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VDSL2 radiation

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1.1	21.02.2007	P. Repond	
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1.1	22.01.2007	C. Monney	
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Management summary

Development of broadband continues at a fast pace. Swisscom Fixnet has just introduced its new television over IP service. This last needs higher bit rates that ADSL can hardly deliver. VDSL2 is the next generation that enable this step forward.

Although VDSL2 is a wire bound technology, a small amount of energy transmitted over the wires is radiated over the air. Under certain circumstances, this radiation could impact other wireless services.

Previous studies have shown that drop wires are very prone of interference because the cable symmetry is poor, it doesn’t have a metallic screen and the separation distance with an antenna can be very small. From all wireless services, amateur radios can mostly be affected.

Measurement with an amateur radio has allowed us to verify if an interference case is possible and under which conditions. When placing the VDSL2 DSLAM very near from the customer and connecting him with 10m drop wire, the interference is clearly audible and completely covers any radio reception. Although this test case isn’t typical from an installation point of view, it clearly demonstrates that inference is possible.

A second test with the DSLAM placed at 776m distance has shown that the line attenuation is sufficient to avoid any interference to amateur radio, except in a band between 3’760 kHz and 3’800 kHz. This is unavoidable because the interference is caused by the upstream channel of VDSL2. This last is maximal at customer side.

Interference is not only in one direction. When an amateur radio emits, part of this power will enter the VDSL2 router and may disturb the transmission. In fact, even with moderate power, the VDSL2 transmission is interfered each time the amateur radio emits. However, the router synchronises again without any intervention within 20 seconds. The impact of an amateur radio transmission is not limited his own VDSL2 system but will can potentially affect other VDSL2 systems in the neighbourhood as well.

Introduction

For more than 5 years, Swisscom Fixnet has been deploying a broadband access network covering most of Switzerland. ADSL technology has been deployed and fulfils requirements of most Internet users. With the introduction of a television over IP offering, there is the need to increase bit rates. The chosen technology is VDSL2.

VDSL2 higher bit rates are achieved by using broader frequency spectrum than ADSL. While ADSL already stops at 1 MHz, VDSL2 uses frequencies up to 12 MHz and, in a further step, up to 30 MHz. As a cable isn't a perfect transmission medium, an attenuated part of the signal is radiated in the air. This signal may interfere with service such as broadcasting, amateur radio or safety services for example.

This document presents first a theoretical background, followed by simulations and finally field measurements realised with an amateur radio. Only 40m and 80m bands were studied. The 30m, which is less used, wasn't studied due to the difficulty to find amateur radio equipment for this band.

Terms and abbreviations

30m band	Amateur radio band between 10.1 MHz and 10.15 MHz
40m band	Amateur radio band between 7 MHz and 7.15 MHz
80m band	Amateur radio band between 3.5 MHz and 3.8 MHz
ADSL	Asymmetric Digital Subscriber Line
CENELEC:	European Committee for Electrotechnical Standardization
DC	Direct Current
DSLAM	Digital Subscriber Line Access Module
DX	Any station that is hard to hear or contact on a particular frequency
EEC	European Economic Community
EMC	ElectroMagnetic Compatibility
EN	European standard
FM	Frequency Modulation
ITE	Information Technology Equipment
kHz	kilohertz (10^3 Hz)
LCL	Longitudinal Conversion Loss
MHz	Megahertz (10^6 Hz)
NDB	Non Directional Beacon
SSB	Single Side Band
UPBO	Upstream Power back-off
VDSL	Very high bit-rate Digital Subscriber Line (ITU-T G.993.1)
VDSL2	Very high bit-rate Digital Subscriber Line (ITU-T G.993.2)

Referenced documents

[1] Final acts of the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3) Geneva, 1975
[2] Ordonnance sur la protection contre les perturbations électromagnétiques du 1er mai 1979 (plus en vigueur, mais encore utilisée)
[3] Radiation of telecommunications services in and alongside of cables (NB30), RegTP Germany
[4] C. Monney, Kabeluntersuchungen, Leistungs- und Störungsbeeinflussungs-Verhalten von ADSL-Anlagen im Anschlussnetzbereich inkl. Inhouse, November 1997
[5] C. Monney, xDSL: EMC and crosstalk, Swisscom innovations report, April 2000
[6] Frequency Allocations Plan, OFCOM, http://www.ofcomnet.ch/cgi-bin/nafz.pl
[7] Very high speed digital subscriber line transceivers 2 (VDSL2), ITU-T, G.993.2, February 2006
[8] C. Monney, Considerations on VDSL2 frequency usage, October 2005

1 Legal situation in Switzerland

Each telecommunication's equipment placed on the Swiss market has to comply with European standards. These standards ensure that equipment fulfil the minimum requirements concerning electrical safety and EMC. Even if all parts of the network are compliant with EC directive, an interference case might occur. All radio services can be affected. However, broadcasting and amateur radio are the most sensitive one. For the first one, protection requirements are set in [1] and [2]. Federal office for communication has a clear mandate to protect these frequencies. The amateur radio case is a little bit more complex. Although they cannot require protection, OFCOM has to investigate if an amateur radio claims being interfered. As no field limits exist, OFCOM will use German NB30 [3] recommendation as a limit. Nevertheless, these limits will be applied only in disturbance cases.

2 Comparison between theory and measurement

2.1 Introduction

The telecommunication network radiates signals present on the wires. Indeed, copper wires are not absolutely symmetrical and a small portion of the differential mode current injected into a pair is converted into a common mode signal. This conversion is called Longitudinal Conversion Loss. LCL of most access network and indoor cables has been measured in the past [4] and [5]. Measurements with sine waves or ADSL were performed and validated the models.

As VDSL2 equipments are now available, a field measurement can be realised in order to verify the model.

2.2 Amateur radio frequency bands below 30 MHz

Table 1 shows the list of frequency bands allocated to amateur radio below 30 MHz.

Frequency Band f_1/MHz	f_2/MHz	Prio.	Service	Comments on service
0.136	0.138	2	**Amateur**	telegraph
1.810	1.850	1	**Amateur**	phone and telegraph
1.850	2.000	2	**Amateur**	phone and telegraph
3.500	3.800	2	**Amateur**	phone and telegraph
7.000	7.150	1	**Amateur + S**	phone and telegraph
10.100	10.150	1	**Amateur**	telegraph
14.000	14.350	1	**Amateur**	phone and telegraph
18.068	18.168	1	**Amateur S**	phone and telegraph
21.000	21.450	1	**Amateur + S**	phone and telegraph
24.890	24.990	1	**Amateur + S**	phone and telegraph
28.000	29.700	1	**Amateur**	phone and telegraph

Table 1: list of amateur radio frequency bands

2.3 Risk analysis

It has to be noted that, in most cases, the upstream channel will be the critical one. In fact, customer side modems will emit, under certain circumstances, with maximum admissible power spectral density on poor wires. However, in many cases, upstream power back-off performed by VDSL2 reduces the risk associated with high upstream emission levels. In the other direction, the cable attenuation will significantly reduce the radiation near customer side. This is true only if the common mode attenuation is higher than the differential mode one. This was measured in the past and found that common mode attenuation is one order of magnitude higher than differential mode attenuation. Figure 1 shows a calculation based on the implementation of band plan 998 as defined in Figure 2 (annex B of [7]).

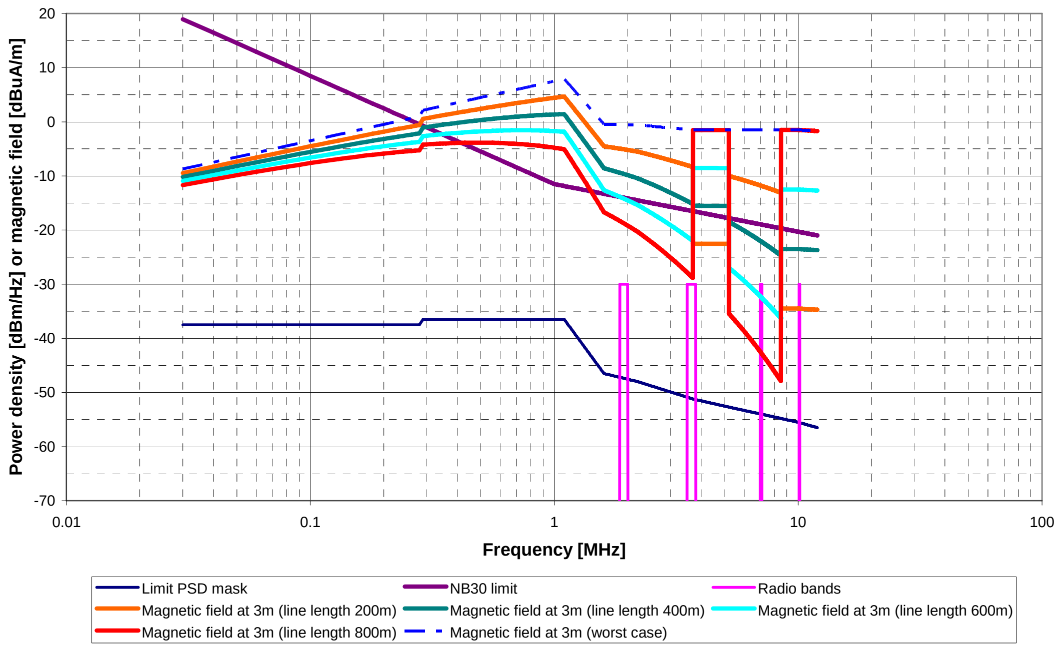

Figure 1: Magnetic field at customer side in function of line length and comparison with limit NB30

Figure 1 shows that emission levels may exceed NB30 limit depending on line length. A shorter line is more critical on downstream channels whereas a longer line is more critical on upstream channels. Radiation may influence broadcasting and amateur radio. Broadcasting is practically not used in these bands and shouldn't cause a problem, at least on a short term. To the contrary, amateur radios use frequencies in both bands. In the lower one, there is a small overlap between 3750 kHz and 3800 kHz. Although this represents about 16% of the available spectrum, this band is heavily used and could create problems. Moreover, the higher part of the band is used as DX frequency for long distance calls. In addition, amateur radios have a band between 10.1 MHz and 10.15 MHz. However, this last is less used.

2.4 Test equipment

A VDSL2 over POTS equipment was used in conjunction with a DSLAM. It is compatible with ITU-T G993.2. The band plan can be found in Figure 2 and Table 2. Plan 998 is used.

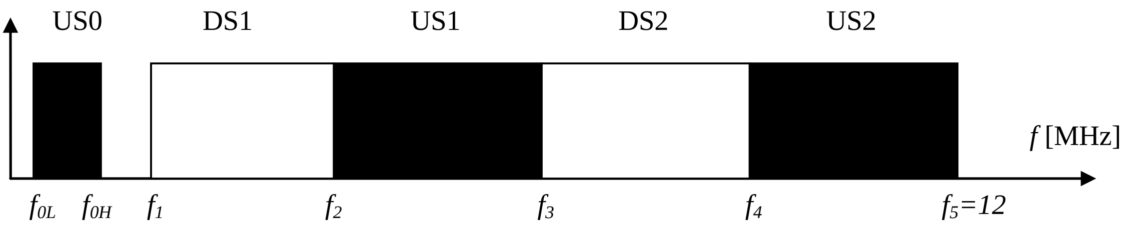

Figure 2: Band plan in the frequency range up to 12 MHz [7]

<table>
<tr><td rowspan="3">Band plan</td><td colspan="7">Band-edge frequencies</td></tr>
<tr><td>f_{0L}</td><td>F_{0H}</td><td>f_1</td><td>f_2</td><td>f_3</td><td>f_4</td><td>f_5</td></tr>
<tr><td>kHz</td><td>kHz</td><td>kHz</td><td>kHz</td><td>kHz</td><td>kHz</td><td>kHz</td></tr>
<tr><td rowspan="4">998</td><td>25</td><td>138</td><td>138</td><td rowspan="4">3750</td><td rowspan="4">5200</td><td rowspan="4">8500</td><td rowspan="4">12000</td></tr>
<tr><td>25</td><td>276</td><td>276</td></tr>
<tr><td>120</td><td>276</td><td>276</td></tr>
<tr><td>N/A</td><td>N/A</td><td>138</td></tr>
</table>

Table 2: Edge frequencies for band plan 998 (Annex B of [7])

2.5 Power spectral density

VDSL2 will be deployed with different power spectrum profiles depending on the loop length. As an illustration, two examples are shown below:

- spectrum profile 90: this profile is used on long lines and equipments send at their maximum allowed power (Figure 3). On “long lines”, US1 is at its maximum and US2 might not be used. On “very long lines”, both US1 and US2 might not be used and upstream is only realised with US0.
- spectrum profile 10: this profile is used on shorter lines. In order to reduce the crosstalk, the upstream channel power is strongly reduced (Figure 4), via a scheme called “upstream power back-off” (UPBO).

Power spectral density is the most important value to know. In fact, all other factors can afterwards be derived from it.

For convenience, power spectral density wasn’t directly measured but is derived from the differential mode current (Figure 3 and Figure 4). In order to speed measurements, all data were taken using a peak detector and holding the maximum value. To compare with the limit set in G.993.2 [7], it is necessary to subtract 10 dB from the PEAK measurement (see [8] for details). In these figures, the green line represents measured data with peak detector and maximum hold, whereas the blue line is the calculated average value. This curve has to be compared with the limit represented with a red curve.

Figure 3: VDSL2 power spectral density with spectrum profile 90

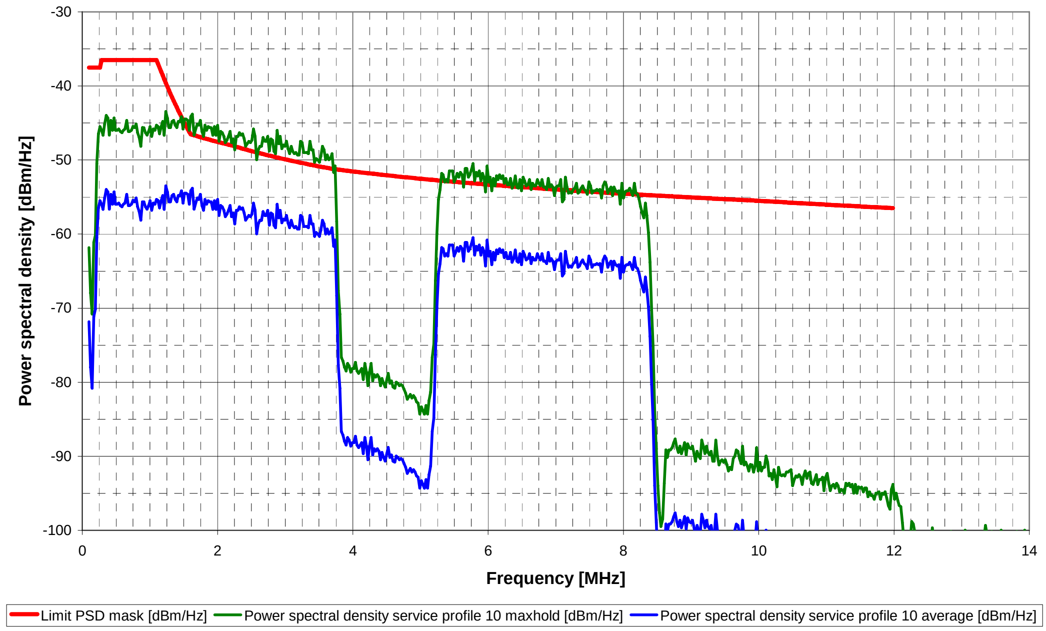

Figure 4: VDSL2 power spectral density with spectrum profile 10

2.6 Test set-up

The tests were realized with Pascal Antenen (HB9IIB) in 1083 Mézières. Figure 5 shows the position of the house, the antenna pole and phone introduction. Figure 6 shows the introduction and Figure 7 shows the antenna position on the roof.

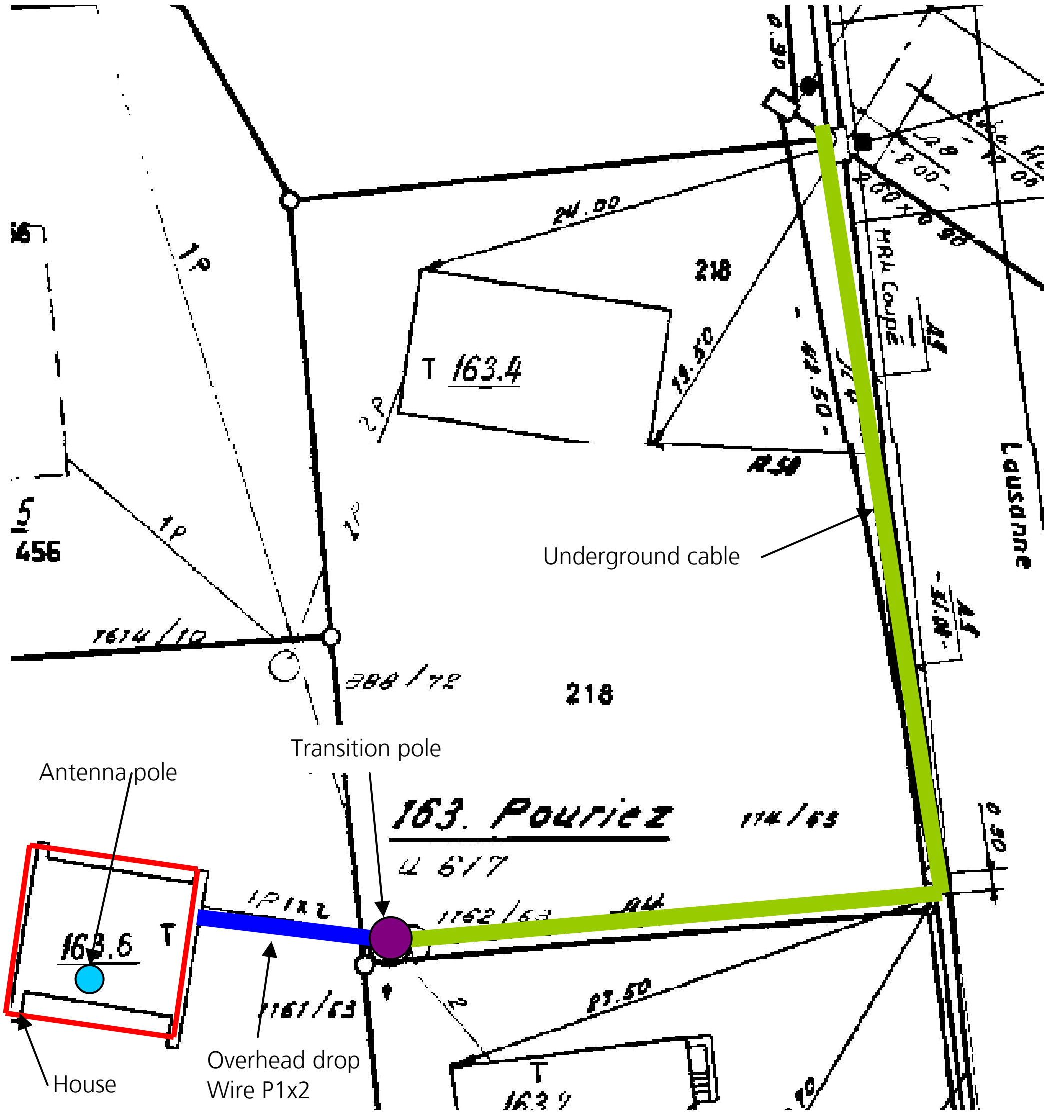

Figure 5: geographic position of house, mast and phone introduction

Figure 6: position of the transition pole and the house (east side)

Figure 7: house and antenna views (west side)

Figure 8: nearer view of the antenna

Figure 9: house introduction

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2.7 Test realisation

A VDSL2 connection was created from the network to the customer. CPE was installed in the basement where the amateur radio equipments are installed.

Two scenarios were tested:

- A worst case scenario: the DSLAM is installed very near to the CPE. DSLAM was installed at the transition pole. The line length outside the building is about 10m. Inside the building, the line length is about 15m. This scenario will never appear on a real basis, but it is the quicker way to verify if a disturbance occurs or not. In addition, it should be mentioned that, in a real deployment on such loops, VDSL2 reduces the transmission level in the upstream direction via UPBO.
- A normal scenario: the DSLAM is installed in the village centre. The line length is 776m, half in 0.4mm, half in 0.5mm diameter.

For both scenarios, the influence of VDSL2 transmission on radio reception as well as immunity of VDSL2 during radio emission was tested.

2.8 Test with a very short line

2.8.1 Introduction

The purpose of this test is to verify if interference between VDSL2 and amateur radio can occur. This situation would practically never appear in the network. Measurements were realised on Saturday, the 2nd of September between 9AM and 12AM. The VDSL2 signal was directly injected at the transition pole (Figure 10). The overhead portion is made of 10m P1x2 drop wire and about 30m house installation. Cable routing inside the house isn't well known.

Figure 10: signal injection at the transition pole

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The derived power spectral density can be found in Figure 11.

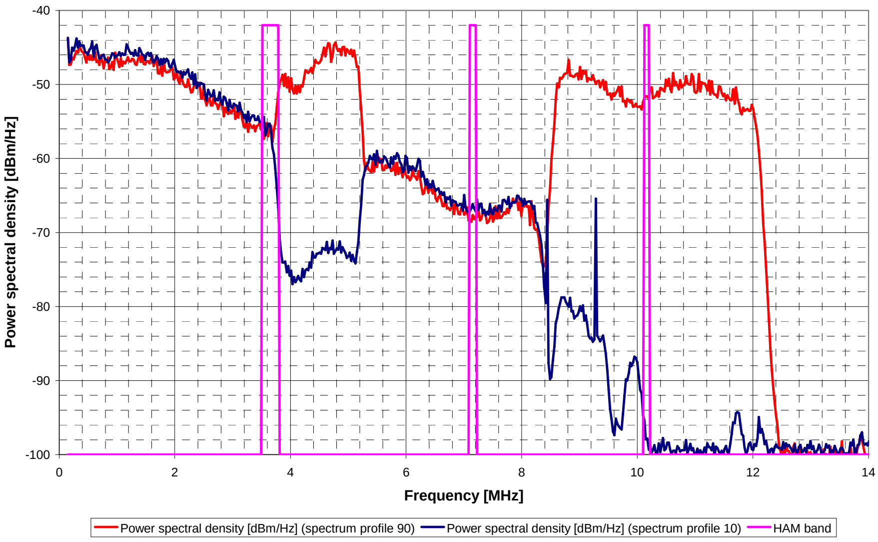

Figure 11: power spectral density for the short line

Without any VDSL2 transmission, the reception level is about S3 in the whole 80m band and between S2 and S3 in the 40m band.

2.8.2 S units

S units are commonly used within amateur radio community. Every amateur owns an S-meter, which allows measuring the voltage at antenna connector. By definition, the difference between two S-points is 6 dB. Unfortunately, most of the S-meter are not compliant and have a difference of 3 to 4 dB between two S-points.

Reception conditions change during the day. Till about 7PM, propagation characteristics are quite poor, resulting in a noise level as low as S2 to S3. During the evening and the night, propagation characteristics are better and noise level increases to about S5.

A noise of S2 to S3 allows the reception of stations emitting with low power whereas a noise level of S9 occults all stations having a lower signal. In reception conditions, a S2 signal is a low signal whereas a S9 signal is a strong signal.

2.8.3 Spectrum profile 90 (see Figure 3 for details)

When spectrum profile 90 is activated, the noise level in the 80m band increases from S3 to S9. There is a less important increase between 3721 kHz and 3768 kHz. In this band, the noise increases to S4-S5. This difference is due to the guard interval between the downstream and upstream bands. As mentioned in Table 2, the break frequency is 3750 kHz.

In the 40m band, there's a similar increase to S9, except between 7020 kHz and 7040 kHz. As shown in Figure 12, there's a power spectrum reduction of about 15 dB between 7020 kHz and 7040 kHz. This is clearly remarkable on radio reception. The noise level decreases from S9 to S5.

It has to be mentioned that this profile was chosen only to determine if interference could occur. In a normal deployment, use of UPBO would drastically reduce the power in the 40m band.

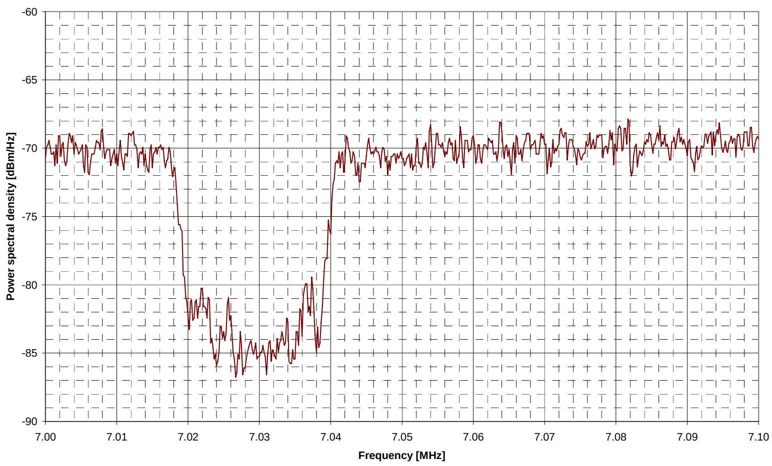

Figure 12: detail of the power decrease between 7020 kHz and 7040 kHz

2.8.4 Spectrum profile 10 (see Figure 4 for details)

Spectrum profile 10 will typically be used for short lines. In this case, UPBO reduces the power in the upstream channel at its minimum that is required for a good transmission.

When spectrum profile 10 is activated, the noise level in the 80m band increases from S3 to S9, except between 3721 kHz and 3800 kHz. As shown in Figure 11, power spectrum density is reduced in upstream bands. In the frequency band 3721 kHz to 3800 kHz, no additional noise can be heard. Reception level remains at S3.

In the 40m band, the situation is exactly the same as with spectrum profile 90 because this band is within a downstream band of VDSL2.

2.8.5 Conclusion

This measurement has clearly shown that VDSL2 transmission systems have an impact on amateur radio reception. This fact should be put into perspective that the access network line was very short. In fact, 40m and 80m bands fall mostly into VDSL2 downstream bands and the signals will be attenuated.

Consequently, a measurement with a more realistic access network line is necessary.

2.9 Test with an access network line

2.9.1 Introduction

Measurements with a very short line have shown that the background noise at the receiver station increases significantly when VDSL2 equipment is installed. This second test set-up aims at discovering if this interference could often occur or if it could occur only in some special situations.

The DSLAM is placed at the village centre, where the next flexibility point of the access network is located. The line is composed of 444m of 0.6mm diameter cable, 322m of 0.5mm diameter cable and 10m drop wire. Figure 13 compares calculated line attenuation based on Swiss model with measurement. Measurement is based on VDSL2 signal measured at customer side. Measured attenuation is only valid up to 3750 kHz because this is the break frequency that marks the beginning of the first upstream band. The frequency band between 3750 kHz and 5200 kHz is an upstream and, as we measure at the line beginning, there won't be an important attenuation. Above 5200 kHz, measured values stay in the measurement noise and are no more significant.

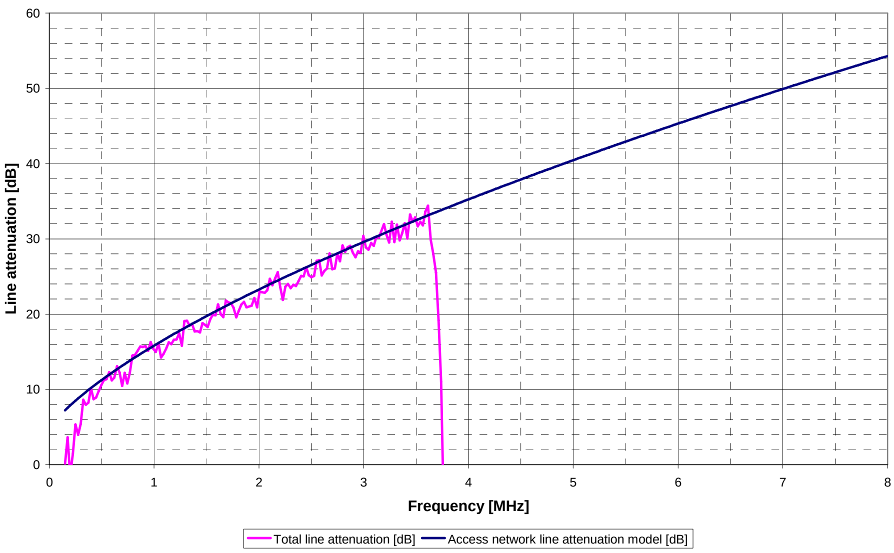

Figure 13: comparison between simulated and measured line attenuations

Power spectral density can be found in Figure 14. The effect of line attenuation for the bands DS1 as well as US1 can clearly be seen. DS2 can no more be distinguished as it stay in the measurement noise. Finally, US2 uses frequencies only till 9'500 kHz. Line attenuation becomes so high that no transmission is possible above 9.5 MHz.

In Figure 14, the blue curve represents the maximum power density that can be achieved on a very short line and without UPBO. The brown curve shows the power spectrum density measured on the 776m long line. Attenuation can be clearly seen in DS1 band.

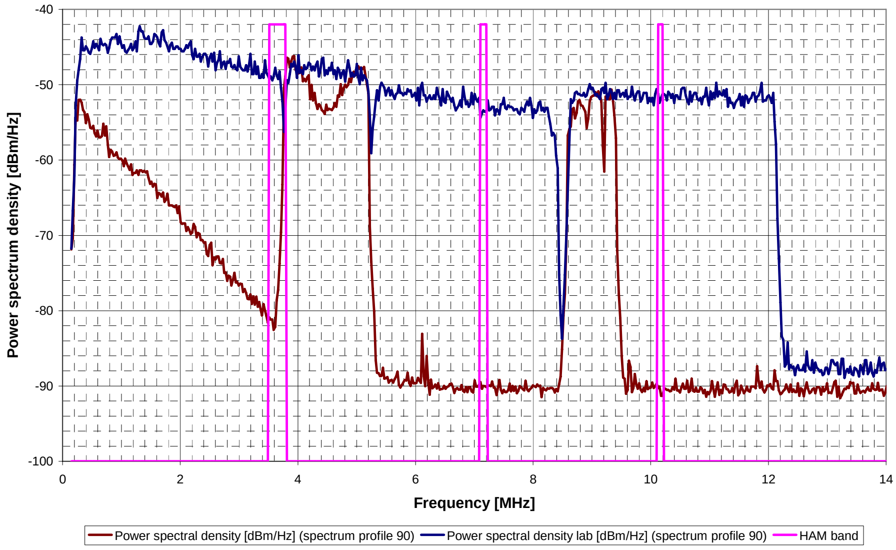

Figure 14: power spectral density for the line compared with laboratory measurement

Due to the length of the line, the only type of profile that can be implemented is the spectrum profile 90. UPBO is no longer in operation.

Without any VDSL2 transmission, the reception level is about S3 in the 80m and 40m bands.

2.9.2 Spectrum profile 90 (see Figure 3 for details)

In the 80m band, there's no noise increase at the receiver due to the attenuation of the line (see Figure 14). The noise remains at S3, except in the band between 3760 kHz to 3800 kHz where it increases to S9 because of the overlap with the not attenuated upstream channel. This change can be seen in Figure 15.

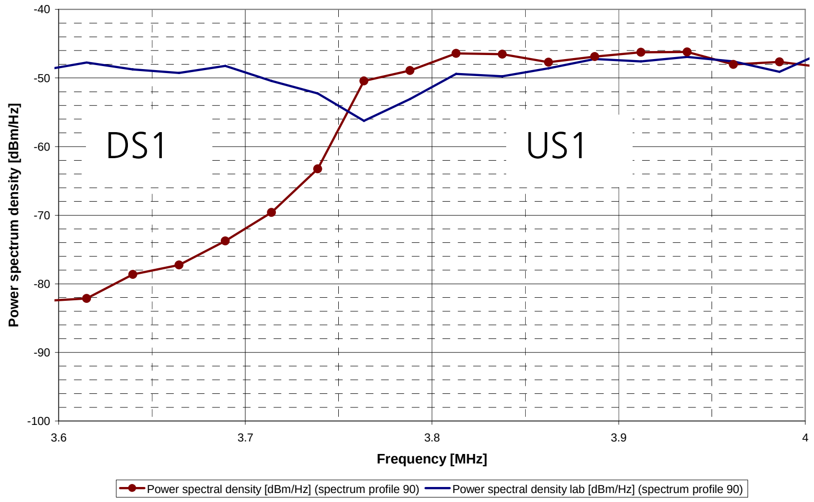

Figure 15: power spectral density for the line compared with laboratory measurement in the frequency band between 3600 and 4000 kHz

In the 40m band, the receiver noise remains at S2-S3 in the presence of VDSL2 signals because the line length attenuates the signal. At these frequencies, the attenuation is higher than 40 dB and the cable radiation cannot be measured anymore.

2.9.3 Conclusion

The presence of an access network line reduces significantly the interference to amateur radio. The cable attenuation will be in most cases sufficient to avoid interferences, except in the band between 3'750 kHz and 3'800 kHz. This interference depends only on drop wire and indoor cables types.

In the investigated setup, the next flexibility point of the access network was at 776m; no other point in-between was accessible.

3 Immunity

3.1 Introduction

Amateur radio can emit with a peak power of 1’000W measured at transmitter antenna connector. The electromagnetic field generated by this radiated energy will create a common mode current on the telephone line, which will in turn be transformed into differential mode. It is probably the differential mode current that disturbs the DSL equipment.

3.2 Effect of amateur radio transmission on VDSL2

Some simple tests were realised with a amateur radio liaison at different frequencies. 100W was sent by the radio transmitter, which is the power that can be generated without amplifier.

The far field can be computed by

$$E = \frac{7 \cdot \sqrt{P \cdot G}}{d}$$

With

P: the power at antenna connector

G: the antenna gain (assumed to be 1)

d: the separation distance

For a separation distance of 10m and a power of 100W, one can compute that the field is about 10V/m. This field is given only in order to get an order of magnitude. In fact, the separation distance is too small taking into account the antenna size.

At 7MHz and with a FM modulation, the VDSL2 router is disturbed and needs a re-synchronisation. Even if the amateur continues to emit, a synchronisation is possible. In this case, VDSL2 equipment won’t use frequencies that are in use by the amateur radio.

The same occurs at 3.78 MHz with FM modulation. However, with SSB modulation, the transmission isn’t impacted. This effect is due to the lower power transmitted by SSB. In fact, one of the bands of the AM modulation is suppressed, as well as the carrier. Only the useful signal contained in one band is transmitted and strongly depends on signal. SSB is mostly used in the 80m band.

At 14 MHz, which is outside VDSL2 band, the transmission isn’t impacted, even with 1’000 W. This shows that the input filter of the VDSL2 equipment is sufficiently efficient in rejecting out-of-band interference.

3.3 Conclusion

VDSL2 transmission is impacted when amateur radio transmits, even with common emission power. This impact won’t be only limited to its own installation, but may influence other VDSL2 transmissions within a distance of tens of meters.

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4 Conclusion

Measurements have shown that amateur radio can be influenced by VDSL2 transmission and vice versa. In fact, unintended emission from VDSL2 may impact radio reception in both 80m and 40m bands. However, the access network line length attenuates the signal received at customer. This attenuation will, in most cases, be sufficient so that no noise increase could be heard at receiver side. This applies to the whole 40m and 80m bands, except between 3’760 kHz and 3’800 kHz. This portion stays within a VDSL2 upstream band and cable attenuation has no impact on it. However, upstream power back-off may reduce the impact on radio reception.

If an interference case would anyway appear due to unfavourable conditions, it is possible to suppress the perturbation by shutting off the emission of VDSL2 in the affected band (notching). The replacement of the drop wire by a cable could be exceptionally a solution too.

VDSL2 transmission will be broken every time a liaison is established with a power of 100W, which is commonly used by amateur radio. Liaison recovers by itself, but needs some 20 seconds. This would render difficult the simultaneous use of radio and PC installations. Finally, this interference won’t affect only the amateur radio himself but also neighbours within a distance of about 50m.

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