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*Technical Report*

**Access, Terminals, Transmission and Multiplexing (ATTM)**
**Study of issues related to POTS injection in the customer wiring from xDSL VoIP Home Gateway**

Reference
DTR/ATTM-06016

Keywords
ADSL, VDSL, POTS, splitter

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# Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

It addresses the major issues related with the performances of VoIP customer installations exploiting the re-injection of the POTS service locally generated by the Home Gateway in the customer premises wiring, without electrically disconnecting it from the external line.

The present document is fully in line with the initiative "eEurope 2002 - An Information Society For All", under "The contribution of European standardization to the eEurope Initiative, A rolling Action Plan" especially under the key objective of a cheaper, faster and secure Internet.

# Introduction

Current ETSI standards on POTS/xDSL filters are based on the assumption of a classic xDSL deployment, either from the exchange or from the cabinet, with the POTS signals respectively injected at the central office or at the cabinet side of the local loop.

Voice over IP (VoIP) technology is however progressively replacing the traditional telephone service provided from the Central Office. This technology, originally mainly used by IP Operators to complement their "triple play" offer, is now being increasingly adopted also by the incumbent Operators to significantly cut the costs of the Central Office Switching Equipment and of the copper access network and to integrate the telephone service provision into the multimedia IP transmission and management platforms.

In the VoIP telephony provision scenario the POTS signals are typically locally generated from the POTS interface of the Home Gateway. However, despite having abandoned the access network existing infrastructure, VoIP operators are still willing to take advantage of the existing customer wiring and POTS terminals, in order to achieve the seamless transition from the traditional POTS service to IP telephony. To this purpose, the POTS signals are locally re-injected in the user premises networks. To allow the self-installation by the customer for minimising the deployment time and costs, and to accommodate the constraints implicit in distributed architectures, the re-injection technique is used for distributed architectures without galvanically separating the customer wiring from the external line.

The resulting operating conditions of distributed filters when used in these applications are quite peculiar and differ substantially from those assumed as a basis for their standardisation. The present document addresses the associated technical issues.

# 1 Scope

The present document identifies the major issues affecting the speech and xDSL performances of customer installations exploiting the VoIP telephony provision through the re-injection of the analogue telephony service, as generated at the POTS interface of the xDSL Home Gateway, in the customer premises network without electrically disconnecting it from the external line.

# 2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

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The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

## 2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area. For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] ETSI TS 102 971: "Access and Terminals (AT); Public Switched Telephone Network (PSTN); Harmonized specification of physical and electrical characteristics of a 2-wire analogue interface for short line interface".

[i.2] ETSI TR 102 021: "Terrestrial Trunked Radio (TETRA); User Requirement Specification TETRA Release 2".

[i.3] ETSI TBR 038: "Public Switched Telephone Network (PSTN); Attachment requirements for a terminal equipment incorporating an analogue handset function capable of supporting the justified case service when connected to the analogue interface of the PSTN in Europe".

[i.4] ETSI ES 203 038: "Speech and multimedia Transmission Quality (STQ); Requirements and tests methods for terminal equipment incorporating a handset when connected to the analogue interface of the PSTN".

[i.5] ETSI ES 201 970: "Access and Terminals (AT); Public Switched Telephone Network (PSTN); Harmonized specification of physical and electrical characteristics at a 2-wire analogue presented Network Termination Point (NTP)".

[i.6] ETSI TS 101 952-1: "Access network xDSL transmission filters; Part 1: ADSL splitters for European deployment; Sub-part 1: Generic specification of the low pass part of DSL over POTS splitters including dedicated annexes for specific xDSL variants".

[i.7] ETSI TS 101 952-1-5: "Access network xDSL transmission filters; Part 1: ADSL splitters for European deployment; Sub-part 5: Specification for ADSL over POTS distributed filters".

[i.8] EN 60950-1: "Information technology equipment - Safety - Part 1: General requirements".

[i.9] IEEE 802: "IEEE Standard for Local and metropolitan area networks".

[i.10] IEEE 802.11: "IEEE Standard for Information technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.11] Broadband Forum TR-127: "Dynamic Testing of Splitters and In-Line filters with xDSL Transceivers".

# 3 Definitions, symbols and abbreviations

## 3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

**access network:** network connecting the Local Exchange with the customer wiring. Often referred to as "local loop"

**Customer Premises Network (CPN):** in-house IP network connecting the Home Gateway to the customer IP devices

**distributed filter:** low pass filter that is added in series with each of the parallel connected POTS TEs

NOTE: Each of the parallel connected filters (in the in-house cabling) is known as a distributed filter. These filters are also known as In-line filters or microfilters.

**far end echo:** speech that is fed back to the talker in a telephony connection with a round trip delay (i.e. the delay between talking and hearing the feedback) greater than 5 ms, resulting in a distinguishable echo

**FXS port (interface):** POTS interface of Home Gateways

**home gateway:** gateway between the Access Network (AN) and the Customer Premises Network (CPN)

NOTE: For the purposes of the present document the Home Gateway, besides implementing the xDSL and networking functionalities allowing the customer access to IP services, also features a local POTS interface allowing the access to the VoIP telephony services by means of plain POTS terminal equipment.

**hybrid:** circuit used in the POTS transmission link in COs and HGs (provided with POTS interface) for implementing the four wires/two wires transition between the speech codec and the POTS interface

NOTE: This circuit operates as a bridge with an internal balance impedance which is intended to match as well as possible the impedance presented by the POTS line.

**local loop:** See access network.

**microfilter:** distributed filter

**off-hook:** state of the POTS equipment at either end of a loop connection when the NTP terminal equipment is in the steady loop state

**on-hook:** state of the POTS equipment at either end of a POTS loop connection when the NTP terminal equipment is in the quiescent state

**passive splitters**: splitters containing exclusively passive components

**POTS re-injection:** delivery scheme by which the POTS service, as locally generated from the POTS interface of the xDSL Home Gateway, is injected into the customer premises telephone wiring without electrically disconnecting it from the external line

**POTS/xDSL splitter:** circuit separating the transmission of POTS signals and DSL signals, enabling the simultaneous transmission of both services on the same twisted pair

**sidetone:** speech that is fed back to the talker in a telephony connection with a round trip delay (i.e. the delay between talking and hearing the feedback), of less than approximately 5 ms, making it indistinguishable from the original utterance

**triple play services:** services combining Data, Voice and Video

**unbundling:** process whereby a local loop owned and operated by a providing operator is made available in whole or in part to a requesting operator for the provision of services to a user

**xDSL:** covers ADSL and VDSL families only

NOTE: E.g. SDSL is not covered by this abbreviation in the present document.

## 3.2 Symbols

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

$RL_{CO}$ Return loss at the POTS interface of the POTS/xDSL splitter at the CO side
$RL_{TE}$ Return loss at the POTS interface of the TE microfilter for the traditional xDSL deployment
$RL_{RI}$ Return loss at the POTS port of the microfilters for the re-injection scheme
$Z_{AC}$ Generic name for the AC POTS impedance models
$Z_{DSL}$ Impedance model of the input filter of a particular xDSL
$Z_{OnHo}$ Impedance modelling multiple parallel on-hook phones
$Z_R$ European harmonized complex reference POTS impedance

## 3.3 Abbreviations

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

AC Alternating Current
ADSL Asymmetric Digital Subscriber Line
CO Central Office

NOTE: ≡ Local Exchange ≡ LE.

CPE Customer Premise Equipment

NOTE: ≡ Terminal Equipment ≡ TE.

CPN Customer premises network

NOTE: See definition.

DC Direct Current
DSL Digital Subscriber Line
DSLAM Digital Subscriber Line Access Multiplexer
ERL Echo Return Loss
ETH Ethernet interface

NOTE: See IEEE 802 [i.9].

FXS Foreign eXchange Station
HG Home Gateway
IP Internet Protocol
LE Local Exchange

NOTE: ≡ Central Office.

NTP Network Termination Point
OLO Other Licensed Operator
PLT Power Line Telecommunication
POTS Plain Old Telephone Service

NOTE: Used throughout instead of PSTN.

PSTN Public Switched Telephone Network
RL Return Loss
STB Set-Top Box
TE Terminal Equipment

NOTE: E.g. Telephone, Fax, Voiceband modem etc.

VoIP Voice over IP
VDSL Very high speed Digital Subscriber Line
WiFi Wireless Fidelity ISO/IEC local area network standard

NOTE: See IEEE 802.11 [i.10] family.

μF microfilter - distributed filter

# 4 The background: from the PSTN to VoIP telephony

The xDSL deployment (originally ADSL) has been originally based on the provision by incumbent Operators of both telephony and xDSL services from the Central Office. In this scenario, VoIP telephony was initially offered only by IP service providers within their triple play services, basing their offer on the use of Home Gateways associating, to the typical networking features of xDSL transceivers, a POTS interface, sometimes referred to as FXS, operating as the POTS interfaces of the PSTN cards of the COs. In case of OLO operators operating within total unbundling arrangements, the VoIP service often replaces the PSTN telephony from the CO and the local loop is only used for carrying xDSL signals.

While abandoning the access network existing infrastructure for telephony provision, VoIP operators are however eager to keep exploiting the existing customer wiring and POTS terminals in order to achieve a seamless transition from the PSTN to IP telephony. To pursue this strategy, in total replacement scenarios the customer POTS wiring is connected to the FXS interface of the Home Gateway.

Depending on the xDSL customer wiring architecture, e.g. centralised splitter vs. distributed filtering, different methods are used for injecting the VoIP telephony service into the customer wiring. These methods are quickly reviewed in the following, paying then particular attention to the one based on the re-injection of the POTS signals in distributed architectures and to its implications on the speech and xDSL performances of customer installations.

## 4.1 Customers plants with centralised splitter

The typical xDSL deployment scheme based on the use of a central splitter at the customer premises is shown in Figure 1. For these plants, the provision of VoIP telephony by OLO operators, intended to replacing the PSTN telephony from the CO, basically occurs by transforming the scheme shown in figure 1 into the one represented in figure 2.

The POTS interface of Home Gateways is standardised by TS 102 971 [i.1], aimed at assuring the correct interworking with POTS CPEs both with respect to POTS signalling and feeding conditions and to the speech transmission performances. In fact, TS 102 971 [i.1] is coherent both with the CPE characteristics, as specified by TS 103 021 [i.2], TBR 038 [i.3] and TS ES 203 038 [i.4], and with the PSTN access characteristics, as presented at the NTP, specified by ES 201 970 [i.5].

In particular, the loop current generated by the POTS interface of HGs is required to be in the range between 18 mA and 70 mA, 25 ÷ 40 mA recommended, and the open circuit DC voltage is required not to exceed 78 V, but not be less than 38 V. The open circuit ringing AC voltage is required not to exceed 100 $V_{rms}$ at the POTS interface and the total harmonic distortion is required not to exceed 10 %. In case of ringing without DC, the transitions from ringing voltage to DC are required to occur without any waveform discontinuity.

As concerns the speech transmission aspects, the impedance presented by the POTS interface of the HG when in the loop state is specified to be the reference ETSI impedance $Z_R$, and the hybrid used in the HG for implementing the four wires/two wires transition between the speech codec and the POTS interface is also required to be balanced against $Z_R$.

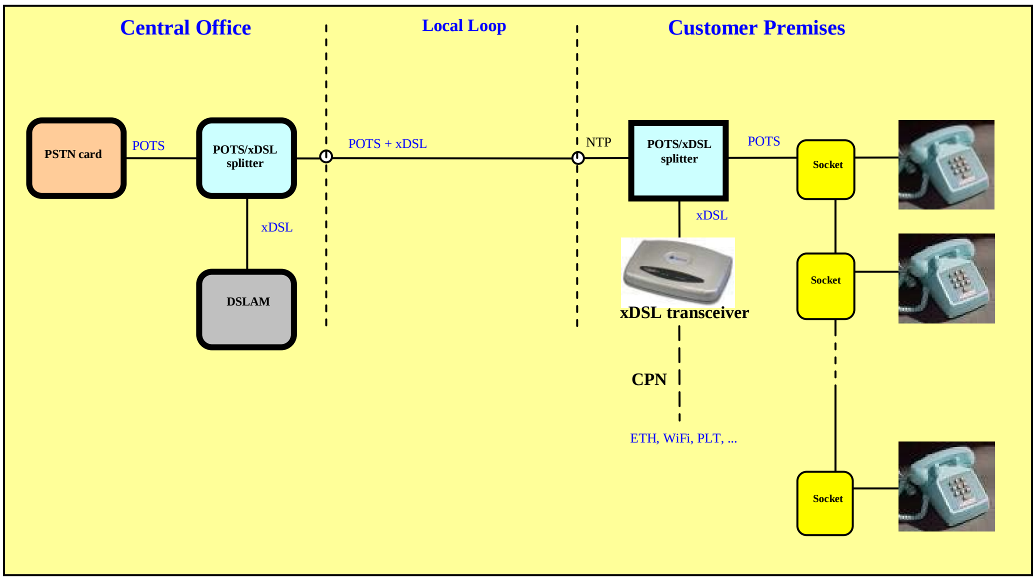



**Figure 1: Telephony and xDSL deployment from the CO - centralised splitter**

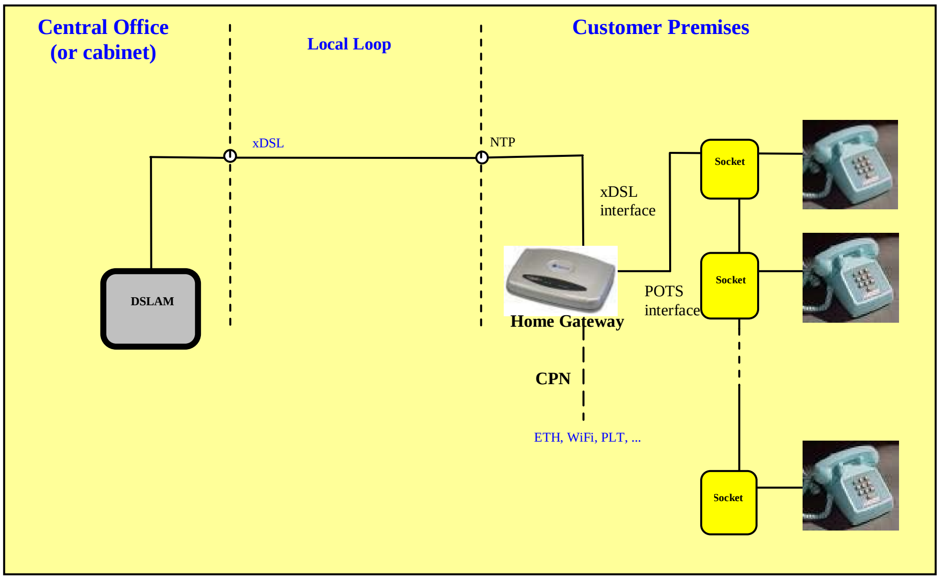



**Figure 2: Total replacement of PSTN by VoIP telephony**

The compliance with mentioned ETSI standards by the POTS interface at the HG and by the POTS CPEs assures the optimal speech transmission performance of the VoIP delivery scheme as shown in figure 2. However, this approach has some drawbacks from the point of view of provisioning time and cost and of the customer installation flexibility. Namely:

- The switchover from the PSTN deployment (see figure 1) to VoIP deployment (see figure 2) requires the technical intervention at the Customer premises by the Operator staff, or by outsourced technical personnel, for removing the splitter and sectioning the customer plant from the external network.

- To avoid any lack of service to the Customer, the mentioned switchover should be perfectly synchronised with the discontinuation of the PSTN service and with the completion of the associated number portability procedure.
- In order not to re-wire the customer premises, the HG is better connected at the NTP or at the first socket.

The last point is quite relevant as the key driver of the triple-play offer are the multimedia services, normally delivered from a set-top-box conveniently placed near a TV screen and connected to the CPN coming from the HG. This constraint may result into the need to set-up in the customer premises a high speed data connection between the HG and the STB, which would be avoided if the HG could be placed close to the latter. For the above mentioned reasons there may be a strong business case for some Operators to adopt, as far as possible, distributed filtering architectures as an alternative to the one illustrated in figure 2.

## 4.2 Customer plants with distributed filtering

The functional diagram of a typical xDSL platform based on distributed filtering is as shown in figure 3. The distributed filters are intended to be a convenient solution enabling the self-installation by the user. The performance of both the POTS and xDSL services may however be reduced when using distributed filters instead of a central splitter. It is however known that this potential impairment is not significant in ADSL deployments, while in VDSL applications the distributed architecture generally results into a decrease of the theoretically available bit rate due to the multiple reflections in the customer wiring. This notwithstanding, this may be considered as a fair price to be paid by those Operators aiming at a faster and cheaper VDSL development.

In the example shown in figure 3 the xDSL transceiver is connected to the second socket of the customer plant, but it would work even if connected to any other socket. The provision of VoIP telephony in a "total PSTN replacement" scenario is achieved by transforming the scheme shown in figure 3 into the one represented in figure 4, where the HG can be connected to any socket of the customer wiring. Contrarily to figure 2, in this case no sectioning occurs at the NTP interface and the customer installation can be easily modified by the user itself.

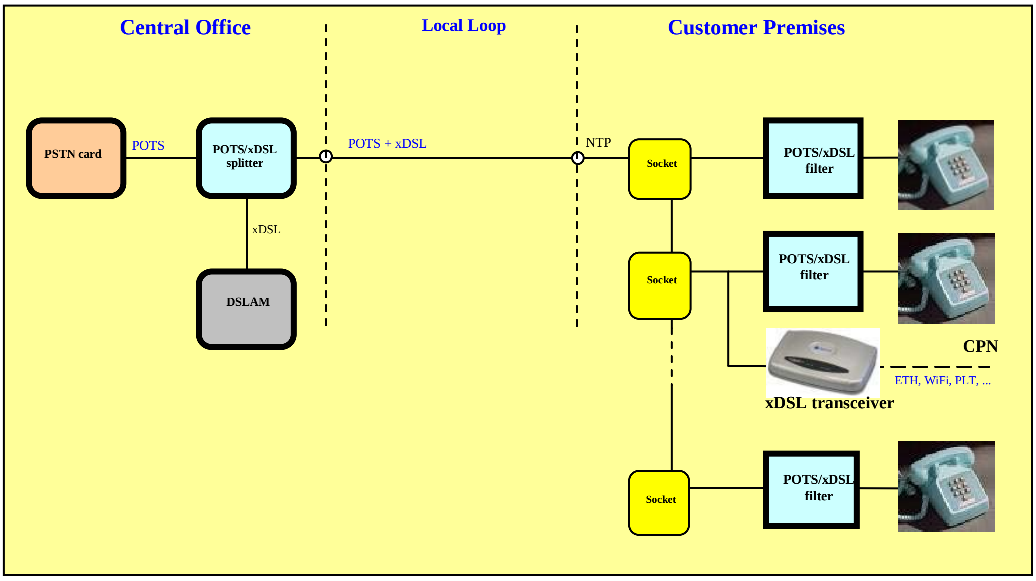



**Figure 3: Functional diagram of a typical xDSL platform based on distributed filtering**

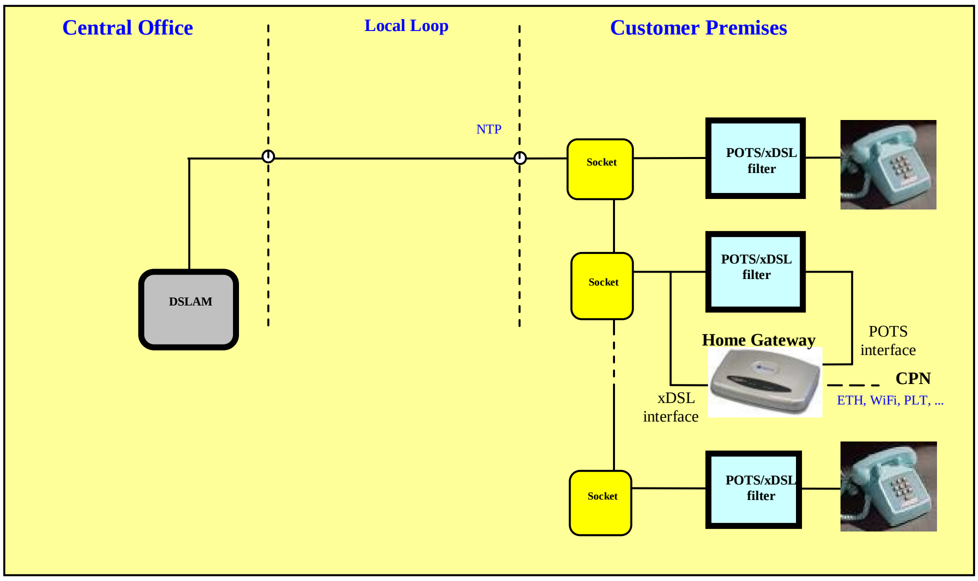



**Figure 4: Total replacement of PSTN by VoIP telephony (distributed filtering architecture)**

As shown in figure 4, the POTS (FXS) interface of the Home Gateway is re-injected into the customer wiring by means of a POTS/xDSL filter, the same way as the PSTN port of the CO is connected to the loop through the POTS splitter (see figure 1). A major difference however exists with respect to the classic PSTN deployment from the CO as in this case the POTS interface is located at the same side of the local loop as the customer wiring, this resulting into a number of functional differences with respect to the classic scheme:

- the local loop is no longer a transmission line for the POTS signalling and telephony signals, but it only acts as a load in the POTS transmission chain, which is totally within the customer wiring;
- both the terminal side and the line side of the POTS connection are close to the customer xDSL transceiver, while in the classic deployment schemes (see figures 1 and 3) the CO side of the POTS connection is closer to the network transceiver (DSLAM);
- safety issues may arise if the Home Gateway used has been developed by targeting only the total replacement scenario depicted in figure 2, where the customer plant is electrically isolated from the local loop. In fact, in this case the HG could have been developed without galvanically isolating its POTS interface from the other circuits and metallic accessible parts, as is mandatory for the public line interfaces of telecommunication equipment (see clause 5.3).

From the provisioning point of view, to avoid any lack of service to the customer and to prevent conflicts between the CO and HG POTS interfaces, also in this case the self-installation of the VoIP delivery configuration should be synchronised with the discontinuation of the PSTN service from the network and with the completion of the associated number portability procedure by the previous Operator. Suitable provisioning procedures or appropriate technical means are then to be put in place for assuring that the POTS interface of the HG is connected to the customer wiring only after the PSTN service discontinuation has occurred.

# 5 Technical issues of POTS re-injection

As described above, the VoIP provision by POTS re-injection techniques significantly modifies the operating conditions of the customer loop and of the POTS/xDSL microfilters, as compared with those assumed as their originally intended use, on which the requirements and test methods of applicable technical standards are based. This applies in particular to the POTS path configuration, and then to the associated speech transmission performances, and to the potentially different susceptibility of xDSL transceivers to POTS disturbances.

## 5.1 Speech transmission quality

Two aspects are of utmost interest when comparing the speech transmission performances of the traditional xDSL deployment scheme based on distributed filtering against the VoIP deployment scheme based on re-injection: Frequency Response Characteristics and Return Loss performances.

To investigate these issues, the POTS transmission paths shown in functional diagrams in figures 3 and 4 can be instanced as in figures 5 and 6 respectively.

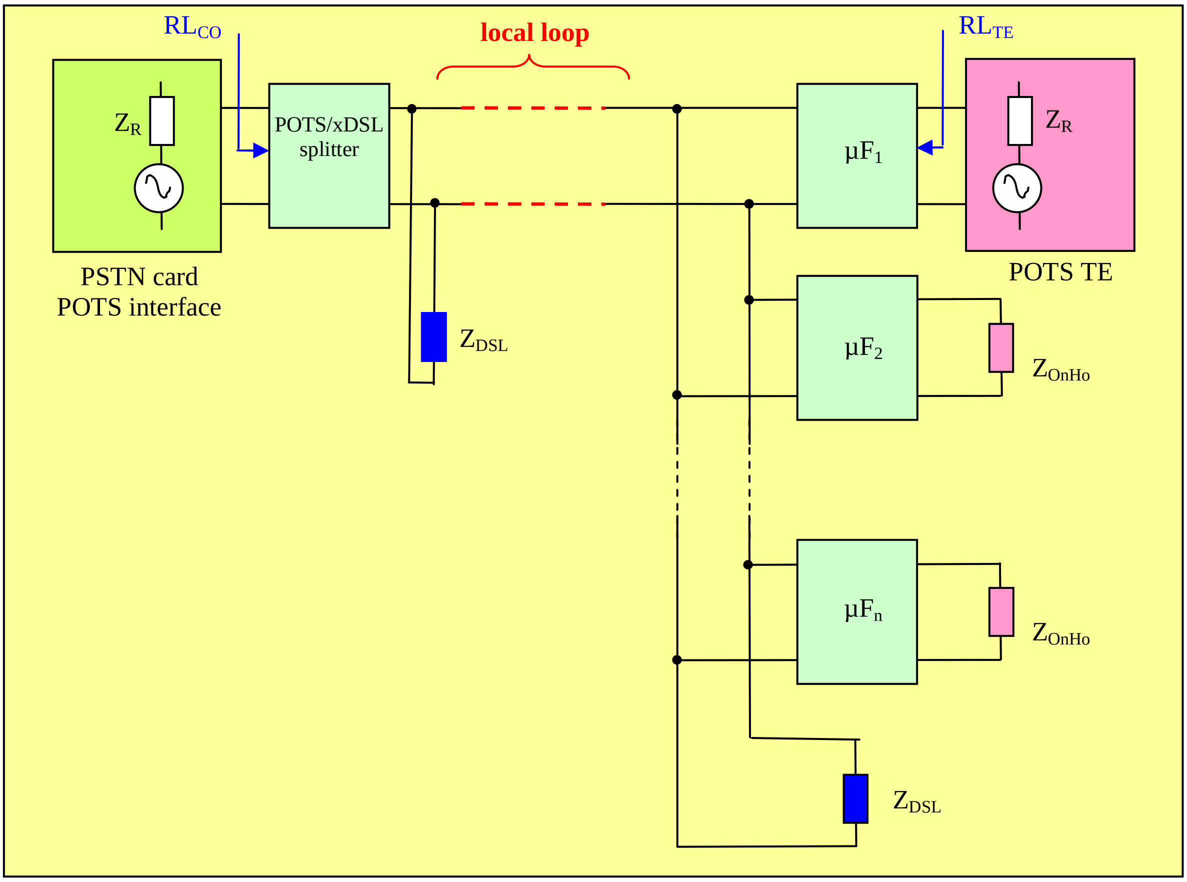



**Figure 5: POTS transmission path of traditional xDSL deployment**

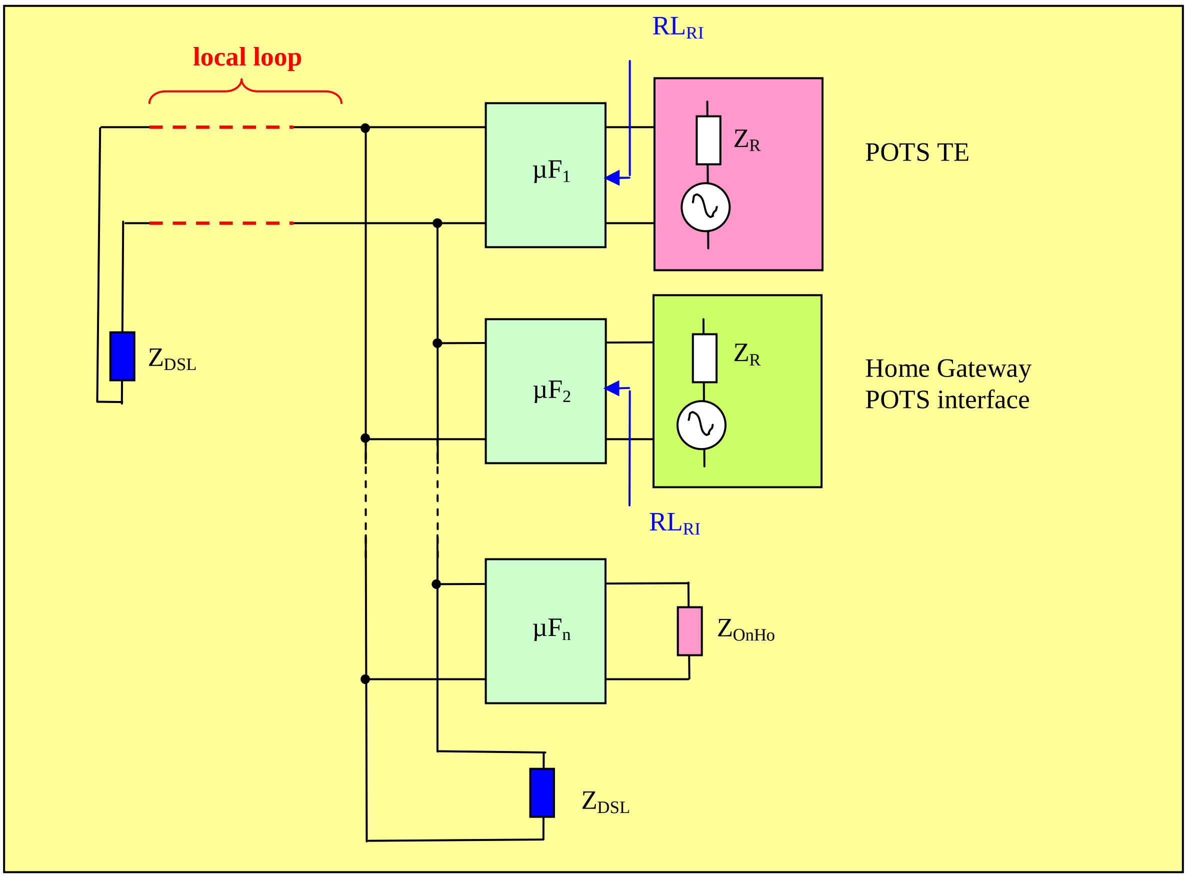


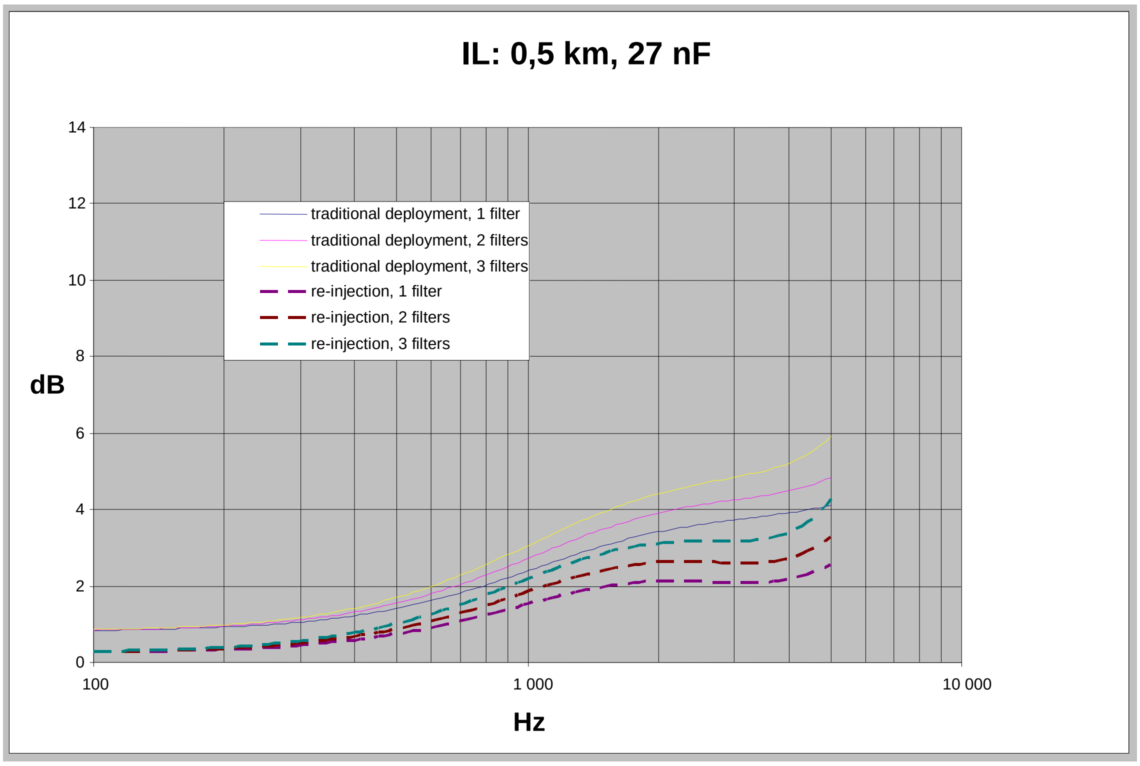

**Figure 6: POTS transmission path of xDSL deployment with VoIP re-injection**

### 5.1.1 Frequency response characteristics

To study how the frequency response characteristic of the POTS path is affected by the xDSL deployment schemes, the frequency responses from the POTS interface of PSTN card (either CO or HG) to the POTS TE of the circuits shown in figures 5 and 6 have been measured on a laboratory simulation with the following system parameters:

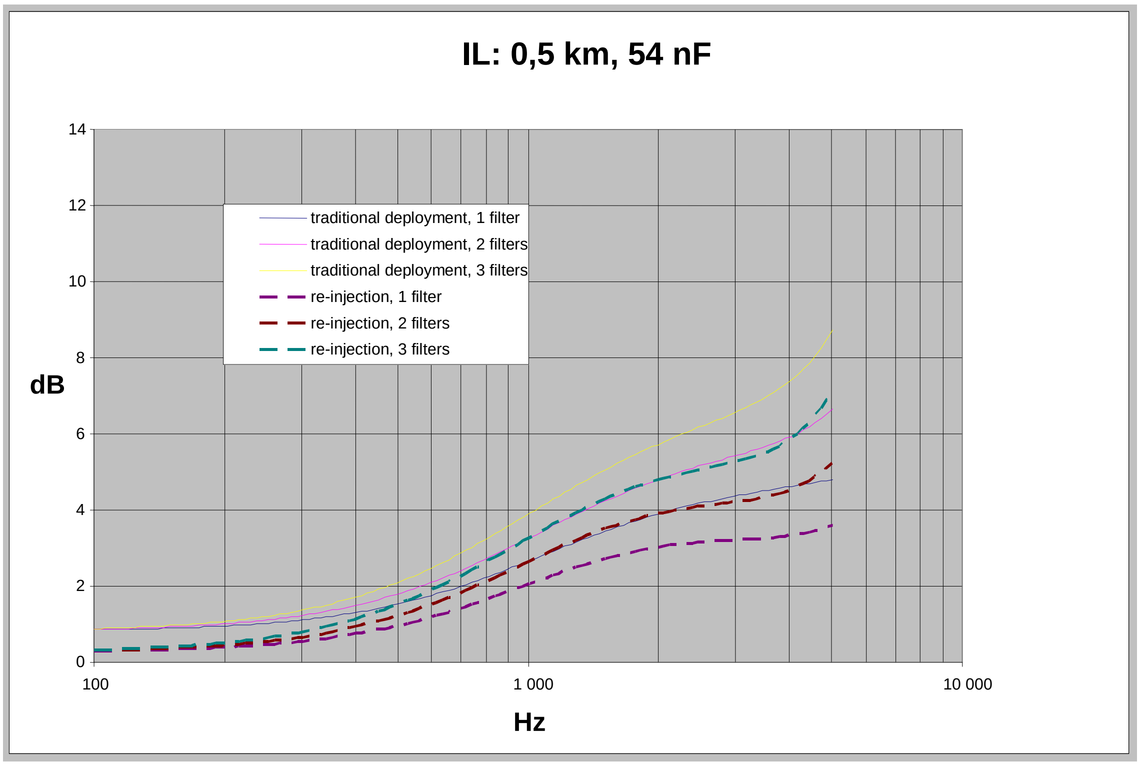
- Local loop cable: Ø 0,4 mm (270 Ω/km, 40 nF/km).
- Cable lenghts: 0,5 km; 1,5 km.
- Microfilter types: low capacity (27 nF); high capacity (54 nF) (both complying with TS 101 952-1-5 [i.7]).
- Number of microfilters connected: 1 to 3 (additional to the microfilter connecting the POTS interface of the HG in the re-injection scenario).

Due to the reciprocity of passive networks, the frequency responses from the POTS interface to the POTS TE and, in the reverse direction, from the POTS TE to the POTS interface are identical. Figures 7 and 8 show the Insertion Loss performance of the POTS path of the traditional xDSL deployment (see figure 5) vs. the same for the re-injection scheme (see figure 6). Irrespectively from the microfilters capacity, it can be noted that the frequency responses with re-injection are more "flat" and generally less attenuated than the same achieved by the traditional scheme. This can be explained by considering that, as in the re-injection scheme the local loop is not interposed in the POTS signal path (see figure 6), its de-emphasis effect on the frequency response characteristics is less important than in the traditional deployment.




NOTE Cable length: 0,5 km. Low capacity microfilters.

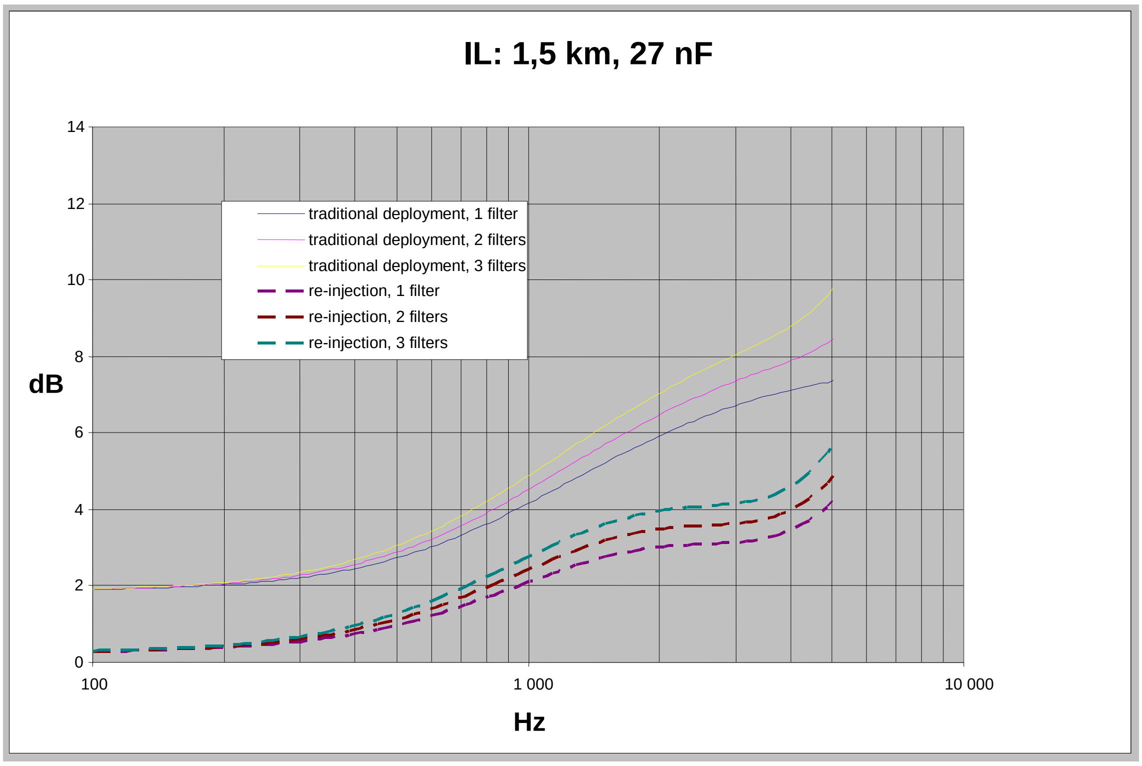
**Figure 7: Insertion loss of the POTS path of a traditional xDSL link (see figure 5) vs. a re-injection link (see figure 6)**




NOTE Cable length: 0,5 km. High capacity microfilters.

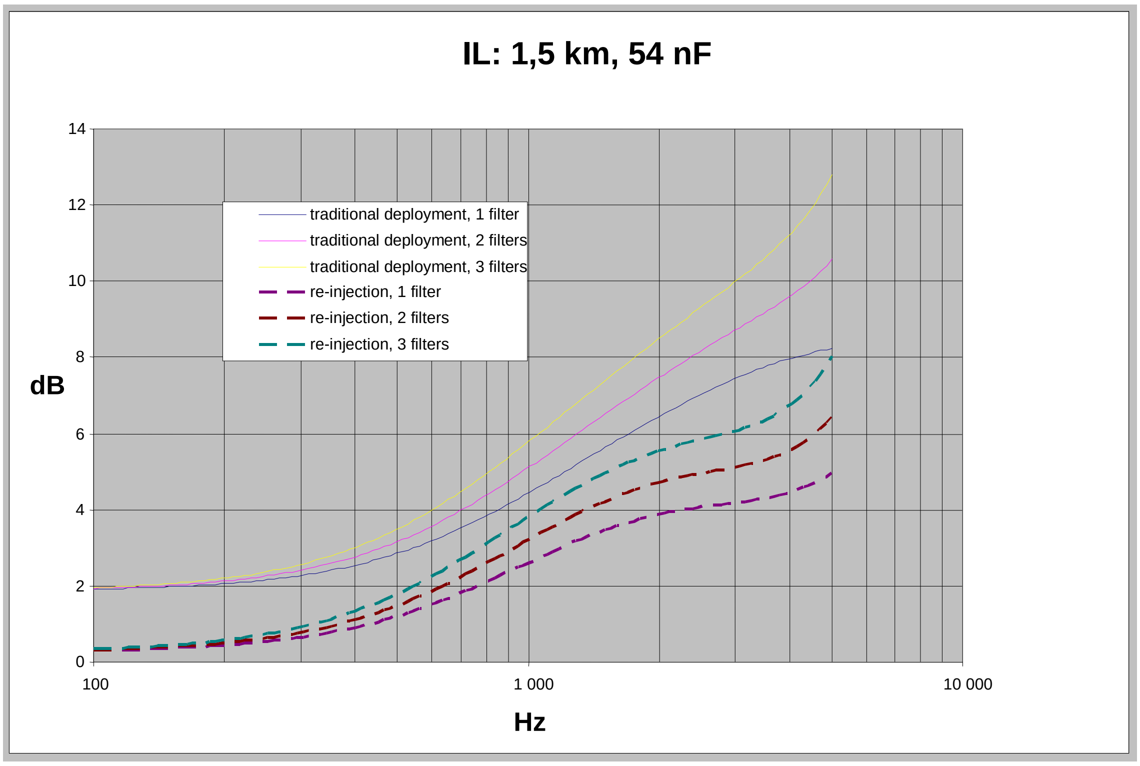
**Figure 8: Insertion loss of the POTS path of a traditional xDSL link (see figure 5) vs. a re-injection link (see figure 6)**

The same observations made for a short local loop also apply to a longer one, as shown in figures 9 and 10 for the 1,5 km loop.




NOTE: Cable length: 1,5 km. Low capacity microfilters.

**Figure 9: Insertion loss of the POTS path of a traditional xDSL link (see figure 5) vs. a re-injection link (see figure 6)**




NOTE: Cable length: 1,5 km. High capacity microfilters.

**Figure 10: Insertion loss of the POTS path of a traditional xDSL link (see figure 5) vs. a re-injection link (see figure 6)**

With the longer loop the advantage of the re-injection scheme, as compared with the traditional one, is even more evident, both with respect to the lower attenuation and to the frequency response linearity. In general, all frequency responses show a de-emphasis behaviour of the POTS path response, but this is less evident for the re-injection scenario. As an example, it can be noted that, for low capacity microfilters (see figure 9), the re-injection scenario with three microfilters connected exhibits the same overall de-emphasis as the traditional scenario with just one microfilter connected.

## 5.1.2 Return Loss

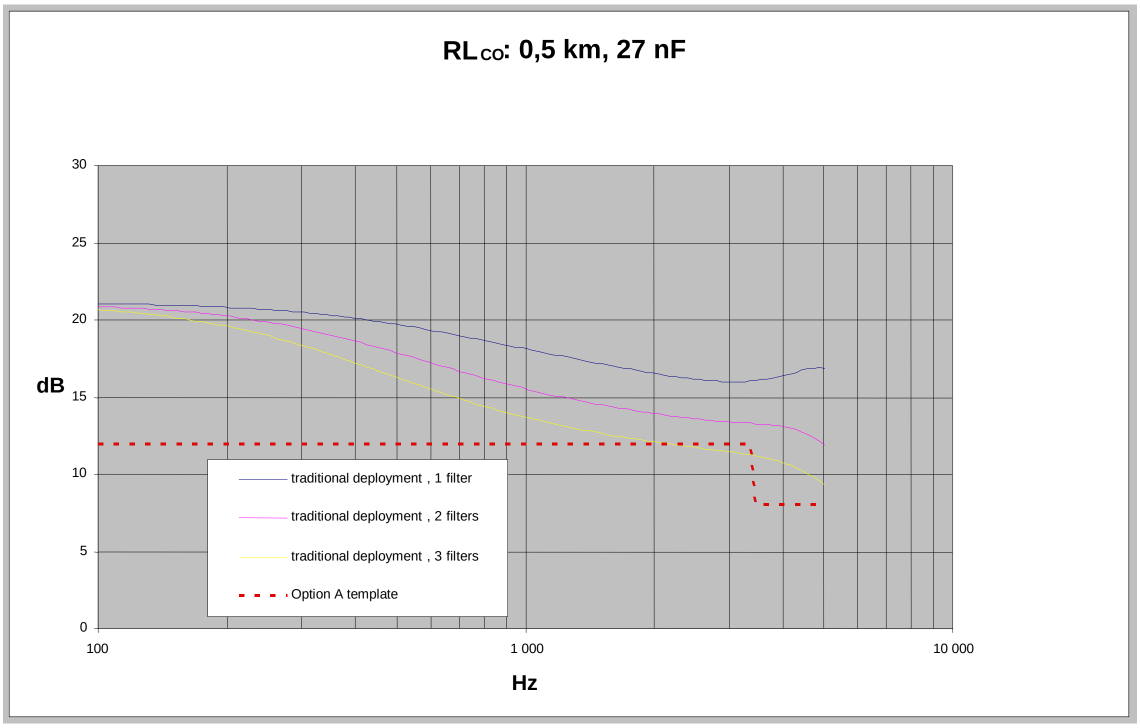
Return Loss has a primary influence on speech quality. In fact, from the RL at the POTS interface depends the echo return loss (ERL) provided by the telephone hybrids implemented either in the POTS card of the Local Exchange or in the FXS interface of the Home Gateway. A poor balance of these hybrids, typically optimised for balancing the $Z_R$ impedance, results into a far-end echo effect particularly harmful in VoIP links, where a substantial round-trip delay occurs due the speech processing and packetisation mechanisms.

For the traditional xDSL deployment scheme two different RL values apply (see figure 5):

- **$RL_{CO}$**: Return loss at the POTS interface of the POTS/xDSL splitter, with the TE microfilter terminated by the $Z_R$ impedance (this parameter affects the ERL provided by the hybrid implementing the 2wires/4 wires transition).
- **$RL_{TE}$**: Return loss at the POTS interface of the TE microfilter, with the POTS/xDSL splitter terminated by the $Z_R$ impedance (affecting the sidetone loudness rating of the POTS speech terminals).

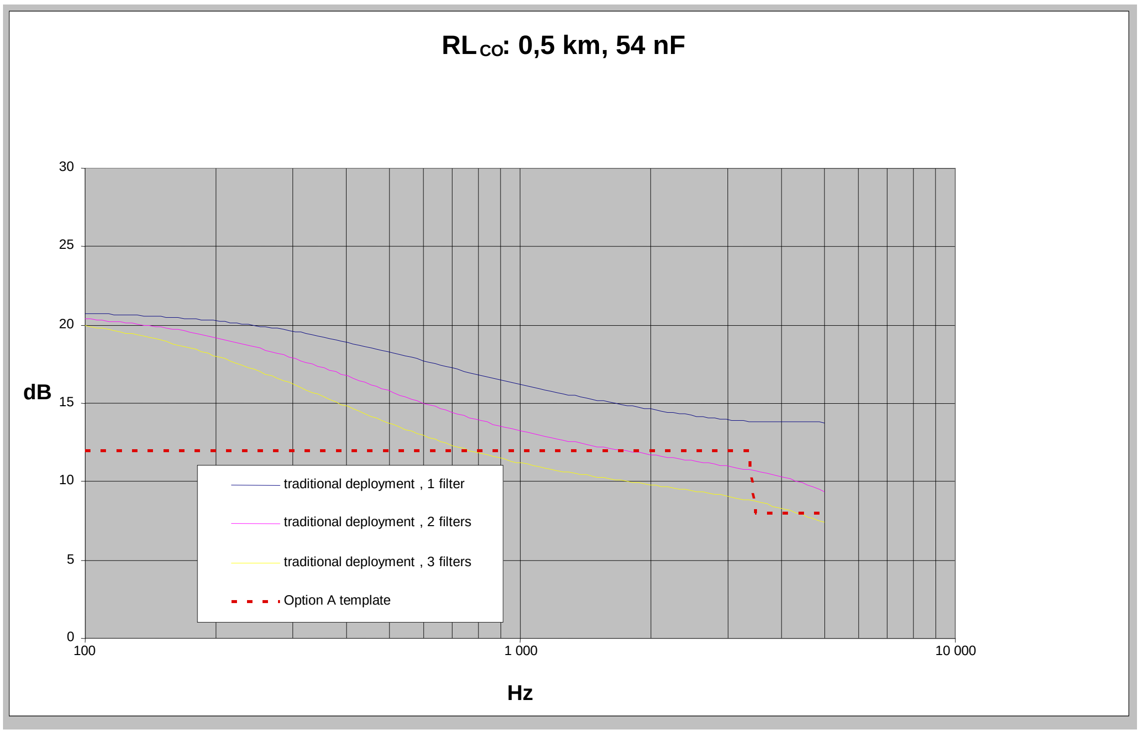
Due to its inherent symmetry, only one RL value (**$RL_{RI}$**) applies to the re-injection scheme (see figure 6). In fact the same impedance is presented by the POTS interfaces both of the microfilter connected to the FXS interface of the HG and of the microfilters connected to the TEs.

The Return Loss measured at the POTS interface of the CO splitter for the traditional xDSL deployment ($RL_{CO}$) is reported in figures 11 to 14, respectively for low and high capacity filters and for 0,5 km and 1,5 km links. It is shown that the RL at the POTS card interface, as compared against the "Option A" template of TS 101 952-1 [i.6] and TS 101 952-1-5 [i.7], is better for the longer line lengths but is generally adequate also for shorter lenghts. This applies in particular when low capacity microfilters are used.



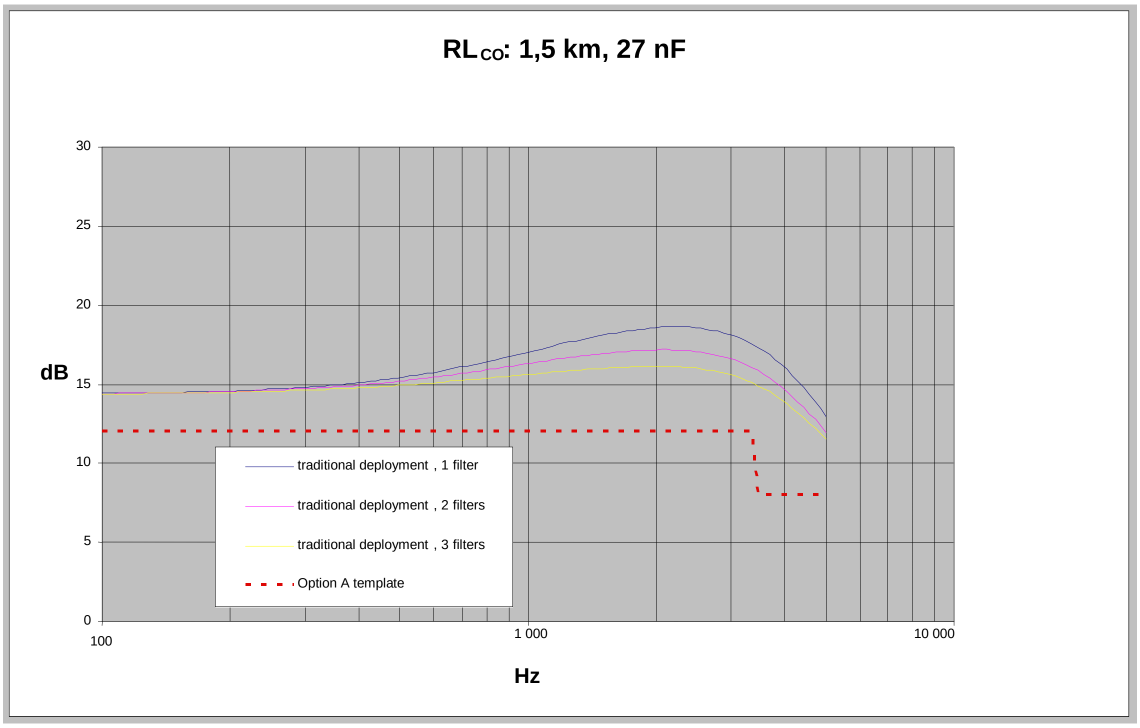

NOTE: Cable length: 0,5 km. Low capacity microfilters.

**Figure 11: Return loss at the POTS interface of the CO splitter for traditional xDSL deployment (see figure 5)**



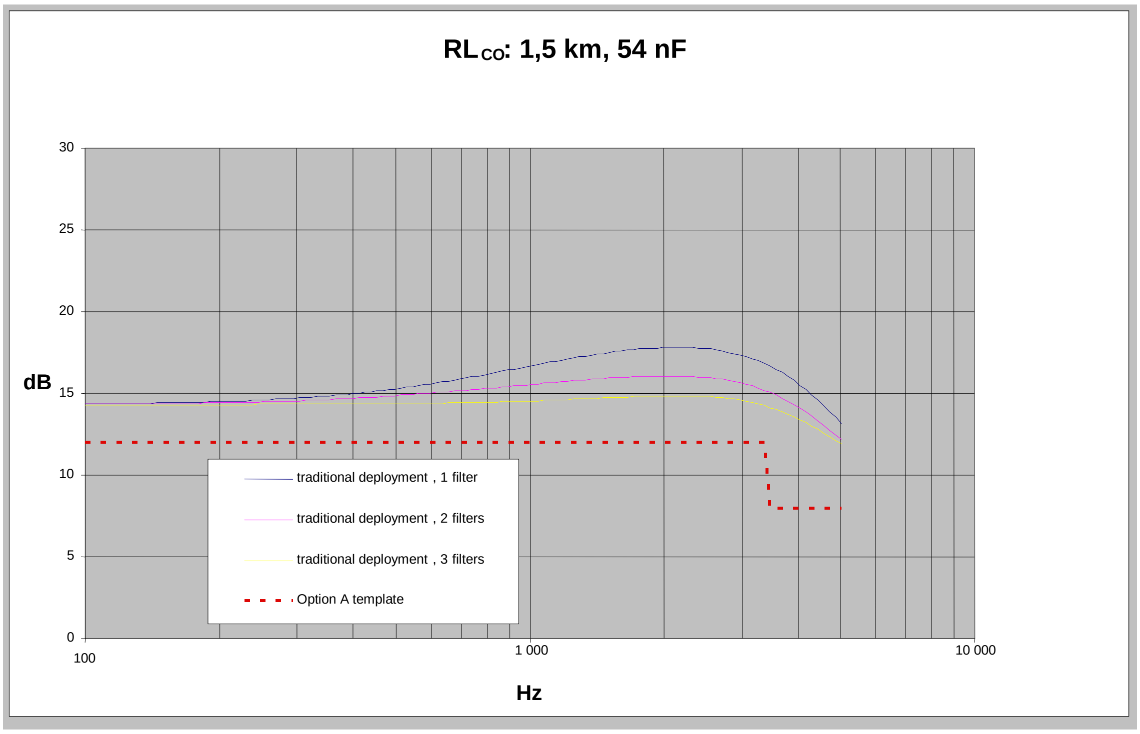

NOTE: Cable length: 0,5 km. High capacity microfilters.

**Figure 12: Return loss at the POTS interface of the CO splitter for traditional xDSL deployment (see figure 5)**




NOTE: Cable length: 1,5 km. Low capacity microfilters.

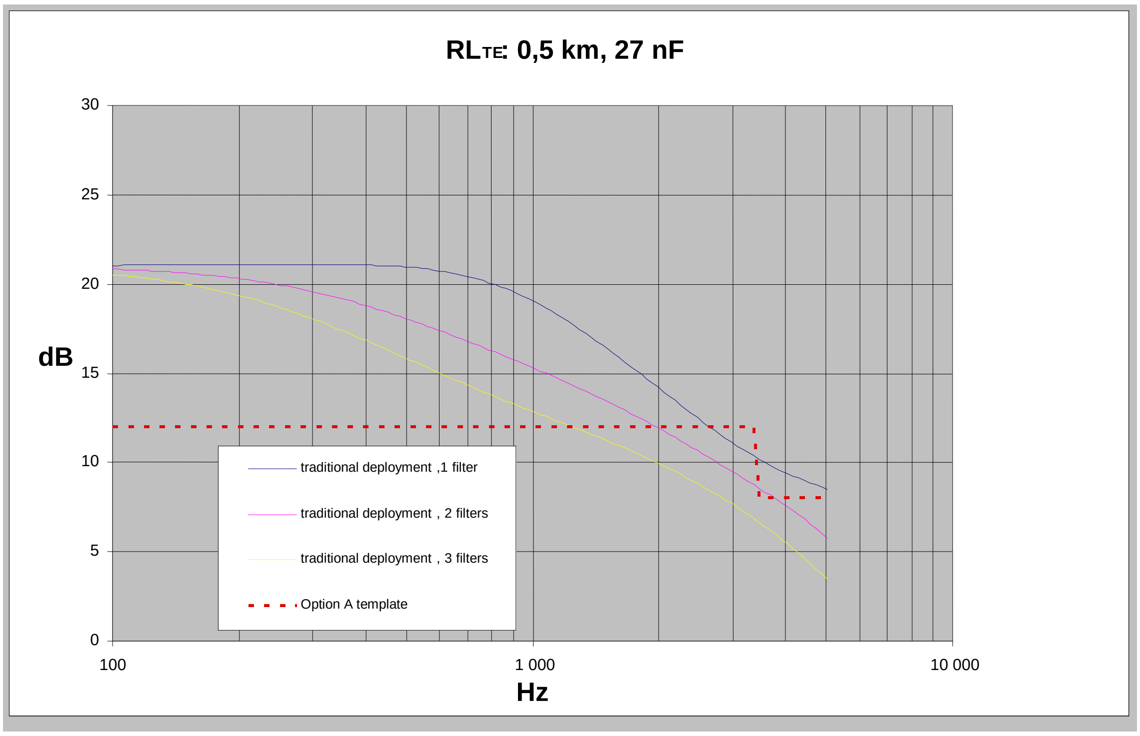
**Figure 13: Return loss at the POTS interface of the CO splitter for traditional xDSL deployment (see figure 5)**




NOTE: Cable length: 1,5 km. High capacity microfilters.

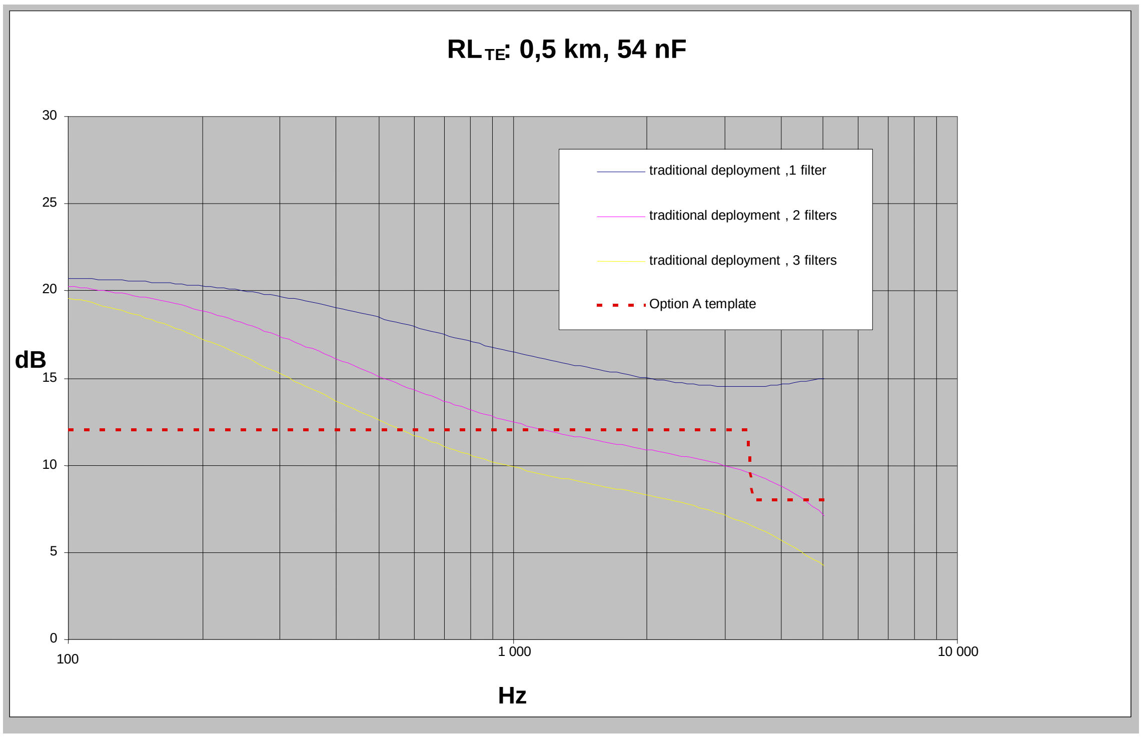
**Figure 14: Return loss at the POTS interface of the CO splitter for traditional xDSL deployment (see figure 5)**

The Return Loss measured at the POTS interface of the microfilters for the traditional xDSL deployment ($RL_{TE}$) is shown in figures 15-18, respectively for low and high capacity filters and for 0,5 km and 1,5 km links.



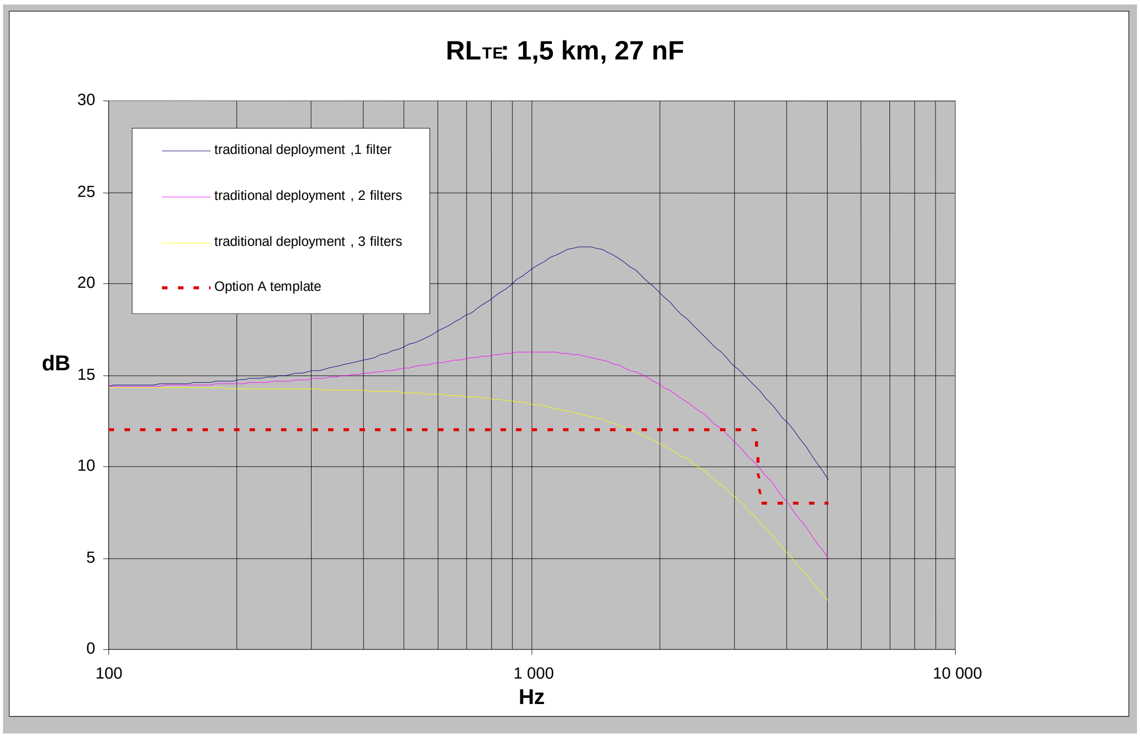

NOTE: Cable length: 0,5 km. Low capacity microfilters.

**Figure 15: Return loss at the POTS interface of the microfilters for traditional xDSL deployment (see figure 5)**



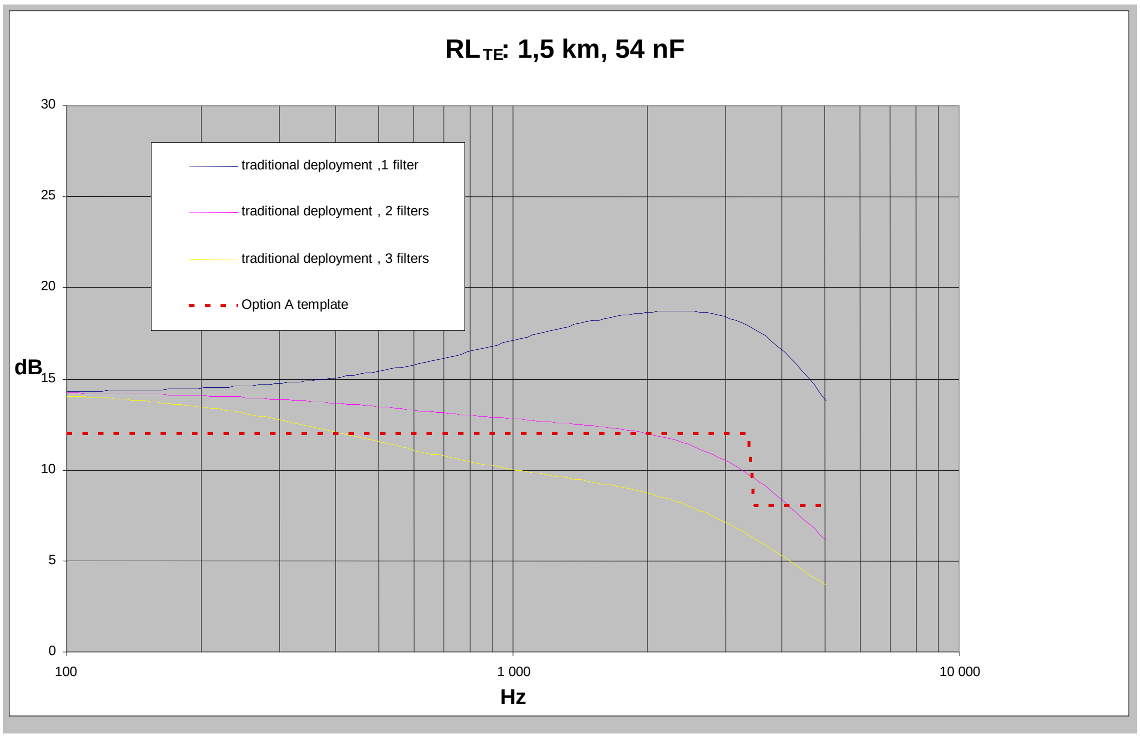

NOTE: Cable length: 0,5 km. High capacity microfilters.

**Figure 16: Return loss at the POTS interface of the microfilters for traditional xDSL deployment (see figure 5)**




NOTE: Cable length: 1,5 km. Low capacity microfilters.

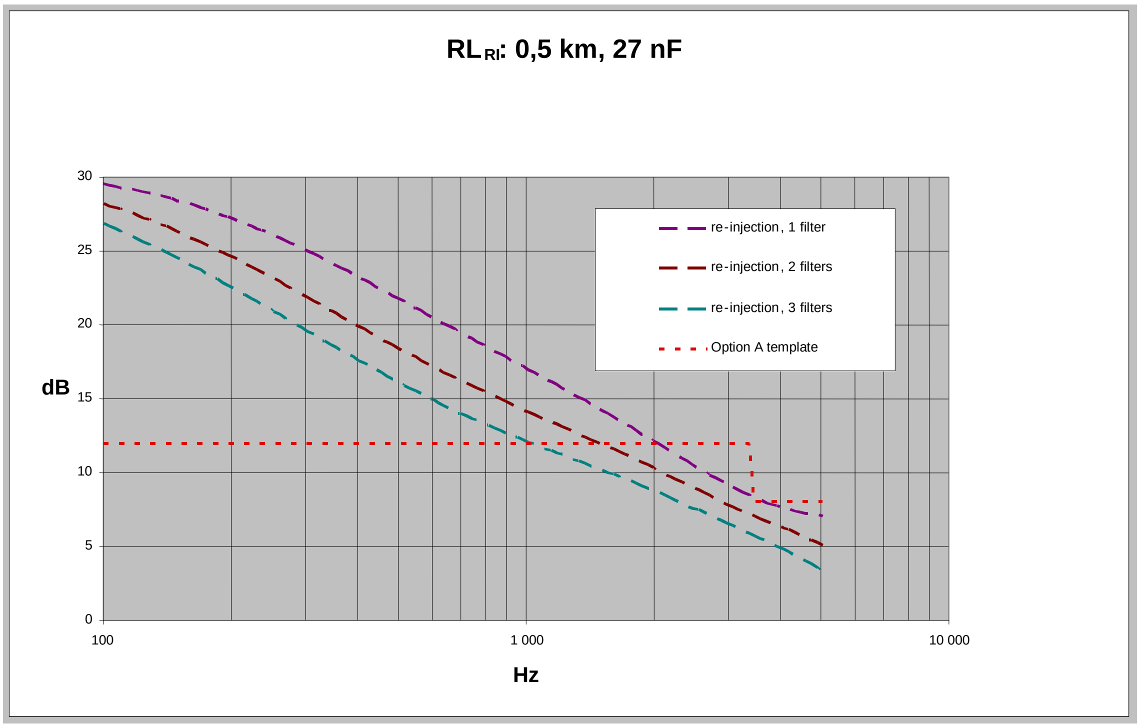
**Figure 17: Return loss at the POTS interface of the microfilters for traditional xDSL deployment (see figure 5)**




NOTE: Cable length: 1,5 km. High capacity microfilters.

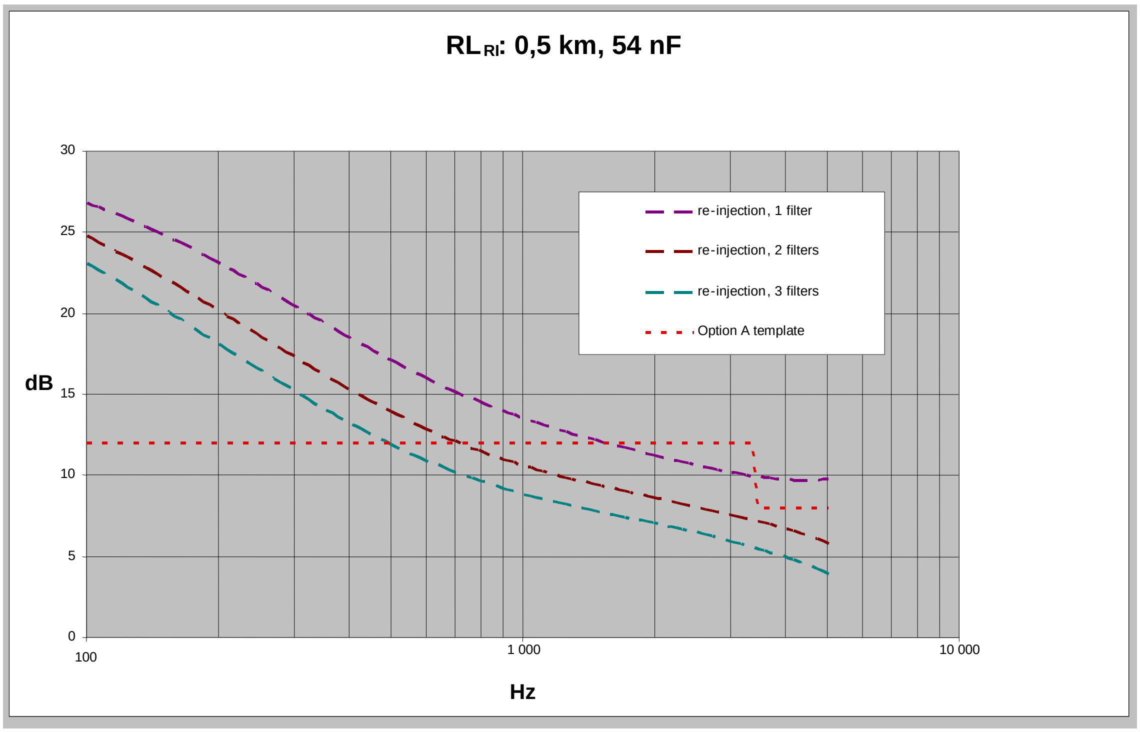
**Figure 18: Return loss at the POTS interface of the microfilters for traditional xDSL deployment (see figure 5)**

Figures 19 to 22 finally show the Return Loss at the POTS interface of microfilters in the re-injection scenario ($RL_{RI}$). Also in this case the results are given for low and high capacity filters and for 0,5 km and 1,5 km links.



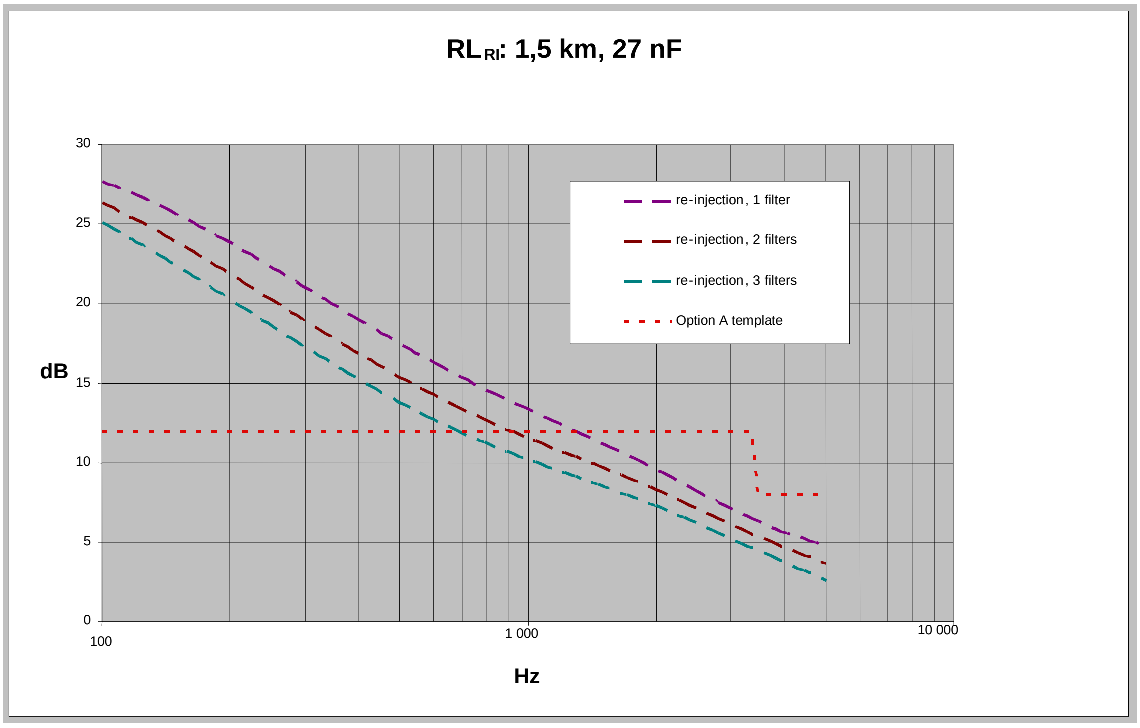

NOTE: Cable length: 0,5 km. Low capacity microfilters.

**Figure 19: Return loss at the POTS interface of the microfilters in the re-injection scenario (see figure 6)**



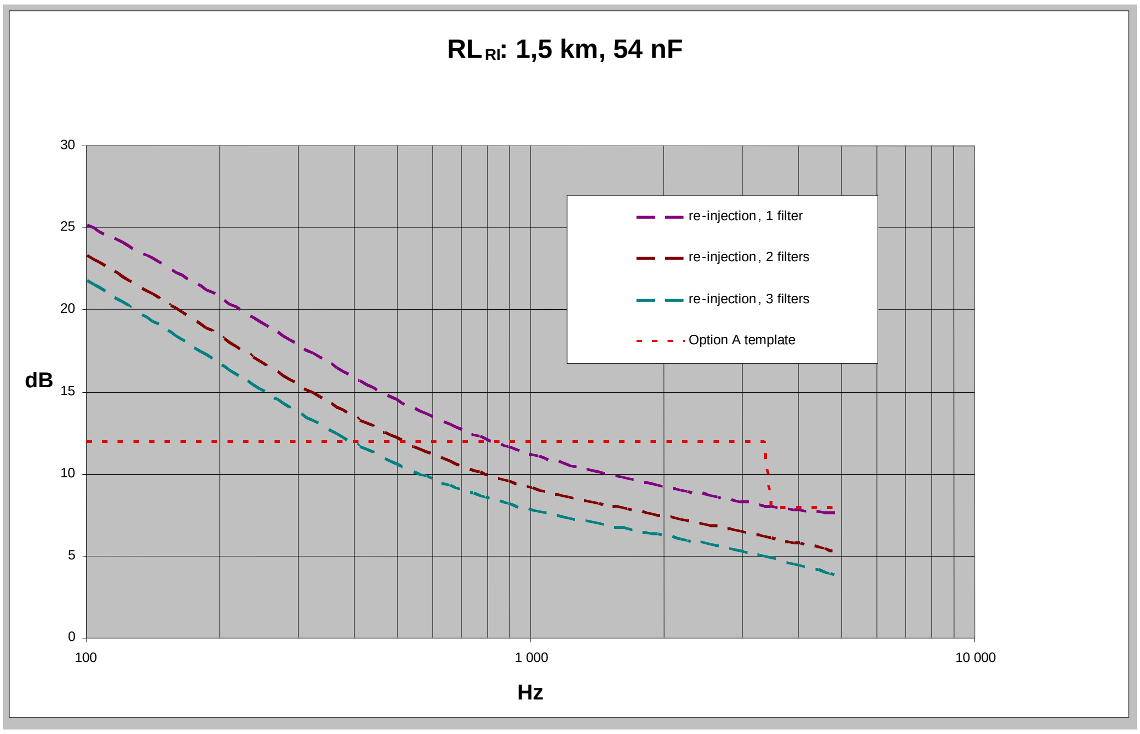

NOTE: Cable length: 0,5 km. High capacity microfilters.

**Figure 20: Return loss at the POTS interface of the microfilters in the re-injection scenario (see figure 6)**




NOTE: Cable length: 1,5 km. Low capacity microfilters.

**Figure 21: Return loss at the POTS interface of the microfilters in the re-injection scenario (see figure 6)**




NOTE: Cable length: 1,5 km. High capacity microfilters.

**Figure 22: Return loss at the POTS interface of the microfilters in the re-injection scenario (see figure 6)**

By comparing figures 11 to14 against figures 19 to 22 it can be seen that, under the assumed conditions, the hybrid is better balanced in the regular xDSL deployment than in the re-injection scheme. In other words, while the hybrid of the POTS card of the CO is properly balanced against the $Z_R$ impedance, the hybrid implemented in the FXS interface of the HG in re-injection scenarios should be rather balanced against an impedance different from $Z_R$. If balanced against $Z_R$, echo cancellation is most likely needed in the HG in order to prevent the occurrence of annoying far-end echo effects.

By comparing figures 15 to18 against figures 19 to 22 it turns out that the impedance balance at the TE side is not so strongly different in the two considered scenarios as compared with the balance at the CO POTS interface. In fact, while with only one microfilter connected, the traditional xDSL deployment still shows a definitely better impedance match at the TE port, this difference gets less significant as more microfilters are connected. The RL behaviour at the terminal side is however not as relevant from the speech quality point of view as that at the CO side as it affects the sidetone effect of speech terminals, which is less influential than far-end echo on the overall quality of speech communications. Nevertheless, if not well balanced telephone sets, e.g. with a high sidetone effect, are connected in the re-injection scenario, these "borderline" devices risk getting unstable due to the worse impedance termination. It may then be wise to specify a termination impedance of the FXS interface of HGs different from $Z_R$ when supporting re-injection applications.

As a conclusion, the impedance balance at the POTS interfaces of CO/HG is better in the traditional xDSL connection than in the re-injection scenario. The impedance balance of the 4wire/2wire transition hybrid built in the FXS interface of the HG should then be preferably modified when supporting re-injection applications. The impedance balance differences at the TE side are less significant but can lead to criticalities in case telephone sets are connected with "borderline" sidetone performances. This suggests the opportunity to optimise also the FXS port impedance of the HG when supporting re-injection applications. Further informations on this subject are provided in annex B.

## 5.2 xDSL transmission integrity

One important difference between the traditional xDSL deployment (see figures 1 and 3) and the distributed re-injection scenario (see figure 4) is that in the latter case both the terminal side and the line side of the POTS link are close to the customer xDSL transceiver (HG) while, in the classic deployment, the CO side of the POTS connection is closer to the network transceiver (DSLAM). In other words, in the re-injection scheme the line no longer acts its smoothing effect on the voltage transients and on the high frequency distortion components of POTS signalling. As a consequence in re-injection schemes the xDSL interface of the HG may be exposed to worse POTS disturbances than in the traditional xDSL deployment.

To quantitatively assess the extent of this potential criticality, the results of tests are here reported, carried out for comparing the on-hook/off-hook transient voltages at the xDSL interface of the HG in the traditional and in the re-injection scenarios, as shown in figures 23 and 24. To maximise the sensitivity of these tests, the DC feeding from the CO POTS card and from the FXS interface is applied through an highly inductive feeding bridge (48 V, 2 x 400 Ω, 2 x 5 H), without current or voltage limitations. Besides, the hook simulation does not include any spark quench circuits. The shown results then exceed somehow the criticality of real operating conditions but are quite indicative of the higher sensitivity of the re-injection scenario to POTS generated disturbances.

The transients recorded at the xDSL interface of the HG for the traditional deployment (see figure 23) are shown in figures 25 to 27, respectively for 1, 2 and 3 microfilter installations (27 nF).

The transients recorded at the xDSL interface of the HG for the re-injection scenario (see figure 24) are shown in figures 28 to 30, respectively for installations with 1, 2 and 3 microfilters (plus the microfilter connected to the FXS interface).

The recorded on-hook transient voltage swings are summarised in Table 1. As anticipated, a systematic difference exists between the overvoltages measured in the two scenarios, due to the greater smoothing effect operated by the local loop in the traditional xDSL deployment.

**Table 1**

| Nr of (27nF) microfilters connected | On-hook voltage transient at the xDSL input of the HG | |
|---|---|---|
| | **Traditional xDSL deployment** | **Re-injection scenario** |
| 1 µfilter | 304 V | 410 V |
| 2 µfilters | 304 V | 390 V |
| 3 µfilters | 256 V | 333 V |

From the reported results it may be concluded that, to make up for the higher exposure of the xDSL transceiver to POTS disturbances, it may be worth implementing suitable measures in the re-injection scenario to mitigate the potentially negative effects of POTS signalling on the xDSL transmission performances.

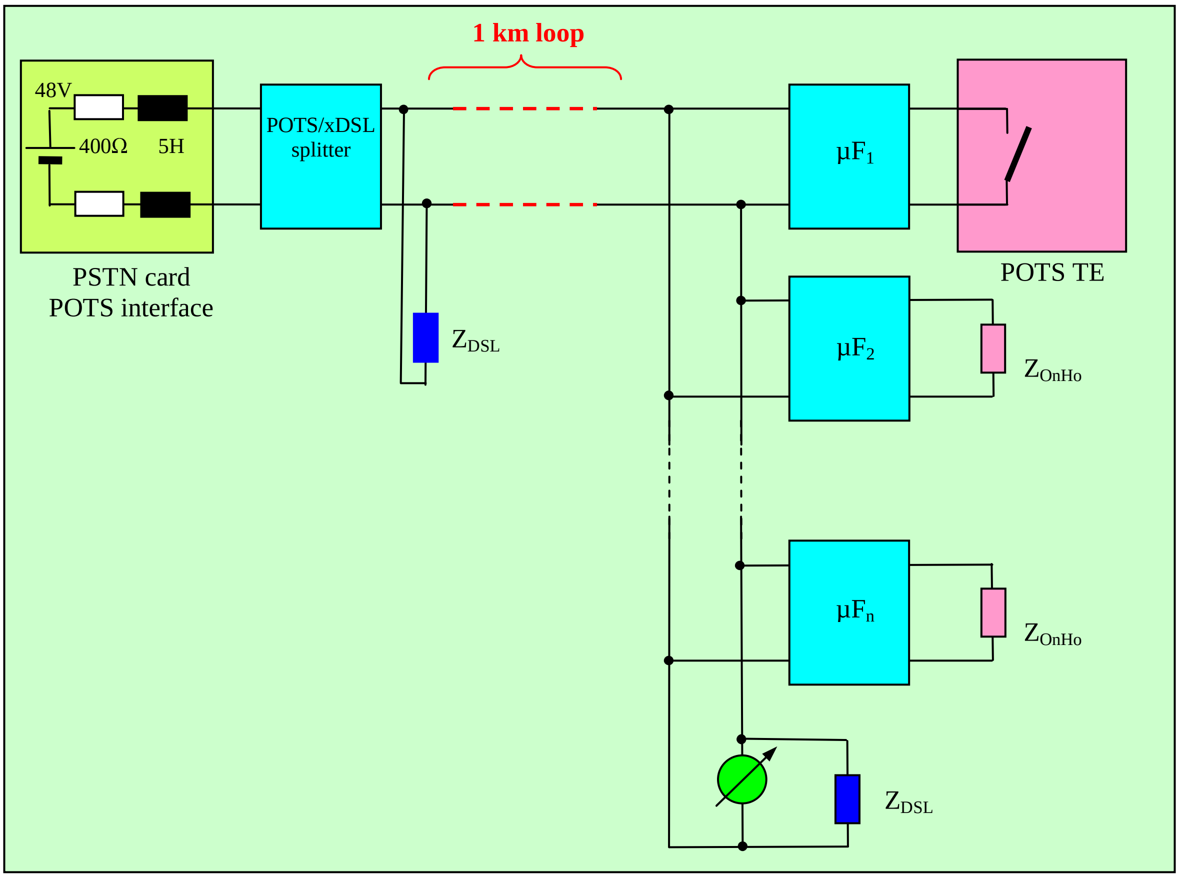



**Figure 23: test of the on-hook/off-hook transients at the xDSL interface of the HG for the traditional xDSL deployment**

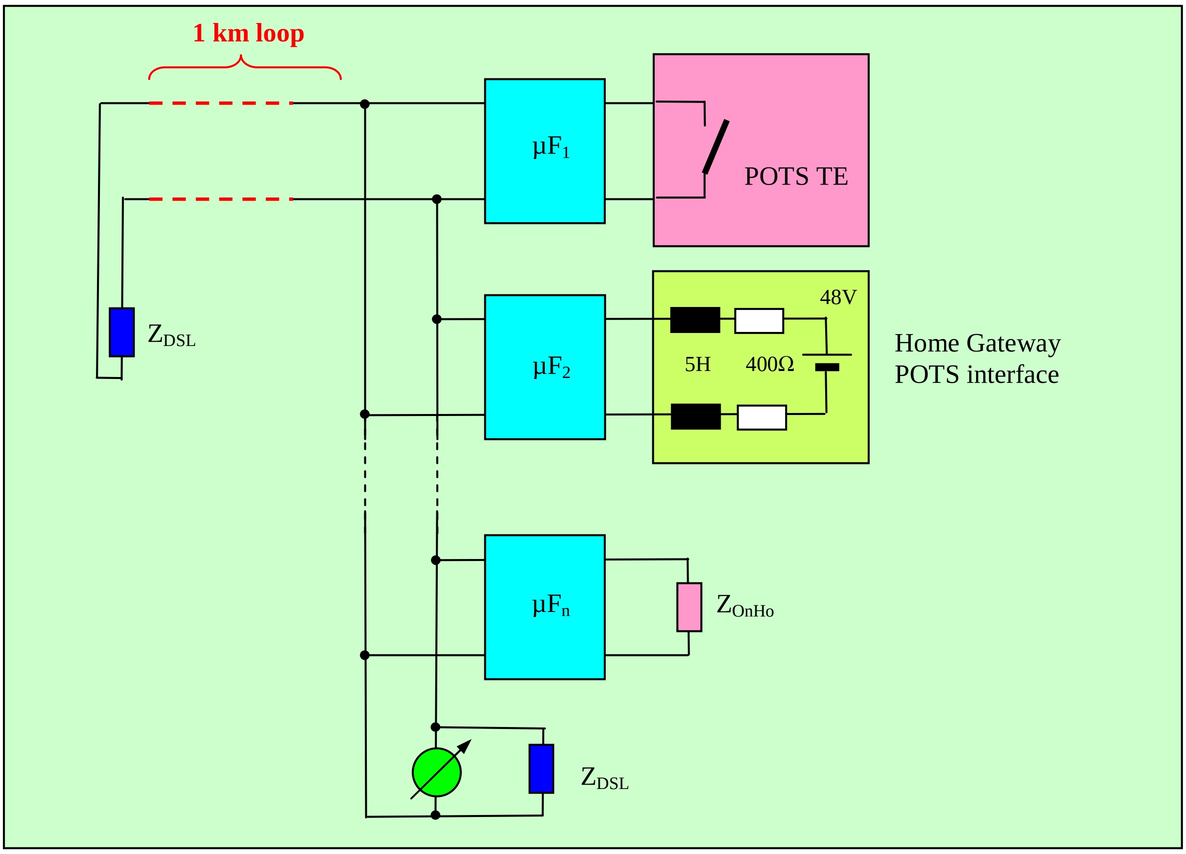



**Figure 24: test of the on-hook/off-hook transients at the xDSL interface of the HG for the re-injection scenario**

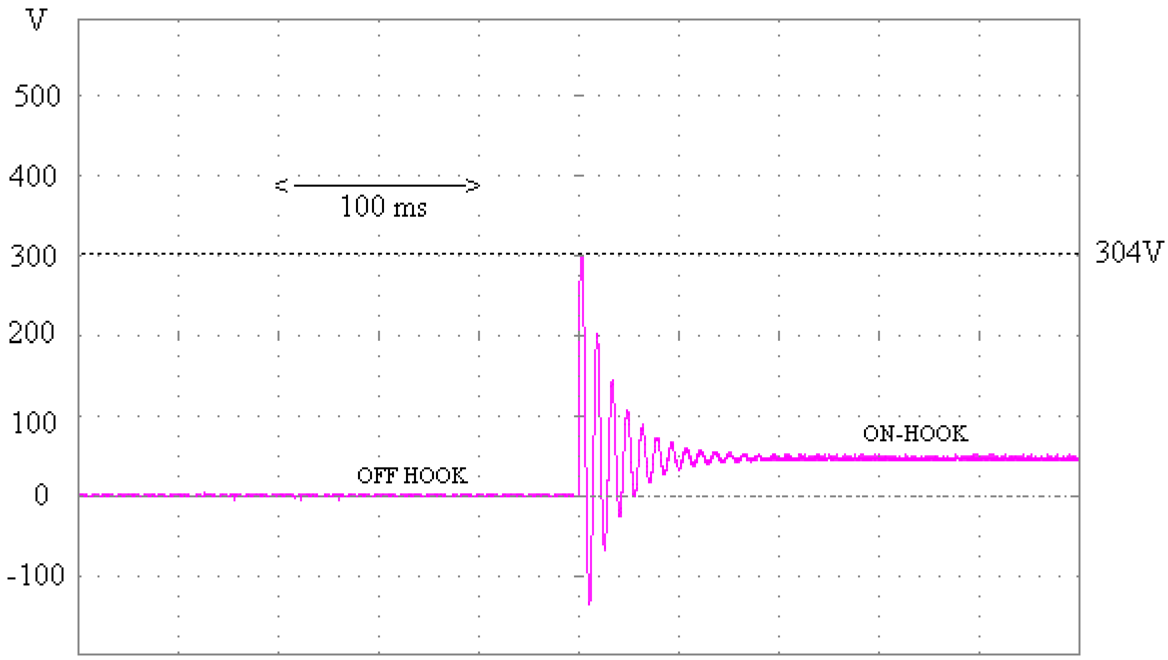



**Figure 25: Off/on-Hook transients. Traditional xDSL deployment. One microfilter.**

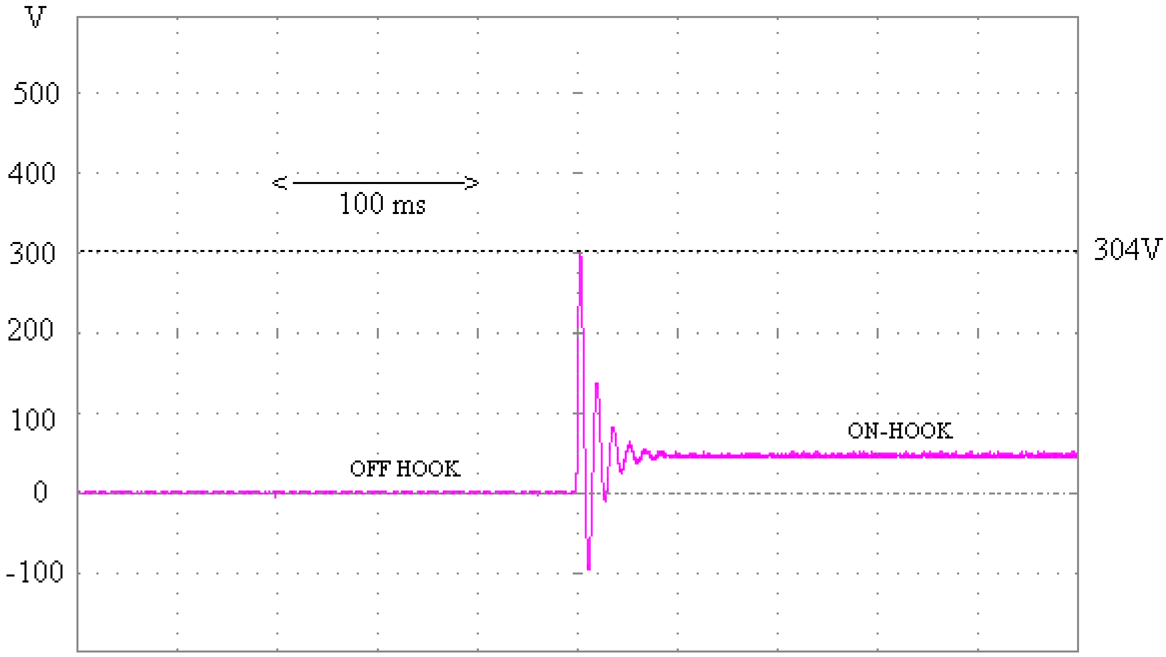



**Figure 26: Off/on-Hook transients. Traditional xDSL deployment. Two microfilters.**

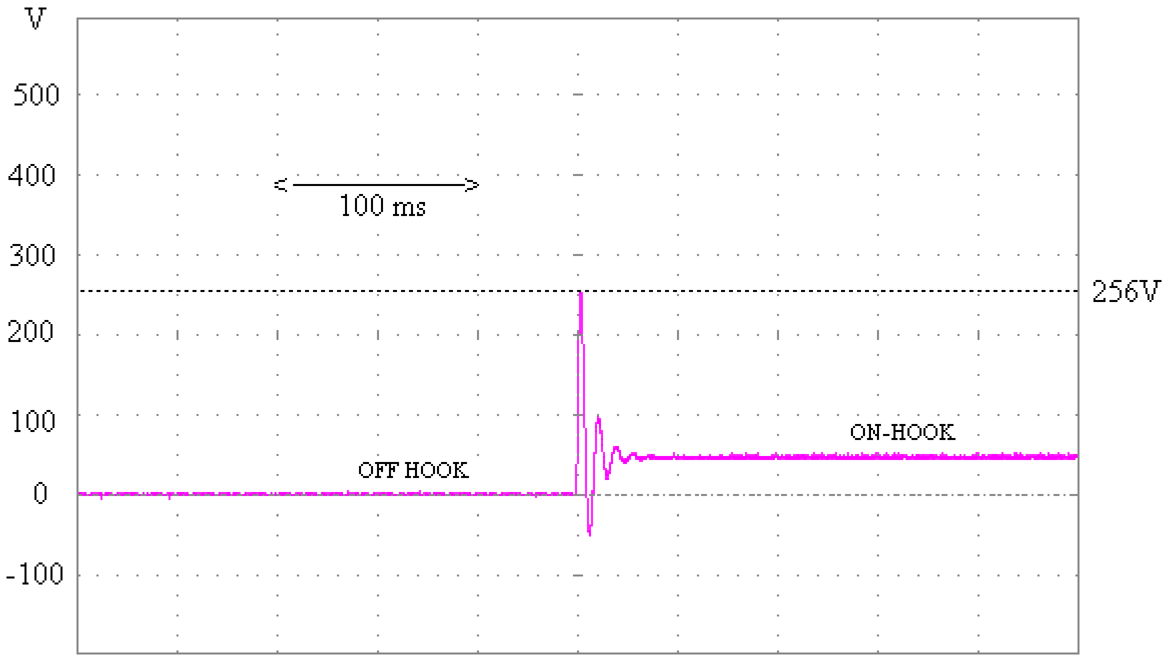



**Figure 27: On-Hook transient. Traditional xDSL deployment. Three microfilters.**

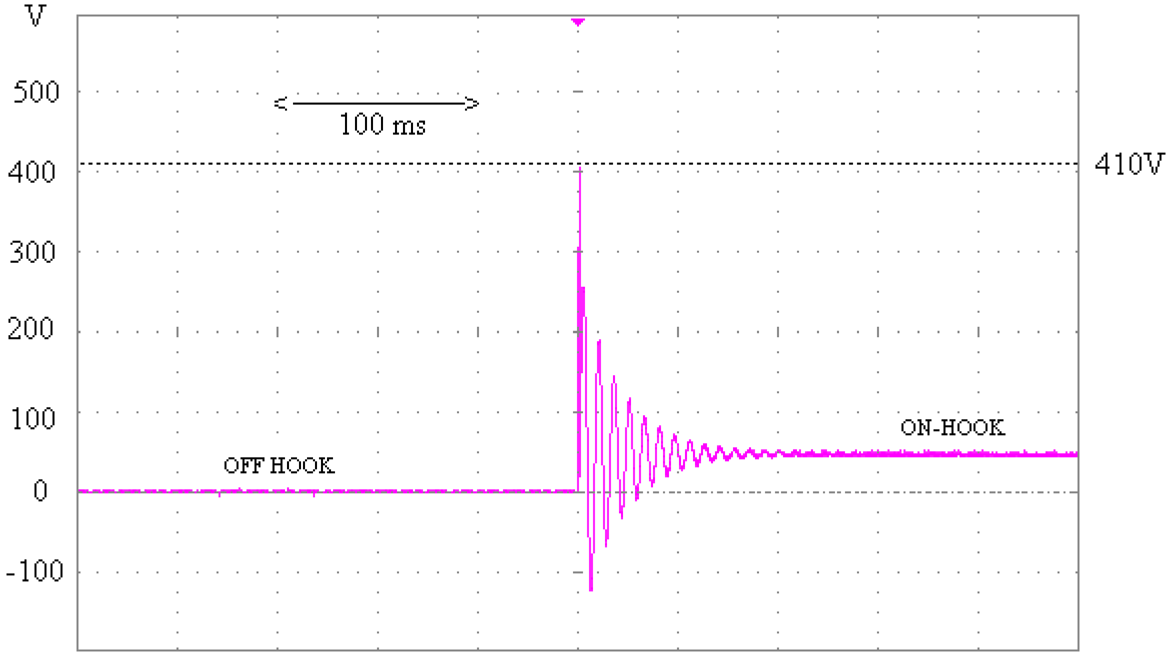



**Figure 28: On/off-Hook transients. Re-injection scenario. One microfilter.**

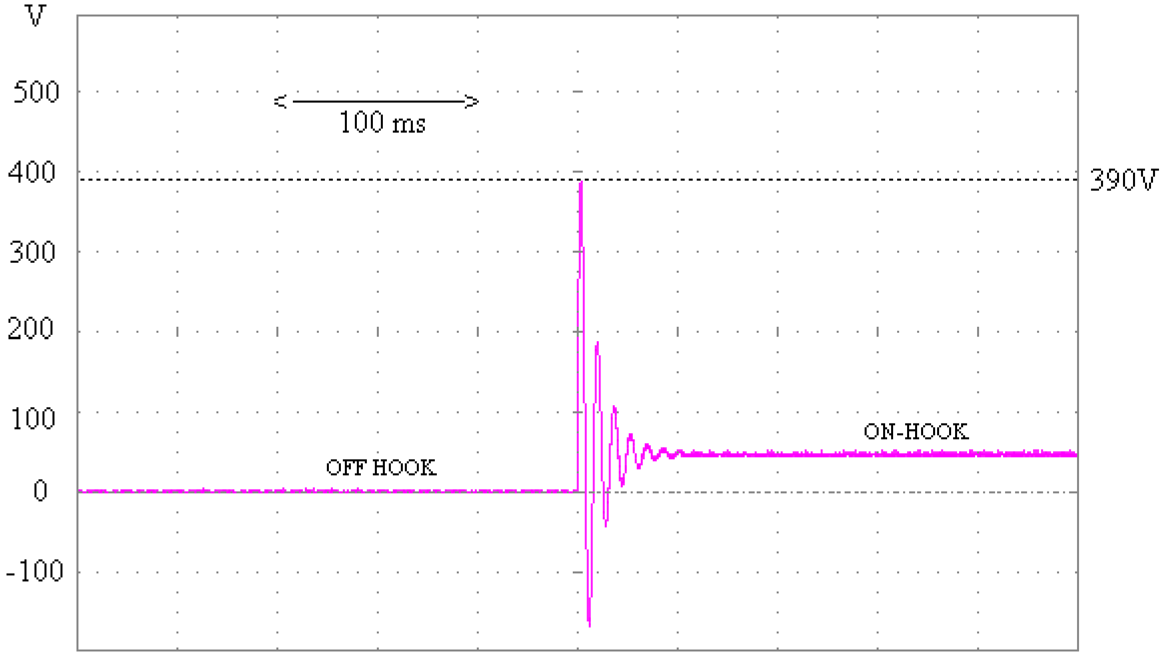



**Figure 28: On/off-Hook transients. Re-injection scenario. Two microfilters.**

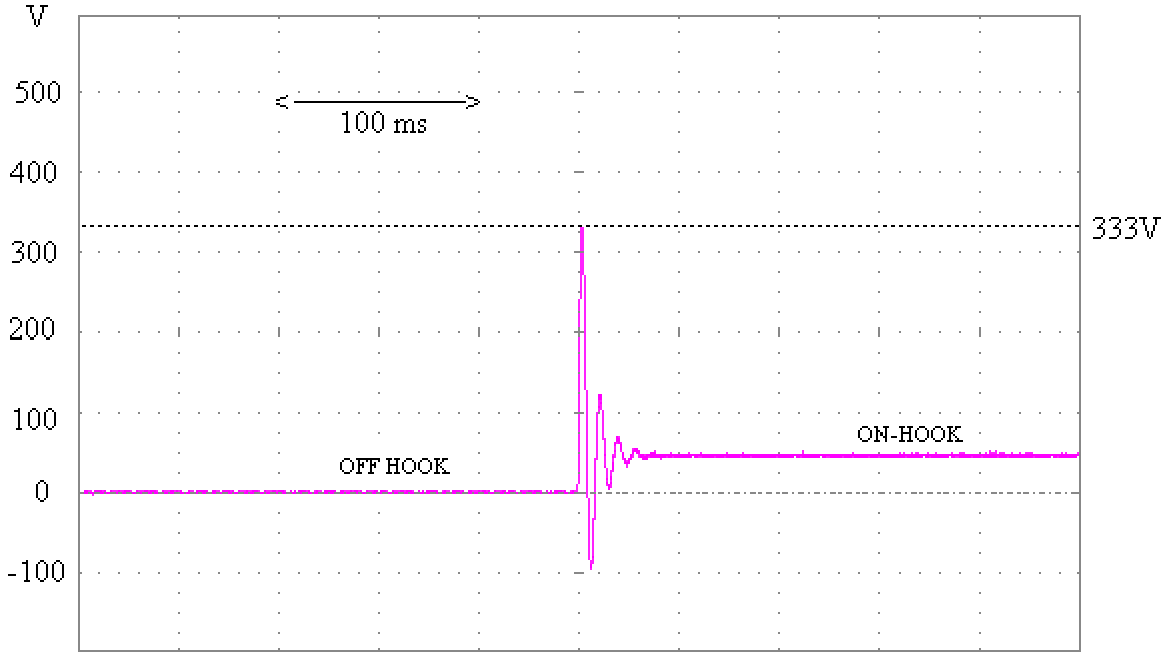



**Figure 30: On/off-Hook transients. Re-injection scenario. Three microfilters.**

## 5.3 Safety considerations

The **xDSL interface** of Home Gateways is required to be of type TNV-3, according to EN 60 950-1 [i.8], as its terminals can be subject to overvoltages from the local loop. It is then required to be suitably galvanically insulated both from the other interfaces of the HG and from its accessible conductive parts, in order to protect the user against electric shocks arising from these overvoltages.

In the total POTS replacement scenario implemented as shown in figure 2 the **FXS interface** of the HG is not connected to the local loop. In this case it can be of type TNV-2 [i.8], i.e. not separated from the accessible conductive parts of the HG. However, this is not the case of the POTS re-injection scheme (see figure 4) where the FXS interface is galvanically connected to the external line through the associated FXS microfilter.

As a consequence, Home Gateways provided with a FXS interface of the TNV-2 type, then developed for supporting the traditional scenario, **can not be used for implementing re-injection schemes** as this would expose the user to overvoltage hazards. For re-injection applications either HGs with a TNV-3 FXS interface are required to be used or, if a HG with a TNV-2 FXS interface is adopted, a suitable galvanic insulator is required to be interposed between this interface and the customer plant wiring.

# 6 Conclusive remarks

The analysis carried out in the present document shows that, irrespectively from the microfilters capacity, the frequency response in the POTS band of re-injection based xDSL schemes is more "flat" and generally less attenuated than that achieved in the traditional xDSL provision. With longer loops this advantage is even more evident, both with respect to the signal attenuation and to the frequency response linearity. It can then be concluded that, from the POTS transmission point of view, the re-injection architecture assures adequate performances and, consequently, that **microfilters designed according to the current standards work equally well in the re-injection environment**.

As concerns the far end echo problems, it has been shown that, while the hybrids of the POTS card of the CO properly operate when balanced against the $Z_R$ impedance, **the hybrids implemented in the FXS interface of HGs intended to support re-injection scenarios should be balanced against an impedance different from $Z_R$**. In fact, if balanced against $Z_R$, additional echo cancellation would be most likely needed in the HG in order to prevent the occurrence of annoying echo effects. Further information on FXS impedance optimisation is provided in annex B.

The impedance balance at the TE side is not so strongly different in the two considered scenarios. Nevertheless, if not well balanced telephone sets, e.g. with an intrinsically high sidetone effect, are connected to re-injection schemes, these "borderline" devices risk getting unstable unless **a termination impedance of the FXS interface of HGs different from $Z_R$, is adopted**. Also this subject is further addressed in annex B.

It has also been shown that the transients and disturbances at the xDSL interface of HGs due to POTS signalling are potentially more relevant in re-injection schemes than in the traditional xDSL provision. **It may be then worth considering the implementation of suitable mitigation measures in the re-injection scenario to reduce the negative effect of POTS signalling on the xDSL transmission performances.** The effectiveness of such measures should be tested by functional testing methodologies on the same line as to those specified in TR-127 [i.11].

Finally, to safeguard the user safety, **the FXS interface of Home Gateways supporting re-injection is required to be of the TNV-3 type,** as specified by EN 60950-1 [i.8].

# Annex A: AC terminating impedances

In this annex some AC terminating impedances used for POTS/xDSL splitter testing and specification are described. The reported information is taken from relevant ETSI standards (e.g. TS 101 952-1 [i.6]) and is here provided only for the reader convenience. Only the impedances mentioned in the present document are here described.

## A.1 $Z_{DSL}$: xDSL transceiver related impedances

For the purposes of the present document $Z_{DSL}$ represents the impedance of the DSLAM and of the Home Gateway. Its impedance model is as shown in figure A.1.

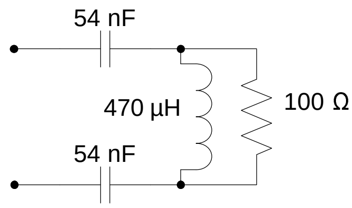



**Figure A.1: Schematic diagram of the impedance $Z_{DSL}$**

## A.2 $Z_R$: CPE and POTS interface off-hook impedance

For most splitter requirements relating to voice band frequencies, the ETSI harmonised impedance $Z_R$ is used. In fact, it is specified both as POTS CPE impedance [i.3] and as impedance of the POTS port of the HG [i.1]. Its impedance model is as shown in figure A.2.

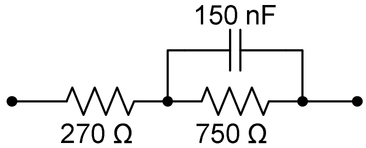



**Figure A.2: Impedance $Z_R$**

## A.3 $Z_{OnHo}$: Impedance On-hook

$Z_{OnHo}$ is used to model multiple on-hook telephones in parallel with a single off-hook phone. It has been introduced for testing multiple parallel distributed filters. Its impedance model is shown in figure A.3.

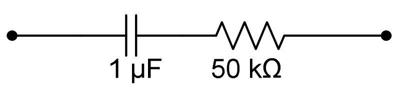



**Figure A.3: Impedance $Z_{OnHo}$**

# Annex B: Optimisation of the input and balance impedances of the POTS interface of Home Gateways intended for re-injection applications

To preliminarily assess the possible improvements achievable by optimising the impedances of the POTS (FXS) port of HGs when intended for re-injection applications, the xDSL deployment scenario shown in figure 6 has been further analysed by assuming the implementation of the FXS interface with both input and balance impedances different from $Z_R$. Due to the exploratory scope of this analysis, the study has been restricted to the case of low capacity microfilters.

To improve the HG hybrid balance, the impedance presented to the POTS interface of the HG has been measured and the Return Loss (RL) maximised **by considering a balance impedance different from $Z_R$**.

The input impedance of the FXS port has then been optimised by measuring the impedance presented to the TEs and by calculating the RL with respect to $Z_R$. **An FXS impedance different from $Z_R$ was considered, such to maximise the RL at the TE interface**.

## B.1 Balance impedance optimisation

The polar plots of the impedances presented to the FXS interface in the re-injection scheme shown in figure 6, equipped with low capacity microfilters, are shown in figures B.1 and B.2 respectively for 0,5 km and 1,5 km local loop connections. Also the polar plot of $Z_R$ is there reported.

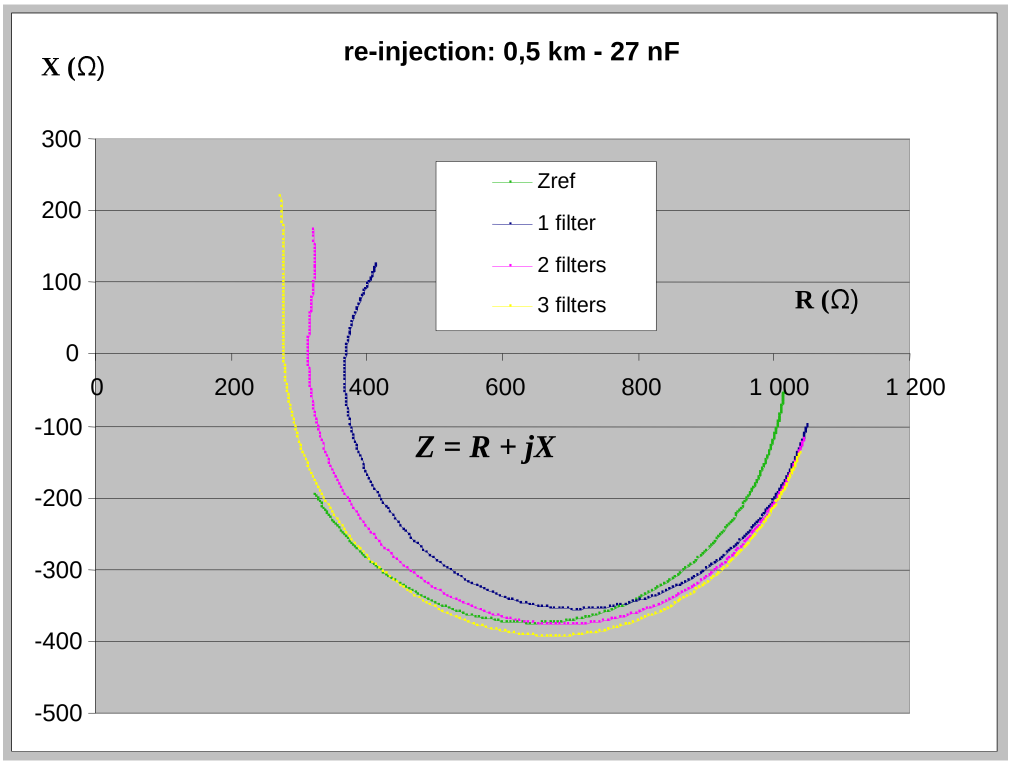



**Figure B.1: Impedances presented at the FXS port - 0,5 km local loop**

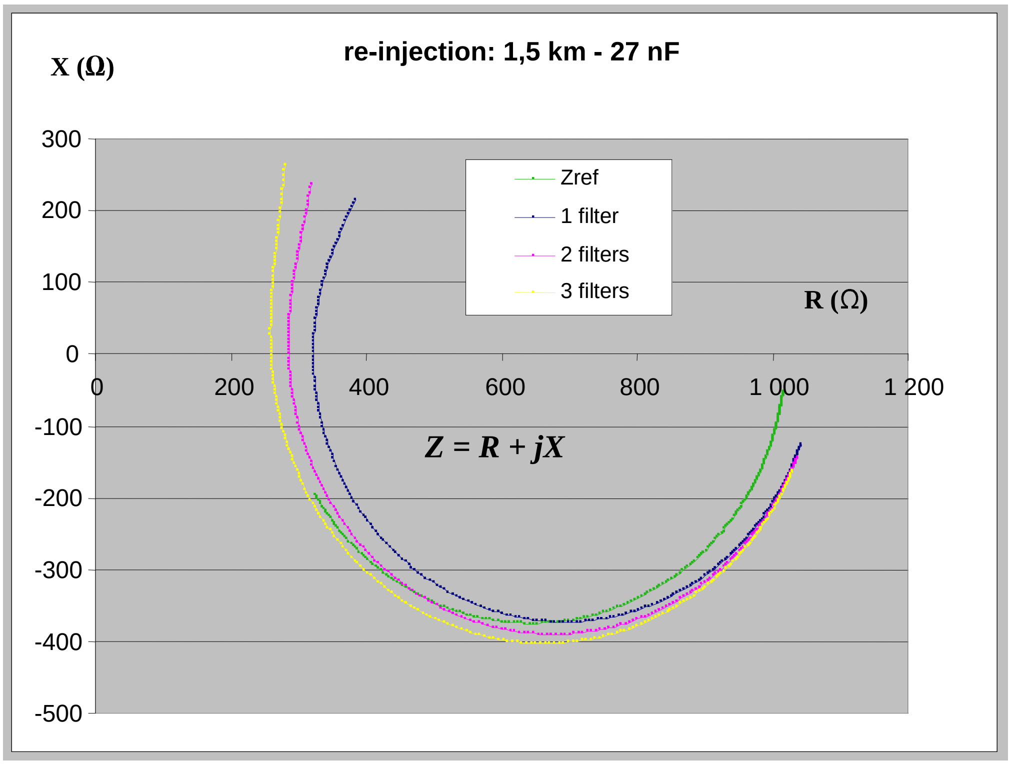



**Figure B.2: Impedances presented at the FXS port - 1,5 km local loop**

The Return Loss of these impedances, calculated with respect to $Z_R$, is reported in figures B.3 and B.4 respectively for 0,5 km and 1,5 km local loop connections. It may be noted that the calculated results well match the measured values, previously reported in figures 19 and 21.

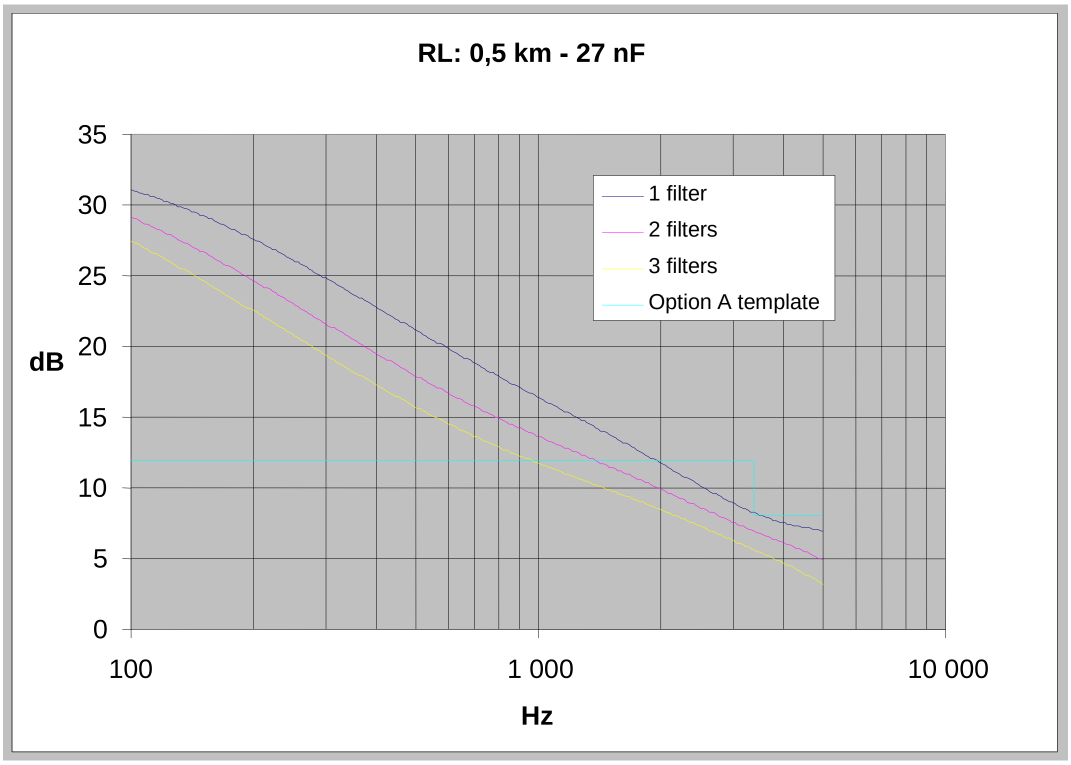



**Figure B.3: Return Loss (with respect to $Z_R$) of impedances presented at the FXS port - 0,5 km local loop**

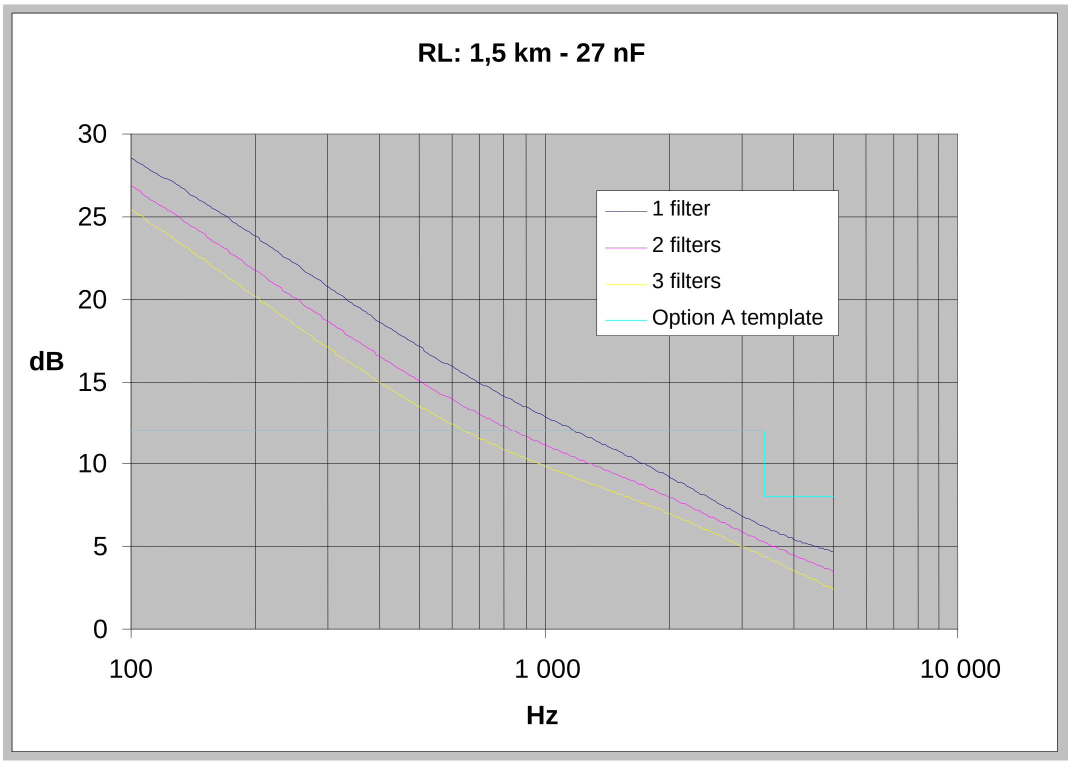



**Figure B.4: Return Loss (with respect to $Z_R$) of impedances presented at the FXS port - 1,5 km local loop**

From the impedance plots of figures B.1 ad B.2 it is evident that the poor RL values at higher frequencies are due to the inadequate reactive component of the balance impedance. An alternative balance impedance has then been considered with an increased condenser capacity and a slightly modified series resistor (see figure B.5).

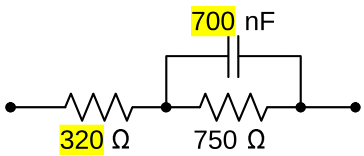



**Figure B.5: Alternative balance impedance $Z_{bal}$ of the HG hybrid (for 2 wires/4 wires transition)**

The impedance plots reported in figures B.6 and B.7 show that the new balance impedance better matches the impedances presented at the FXS port at higher frequencies. The respective RL calculations, reported in figures B.8 and B.9, when compared with figures B.3 and B.4 provide a quantitative estimation of the achieved improvement.

These results, albeit of a preliminary nature, indicate that **it is worth specialising the balance impedance of the POTS (FXS) port of Home Gateways when intended for supporting re-injection applications**.

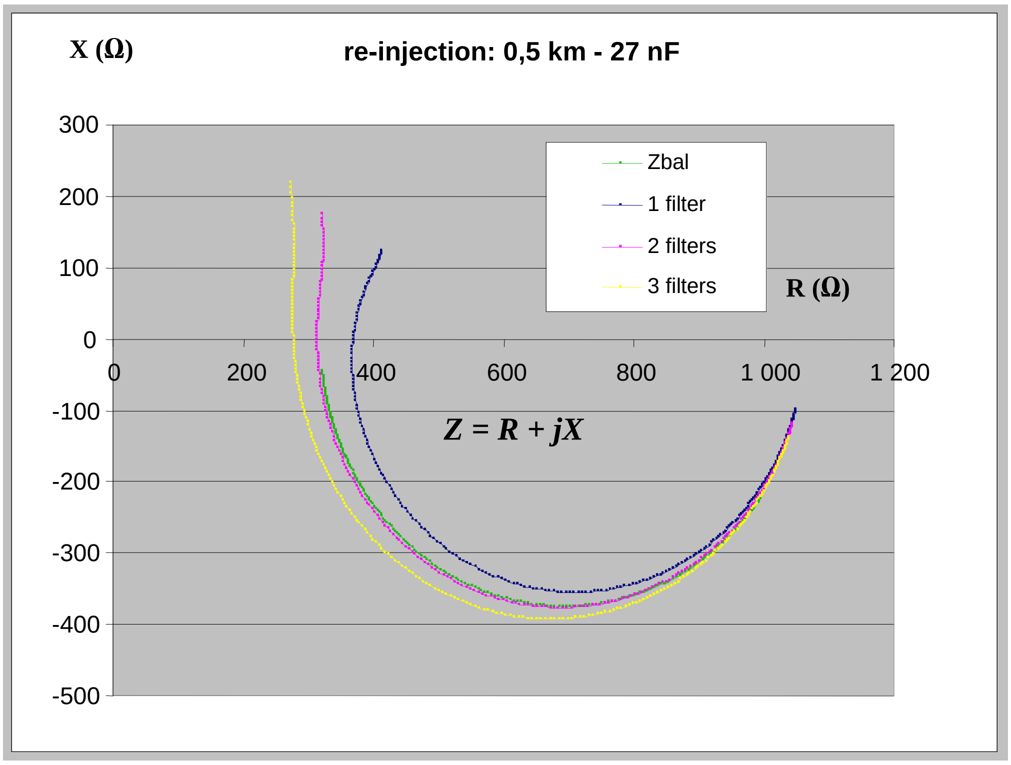



**Figure B.6: Impedances presented at the FXS port, comparison with new balance impedance $Z_{bal}$ - 0,5 km local loop**

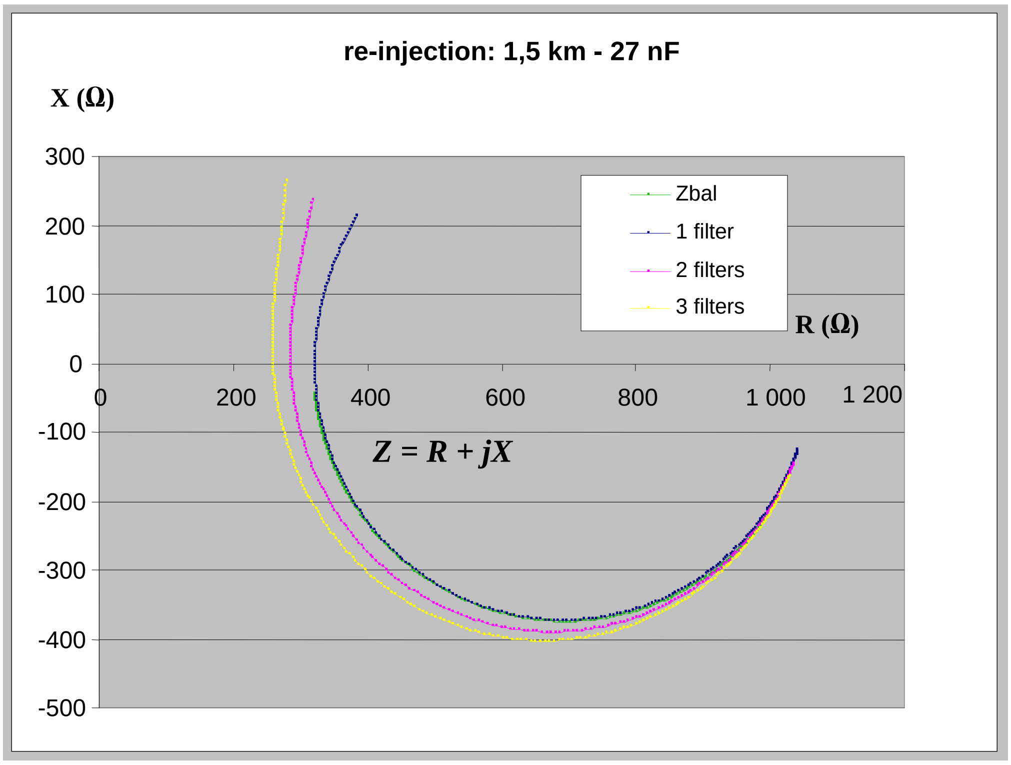



**Figure B.7: Impedances presented at the FXS port, comparison with new balance impedance $Z_{bal}$ - 1,5 km local loop**

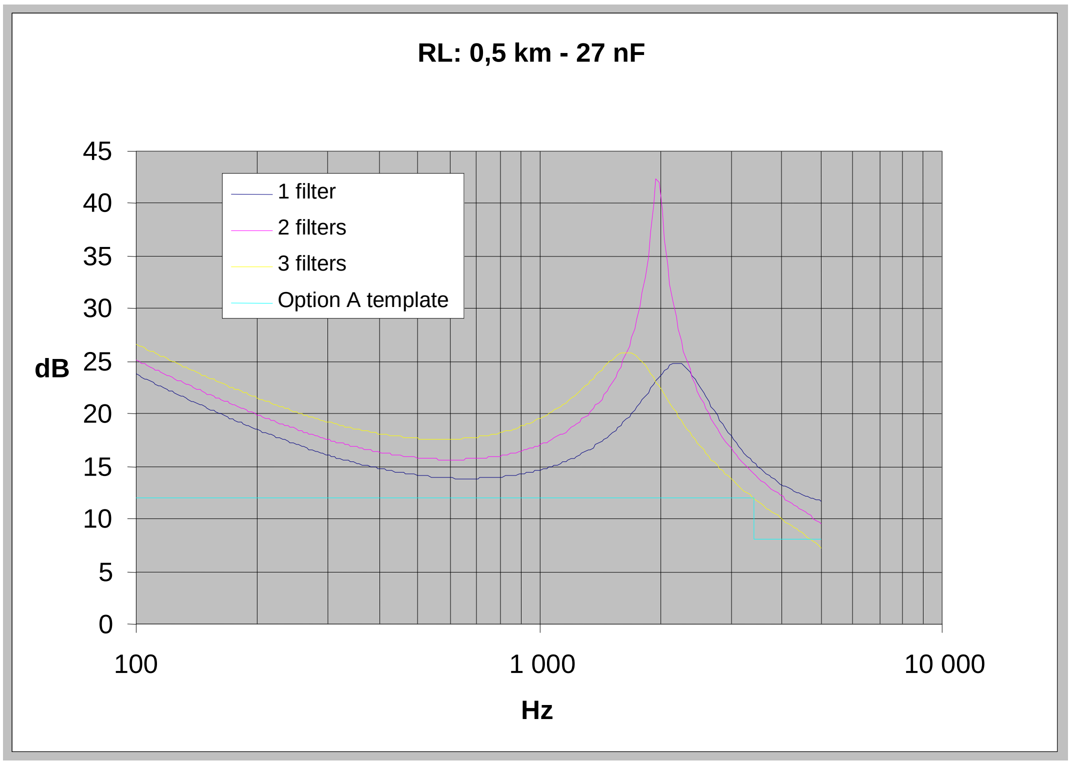



**Figure B.8: Return Loss (with respect to $Z_{bal}$) of impedances presented at the FXS port - 0,5 km local loop**

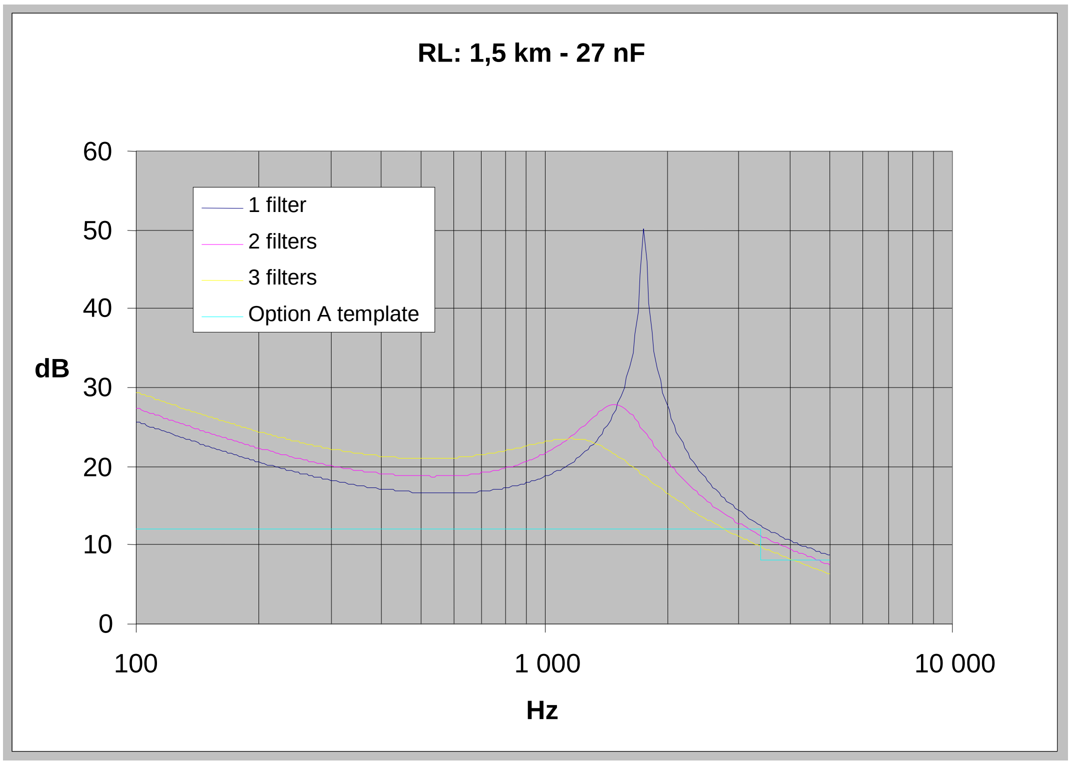



**Figure B.9: Return Loss (with respect to $Z_{bal}$) of impedances presented at the FXS port - 1,5 km local loop**

# B.2 Input impedance optimisation

To improve the impedance balance of TEs connected to re-injection systems, responsible for the sidetone effect of telephone sets, it is implausible to act on the internal balance impedance of the POTS terminals, as it is constrained by terminal standards (e.g. [i.4]). The only way to improve the CPE sidetone in re-injection environments consists then in acting on the input impedance of the FXS interface in such a way that the impedance presented to the CPEs better approximates $Z_R$.

The impedance presented to CPEs for a $Z_R$ temination at the FXS interface is as shown in figures B.10 and B.11. From these results it is clear that, to better match $Z_R$, the reactive part of the FXS impedance should be reduced. As an example, the impedances presented to the TE for a purely resistive FXS termination (1 020 Ω) are shown in figures B.12 and B.13.

The resulting RL with respect to $Z_R$ at the TE interface, reported in figures B.14 and B.15, is improved with respect to the same obtained for a $Z_R$ terminated FXS impedance, previously shown in figures B.3 and B.4.

Again, it is demonstrated that, despite the preliminary nature of these results, **it is clearly worth specialising also the input impedance of the POTS (FXS) interface of Home Gateways when intended for supporting re-injection applications**.

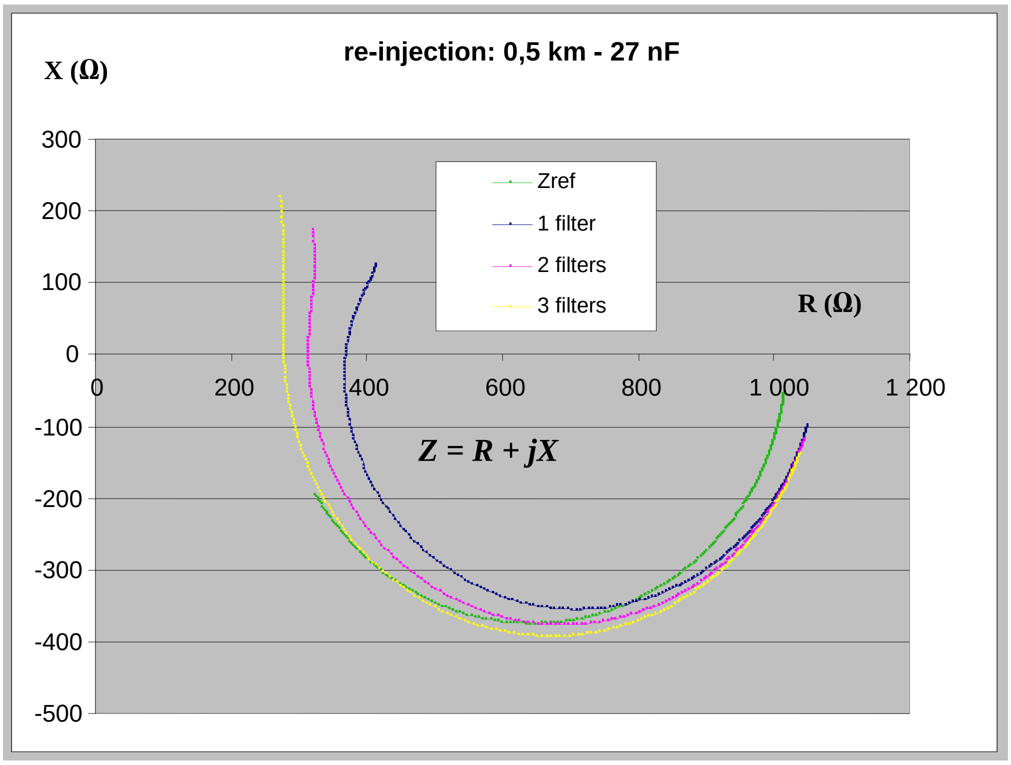



**Figure B.10: Impedances presented at the TE port for FXS=$Z_R$ - 0,5 km local loop**

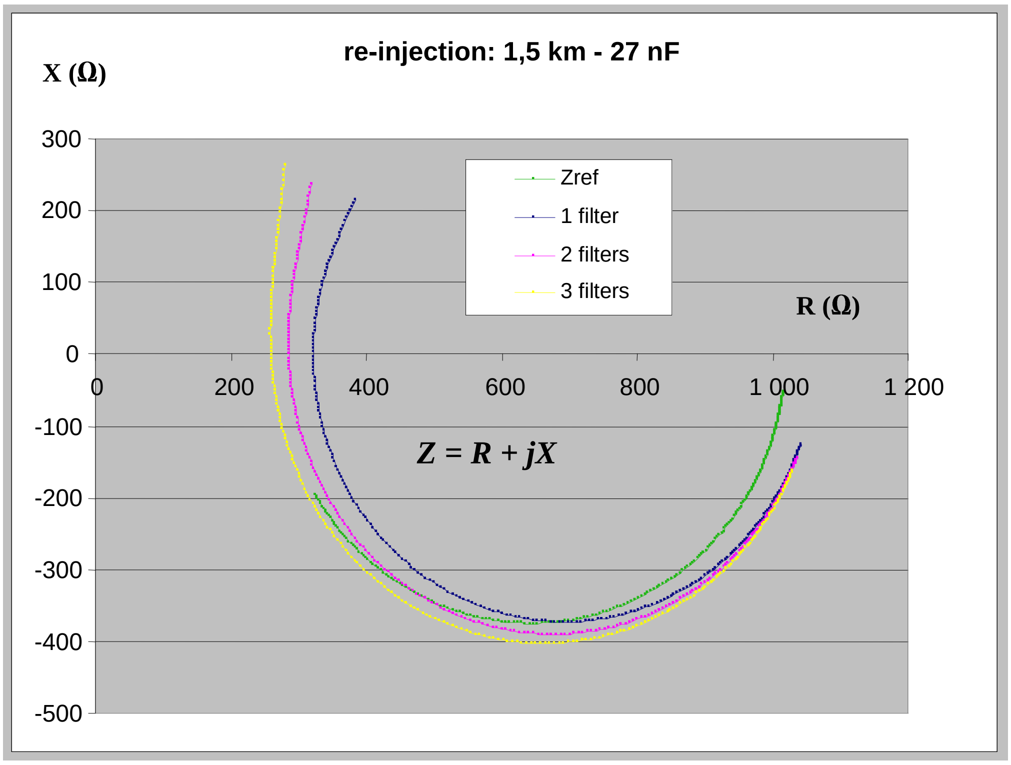



**Figure B.11: Impedances presented at the TE port for FXS=$Z_R$ - 1,5 km local loop**

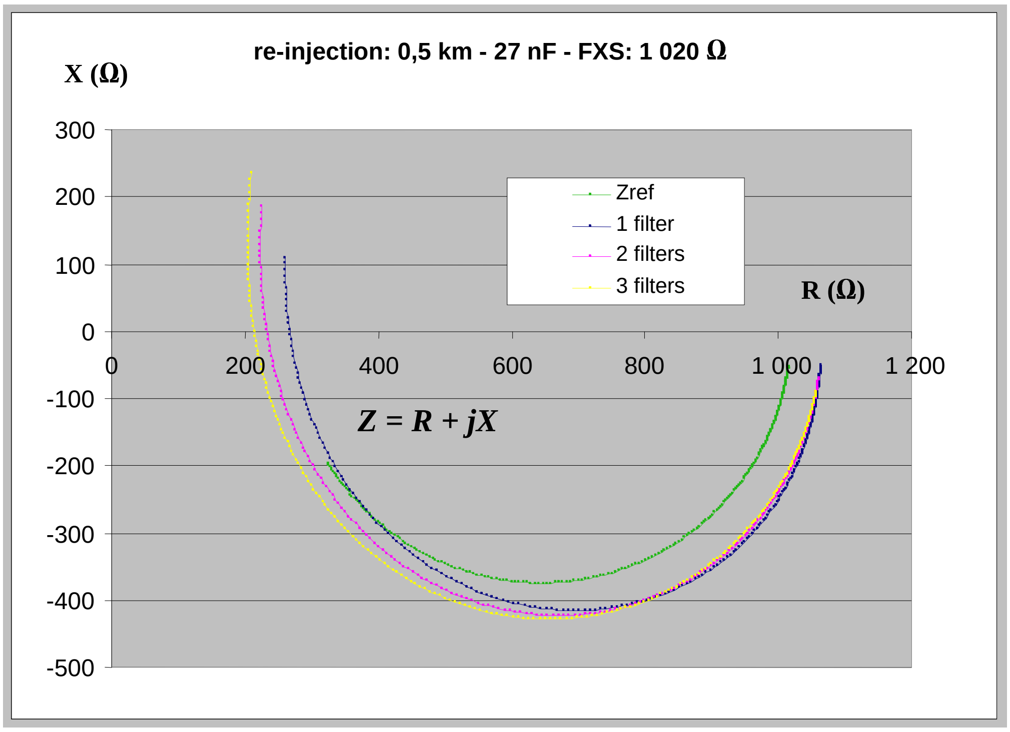



**Figure B.12: Impedances presented at the TE port for FXS = 1 020 Ω - 0,5 km local loop**

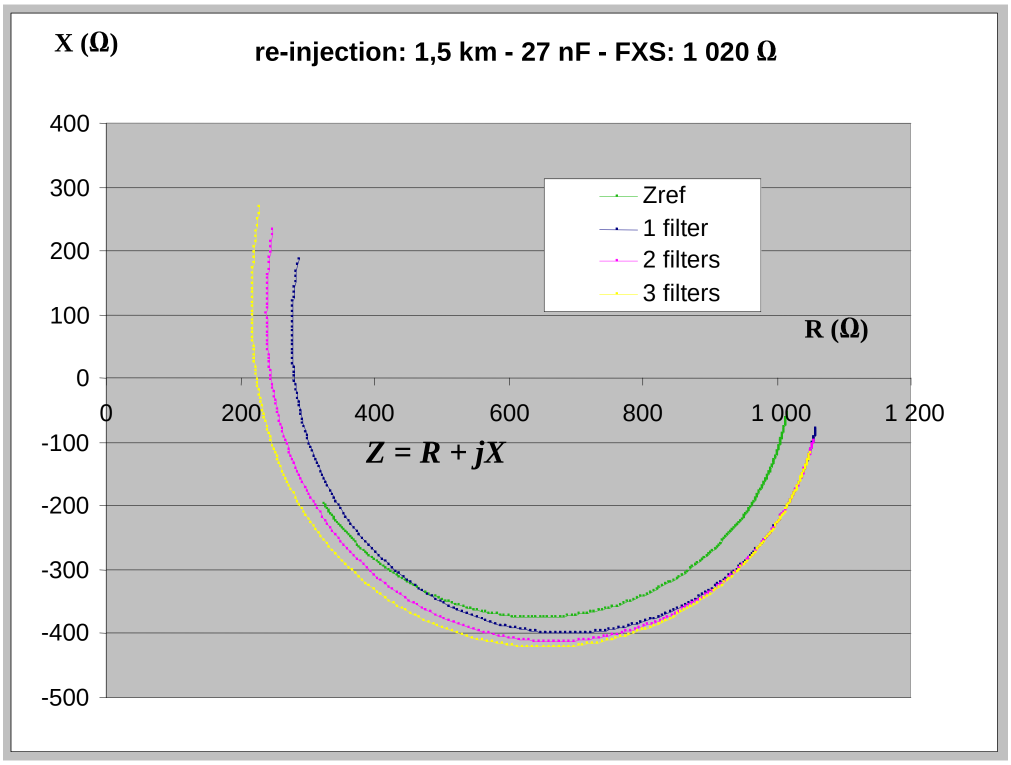



**Figure B.13: Impedances presented at the TE port for FXS=1 020 Ω - 1,5 km local loop**

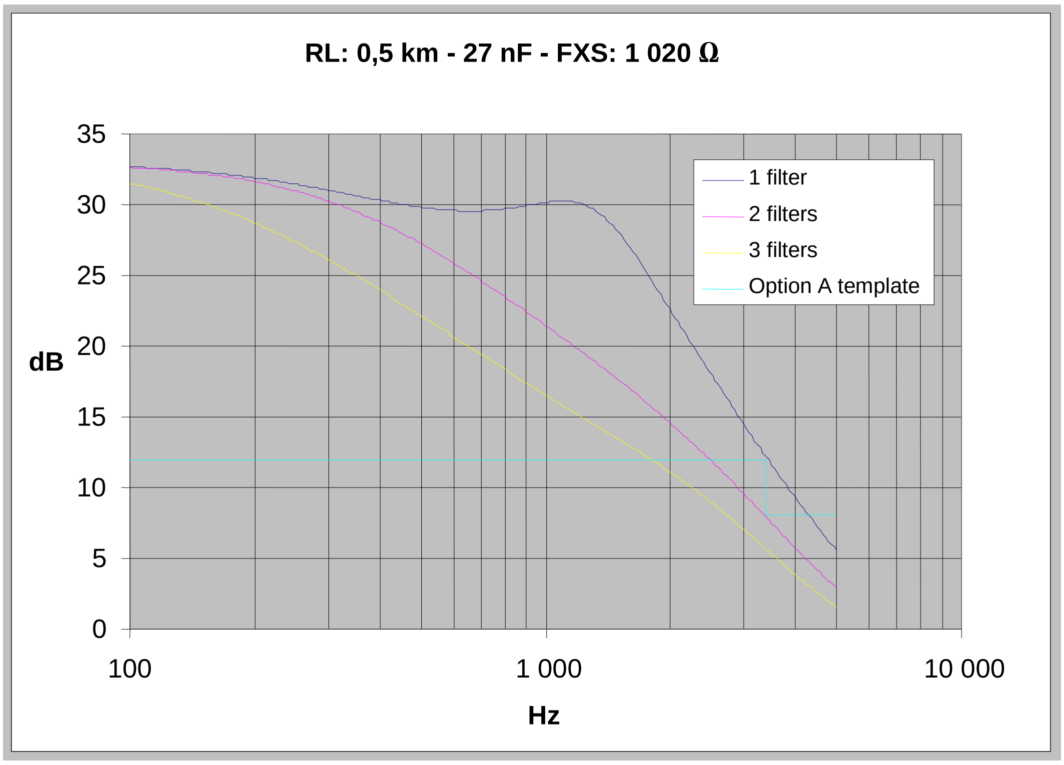



**Figure B.14: Return Loss (with respect to $Z_R$) of impedances presented at the TE port (FXS = 1 020 Ω) - 0,5 km local loop**

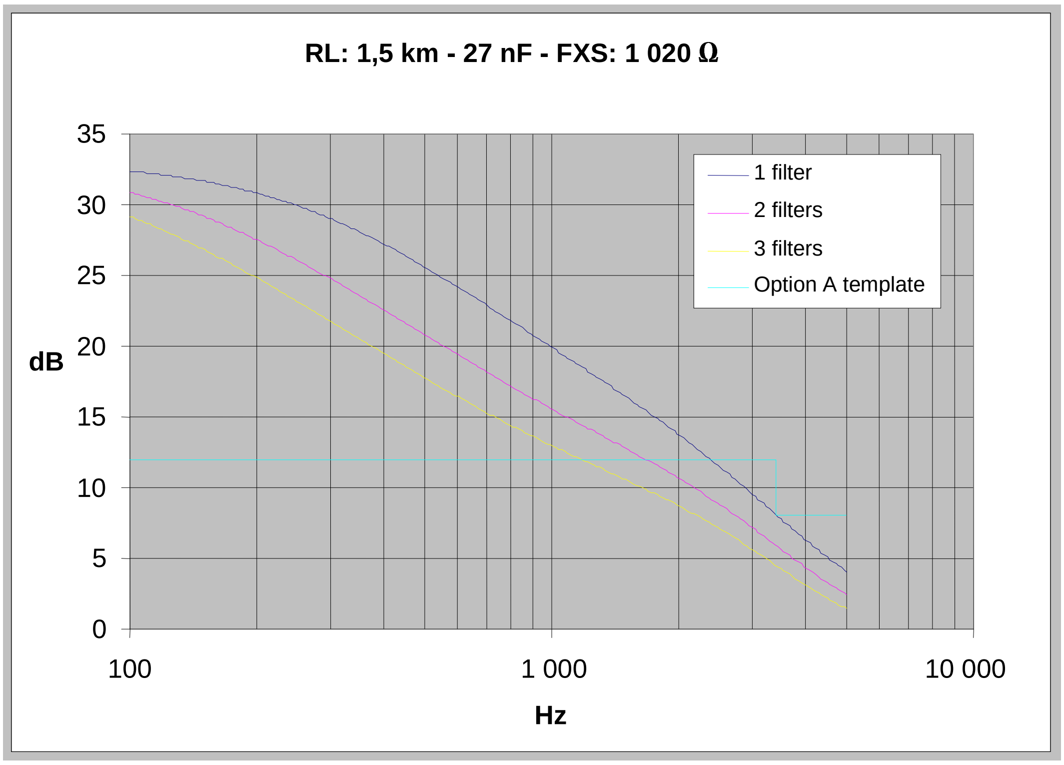



**Figure B.15: Return Loss (with respect to $Z_R$) of impedances presented at the TE port (FXS = 1 020 Ω) - 1,5 km local loop**

# B.3 Conclusions on impedance optimisation

These preliminary results indicate that **it is worth specialising the balance and input impedances of the POTS (FXS) port of Home Gateways intended for supporting re-injection applications**.

The optimal balance impedance should have a reactive component higher than $Z_R$, like the impedance model shown in figure B.5.

On the contrary, the optimal input impedance should have a reactive component lower than $Z_R$. The purely resistive implementation considered in the study is likely to represent an acceptable compromise.

# History

| Document history | | |
|---|---|---|
| V1.1.1 | March 2010 | Publication |
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