MARKETING REPORT

MR-261

Motivation for Testing xDSL Splitters and In-Line Filters

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Comments or questions about this Broadband Forum Marketing Report should be directed to info@broadband-forum.org.

Editors	Andre Holley Peter Reusens	Sparnex Instruments LAN
White Papers Chair	Sarah Banks Vanessa Nacamura	Cisco Nokia Siemens Networks
Chief Editor	Michael Hanrahan	Huawei

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Executive Summary

Technical Report TR-127 of the Broadband Forum is an xDSL system test. It checks primarily if xDSL splitters used at the Central Office (CO) and at the Customer Premise Equipment (CPE) side are capable of protecting the xDSL signals against voltages and other disturbances present on a telephone line. To achieve this, TR-127 contains a series of tests, which model all signals of the Plain Old Telephone Service (POTS) in a realistic way, which includes all POTS disturbances and transients that may affect xDSL.

Splitter devices should be tested dynamically in an xDSL system:

ADSL and VDSL (xDSL in short) are carrying High Speed Internet, IPTV and VoIP. Therefore, the Bit Error Ratio (BER) of xDSL can significantly impact the quality of the delivered services and consequently the user experience. Splitters or filters passing TR-127 can guarantee the necessary quality to pass triple-play service with a low BER.

A splitter is used at the CO side and either a splitter or in-line filters (a.k.a. "micro-filters") are used at the CPE side for the deployment of xDSL. They should minimize interference into the broadband xDSL from signals of the traditional POTS service and other sources from the network side / or upstream. Particularly poor quality splitters and filters are known to be sources of errors and signal losses induced in xDSL. These splitter devices must have sufficient quality to achieve the required xDSL performance. Therefore it is recommend that splitters and filters be tested dynamically, which can only be achieved by the complete xDSL system test in TR-127.

Before TR-127 was compiled, splitters and filters were only tested according to the static test of ETSI or ATIS. While still necessary these tests are known to be insufficient to guarantee the correct operation under dynamic conditions.

It is concluded that splitters successfully passing TR-127 can guarantee a virtually error free performance of a system of xDSL transceivers including the splitters. The usefulness of TR-127 lies in its testing xDSL systems and splitters dynamically, together with POTS voltages, signals and other disturbances. This issue is not addressed by other specifications.

TR-127 Issue 2 also achieves dynamic tests for ISDN splitters. MR-261 will concentrate on the POTS splitters only.

The importance of dynamic testing is emphasized. Only dynamic tests as opposed to static ones, can guarantee the necessary QoS for triple-play xDSL services. MR-261 concludes with a brief description of TR-127 test suite, and provides a set of conclusions and best practice recommendations for splitter design and deployment.

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1 Introduction

ADSL and VDSL (xDSL in short) are attractive systems because they allow the merging of the xDSL signal with the Plain Old Telephone Service (POTS) on a single twisted pair line, with little mutual disturbance.

When xDSL and the POTS service coexist on a single telephone line, the signals must be merged by a set of multiplexing filters, i.e. the splitters or in-line filters as shown in Figure 1. If these splitters or filters are of poor quality design, the Bit Error Ratio (BER) of the xDSL will suffer, and the quality of the triple-play services over the xDSL will deteriorate.

Before the creation of TR-127 by the Broadband Forum, splitters were tested according to static ETSI and ATIS standards. These tests impose static requirement on xDSL splitters and in-line filters. However, these ETSI and ATIS standards protect primarily the quality of the POTS signals. Therefore, although necessary, these static tests are not sufficient, because they do not test the actual dynamic rejection of the POTS signals and transients, which can affect the BER of the xDSL.

Dynamic tests of xDSL systems were developed by the Broadband Forum since its earliest existence. Both functional tests and performance tests of both ADSL and VDSL were created. However, other existing TRs of the Broadband Forum do not fully test xDSL in the presence of the splitters with complete POTS signals. Only Broadband Forum TR-127 tests the complete combination of splitters, in-line filters and xDSL modems with the POTS DC, ringing and transients.

Why is the testing of xDSL splitters and in-line filters according to TR-127 needed?

- The existing POTS signals were never intended to be xDSL friendly: a 50 V DC battery, a strong 90 V AC ringing, with large currents and a number of spiky disturbances.
- A POTS splitter or in-line filter can only reduce the POTS transients on the telephone line. Therefore, xDSL is using digital protection to correct errors, but only TR-127 will test if the error correction capability is able to keep the xDSL quality sufficiently high (i.e. virtually error free), when subjected to the POTS signals such as ringing, spiky transients, etc.
- Also non-linear devices or distortion in components inside the splitters can affect the xDSL transmission, which is only testable according to TR-127.

TR-127 is of critical value in testing the interaction between xDSL and splitters in the presence of actual POTS signals. This is particularly important in the case of in-line filters.

1.1 Potential Extended Use of TR-127

The concept of replacing one “baseline” splitter by another one as the DUT is used in TR-127 and can be extended to other uses. For instance, it is possible to quantize the xDSL capacity drop due to the non-linearity of surge protections, bridged taps or wire unbalance. The quantization starts with one of the baseline tests, and instead of replacing one baseline splitter by a splitter DUT, the extra element to be tested is inserted to the test set-up.

As an example, the effect of an in-house network on a VDSL system with in-line filters can be quantified. As a first step, the system calibration and the test with baseline filters is executed.

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As a subsequent step, the extra bridge taps that model the in-house network are added. In this way, the resulting capacity drops can then be seen.

Note that the full POTS DC and AC ringing voltages are present at the input of the xDSL modems. This is an important advantage and benefit of the TR-127.

2 xDSL Splitters & In-Line Filters – Technical Overview

All xDSL systems are used to deliver broadband access to the internet, extended today to "triple-play services". ADSL was first developed to be able to re-use the ubiquitous copper cable plant all over the world for high speed internet, while keeping the POTS service intact under it. VDSL continues to be deployed over POTS.

NOTE: The earlier use of voice-band modems to access the internet was not only slower, but also was incapable of simultaneously telephony and internet access via a single line.

2.1 Ubiquitous Telephone Cables, successfully re-used for xDSL plus POTS

It is often said that "*telephone cables have been buried for a long time, but that they are still very much alive!*" Indeed, telephone cables were given a "second life" by their re-use for xDSL.

The main aspect of the re-use of the existing telephone cables for xDSL is that the POTS service and the new xDSL systems can share a telephone cable, and as such may disturb each other.

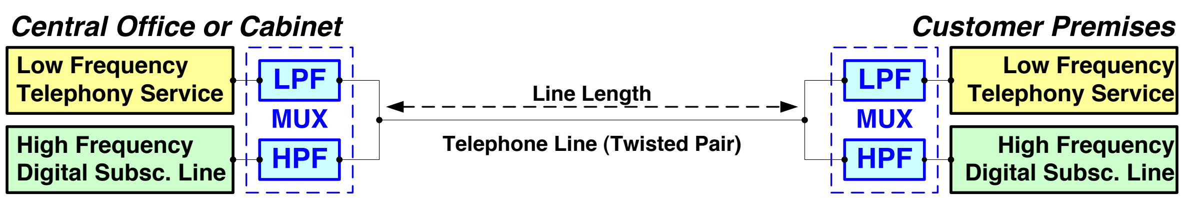

Figure 1: Multiplexing two services with "Mux-filters" on a single telephone line

The coexistence of POTS and xDSL on a single telephone line (or twisted pair) requires the concept of "multiplexing", shown in Figure 1. Multiplexing is abbreviated to "mux". A mux-filter is inserted in each signal: a low pass filter (LPF) in the low frequency telephony signal and a high pass filter (HPF) in the high frequency signals of a Digital Subscriber Line (DSL).

The mux-filters merge and separate the POTS and xDSL signals that are using different frequency bands, as shown in Figure 2. The LPF is called a "splitter". The HPF is always part of the xDSL transceiver.

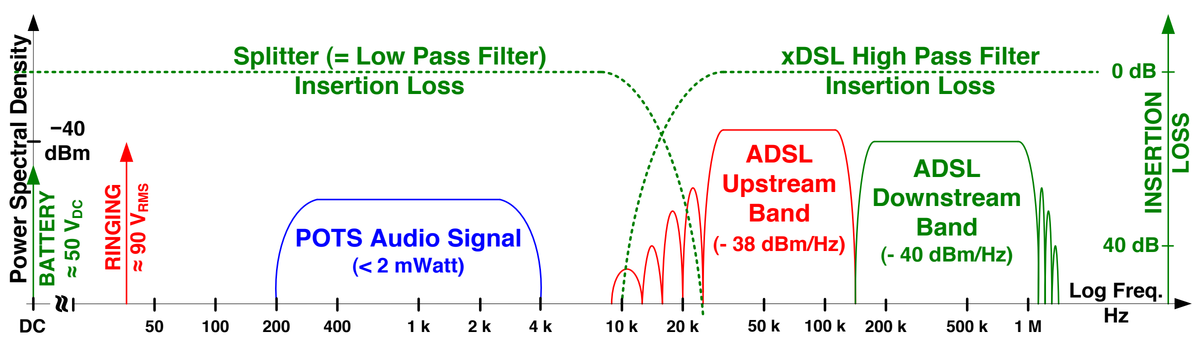

Figure 2: Spectra of POTS and ADSL merged on a twisted pair with mux-filters

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Figure 3 shows the xDSL multiplexing function in more detail. The LPF or "splitter" is added *externally* to the POTS system. The HPF is contained in each xDSL transceiver by design.

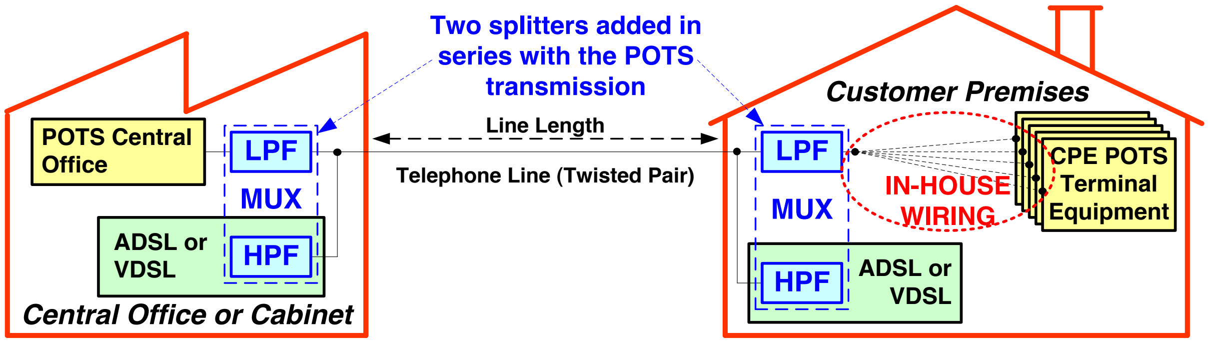

Figure 3: Actual "Multiplexing" POTS and xDSL on a single twisted pair

Often a single splitter is replaced by multiple parallel *in-line filters*, as explained in Section 2.4.1.

2.2 Short Introduction to the POTS Systems

The "Plain Old Telephone Service" or POTS service is using the lower end of the available "spectrum" on the copper pair, leaving the rest of the spectrum for other purposes, such as xDSL.

In general the POTS signals contain the following power components and signaling elements:

- A 2 mW POTS audio signal that is transmitted bi-directionally over a "twisted pair" line.
- The audio is combined with a DC "battery" voltage (≈ 50 V) feeding the phones.
- A DC current signals the off-hook condition to make a call or accept an incoming call.
- A cadenced AC ringing signal (up to 105 V_{RMS}) is superimposed on the DC battery.

At the left side of Figure 2 is the spectrum of the POTS signals: Battery DC, ringing AC and POTS audio. It also shows a possible shape of the rejection by the LPF mux-filter, i.e. the POTS splitter.

2.2.1 Significance of the Ring-Trip Event

Peaks of more than 180 V exist on the line during ringing due the superposition of ringing AC and battery. When a phone is picked up and the ring-trip occurs during a ringing burst, the result is the worst possible current in the POTS environment, due to the combination of high ringing AC and the DC of the battery. The current peaks at 200 mA on short lines, but the duration is limited normally to less than 200 ms. This can be a real challenge to an xDSL system and particularly to the splitters.

2.2.2 POTS and in-house wiring as source of disturbance for xDSL:

The POTS signals were never intended to be combined with xDSL on a twisted pair. Therefore, the POTS signals can be very disturbing for xDSL. The xDSL-unfriendly POTS signals are: 1) battery voltage and its transients, 2) ringing and particularly its cadencing, and 3) DC current and ringing line current and its transients, particularly the ring-trip. However, xDSL tries to protect itself against these strong POTS signals and transients. The splitters, the HPF part of the mux-filters and error correcting techniques are the main elements that protect xDSL. Clearly, the quality of the splitters is important in the protection of xDSL.

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Besides the intrinsic POTS signals and transients, the in-house POTS wiring and other components can degrade the xDSL signal in several ways. The in-house wiring (old, poorly installed, often with long extension cords) and protection devices can cause severe bitrate drops due to non-linearity, or to bridged taps and unbalance. There is also pickup of RFI and EMI noises.

NOTE: Many of the bad effects of in-house wiring on the xDSL performance can be avoided by using a single "master-splitter" instead of in-line filters. See Section 2.4.1.

2.3 Overview of xDSL signals on the copper line

The xDSL systems put the high bitrate signals on the existing telephone cable above the POTS signals, as shown in Figure 2. ADSL signals range between 25 kHz (ITU-T mask for G.992.1) and 1.1 MHz. Figure 2 shows the ADSL spectrum above the POTS spectrum, together with the Insertion Loss of the HPF and LPF. Later the bitrate was increased by widening the ADSL bandwidth for ADSL2plus to 2.2 MHz and then for VDSL2, which pushes the frequency limit to 30 MHz.

Important in xDSL is the existence of error correction techniques, by which the xDSL tries to fight a number of stationary noises and impulsive noises that enter its line port via all kinds of paths.

In general xDSL is very POTS-friendly by design. Indeed, there are very few transients in the xDSL signals, and each xDSL transceiver contains an HPF (i.e. part of the mux-filters), which makes the xDSL transceiver virtually invisible in the POTS audio band. The HPF is explained in the next section. Only the strong xDSL signal (i.e. above 25 kHz) on the line can affect the POTS system, but the POTS system itself is protected by a LPF, i.e. the splitter.

2.4 Multiplexing an xDSL System on a POTS cable carrying a POTS Signal

As introduced in Figure 2 and Figure 3, xDSL & POTS can share a single twisted pair provided that multiplexing filters are used: a HPF and a LPF at each side of the line.

These mux-filters are indispensable to allow two parallel services on the line. Indeed, without mux-filters a POTS system will disrupt xDSL, and vice versa.

These pairs of LPF and HPF mux-filters help in two ways:

- The two mux-filters together assure that the impedance of POTS or xDSL is only active in the band assigned to each system. Outside its pass band each mux-filters is high-Ohmic. This renders POTS virtually invisible in the xDSL band and vice versa.
- Furthermore, the filters also prevent that large POTS signals or residues are detectable in the xDSL transceiver and they assure that xDSL residual signals found in the POTS system are normally below the noise floor in the POTS system.

2.4.1 Single "Master" Splitter versus Multiple In-Line Filters

The LPF can be implemented as a single POTS splitter. The functional diagram of the xDSL "single" splitter configuration is shown in Figure 4. Notice that in the case of a single splitter

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there is a need to add an extra cable, dedicated to connect the xDSL transceiver to the telephone line

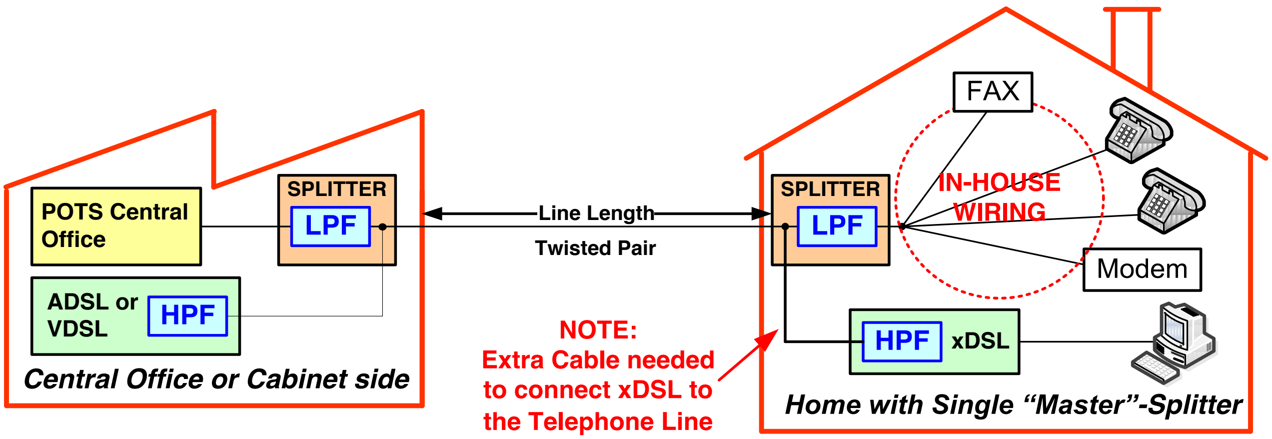

Figure 4: Functional diagram of a single xDSL "master" splitter configuration

At the CPE side there is an alternative to the centrally placed splitter: multiple parallel in-line filters can be installed as shown in Figure 5. They are also known as "micro-filters" or "distributed filters".

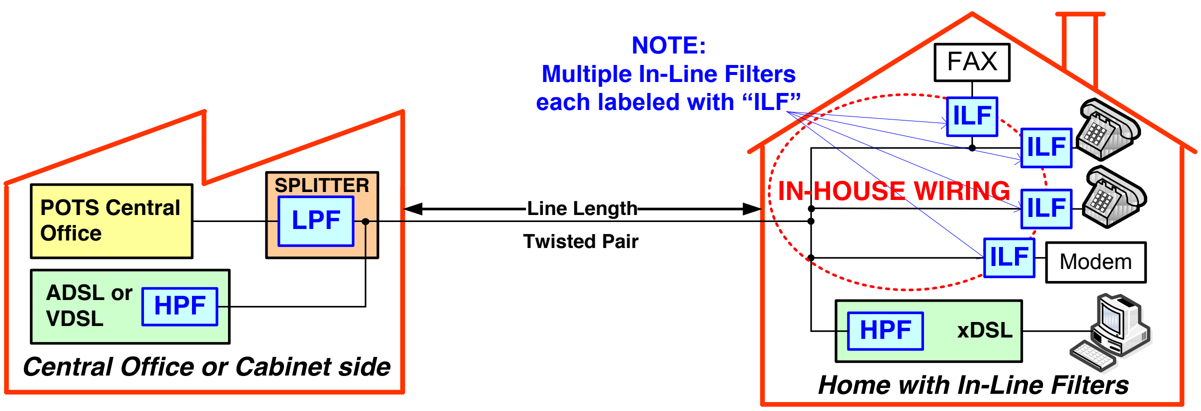

Figure 5: Functional Diagram of the xDSL In-Line Filter configuration

The difference between a single splitter and multiple in-line filters is the position of the in-house wiring. If a single "master"-splitter is used, there is no xDSL signal on the in-house wiring. With in-line filters xDSL is present on the whole in-house wiring, which is not favorable for its quality.

In-line Filter versus Splitters Issues: Many of the bad effects of in-house wiring on the xDSL performance can be avoided by using a single splitter instead of in-line filters.

In general an xDSL "master" splitter is performing much better than xDSL in-line filters. The xDSL rejection of an in-line filter is often only 25 dB. This causes residual xDSL signals to be audible in telephones. Also residual POTS noises can leak through the typical in-line filter, which can affect xDSL, often stretching the xDSL error correction beyond its limits.

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2.5 Disturbance of xDSL by POTS and other noises and disturbances

Section 2.4 explains the multiplexing filters are a HPF in the xDSL modems and the splitter or the in-line filters in the POTS signal stream. These devices attempt to prevent the POTS noise and POTS impedance changes from "leaking" into the xDSL transmission.

However, some residual POTS noise will unavoidably still leak into the xDSL transmission. Moreover, several other sources of signals, distortion and noises are present on the in-house CPE wiring that can affect xDSL.

- DC power (voltage and current), AC ringing (voltage and current).
- POTS Transients, due to cadenced ringing, off-hook and ring-trip.
- EMI and RFI pick-up by the in-house wiring.
- Unbalance due to in-house wiring, and capacity loss due to bridged taps.
- Distortion of protection devices, splitter components and the xDSL HPF.

Static Requirements of xDSL splitters: mainly POTS oriented

When it was attempted to merge ADSL and POTS signals on a twisted pair, the need of the POTS splitters (or in-line filters) was immediately clear. Standardization bodies such as ETSI and ATIS have considered a potential detrimental effect of the splitter on the POTS service and therefore today the static requirements of splitters target mainly the audio quality of POTS.

However, the protection of ADSL or VDSL by the splitters is only specified loosely in the static splitter standards. Mainly a strong insertion loss and good balance is mandated in the xDSL band. Starting at around 30 kHz ETSI requires a loss of 45 or 55 dB for splitters, and ATIS requires even more. Unfortunately the required IL of the "ubiquitous" in-line filters is much less. Also, besides the loss and balance above 30 kHz, very little is required in terms of distortion or protection against common mode noises and shielding against POTS induced noises and transients.

TR-127 fills this lack of requirements in the static specifications of splitters and in-line filters. Section 3 will introduce the TR-127 methodology.

2.6 Network issues caused by poor quality filters and in-house wiring

If the distortion and non-linearity of the splitters or filters is poor, the xDSL signal will suffer an increased BER and dropouts during ringing, off-hook and pulse dialing. Off-hook during a ringing burst is an event that challenges the xDSL error correction at its limits. In the worst case the xDSL will suffer a full retrain, which will last at least 10 seconds.

Particularly "mediocre" in-line filters are also known to "eat" xDSL bitrate capacity. Although the devices might pass the static ETSI or ATIS tests, a single device could already reduce the bitrate, while every additional device reduces the bitrate even more. Drops due to poorly designed in-line filters can be stunning. The inadvertent use of ADSL filters within a VDSL system is known to block the highest part of the VDSL spectrum completely.

Other components known to affect xDSL aggressively are protection devices against lightning and overvoltage. Their non-linearity can damage the xDSL signals, which causes bitrate reduction or synchronization failure often during ringing.

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Note also that in-line filters often have only a limited insertion loss. They leak noisy xDSL residue into the POTS phones. Certain sensitive phones make this noise audible as a hissing sound due to non-linearity in the POTS phone analog circuitry. This effect is absent for splitters.

When in-line filters are used at the customer premises, the in-house wiring becomes the worst element attacking the xDSL signal quality: bridged taps cause xDSL signal reflections, which causes deep comb-shaped dips in the xDSL spectrum. The bitrate loss particularly in VDSL is often massive. Only the use of a single "master" splitter can mitigate this problem.

Finally the in-house wiring is shaped as a big antenna, which picks up all kinds of unwanted RFI and EMI noises, which are transported to the entrance of the xDSL transceiver. This effect is worst when in-line filters are used. A single "master" splitter gives more protection, and particularly when the splitter contains a "common mode" coil, it will reject the RFI and EMI most effectively.

3 Testing DSL Splitters and In-Line Filters according to TR-127

This section contains an overview of the TR-127 testing methodology. The main purpose of TR-127 is to test xDSL Splitters & in-line Filters in a dynamic way. The splitters are tested in a complete xDSL system, and in the presence of actual POTS signals and disturbances. The concept of the system test is shown in Figure 6. For the particular cases of POTS noises the TR-127 contains a complete test suite, which tests the different xDSL components in consecutive tests.

3.1 Generic interworking testing diagram for xDSL over POTS

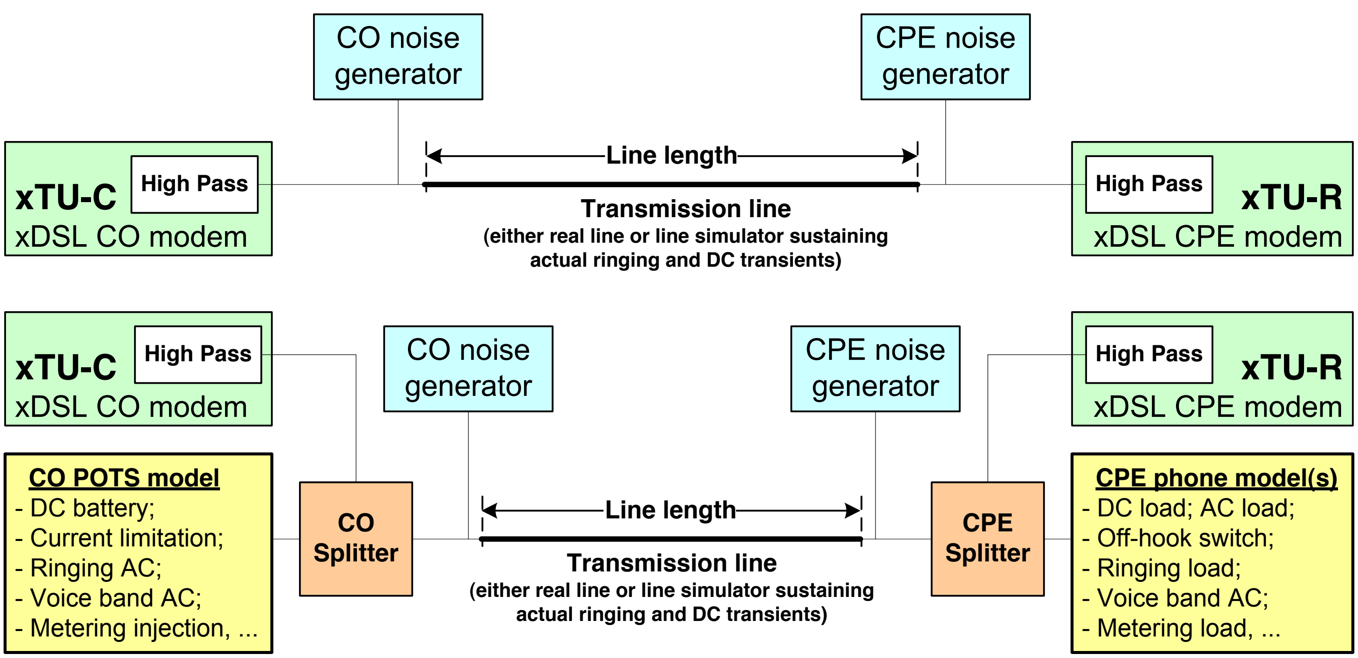

Figure 6: Generic interworking testing diagram for xDSL over POTS

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Splitters and in-line filters are tested in a dedicated test-xDSL-system. As the splitters and in-line filters are being tested in this system it is required to prove that all elements of the test-system itself are working according to same minimum requirements, which will be applied to the splitters or in-line filters under test.

If the components of the test-system fail to be good enough, the test-system will fail to prove the quality of the splitters in the end. Indeed, if errors are seen in the splitter test, they should be caused by the splitters and not by the other components in the test-system. Therefore, the consecutive tests are first proving that all other parts besides the splitters inside the test-system are working properly.

Therefore, the general test setup starts with a calibration test shown in the upper part of Figure 6. With this test the xDSL transceivers are calibrated on the line (a line simulator or an actual cable). All subsequent tests in the test-suite will be compared to these results.

After the calibration test the remaining tests will include a set of two splitters and the CO and CPE POTS models, as shown in the lower part of Figure 6. However, again to allow a gradual check of the system part, the tests with splitters will be done first with two baseline splitters and then with one baseline splitter and one DUT (Device Under Test). The concept is that the DUT splitter should not be "substantially" worse than the baseline splitters used first in pairs in the test setup.

The tests are a sequence that increases the difficulty for the error correction of the xDSL system to mask the induced BER. Gradually the tests add a steady DC voltage, a steady DC current, and a continuous ringing signal. Then transients are added: off-hook transitions, cadenced ringing and ring-trip events. For all tests a system resynchronization is not allowed when testing either splitters or inline filters.

For Triple play splitters or filters there is strong requirement that the achievable bitrate should not drop significantly, that the margin must stay sufficiently high and that the BER is not allowed to increase above 10^{-7}.

For some splitters or in-line filters no "Triple Play" quality is required. In that case the number of CRC errors is counted and reported. This allows ranking these devices.

3.2 On-hook to Off-hook ring-trip transition: a Critical Test in TR-127

The most difficult test in the whole test-suite is the ring-trip test. During this test a series of 120 bursts of ringing sent from the CO POTS model to the CPE POTS model (see Figure 6). The CPE model goes off-hook during each ringing burst. The CO model removes the ringing and the CPE goes back on-hook. In spite of the 120 ring trip events, the BER must stay below 10^{-7} for a triple play splitter for an interleaved profile. This requirement shows that the splitter is capable to sustain the strongest possible DC + AC currents on all line lengths.

3.3 The POTS models

To generate the POTS DC, the ringing and the different POTS transients, a CO and a CPE model were constructed. By attaching these models to an xDSL system as shown in the lower part of Figure 6, including xDSL modems and splitters, the POTS battery voltage, the off-hook currents and all necessary transients can be generated.

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The models are conceived as worst case situations, including (if desired) electro-mechanical relays to cause a maximum amount of noise. According to each service operator noise and in particularly ringing can have different shapes and issues in terms of its “harshness”.

4 Conclusions

A number of important aspects motivating the testing of xDSL Splitters and In-Line presented in MR-261 are:

Successfully passing TR-127 can guarantee a virtually error free performance of a system of xDSL transceivers including the splitters (or in-line filters) in the presence of an active POTS service and other actual noises.

Existing static ETSI and ATIS requirements of splitters and in-line filters do not test the dynamic behavior of splitters and in-line filters in an xDSL test setup.

An xDSL in-house installation with a single “master” splitter is superior in terms of BER and capacity of the xDSL, compared to one with multiple in-line filters, even when these in-line filters are achieving the requirements of TR-127. In-house wiring picks up noise (RFI & EMI) and contains bridged taps, and splitters reject POTS transients better than in-line filters.

In-line filters, i.e. not meeting the requirements of TR-127, can disrupt xDSL transmission and cause an increase in the BER, and they can also cause a severe drop in xDSL bitrate. This might be due to insufficient masking of noise and transients induced by POTS via the in-line filters, which have a limited rejection (e.g. only 25 dB in ETSI). An alternative cause is the non-linear effects in components in poor quality in-line filters.

In-line filters with limited insertion loss leak noisy xDSL residue into the POTS phones. Certain sensitive phones make this noise audible as a hissing sound due to non-linearity in the POTS phone analog circuitry. This effect is absent for splitters, which have a superior insertion loss.

A single master splitter can be equipped with a common mode rejection coil, which rejects RFI and EMI noises. This prevents RFI and EMI to travel from the in-house wiring to the entrance of the xDSL transceiver. In-line filters are incapable of preventing the RFI and EMI induced in the in-house wiring from entering the xDSL transceiver.

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5 References and Terminology

5.1 References

Document		Title	Source	Year
[1]	TR-127 Issue 2	*Dynamic Testing of Splitters and in-line Filters with xDSL Transceivers*	BBF	2010
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[3]	G.992.3	*Asymmetric Digital Subscriber Line transceivers 2 (ADSL2)*	ITU-T	2009
[4]	G.992.5	*Asymmetric Digital Subscriber Line (ADSL) transceivers - Extended bandwidth ADSL2 (ADSL2plus)*	ITU-T	2009
[5]	G.993.1	*Very high speed Digital Subscriber Line transceivers (VDSL)*	ITU-T	2004
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[10]	ATIS-0600016.2008	*Remote End POTS Splitter Requirements.*	ATIS	2008
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[12]	ATIS-TRQ.10.2009	*Splitters Used for Line Splitting and Line Sharing Applications*	ATIS	2009

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5.2 Definitions

Baseline Filter	A splitter that is used to establish the reference levels before adding the DUT.
Distributed filter	Alternative name for In-Line Filter.
In-Line Filter	Individual filters with a splitter function, but protecting each individual telephone device at the Customer Premises.
ISDN	Integrated Services Digital Network, and narrow band DSL system, used for digital telephony and switched digital 64 kb/s channels.
Micro-filter	Alternative name for In-Line Filter.
Master Splitter	Splitter that is used to isolate xDSL frequencies from POTS frequencies at a single point (often called NTP or NID) at the customer's premises.
Multiplexing	Merging two services onto a single transmission medium (e.g. a telephone line) at one end transmitting the together over the medium, to separate them at the other end.
Network Interface Device (NID)	The NID is a device that serves as the demarcation point between the carrier's local loop and the customer's premises wiring. It is placed at the NTP.
Network Termination Point (NTP)	The NTP is the demarcation point between the access pair and the in-house wiring, where often the master splitter is placed. The NID is placed here.
Off-hook	State of the POTS equipment at either end of a loop connection when the CPE equipment is in active state, to make a telephone call.
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.
Plain Old Telephone System	The traditional Public Switched Telephone Network.
Ring-trip	The process of stopping the AC ringing at the Central Office when the telephone being rung is answered.

5.3 Abbreviations

ADSL	Asymmetrical DSL
ATIS	Alliance for Telecommunications Industry Standards
BER	Bit Error Ratio
CO	Central Office
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer

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DUT	Device Under Test
EMI	Electro-Magnetic Interference
ETSI	European Telecommunications Standards Institute
HPF	High Pass Filter, i.e. a filter blocking DC and low frequencies
IL	Insertion Loss
IPTV	Internet Protocol Television
ISDN	Integrated Services Digital Network,
ITU	International Telecommunications Union
LPF	Low Pass Filter, i.e. a filter blocking the upper part of the spectrum
MUX	Multiplexing or Multiplex
NID	Network Interface Device
NTP	Network Termination Point
POTS	Plain Old Telephone System a.k.a. PSTN
PSTN	Public Switched Telephone Network = POTS
RFI	Radio Frequency Interference
RMS or rms	Root Mean Square
TR	Technical Report
VDSL	Very High Speed DSL
VoIP	Voice over Internet Protocol
xDSL	ADSL or VDSL

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