in the modem.

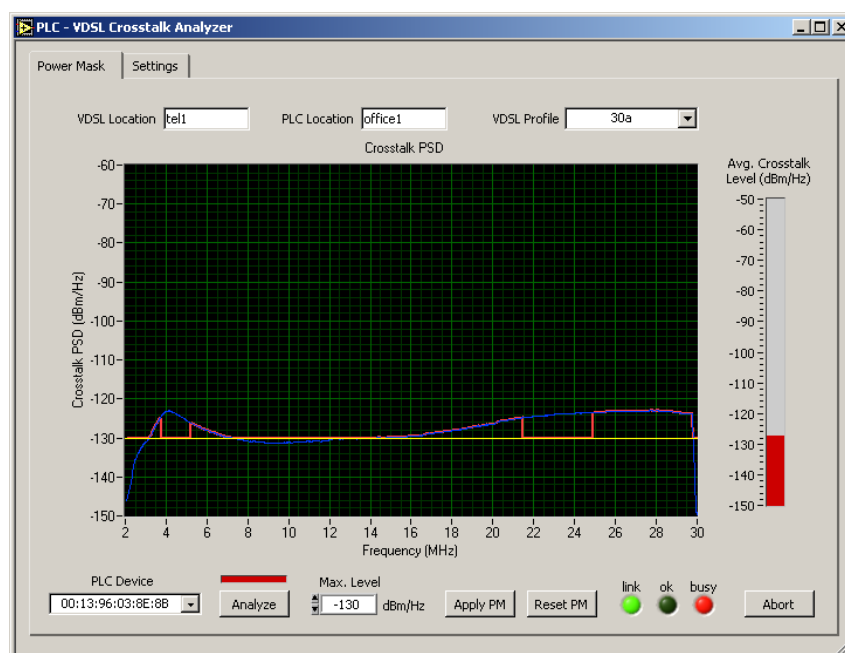


Figure 15: Installer tool to measure PLT interference and modify the PLT spectrum

The algorithm used to calculate the attenuation is very simple. Since the CPE is simulated with a PLT modem, there is no need to convert the frequencies of the carriers. What the PLT modem measures is what a real VDSL2 CPE would see because the AFE is similar. Since the crosstalk level is directly proportional to the level of the differential PLT signal, a relative reduction of the second one will cause a reduction of the first one in the same proportion.

Therefore, the attenuation to apply is the difference between the measured crosstalk level (blue line) and the desired floor level (yellow line) within the downstream bands.

For the particular case of the DS2 PLT modems, the formula to calculate the attenuation of PLT carrier i is the following:

$$Att_i = TargetPSD - CFR_i + 67 + Gain \times 6 \quad \text{Equation (10)}$$

Where $TargetPSD$ is the desired crosstalk level after the mitigation that is supposed to be a constant value across the entire PLT band. CFR_i is the measured signal level for carrier i in dB, as obtained from the FFT conversion. $Gain$ is the gain index of the reception amplifier after the convergence of the AGC; each gain step corresponds to 6 dB. There is a conversion factor (67) that includes the calibration of the AFE in order to produce the result in true dBm/Hz. Finally Att_i is the attenuation in dB that should be applied to the PLT carrier under consideration.

The installer has the possibility to confirm that the calculated power mask produces the expected result by performing a second acquisition of the crosstalk level. If the mitigation is correct, the crosstalk curve will look flat in the downstream bands, as shown in Figure 16.

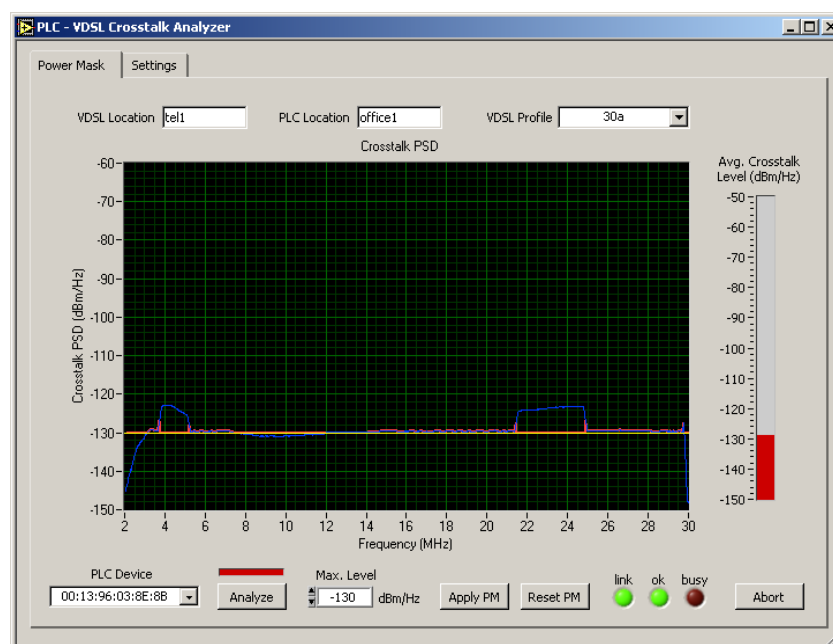


Figure 16: Crosstalk profile after the mitigation has been applied

6.5 Service Provider Tool

When the Service Provider or Telecom Operator detects a problem with the VDSL2 link that could be due to the PLT modems, there are ways to remotely check the coupling level and change the PLT spectrum.

The measurement of the crosstalk level is done indirectly by checking the noise margin of the VDSL2 downstream bands. The operator may need to ask the customer to plug and unplug the PLT modems in order to evaluate the effect on the VDSL2 link. The variation in the noise margin indicates the amount of attenuation required on the PLT spectrum to prevent the adverse effects. The method to obtain this information from the DSLAM is not covered in this document.

The adjustment of the PLT spectrum can be done remotely using the TR-69 protocol that is supported in UPA-compatible PLT chips Aitana™ and Aitana⁺⁺™ running Spirit 4.8 or higher. The RPC method to change the spectrum of the PLT modems is the Download method described in clause A.3.2.8 of the TR-069 Specification [i.10]. This method allows the modem to download a vendor-specific configuration file containing the amplitude values of all the OFDM carriers. The download of this file is started from the ACS. Figure 17 shows a screenshot of the Work Systems ACS interface that controls the download of the configuration file to a PLT modem.

The automation of this process requires a script that is able to read the noise margin data from the DSLAM in the vendor-specific format, correlate the frequencies of VDSL2 carriers to PLT carriers, calculate the attenuation required for each PLT carrier and download the configuration file to the modem using TR-69 [i.10]. Most of the work is related to protocols and data formats, being the data processing a small piece of work.

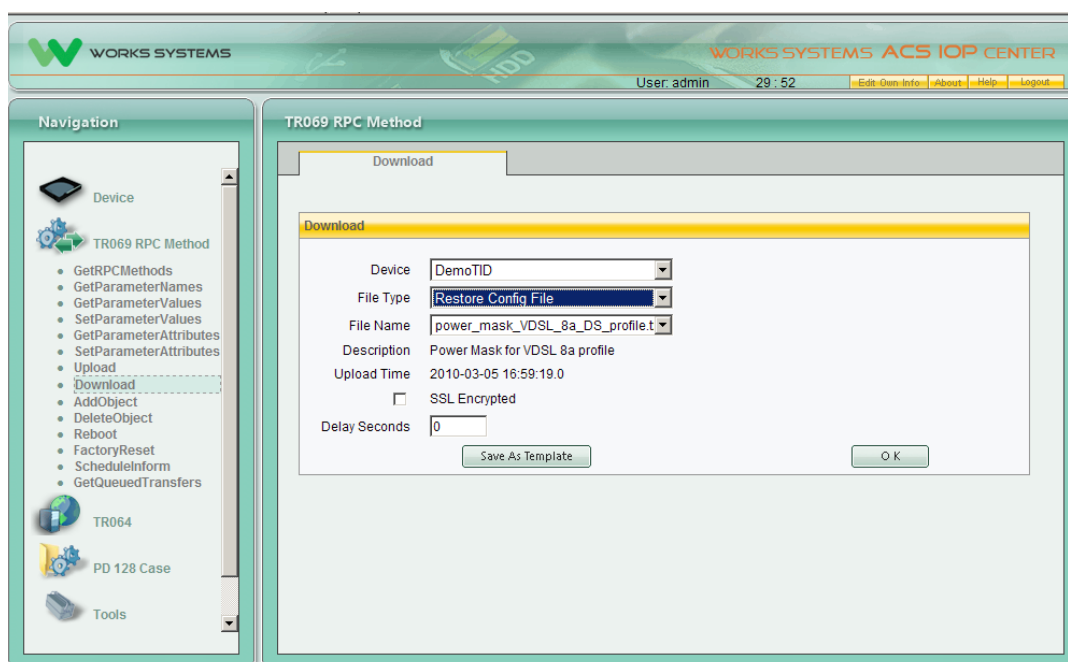


Figure 17: Snapshot of the Work Systems ACS interface to download the configuration file to change the PLT spectrum

The main drawback of this method is that there is no special hardware as in the installer kit that allows a true-value measurement of the crosstalk from the electricity cable to the telephone cable. In addition, a turnkey solution cannot be provided due to the diversity in the formats and protocols to access the VDSL and PLT equipment.

7 Crosstalk measurements in real houses

7.1 Executive summary

The availability of a kit to measure the coupling between electricity and telephone cables opens an interesting opportunity to confirm the measurements performed in the Plugtest. The installer tool described in clause 6.4 allows a quick acquisition and recording of this data for later analysis.

This clause presents the data obtained in measurements performed in several houses in Spain and France and compares the crosstalk level between houses with co-localized cables and separate cables.

7.2 Measurements

The measurements were performed plugging a PLT modem in an electrical outlet and the measurement unit in a telephone outlet. For every house, 2 telephone outlets are tested in combination with 5 to 10 electrical outlets, producing 10 to 20 measurements. Each combination of an electrical outlet and a telephone outlet is called a "pair" from now on.

The installer tool records the crosstalk level measured in every OFDM carrier, producing a set of 1 536 points in the range from 2 to 30 MHz. The resulting data is tagged with the location of the electrical and telephone outlets and recorded in a text file in CSV format. The data is then processed to produce the following results:

The maximum and average crosstalk values for every pair, presented in Figure 18 for Spain and in Figure 19 for France. The first 20 readings of Figure 18 correspond to a house having 20 meters of telephone cable co-localized in the same ducts as the electrical cable. The average crosstalk level is 7 dB higher than in the rest of the houses and the maximum level is 6 dB higher. The average crosstalk levels are between -120 dBm/Hz and -140 dBm/Hz in most of the cases.

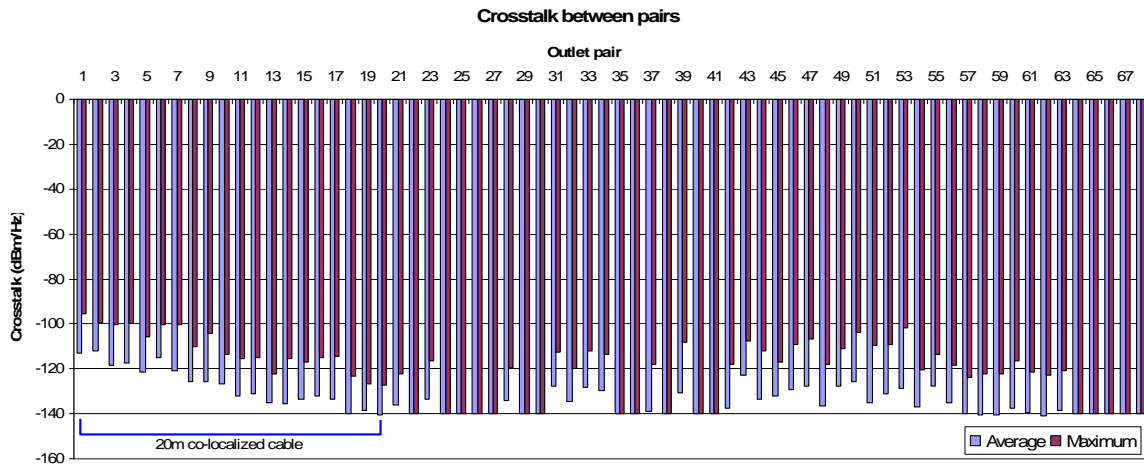


Figure 18: Crosstalk measurements between outlet pairs in Spain

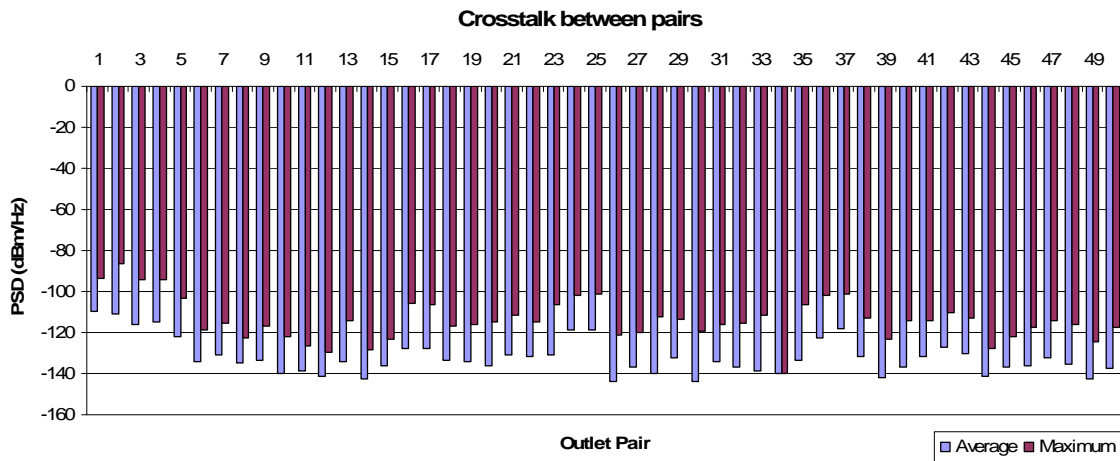
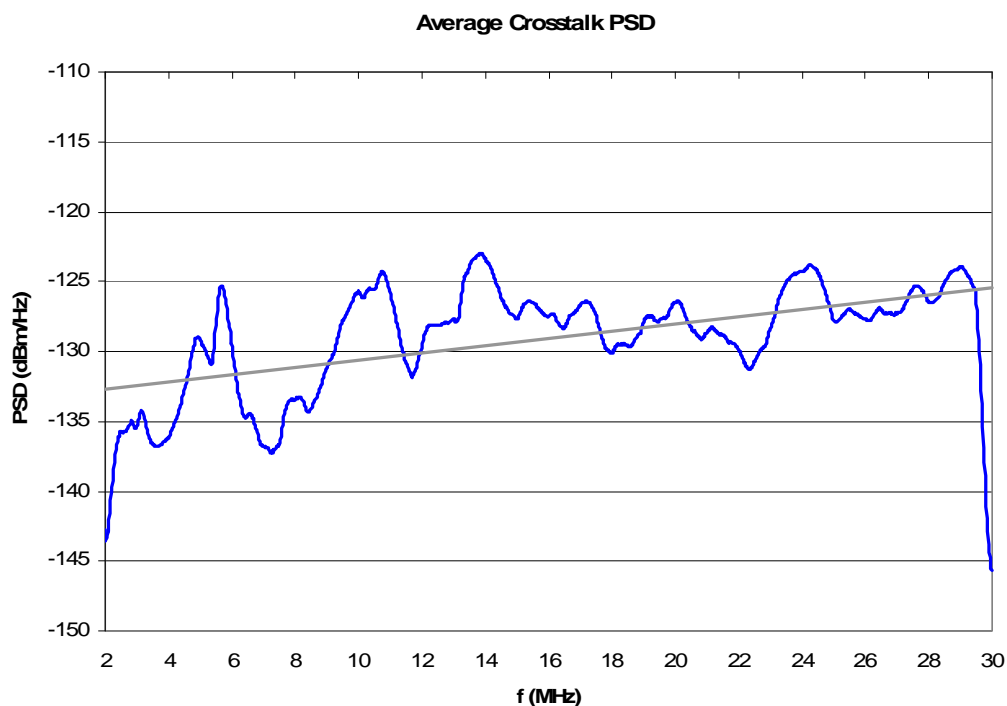


Figure 19: Crosstalk measurement between outlet pairs in France

The mean crosstalk profile as a function of frequency is presented in NOTE: The grey trend line show the dependency with frequency.

Figure 20. This graph averages the crosstalk value for all the pairs, on a carrier by carrier basis. More measurements are required to dilute the statistical dispersion, but the trend line (in grey) shows a dependency with frequency of around 0,27 dB / MHz.

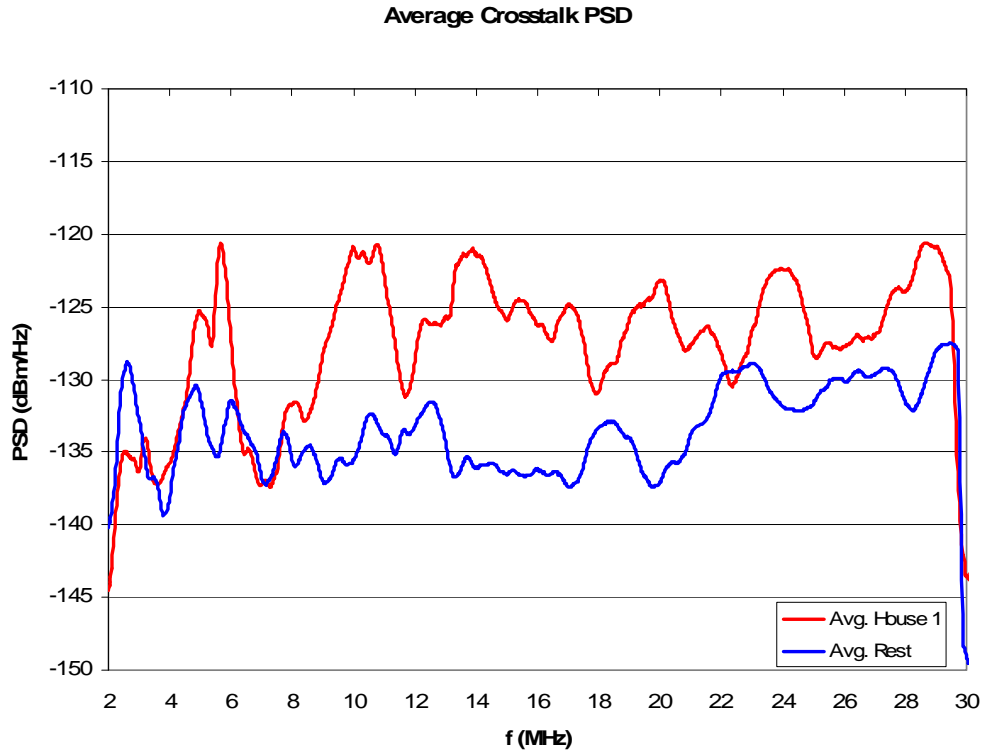


NOTE: The grey trend line show the dependency with frequency.

Figure 20: Average level of all outlet pairs

Another interesting comparison is the mean crosstalk profile of the house with co-localized cables and the rest of the houses. This comparison is presented in NOTE: The red line is a house with 20m of co-localized cable. The blue line is the average of all the other houses with installation according to regulation.

Figure 21.



NOTE: The red line is a house with 20m of co-localized cable.
The blue line is the average of all the other houses with installation according to regulation.

Figure 21: Comparison of average coupling level

Finally, the cumulative distribution of the crosstalk values is calculated for the entire population of samples. The result is presented in Figure 22. This distribution shows that in 90% of the cases the average crosstalk PSD is lower than -120 dBm/Hz, although the peak value is only lower than -102 dBm/Hz for the same percentage.

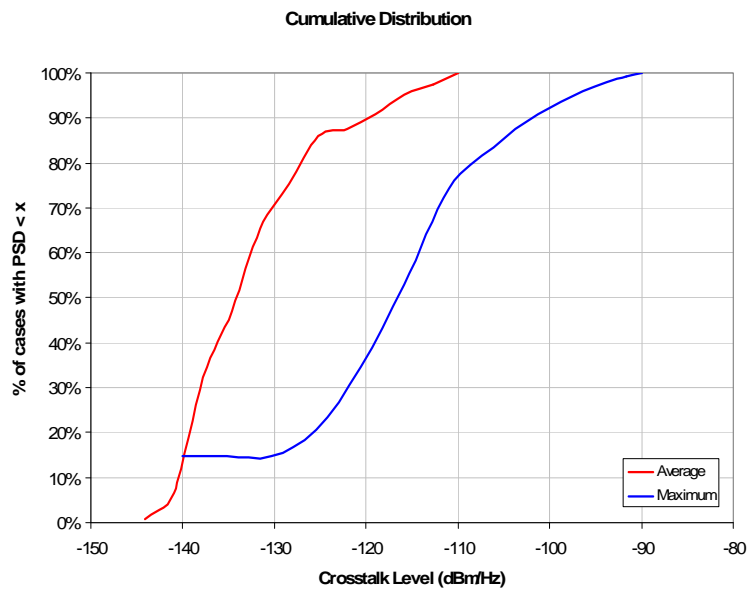


Figure 22: Cumulative distribution of the crosstalk levels for all the measured pairs in France and Spain

8 Effect of the mitigation on a VDSL2 system

8.1 Executive summary

The ultimate goal of the STF is to confirm that the suggested mitigation methods are effective in solving a real interference problem. The ideal test would be checking the noise margin in a real VDSL2 installation before and after the mitigation is applied. However, due to the difficulty to access DSLAM data in the commercial network, the test has been performed in a laboratory where the coupling between electricity cables and telephone cables has been simulated. This clause presents the results of these measurements.

8.2 Measurements

The test has been performed in the following cases:

- 300 m link with 998ADE30 band plan.
- 300 m link with 998ADE17 band plan.
- 600 m link with 998ADE17 band plan.

The crosstalk between electricity cables and telephone cables has been simulated in the lab, producing a worst-case scenario with an average crosstalk level of -110 dBm/Hz and a maximum crosstalk level up to -90 dBm/Hz. This scenario represents the 100th percentile of the field measurements, aiming to prove that the power masking method can solve the interference problem in 100 % of the cases. The test set-up used in the laboratory is presented in Figure 23. The CPE and the modem 3 are plugged alternatively. The modem 3 is a special PLT modem with an analog front-end that is similar to a VDSL2 front-end in order to measure the same signal that the CPE would see. The advantage of using a PLT modem is that we can synchronize on the PLT signal and use the capability of the modem to measure the spectrum.

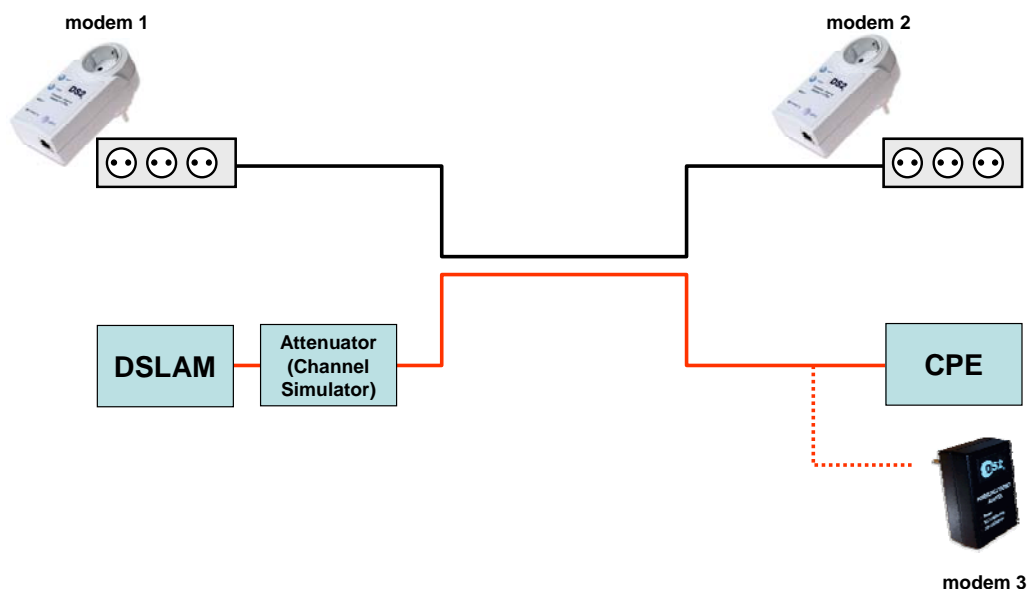


Figure 23: Test set-up to measure the effect of the mitigation

One of the coupling cases is presented in Figure 24. The red line delimits the downstream bands of the 998ADE30 profile. The target is to reduce the crosstalk level to a level of -135 dBm/Hz in the downstream bands. After applying the power mask, the crosstalk level is as presented in Figure 25.

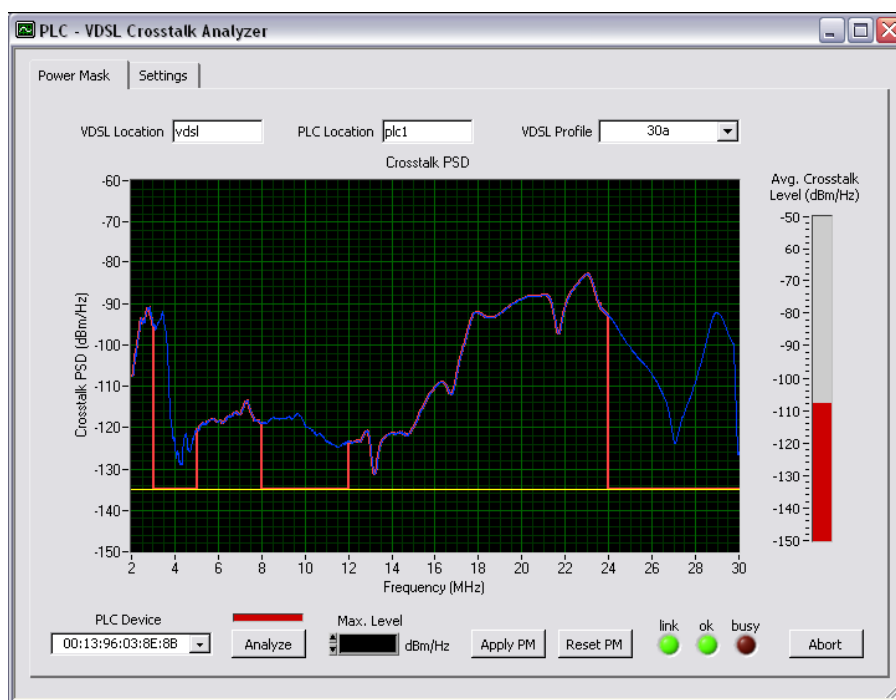


Figure 24: Crosstalk level on the telephone cable in the laboratory test bench

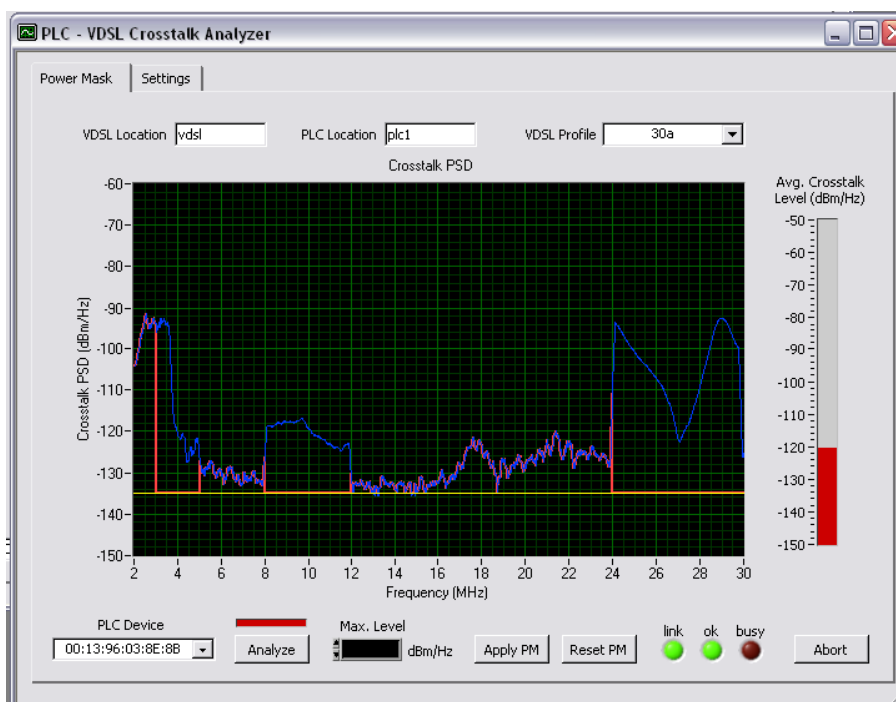


Figure 25: Crosstalk level after applying the power mask in the PLT modems

The noise margin and the downstream bit rate of the VDSL2 link has been measure in three conditions:

- Noise-free, in absence of the PLT modems.
- With normal PLT crosstalk, after the bit-loading of the VDSL2 link is re-negotiated in presence of the noise.
- With masked PLT crosstalk, after the bit-loading of the VDSL2 link is re-negotiated.

The test sequence is the following:

- 1) Connection of DSLAM and CPE, and start of video stream across the link.

- 2) Monitoring of VDSL2 link parameters (noise margin, data rate).
- 3) Connection of PLT modems 1 and 2, and start of PLT traffic across the electrical link.
- 4) Synchronization loss of CPE and re-negotiation of the VDSL2 link.
- 5) Monitoring of VDSL2 link parameters (noise margin, data rate).
- 6) Stop DSLAM and CPE connection, and connect modem 3 in the outlet where the CPE was plugged.
- 7) Crosstalk measurement and application of power mask on modems 1 and 2.
- 8) Remove modem 3 and replace with CPE.
- 9) Monitoring of VDSL2 link parameters (noise margin, data rate).

The following table summarizes the test results.

Table 8: Mitigation test results

VDSL2 Band Plan	Distance (m)	Attenuation (dB)	Noise Margin (dB)		PLT with mitigation	Video after mitigation
			No PLT	PLT w/o mitigation		
998ADE30	300	10,4	10,8 72 720	10,9 48 920	9,1 72 720	OK
998ADE17	300	14,5	8 74 948	8 62 342	6 75 095	OK
998ADE17	600	22,7	8 45 586	8 38 526	8 41 886	Not OK

In the first two cases the power masking mitigated the interference and restored the data rate to the maximum level, although the noise margin is decreased around 2 dB. The video played smoothly in presence of PLT modems. In the third case, the mitigation did not allow getting the maximum speed of the VDSL2 link and the video did not play smoothly.

In theory, a crosstalk level of -135 dBm/Hz would be low enough to allow the full bit-loading in the VDSL2 downstream even when the attenuation of the channel is 22,7 dB. Therefore, further investigation would be required to confirm or correct the results obtained in the third measurement.

9 Conclusions

The coupling model between a power line and a telephone line can be simulated using the transmission line theory. The results obtained are reasonably consistent with the measurements obtained in the PLT-VDSL2 Plugtest in LanPark [i.8]. The small delta is due to the differences in the modelling of the physical characteristics of the cables and the imperfection of the test bench.

A field test campaign has been conducted in France and Spain to complement the measurements of the Plugtest. The statistical results obtained are consistent with the Plugtest data and demonstrate that the average level of PLT signal on telephone cables is low but not uniform over frequency. The maximum crosstalk levels at some frequencies may affect the quality of the VDSL2 communication.

The same Plugtest demonstrated the effectiveness of the splitter filter to reduce the crosstalk of PLT signal over telephone cables produced in the home wiring. The concept of the splitter can be improved adding an adaptive filter to suppress the PLT signal coupled on the telephone wires. This adaptive splitter is proposed in theory but the development is an engineering project that exceeds the resources of STF384.

Another promising algorithm to mitigate the effect of the coupling is the spectral management in the downstream bands. The ideal implementation would require the PLT modem to measure the coupling from the VDSL2 system during the showtime period but none of the existing PLT technologies can perform this analysis.

The practical implementation uses a special PLT modem on the telephone line to measure the crosstalk and calculate the attenuation required on each OFDM carrier. Using this tool the STF has confirmed that spectral management can solve the interference problem on VDSL2 links with a moderate impact on the PLT speed.

All the proposed mitigation techniques require the involvement of the Service Provider to measure or estimate the crosstalk level.

Annex A: Bibliography

- ETSI TS 101 271: "Access TerminalsTransmission and Multiplexing (ATTM); Access transmission system on metallic pairs; Very High Speed digital subscriber line system (VDSL2); [ITU-T Recommendation G.993.2 modified]".
- ITU-T Recommendation G.993.2: "Recommendations Digital sections and digital line system - Access networks Very high speed digital subscriber line transceivers 2 (VDSL2)".

List of figures

Figure 1: Reference configuration.....	7
Figure 2: PSD measured between 2 PLT modems	8
Figure 3: Equivalent source term	9
Figure 4: Calculation process	10
Figure 5: Coupling noise PSD on the VDSL2 lines positioned at different distance (Untwisted, space = 0 cm and wire diameter (dw) = 0,5 mm).....	13
Figure 6: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cat3, space = 0 cm and wire diameter (dw) = 0,5 mm).....	13
Figure 7: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cat 5, space = 0 cm and wire diameter (dw) = 0,5 mm).....	14
Figure 8: Coupling noise PSD on the VDSL2 lines positioned at different distance (Cable untwisted length = 5m, space (variable) and wire diameter (dw = 0,5 mm).....	14
Figure 9: Experimental set up	14
Figure 10: Channel coupling model	16
Figure 11: Block diagram of the interference cancellation system.	17
Figure 12: Spectral management and redistribution of the bit loading in a PLT signal	19
Figure 13: PSD of the PLT crosstalk signal before (red) and after (blue) the modification of the spectrum	20
Figure 14: End-user tool for PLT spectral management	21
Figure 15: Installer tool to measure PLT interference and modify the PLT spectrum	22
Figure 16: Crosstalk profile after the mitigation has been applied.....	23
Figure 17: Snapshot of the Work Systems ACS interface to download the configuration file to change the PLT spectrum	24
Figure 18: Crosstalk measurements between outlet pairs in Spain	25
Figure 19: Crosstalk measurement between outlet pairs in France	25
Figure 20: Average level of all outlet pairs	26
Figure 21: Comparison of average coupling level.....	27
Figure 22: Cumulative distribution of the crosstalk levels for all the measured pairs in France and Spain	27
Figure 23: Test set-up to measure the effect of the mitigation	28
Figure 24: Crosstalk level on the telephone cable in the laboratory test bench.....	29
Figure 25: Crosstalk level after applying the power mask in the PLT modems.....	29

List of tables

Table 1: Experimental results for untwisted telecom wires.....	10
Table 2: Summary of theoretical results for untwisted telecom wires.....	11
Table 3: Experimental results for twisted telecom wires (CAT 3).....	11
Table 4: Summary of theoretical results for twisted telecom wires (CAT3).....	11
Table 5: Experimental results for twisted telecom wires (CAT 5).....	12
Table 6: Summary of theoretical results for twisted telecom wires (cat5).....	12
Table 7: PHY parameters of the VDSL2 profiles.....	16
Table 8: Mitigation test results.....	30

History

Document history		
V1.1.1	September 2010	Publication