Determination of impact of VDSL interference on the Amateur Radio Service.

Final Report v2.0

This report shows the results of testing the impact of VDSL2 RFI on Amateur Radio at six sites selected as representative from those reported in the members survey aimed at determining the extent of the RFI. The sites chosen were close to Baldock to allow Ofcom to conduct their own measurements at these sites.

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The RSGB has been measuring the levels of Radio Frequency Interference (RFI) from VDSL broadband since 2014. Work has included measurements on test sites and at Amateur Stations where RFI was reported as degrading communication. A summary of the levels for 92 locations reported in 2016 recorded typical RFI levels for the VDSL bands. A detailed report covering eleven reported problem locations dated 28/9/2016 was produced, shared with and discussed with BT, Openreach and Ofcom.

As a result of this meeting limited observations from Ofcom concluded that levels observed at amateurs' premises did not constitute Harmful Interference. RSGB refuted this http://rsgb.org/main/files/2012/12/VDSL-RFI-RSGBOfcom-meeting-June-21-2017.pdf and a further set of tests were proposed. These further tests at six locations were performed in Feb - Mar 2018 and an interim report dated 10/10/2018 was produced on those tests. Ofcom then proposed that line balance tests should be performed by Openreach at the six locations that had been used for the 2018 tests. These tests were done by Openreach in 2019 and some line balance issues were found. Some of these that were on the Openreach Network were addressed by Openreach but others on customers' premises due to self-install VDSL were not addressed.

In July - August 2019, Ofcom made a second visit to each of three locations where Openreach had addressed line balance issues and repeated the VDSL RFI measurements to evaluate the effect of the work done by Openreach. RSGB also attended and did its own tests including evaluation of the measurement procedures and limits defined in CEPT ECC Recommendation (09)02 [2] for assessing the level of disturbance emission generated by VDSL networks.

To better quantify the impact RSGB decided to undertake the following activities:

A. Conduct a survey of members to determine how many amateurs were experiencing problems with VDSL RFI
B. Determine signatures for VDSL to enable measurement of the VDSL signal strength
C. Measure the levels of VDSL signals received at representative amateurs' sites selected from the survey results
D. Determine the variation in RFI level with location using a drive by Field Strength Logger
E. Determine the impact of VDSL signals at these sites by simultaneous comparison with signals receivable at nearby sites where VDSL RFI was at a much lower level ("Here" and "There" testing)

A. VDSL Survey

A simple to identify signature for VDSL signals was needed to quantify the level of signals received by each amateur to allow comparison between the sites. VDSL separates upstream and downstream transmissions into alternate bands with a guard-band between them. No VDSL tones are transmitted in the guard-band. Measuring the levels 50kHz below, within and 50kHz above the guard-band gives step levels whose magnitudes are a good indication of the VDSL RFI level. As measurements are only compared within a 100kHz window any variations in antenna gain do not affect the readings. The step sizes derived can be compared across sites even if the sites use widely differing antennas. A survey was devised and completed online by 1300 amateurs reporting these step sizes. The results of this survey were reported in RadCom December 2017 pages 48 and 61 and can be summarised as:

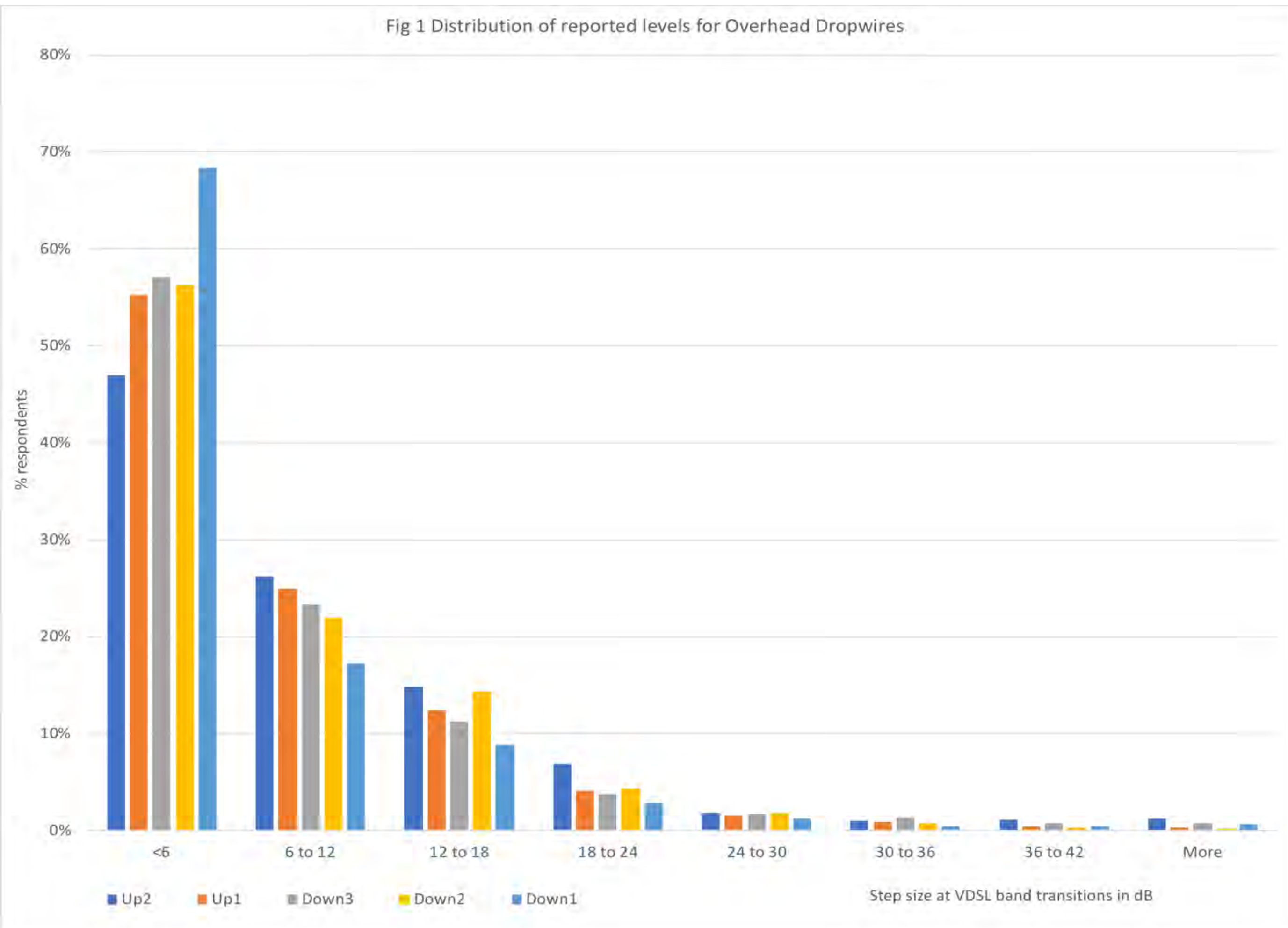
1. *More than 50% of survey respondents are suspected as suffering from degraded signals where VDSL is the suspected source*
2. *Downstream is strongest near to cabinet - as it is the sum of many VDSL connections emanating from the cabinet whereas further from the cabinet it is only the sum of nearby neighbours' lines*
3. *Upstream is strongest further from the cabinet as the modems use higher upstream signal strength to overcome line losses in longer lines*
4. *Overhead drop-wires may act as resonant antennas and the RFI level depends on their length and their proximity to amateur's antenna*
5. *In house extension wiring also acts as an antenna and causes RFI particularly near dense housing - flats or townhouses - Sky Q has a third antenna the mains wiring connection with the capability for PLT*
6. *RFI is worst if amateur antenna is in the near field of overhead wires or extensions*

More than 50% of our survey respondents found steps of more than 6dB at one or more VDSL band transitions, half of these or more than 25% found steps of more than 12dB. Histograms for each of the VDSL bands are shown in Figure 1.

The percentages are shown separately for overhead and underground feeds in table 1

This shows more problems with RFI from upstream than downstream. Actual RFI Levels found for underground feeds were higher than expected at only 5 to 10dB below overhead drop-wires. We believe in house extensions act as the antenna in these cases. Detailed comparison for different bands is plotted in Fig 1 below.

Table 1	>6dB (4x)	>12dB(16x)	>6dB(4x)	>12dB (16x)
Up 2	53%	27%	35%	16%
Up 1	45%	20%	33%	15%
Down 3	43%	19%	32%	13%
Down 2	42%	21%	33%	12%
Down 1	31%	14%	26%	12%



This shows the number of stations suffering RFI but not the impact of that interference on the Amateur Service

B. Measurement of VDSL radiated signal strength

A more accurate signature was needed to separate the contribution from the VDSL2 RFI from other signals and other sources of RFI. Often VDSL2 interference goes unrecognised since it looks like background noise just many dB's higher in strength. This is not surprising as any characteristic of a communication system that is distinguishable from white noise represents inefficiency in the use of the spectrum.

Overview

To detect modern digital communications signals such as VDSL2 one needs to understand the coding technique and any aspects of that which are less random. The most significant feature of a VDSL2 signal that is not effectively random is the Cyclic Extension that occurs between symbols. A VDSL2 system has a typical symbol rate of 4000/second. Before one can do any analysis, one needs to align one's measurement system with the symbol timing. VDSL2 timing parameters are established during a training phase however it is not practical for a passive measurement system to obtain this information directly.

An introduction to Cyclic Extension.

In any communication system which encodes data into symbols a limiting factor is inter symbol interference. This results from dispersion in the media such that signals arrive spread out in time relative to when transmitted. To avoid dispersed signals impinging on the following symbol one needs to leave gaps between symbols to allow time for the transient response "ringing" of the line to die down. If the signal were to drop to zero immediately during the inter-symbol gaps this would cause distortion leading to inter channel interference. To avoid this for VDSL2 part of the front of each symbol is repeated and appended to its rear forming a cyclic extension. This "cyclic extension" (CE) is gradually faded out as the front of the next symbol is faded in minimising harmonic distortion.

Detection of the Cyclic Extension

The cyclic extension provides us with both the symbol alignment information and a method of measuring the strength of the interfering VDSL2 signal. To detect the cyclic extension in a wave file signal from an SDR we need to do a correlation between the signal recorded by the SDR and a point on the same recording exactly one un-extended symbol period later. The correlation is done over a window of length CE. The un-extended symbol period is 1/4312.5 seconds = 231.884us. The extended symbol period is 1/4000 = 250us. Thus the length of the CE is 250 - 231.884 = 18.116us. A more detailed description is included in RadCom November 2018 pp 28 to 32.

Processing in Lelantos

To do the correlation to detect the CE one needs to derive waveform samples delayed by 231.884us and correlate these with the original SDR wave file waveform. Lelantos does this by constructing a non-integral delay filter at the sample rate of the wav file. Then, knowing the symbol rate, it does this correlation accumulating cyclically per symbol. This produces a waveform with peaks that correspond to the positions of the cyclic extension (CE) for each of the VDSL2 line(s) from which interference is detected. In the following screen shot this is shown as the bottom right graph. The horizontal axis of that graph is marked in degrees. The correlation peak at 0 degrees is the correct width for a cyclic extension. The blue markers on the axis show the expected width. 360 degrees corresponds to the end of the symbol and the repeat of the CE peak. You can see that there is a second weaker VDSL2 line at 275 degrees. (This shows that VDSL2 vectoring is not in use as the multiple lines symbols would all be phase locked.)

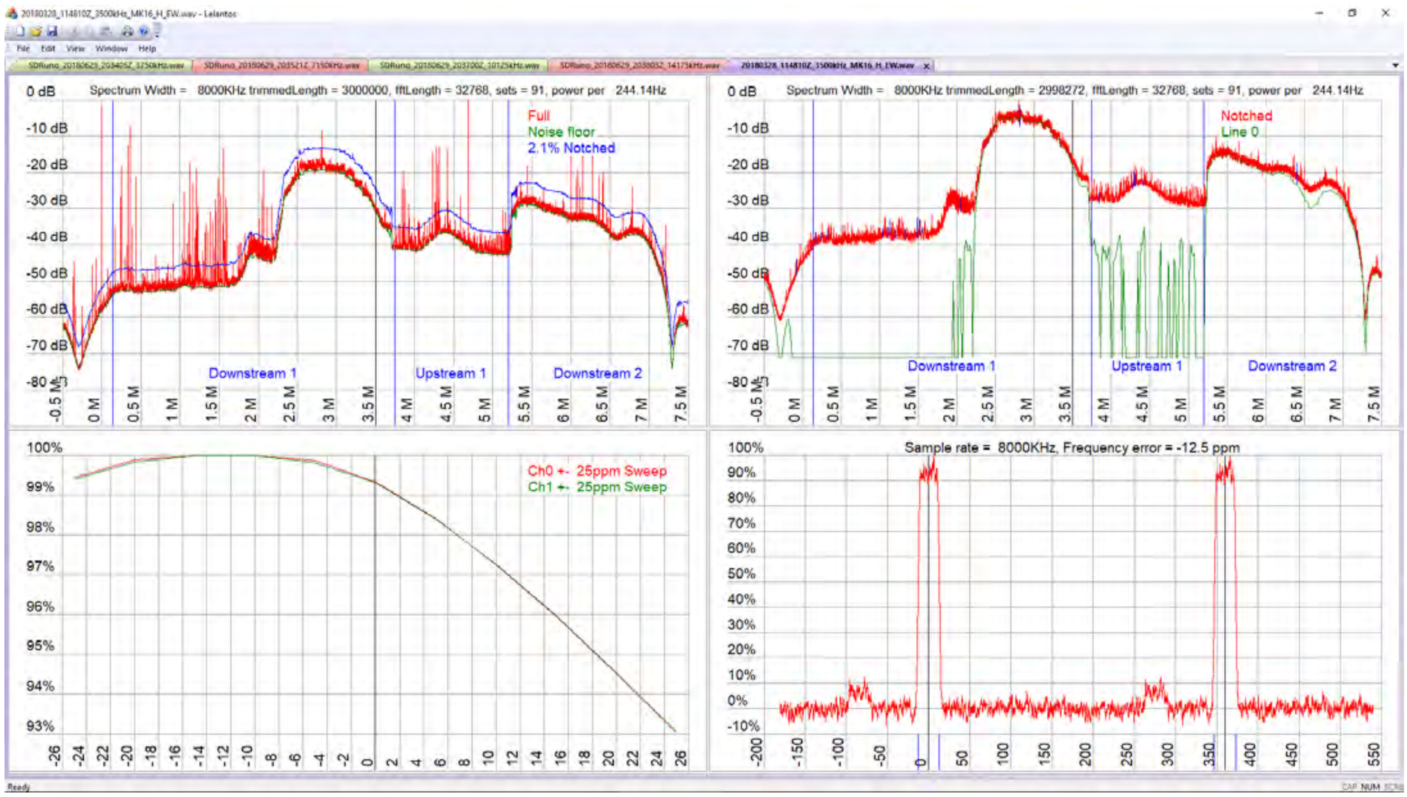


Figure 2 output from Lelantos VDSL measurement package

Due to small calibration errors in the frequency of the SDR sampling the exact sample rate can be slightly off. The bottom left graph shows that Lelantos did a sweep to find the peak and concluded that the sampling rate was off by -12.5 parts per million. The very close accuracy is extra confirmation that we are seeing VDSL2.

The top left graph in the screen shot shows the full spectrum of the SDR wave file. This spectrum is shown as power per 244.14 Hz (8MHz / FFT length 32768). It is accumulated over the 3 Million waveform samples as the graph heading says. The gain of the SDR and loop is unknown so 0dB is shown as the strongest peak.

Strong peaks due to narrow band signals can cause beat effects during the correlation that is done to detect the VDSL2 CE. To avoid this problem Lelantos identifies all peaks that are more than 6dB above the local noise floor and notches them out. The top left graph shows the noise floor (green) and the 6dB threshold (blue). In this case a total of 2.1% of the bandwidth is notched out in removing these multiple peaks.

During the first stage of processing these notches are applied and the new samples generated. The top right graph shows the result when these processed wave samples are then spectrum analysed. These wave samples are the ones that are in fact used to produce the correlation shown in the bottom right graph. Since the VDSL2 signal is broad band the notching out of 2.1% of its channels does not otherwise affect the correlation.

The strength of the VDSL2 interference reported in the bottom right graph is +7.5dB when compared with the total power of all other signals in the 8MHz bandwidth excluding the 2.1% notched. The 2.1% can be thought of as the signals that would be received in the presence of the VDSL RFI.

C. Survey of levels in areas near the selected sites

At some locations, we used a spectrum analyser / CISPR 16 receiver the Rohde and Schwarz FSH8 to record these transitions at the members premises and also at nearby quiet locations to validate results from the other testing.

These results are included below.

D Drive by Measurements using a Field Strength Logger

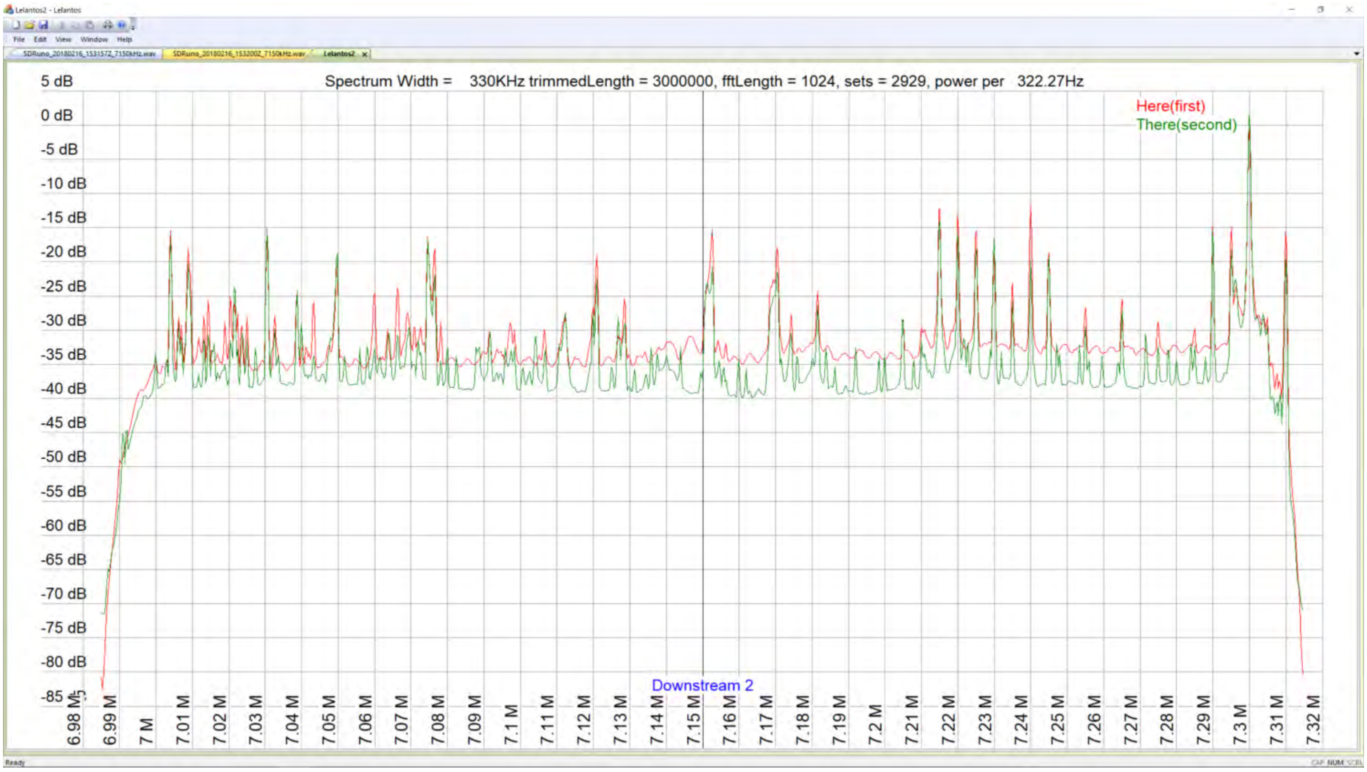
Next we wanted to find out how the VDSL RFI changed in locations close to the problem amateur sites. We used a vehicle mounted loop antenna with a Field Strength Logging package (Winradio Excalibur SDR fed from a Wellbrook ALA1530 active loop) this allowed the VDSL levels to be recorded at each of the members survey frequencies whilst driving along the nearby roads. The technique was described in the January 2018 RadCom pages 64 to 66.

These levels were then plotted on contour maps to quickly show hotspots of RFI and also to find quiet spots for Here and There comparisons. Results for two upstream bands shown below.

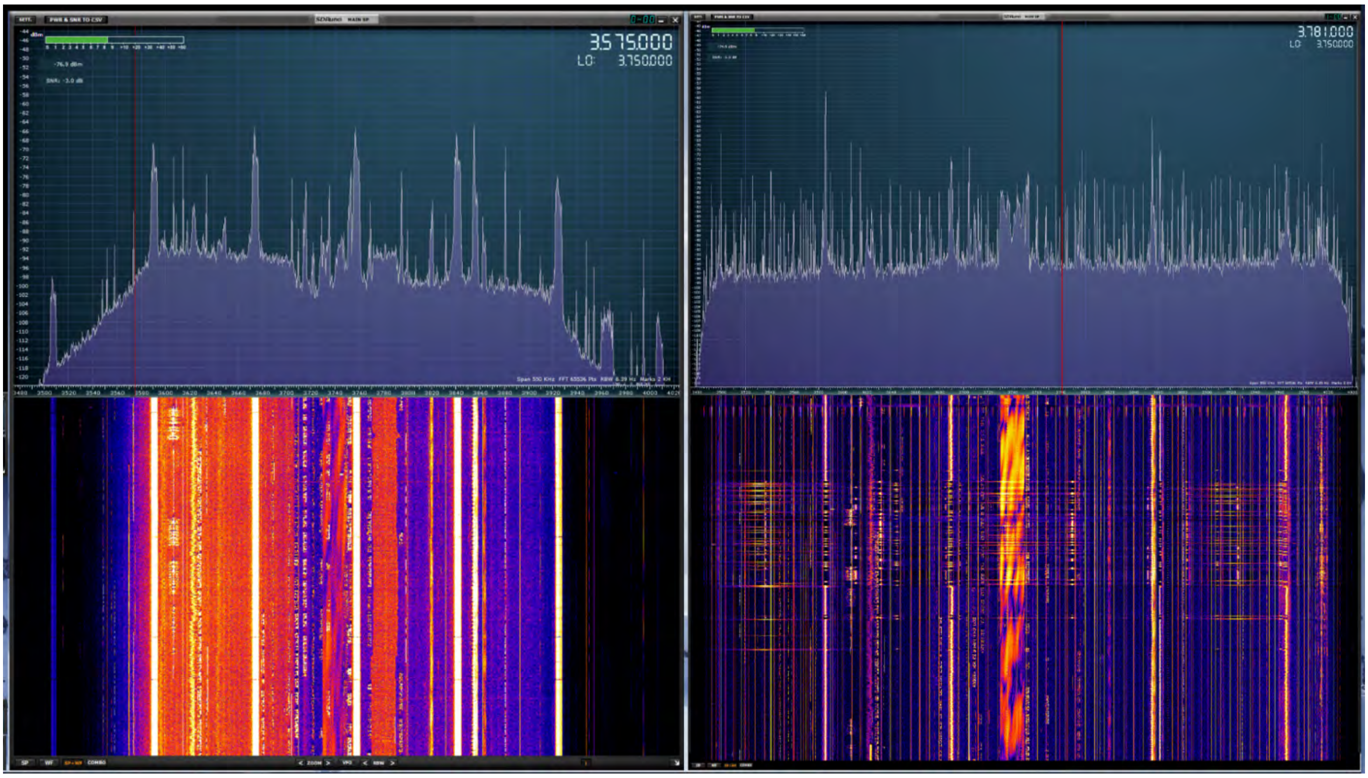
In the example above the two upstream bands present different hot spots at different locations indicating the system tends to use one or the other of these upstream bands.

E Here and There comparison of signals receivable

Comparison of spectra at the two locations from simultaneous recordings using equipment of the same type at nearby locations clearly shows the obscuration of many signals by the VDSL RFI noise level. In this example in this timeslot about 90 signals can be seen at the "There" location (green line) and under half of those can be seen at the "Here" location (red line). The red line also clearly shows the 4.3125kHz ripple characteristic of VDSL signals.



Playing back the recordings at the same time for Here and There locations allows the Waterfall displays to be compared.



The ability to playback and listen to different signals present on different frequencies enables a complete log of signals recorded to be made. The waterfall is particularly useful to select the signals to playback as the recording is cycled through until all the signals have been logged. As can be seen the RFI present at the Here location on the left clearly masks many of the recorded signals visible at the nearby There location. Appendices 1 to 6 contain results from each of the six sites selected for more detailed testing.

Conclusions

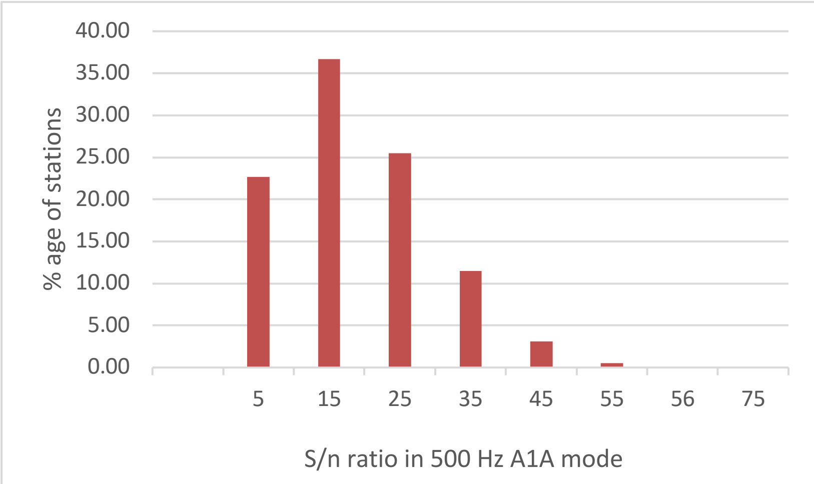
This testing clearly shows the extent and impact of the VDSl RFI on radio communication at LF through HF.
The table below compares the step sizes found by the different measurement methods at the six sites selected for study

Summary table of results per site

postcode	Test setup	D1L	D1U	U1L	UIU	D2L	D2U	U2L	U2U	D3L	D3U	distance antenna to telephone wires	Distance to BT fibre cabinet
PE16	RSGB Survey(dB step)	6	18	0	0	12	6	6	6	6		15	50
	EB200 (dB step)		10	5	3	12	10	8	14	5	5		
	lelantos (dB step)		14	6									
	driveby max (dBµV/m)		41	42	42	38	37	52	46	37	34		
	driveby min(dBµV/m)		19	22	22	26	24	33	35	24	26		
MK16	RSGB Survey(dB step)	0	0	0	0	12	12	0	0	0	0	30	500
	EB200 (dB step)	22	8	4	3	12	15	3	5	12	15		
	lelantos (dB step)		7	2	0	12	13	10	8	8	14		
	driveby max (dBµV/m)												
	driveby min(dBµV/m)												
CB1	RSGB Survey(dB step)	0	10	0	0	20	0	0	6	6	12	11	153
	EB200 (dB step)						8	5	6	5	5		
	lelantos (dB step)						8	5	4		4		
	driveby max (dBµV/m)		33	32	31	40	37	40	38	30	40		
	driveby min(dBµV/m)		18	18	19	16	23	24	23	22	24		
SG4	RSGB Survey(dB step)	12	6	0	6	18	6	6	6	12		U/G	35
	EB200 (dB step)		12	8				7	8	10	6		
	lelantos (dB step)		8	10									
	driveby max (dBµV/m)												
	driveby min(dBµV/m)												
PE28	RSGB Survey(dB step)			6		6	12		24	6			
	spec anal (dB step)		3	2									
	lelantos (dB step)							8	8				
	driveby max (dBµV/m)												
	driveby min(dBµV/m)												
CB8	RSGB Survey(dB step)	6	6	0	0	6	0	10	10	0	10	5	101
	EB200 (dB step)		8	6						5			
	lelantos (dB step)			5	15								
	driveby max (dBµV/m)												
	driveby min(dBµV/m)												

How do we assess the Impact of this RFI from VDSL on the amateur service? There are no minimum signal levels associated with amateur service communications, so to properly assess the service's susceptibility to harmful interference it is necessary to examine the actual pattern of communication in the service. The amateur service Reverse Beacon Network [1] provides a real-time database of amateur A1A mode signals automatically monitored at several hundred receiving stations around the world and globally aggregated. To arrive at some indication of the typical signal to noise ratio of communication in the amateur service, the data from these monitoring stations over an extended period has been analysed.

The chart below shows the distribution of A1A signal levels in the amateur service drawn from 528,280 data points.
Distribution of typical S/N ratio in amateur service communications.



Measurements made and reported from these VDSL studies show levels of 30dB obscuration of amateur signals are quite common; from the graph above we can see that 30dB rise in the RFI level would prevent reception of 85% of the signals which would be received if the RFI were absent.

This clearly shows that VDSL RFI Degrades, Obstructs and Repeatedly Interrupts the Amateur Service which is operating under its licence to communicate and thus constitutes harmful interference under the Radio Regulations.

We plan to repeat our request to Openreach to consider the following actions to reduce RFI

a) Improve Line Balance where necessary – we have a mechanism in place to request line balance on nearby lines via the EMC Committee but this is very slow
b) Clean-up self-installs – often at neighbouring properties. Openreach should make available Openreach NTE5C Socket with MK4 VDSL Plate in a form suitable for retrofitting. This could potentially increase download speeds and improve immunity.
c) Remove upstream band interference by universally notching 10.1 to 10.15MHz with guard-bands and by increasing the D1 to U1 guard-band to always protect 3.7 to 3.8MHz emergency frequencies
d) Selectively notch amateur bands in downstream (particularly 14MHz band) at affected sites
e) Reroute the overhead cables so they are further from the amateurs' antennas when necessary
f) Provide FTTP instead of FTTC at problem locations

We also suggest that in future Ofcom adopts the standard technique for measuring emissions from telephone lines

a) agree that in future, when assessing the level of disturbance emission generated by VDSL networks, they will use the measurement procedures defined in CEPT ECC Recommendation (09)02 [2] and the limits specified in Annex 1 of [2] for safety frequency ranges (from [3]).

Ofcom have prepared their report on the testing they conducted at the sites in the appendix which shows the same levels of RFI from VDSL. (reference to be included when published)

Dr John Rogers (M0JAV) Dr David Lauder (G0SNO) Dr Martin Sach (G8KDF) 27/09/2019

References

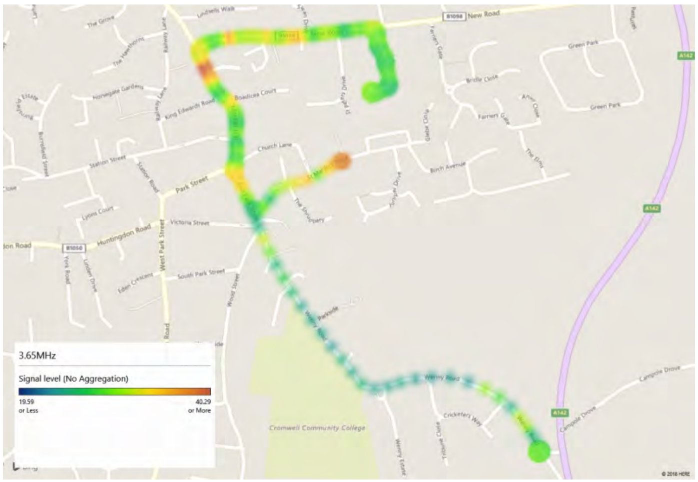
[1] The Amateur Service Reverse Beacon Network
http://www.reversebeacon.net/
Accessed 27/09/2019

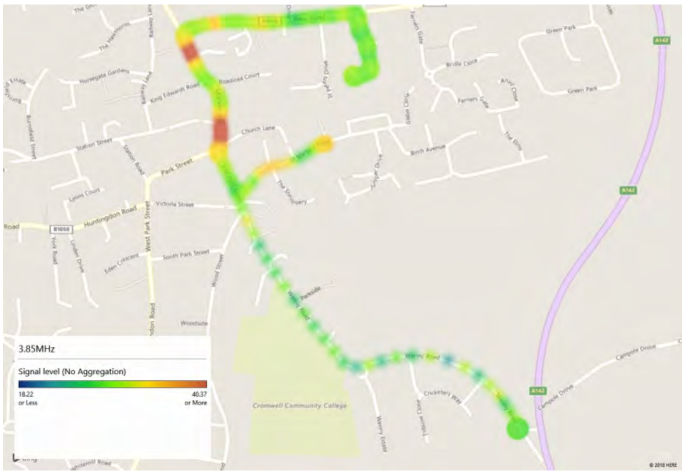
[2] Electronic Communication Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), ECC Recommendation (09)02, Specification for the measurement of disturbance fields from telecommunications systems and networks in the frequency range 9 kHz to 3 GHz
https://www.ecodocdb.dk/download/15bf8059-cf36/REC0902.PDF
Accessed 27/09/2019

[3] Electronic Communication Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), ECC Recommendation (05)04 Criteria for the Assessment of Radio Interference Caused by Radiated Disturbances from Wire-line Telecommunication Networks
https://www.ecodocdb.dk/download/7d643c5d-338d/REC0504.PDF
Accessed 27/09/2019

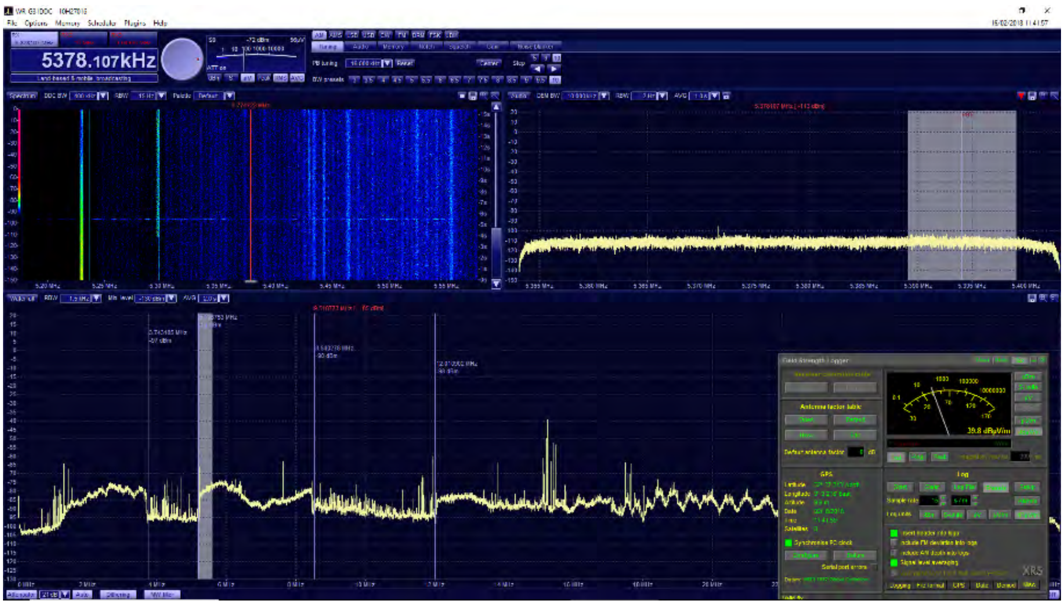
Appendix 1 VDSL measurement at PE16 location

A1.1 PE16 location - signal strength contour maps, 3.65 MHz - 3.85 MHz



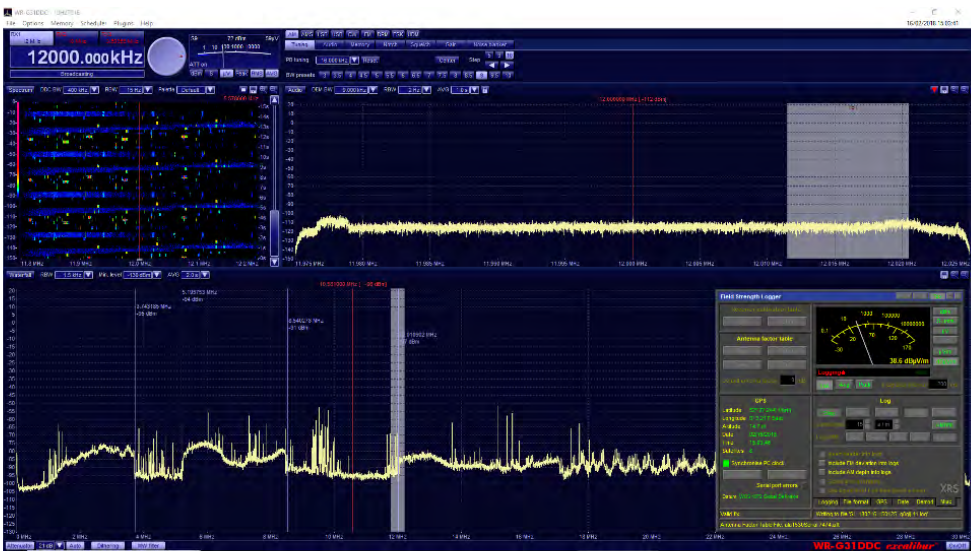


A1.2 PE16 location - spectrum at 'Here' location, 5.378 MHz

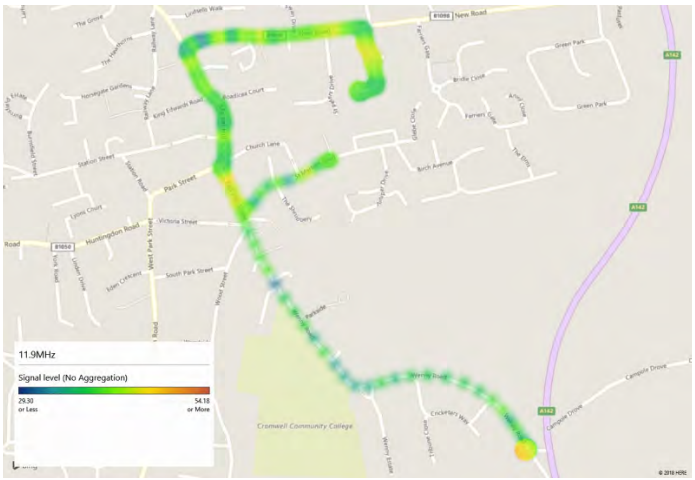


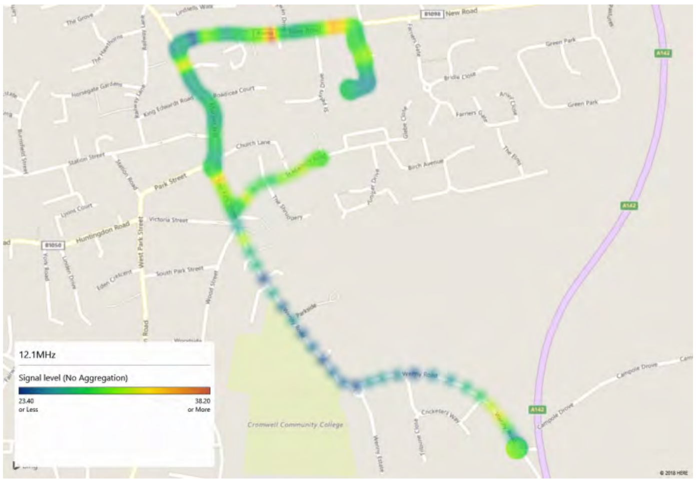
A1.3 PE16 location - signal strength contour maps, 5.1, 5.3, 8.4, 8.6 MHz

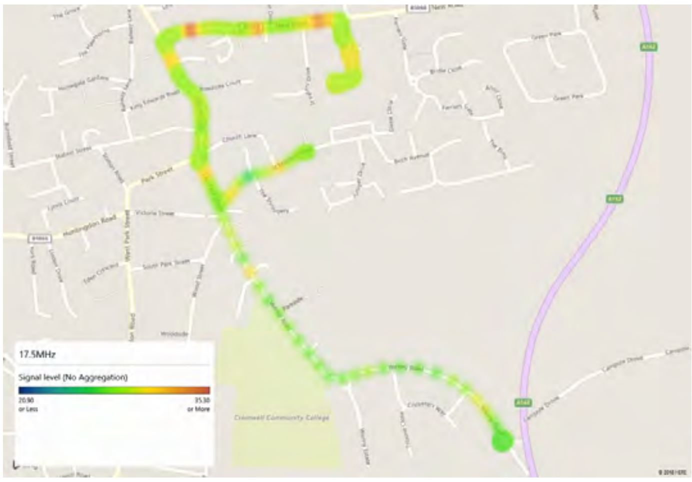
A1.4 PE16 location - spectrum at 'Here' location, 12 MHz



A1.5 PE16 location - signal strength contour maps, 11.9, 12 and 17.5 MHz

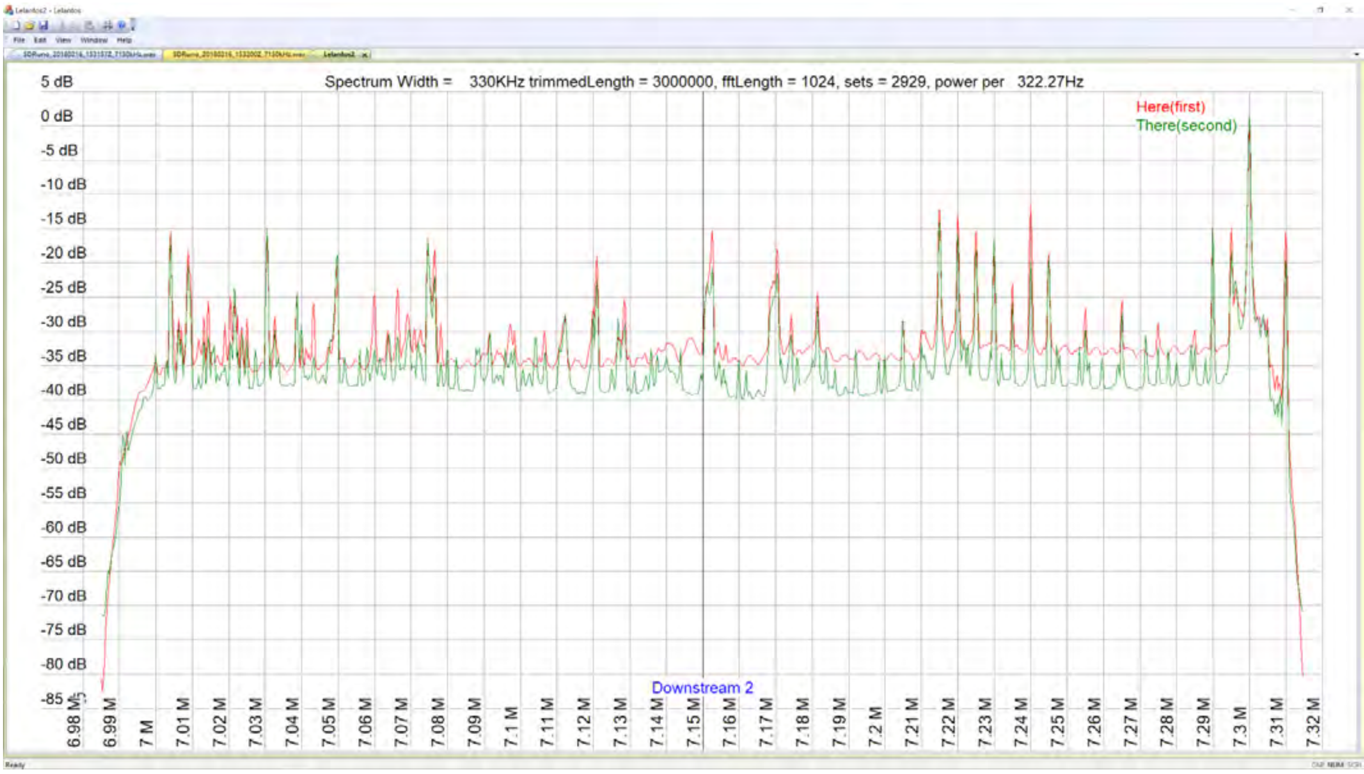




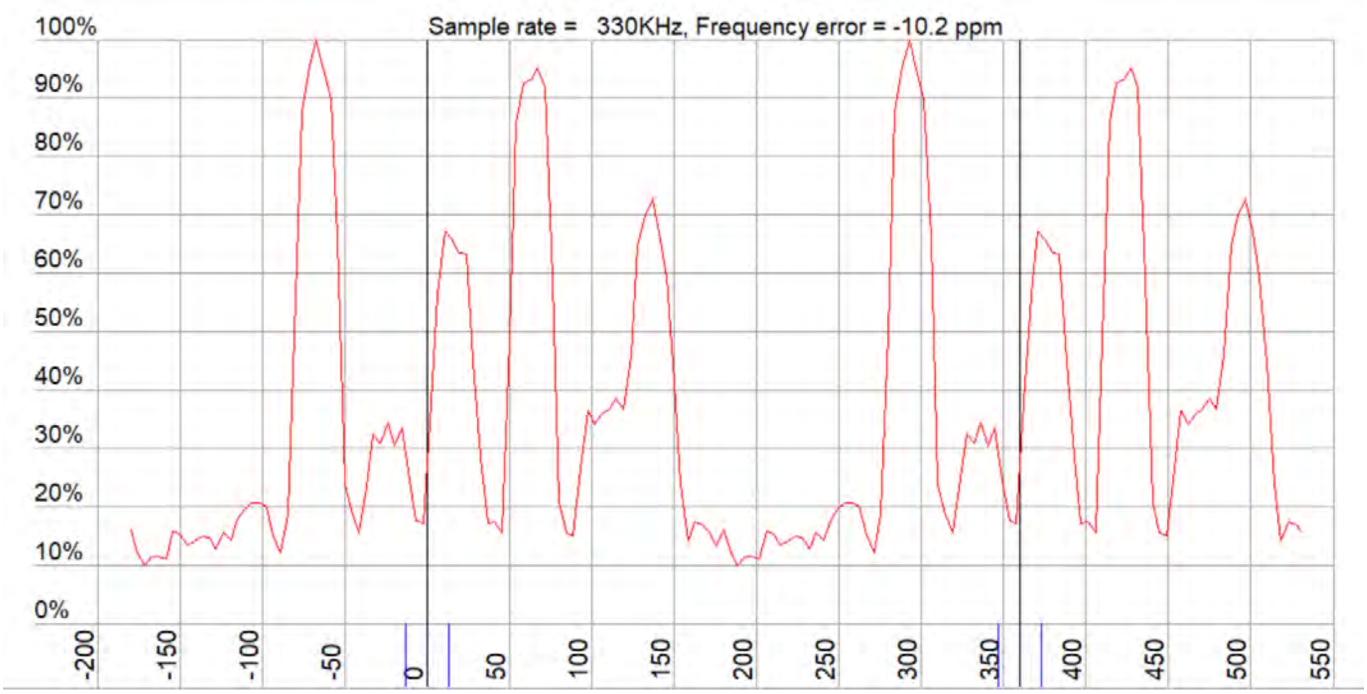


Using the Lelantos analysis package a lot of other details about the RFI from VDSL can be extracted. First, a comparison for signals at the amateur's location and at a nearby quiet location clearly shows that the majority of signals are obstructed by VDSL RFI.

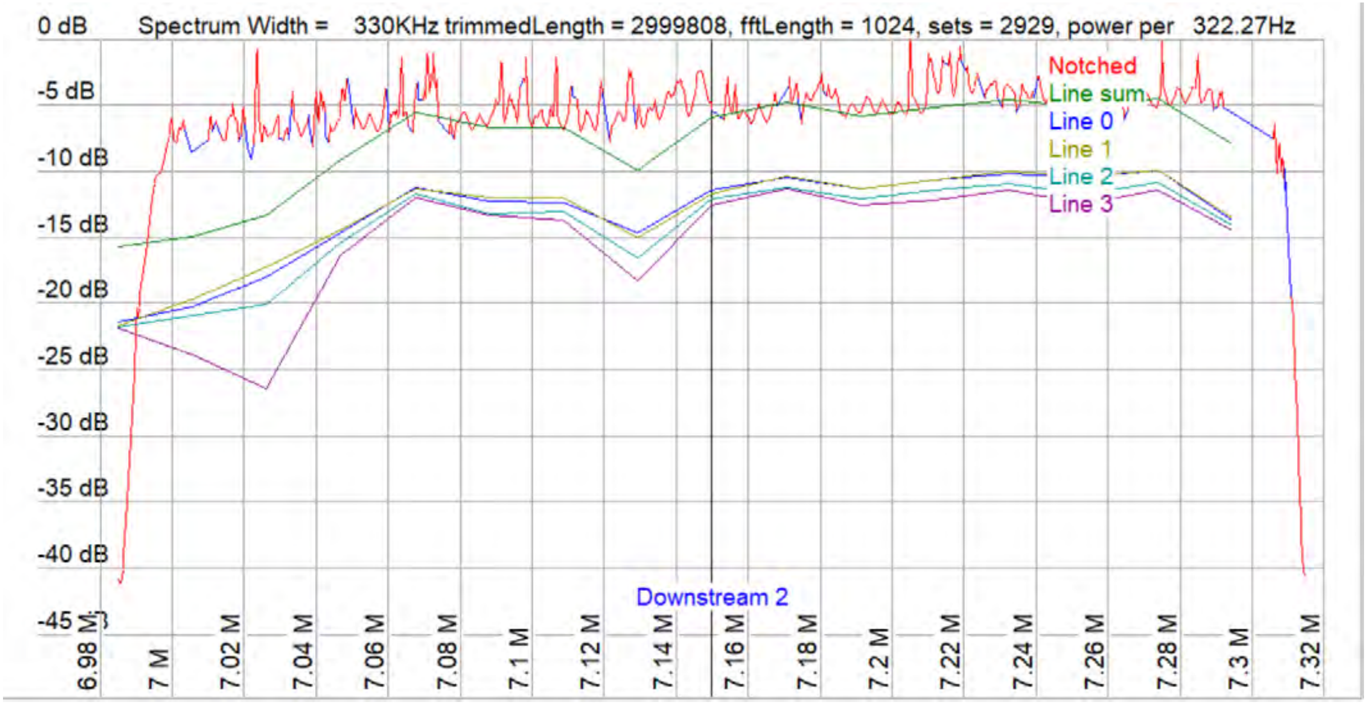
A1.6 PE16 location - 'Here and there' measurements with SDR recordings and Lelantos software



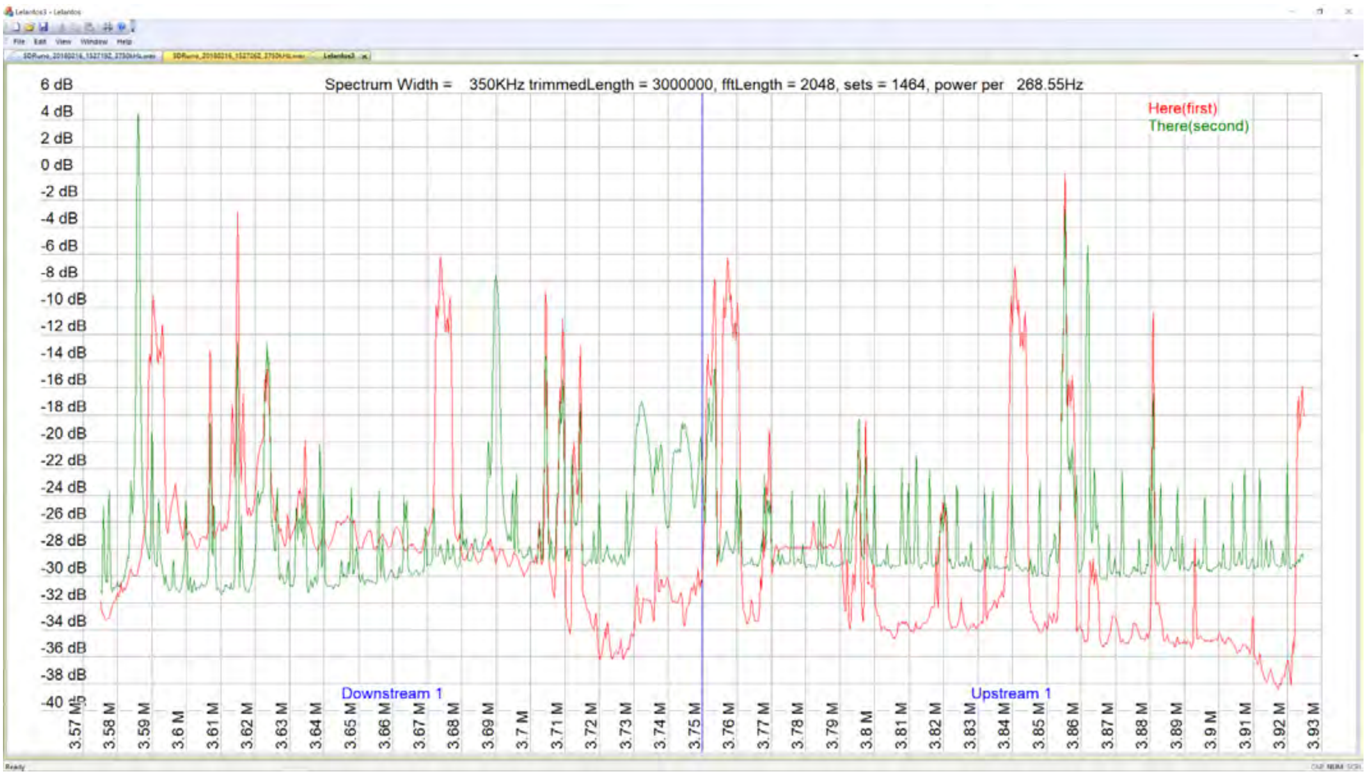
Secondly using the correlation analysis it is possible to determine how many VDSL RFI sources are being detected. In this case Lelantos shows two strong and four weaker correlated VDSL sources

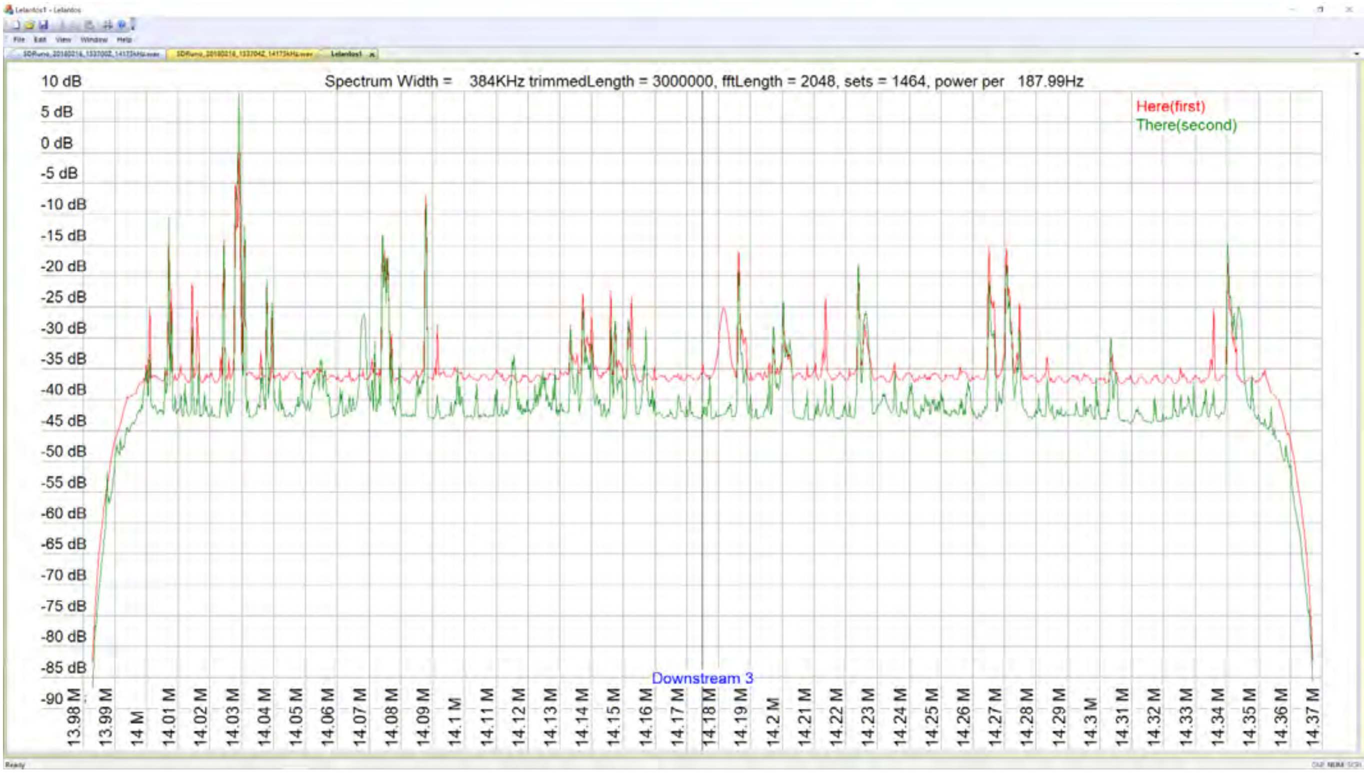


Next the power in the spectrum can be measured for each of the individual VDSL lines and summed to give the total power from the VDSL lines, in this case the power level of VDSL RFI being only 6 dB lower than the peak level of real signals at the here location.



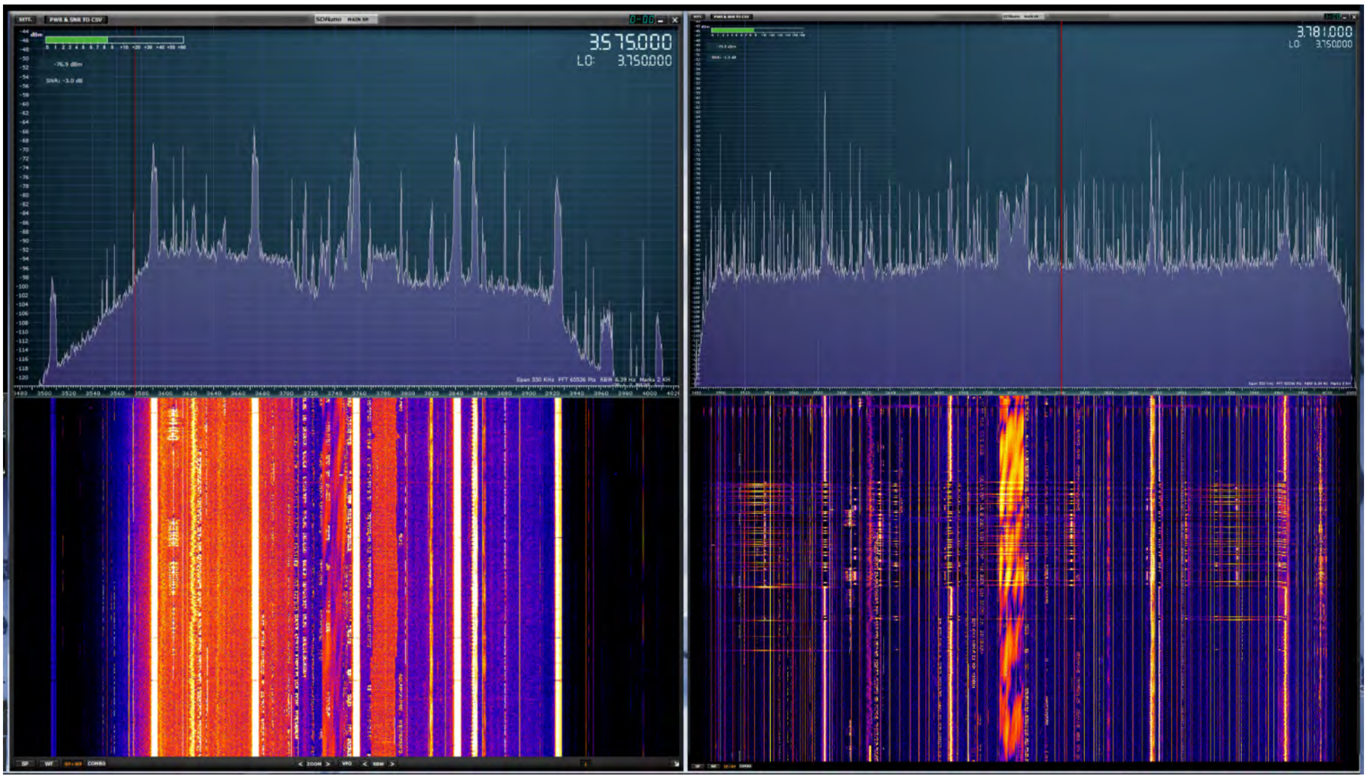
Similarly the 'here and there' compared spectrum at 3.65MHz





The extra signals are clearly visible and Lelantos can find no significant correlation of a VDSL signal at the 'There' location for any of the bands.

A1.7 PE16 location - 'Here and there' waterfalls



Large number of extra signals visible at quieter location.

Appendix 2 VDSL levels at MK16 location

For other locations we have presented a subset of the total measurements, which still give the overall picture of the RFI problems.

A2.1 MK16 location - 'Here and there' measurements with spectrum analyser

The following measurements are with Rohde & Schwarz FSH8 spectrum analyser and a Wellbrook ALA1530 loop antenna S/N 7000 with a 1.8 MHz HPF. The amplitude units are dB(uV), the antenna factor has not been included and the purpose of the traces is to compare the relative signal levels at the two locations.

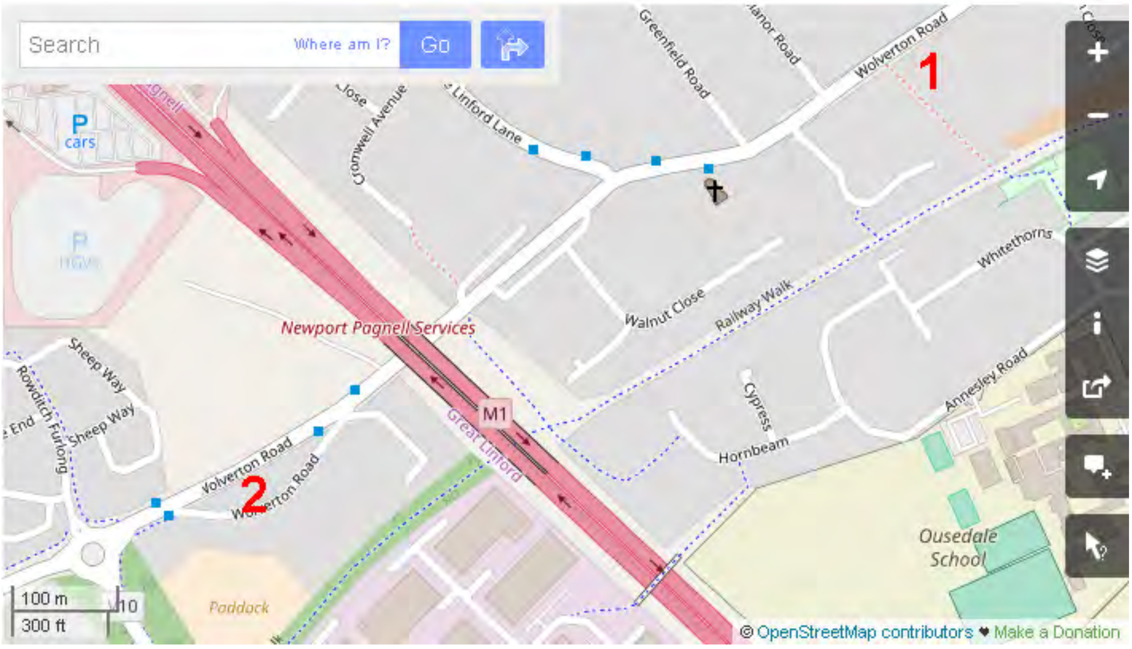
The map below shows the two locations. Location 1 is in the radio amateur's back garden (here) and Location 2 is approx. 750 metres south-west (there).

Trace0691, 0 - 30 MHz, Location 1, North/South

Trace693 0 - 30 MHz, Location 2, North/South

Trace0692, 0 - 30 MHz, Location 1, East/West

Trace694 0 - 30 MHz, Location 2, East/West

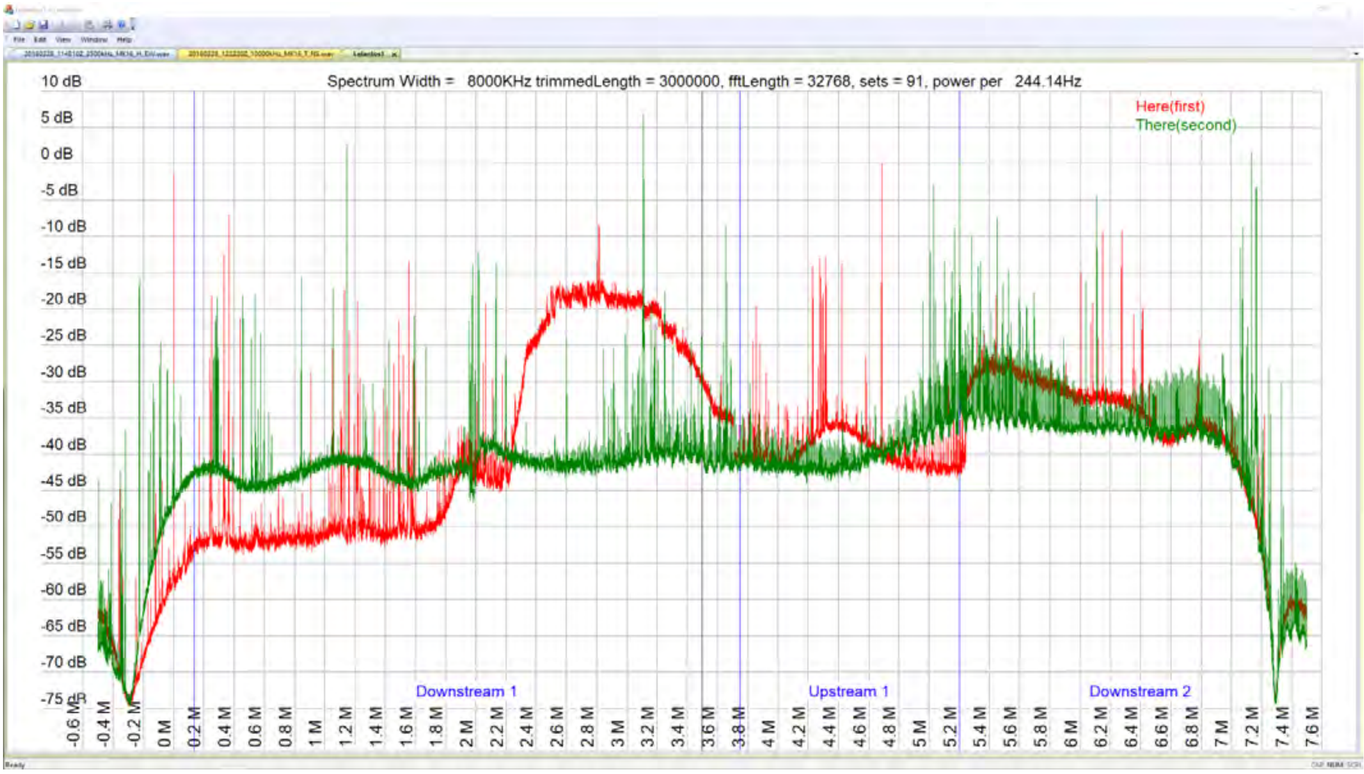


Location 1, radio amateur's location, Location 2, nearby reference location

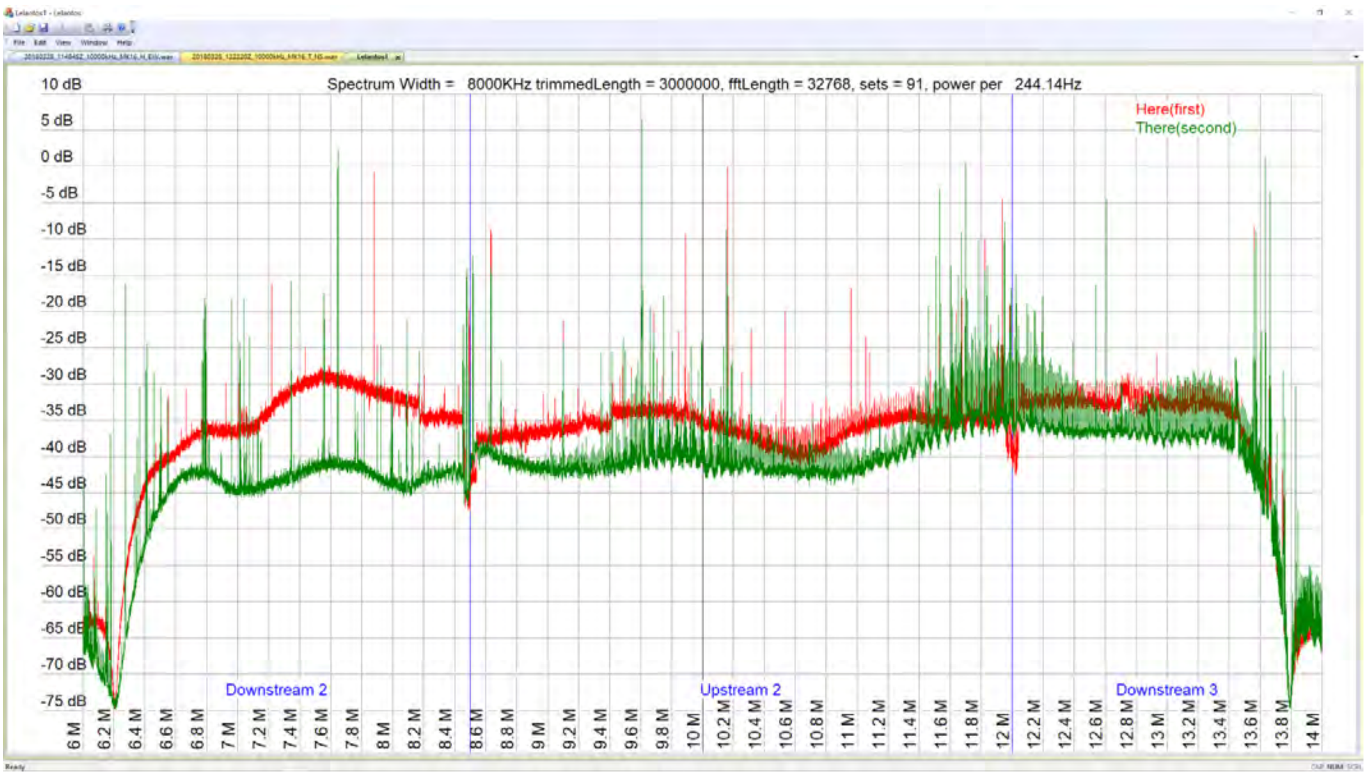
A2.2 MK16 location - 'Here and there' measurements with SDR recordings and Lelantos software

All measurements are with .WAV file recordings made using a Wellbrook ALA1530 loop antenna S/N 7000 with a 1.8 MHz HPF, an SDRplay RSP1 and SDRUno software. The .WAV files were analysed using Lelantos software release 111. The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording.

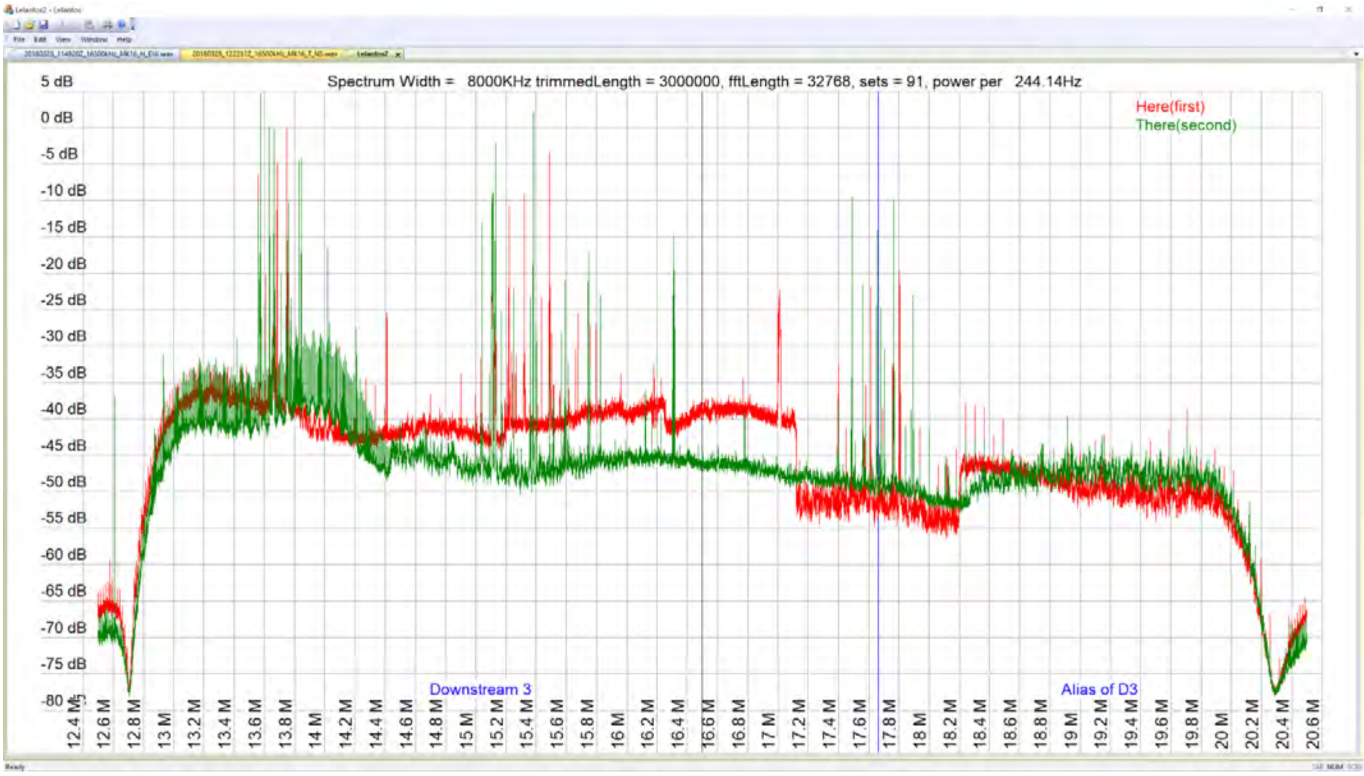
At Location 1, an East-West orientation of the antenna was used as this gave a higher signal level than North-South. At Location 2, a North-South orientation of the antenna was used as this gave a higher signal level than East-West.



Lelantos 1.8 - 7 MHz. Location 1 (here), East-West showing very significant VDSL noise, Location 2 (There), North-South showing moderate VDSL noise. Note in DS1 band, noise at Location 1 is 23dB above location 2.



Lelantos 6.5 - 13.5 MHz Location 1 (Here), East-West showing very significant VDSL noise, Location 2, (there) North-South showing some VDSL noise. Note in DS2 noise at Location 1 is 10dB higher than at Location 2.



Lelantos 13 - 20 MHz.
Location 1 (Here), East-West showing very significant VDSL noise. Location 2, (There) North-South showing barely detectable VDSL noise

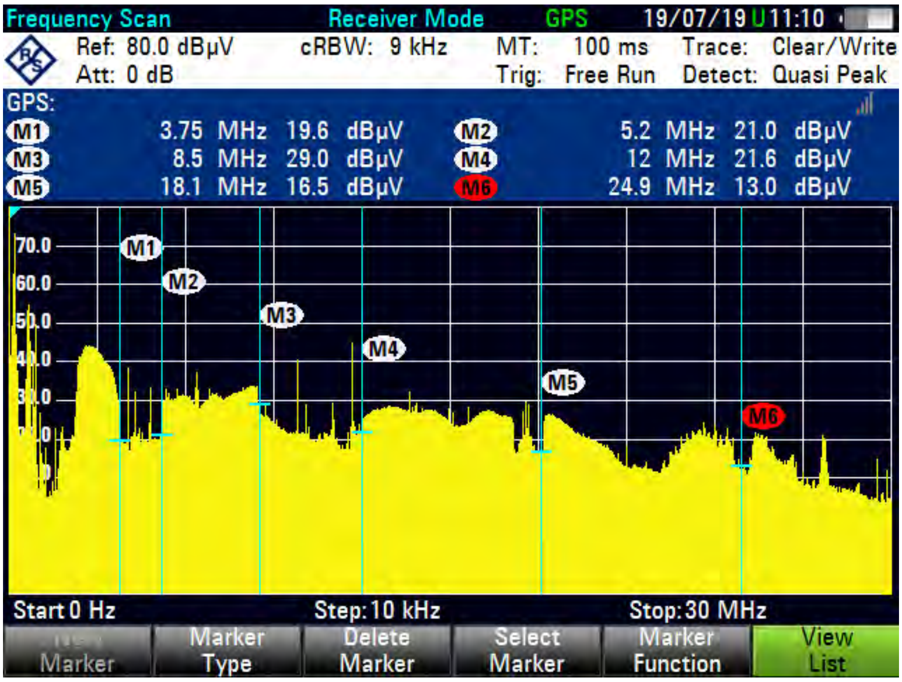
A2.3 MK16 location - Spectrum Analyser measurements 3 m from dropwire

On 19 July 2019, the day of the Ofcom second visit, measurements were also made by RSGB to assess the level of disturbance emission generated by the telecommunications network using measurement procedures defined in CEPT ECC Recommendation (09)02 [2].

The following measurements are with Rohde & Schwarz FSH8 spectrum analyser in Receiver mode with Quasi-Peak (QP) detection and 9 kHz bandwidth. The frequency range was 0 - 30 MHz with 10 kHz receiver step size, giving a total of 3000 measurements. The measuring antenna was a Wellbrook ALA1530 loop antenna S/N 7474 and a separate 1.8 MHz High Pass Filter (HPF) was used.

The measuring antenna was mounted on a non-conductive tripod with the lowest part of the antenna 1 m above ground. The measuring location was outdoors near the front door of the house, 3 m horizontally from the telecommunications network (overhead dropwire) but the location had not been selected as having the maximum disturbance field strength. The measuring antenna was rotated and tilted to give the maximum disturbance signal from the telecommunications network.

The amplitude units are dB(uV), the antenna factor has not been included. The purpose of the test is to evaluate the measurement procedures and limits defined in CEPT ECC Recommendation (09)02 [2].



Trace0843, 0 - 30 MHz, 10 kHz step, 9 kHz RBW, QP Detector

Appendix 3 VDSL measurements at CB1 location

A3.1 CB1 Location - Signal strength contour map, 3.65 MHz

A3.2 CB1 Location - Spectrum at Here location, 3.85 MHz

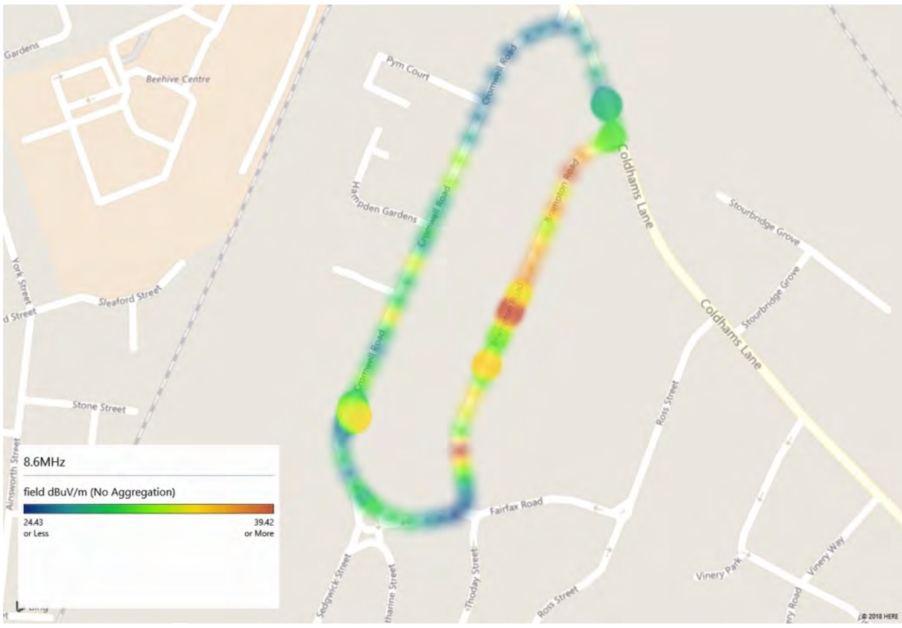
A3.3 CB1 Location - Signal strength contour maps, 3.85 MHz and 5.1 MHz

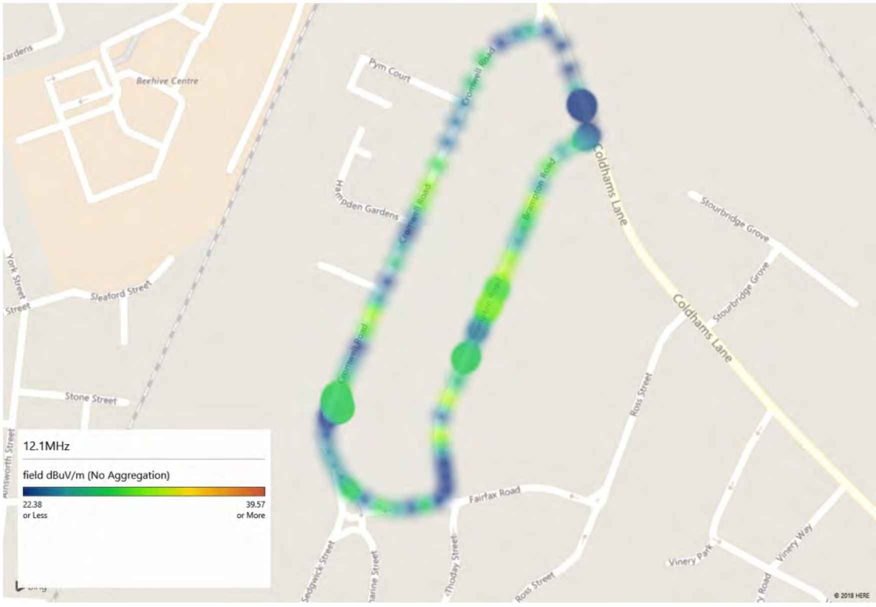
A3.4 CB1 Location - Spectrum at 'Here' location, 5.673 MHz

A3.5 CB1 Location - Signal strength contour maps, 5.3 MHz and 8.4 MHz

A3.6 CB1 Location - Spectrum at 'Here' location, 8.6 MHz

A3.7 CB1 Location - Signal strength contour maps, 8.6 MHz, 11.9 MHz, 12.1 MHz & 17.5 MHz

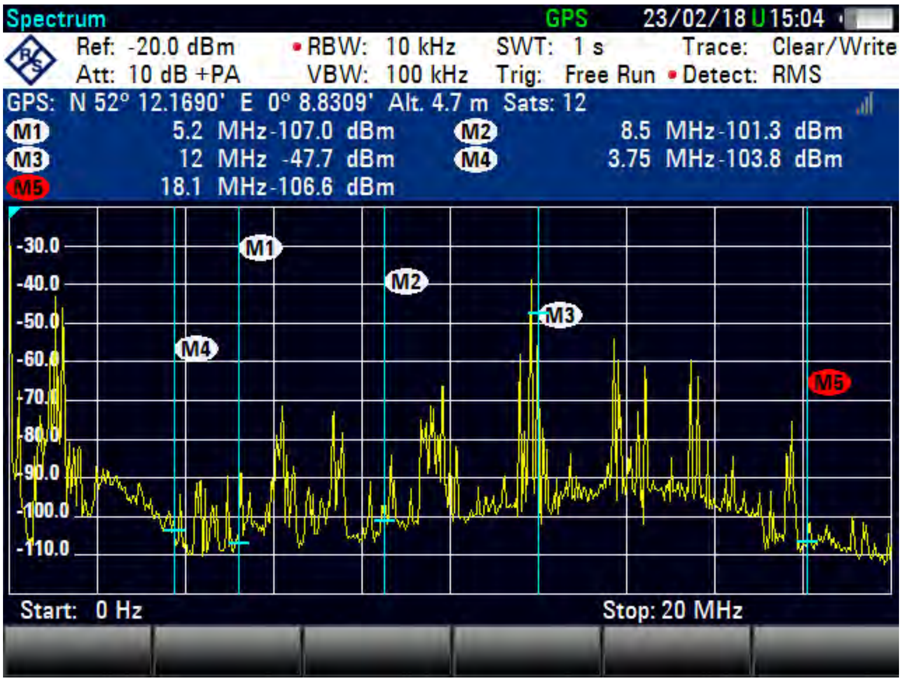



12.1MHz
field dBuV/m (No Aggregation)
22.38
or Less
39.57
or More


17.5MHz
field dBuV/m (No Aggregation)
19.15
or Less
40.01
or More

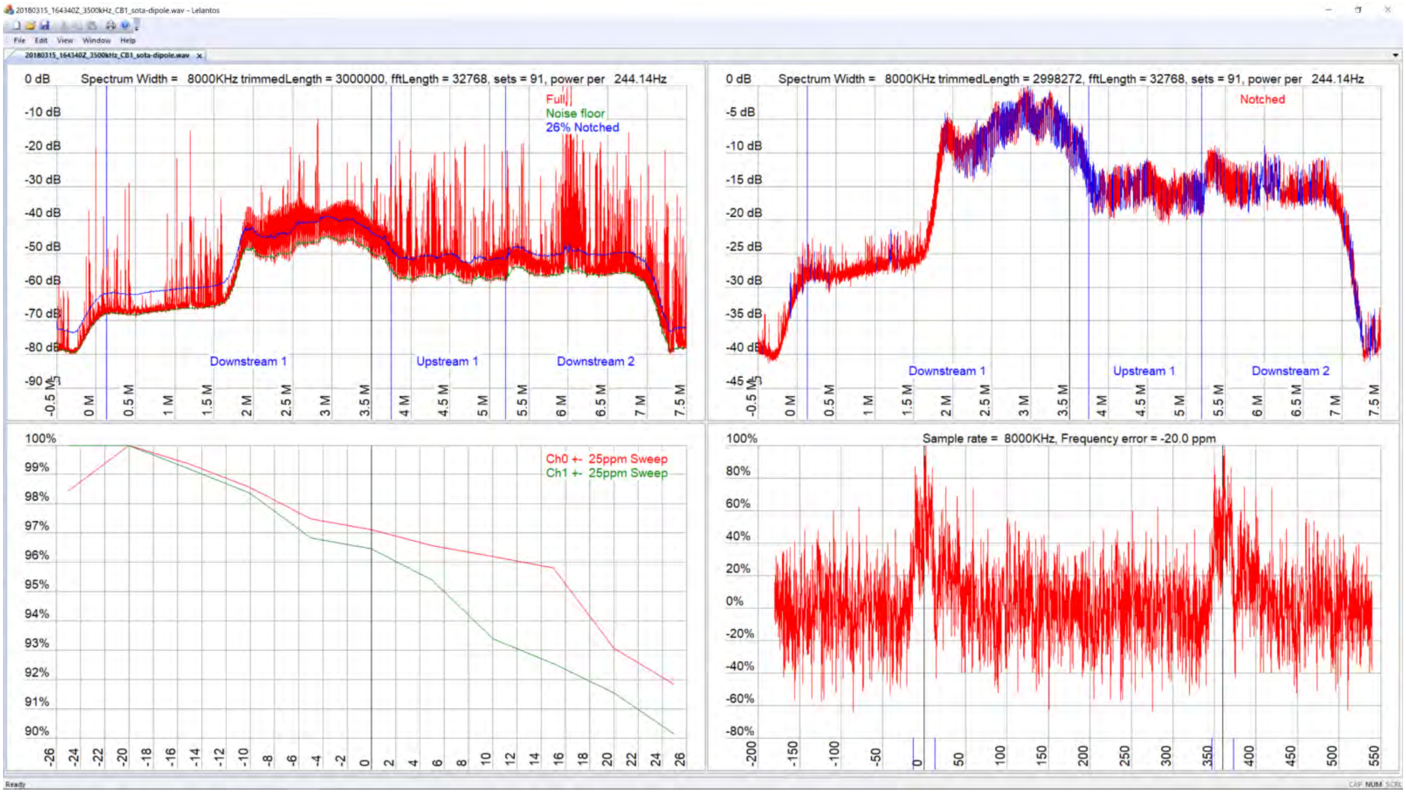
A3.8 CB1 Location - measurements with spectrum analyser

The following measurements are with Rohde & Schwarz FSH8 spectrum analyser and a temporary "Sotabeam" type portable wire dipole antenna on the 14 MHz setting with no HPF. The amplitude units are dB(uV), the antenna factor has not been included but using short dipole antenna factors from EN55016-1-4:2010 Fig A.1 the antenna factor at 1.4 MHz would be approximately 20 dB higher (i.e. lower gain) compared to the antenna factor at 14 MHz.

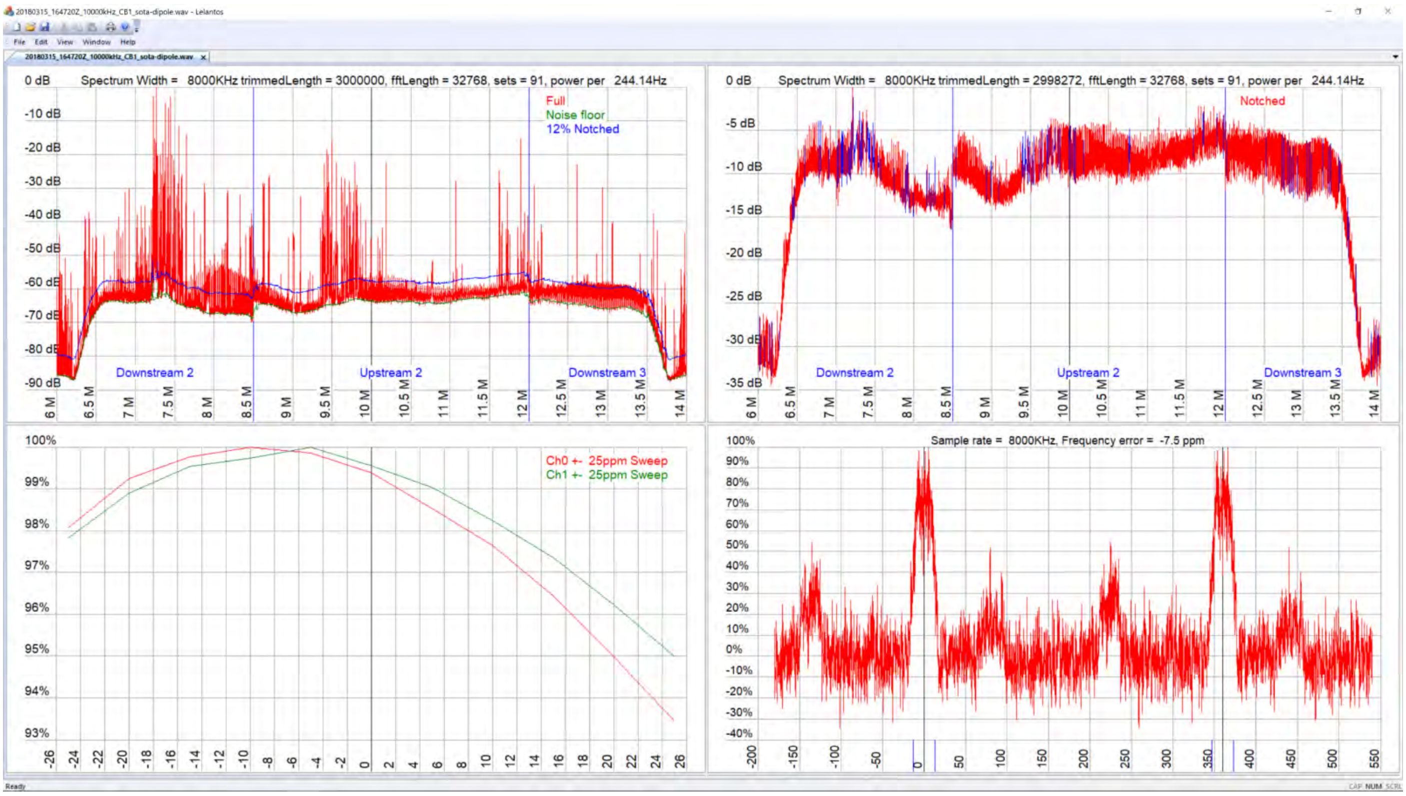


0 - 20 MHz, 14 MHz wire dipole 10 kHz RBW

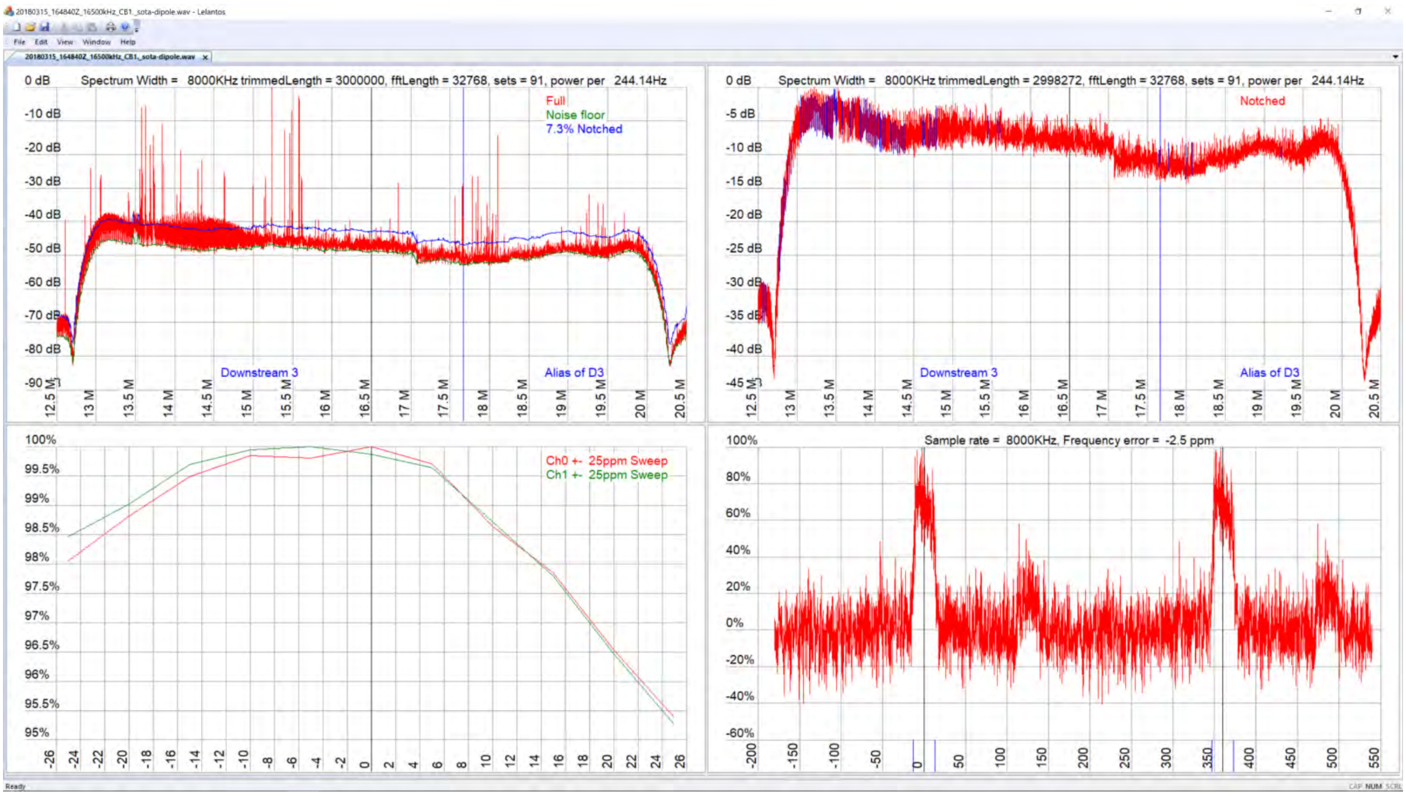
The following measurements are with .WAV file recordings made using a temporary "Sotabeam" type portable wire dipole antenna on the 14 MHz setting, an SDRplay RSP1 with no HPF and SDRUno software. The .WAV files were analysed using Lelantos software release 111. The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording.



Lelantos 0 - 7 MHz, showing that level of VDSL noise is small relative to other signals/interference



Lelantos 6.5 - 13.5 MHz, showing that level of VDSL noise is significant relative to other signals/interference



Lelantos 13 - 20 MHz, showing that level of VDSL noise is significant relative to other signals/interference

The predominant source of interference at 2 - 4 MHz appears to be an unidentified non-VDSL source but VDSL interference appears to be significant at 7 - 14 MHz

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Appendix 4 VDSL measurements at SG4 location

A4.1 SG4 location - measurements with spectrum analyser

The following measurements were made with Rohde & Schwarz FSH8 spectrum analyser and a Wellbrook ALA1530 loop antenna S/N 7000 with 1.8 MHz HPF. The amplitude units are dB(uV), the antenna factor has not been included.

The measurement location was in the garden near the timber summer house.

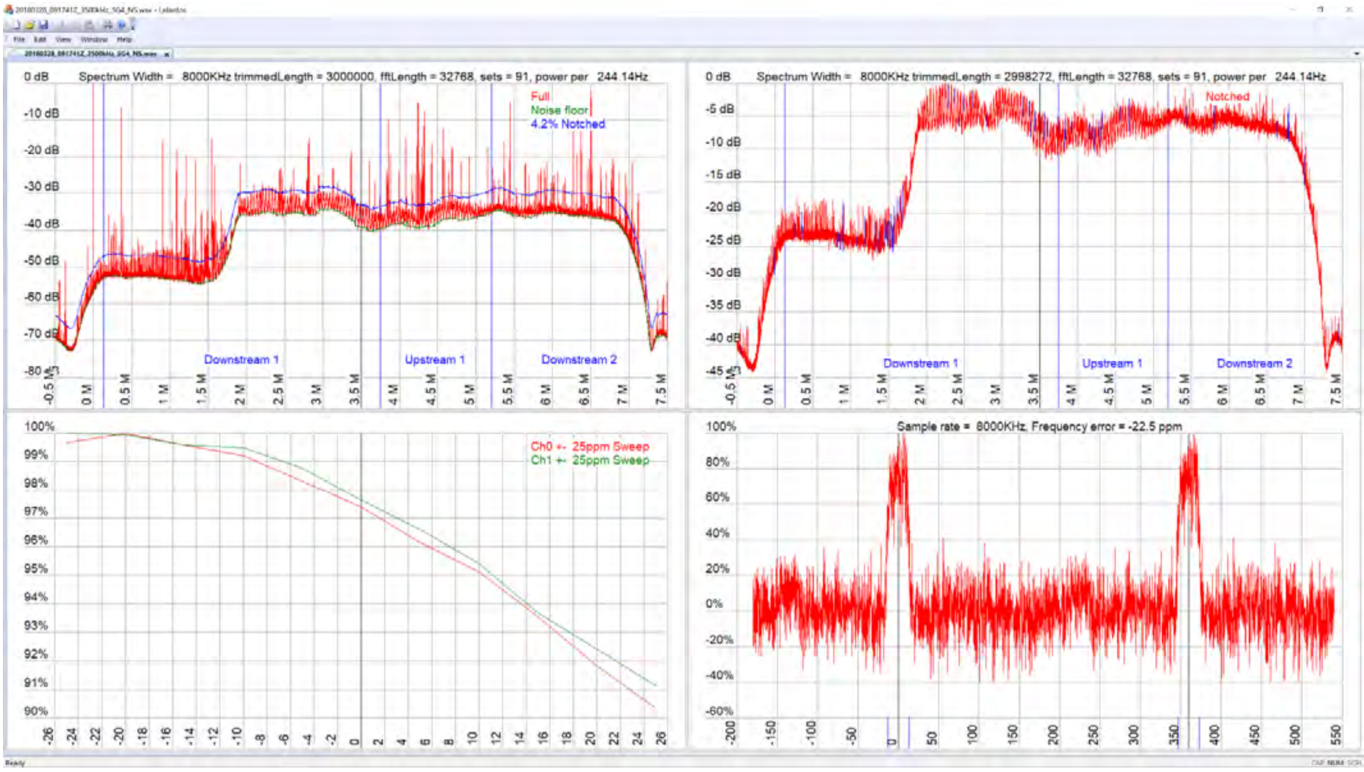
Trace0685, 0 - 30 MHz, North/South

Trace0686, 0 - 30 MHz, East/West

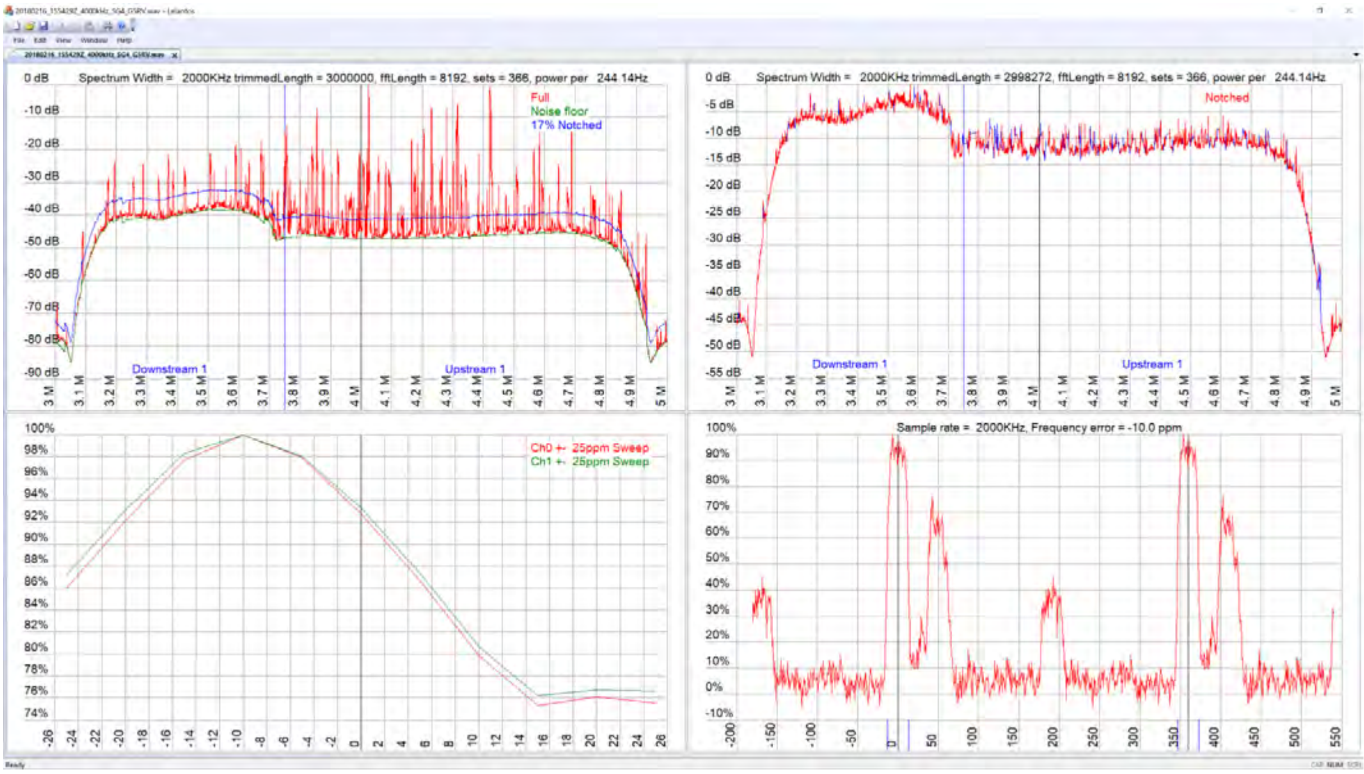
A4.2 SG4 location - measurements with SDR recordings and Lelantos software

The following measurements are with .WAV file recordings made using a Wellbrook ALA1530 loop antenna S/N 7000 with a 1.8 MHz HPF, an SDRplay RSP1 and SDRUno software. The .WAV files were analysed using Lelantos software release 111.

The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording. The measurements were made on 28/03/2018.



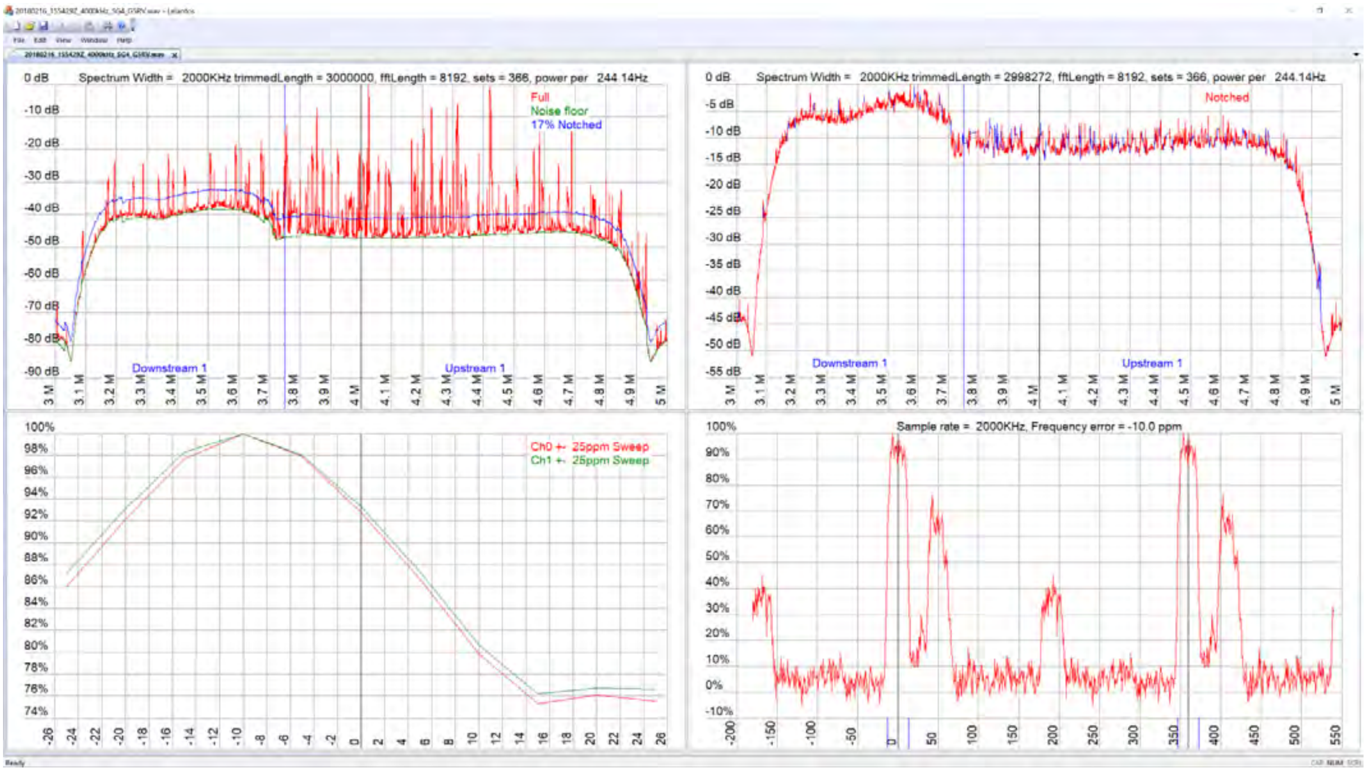
Lelantos 1.8 - 7 MHz, North-South showing some VDSL noise



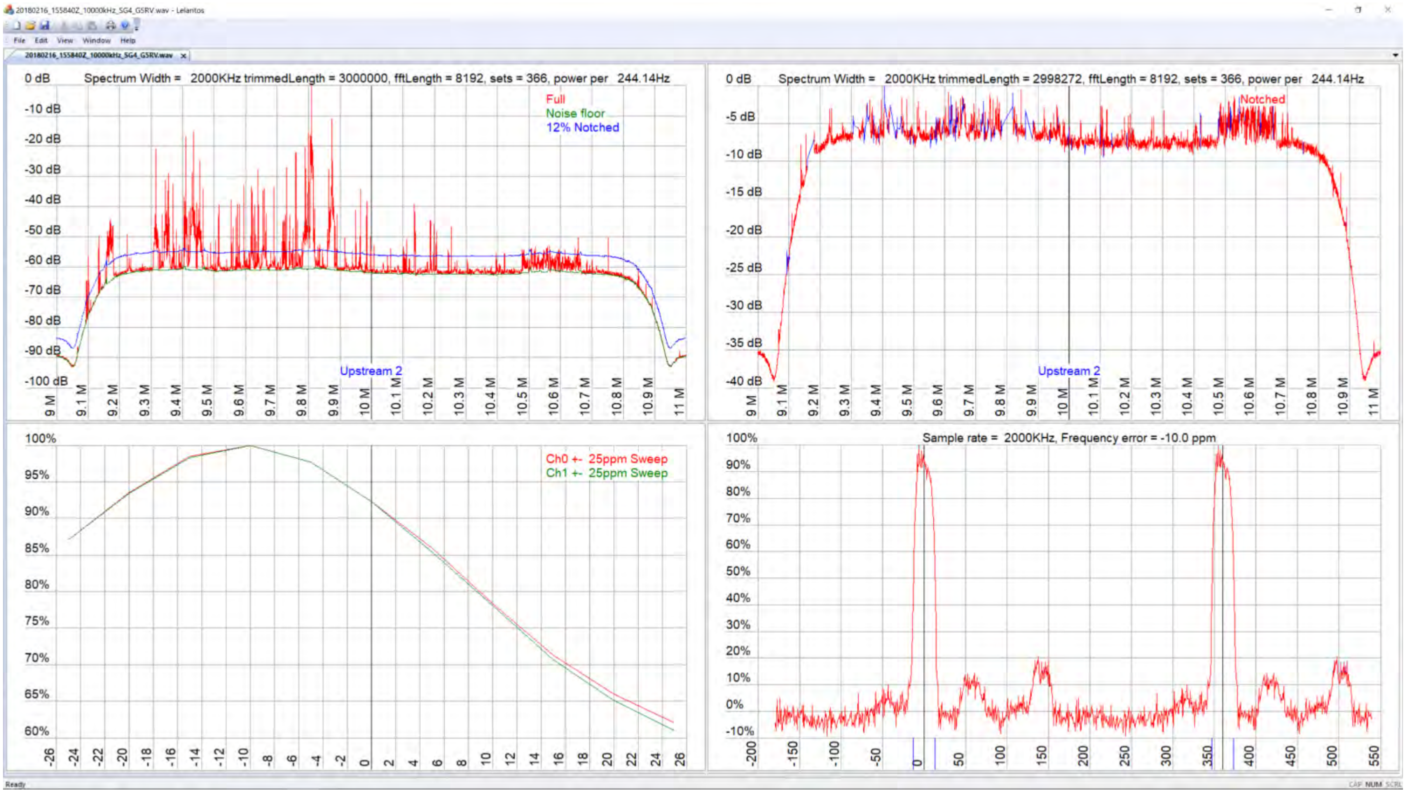
Lelantos 1.8 - 7 MHz, East-West showing significant VDSL noise

The following measurements are with .WAV file recordings made using a G5RV type wire antenna with an SDRplay RSP1 no HPF and SDRUno software. The .WAV files were analysed using Lelantos software release 111.

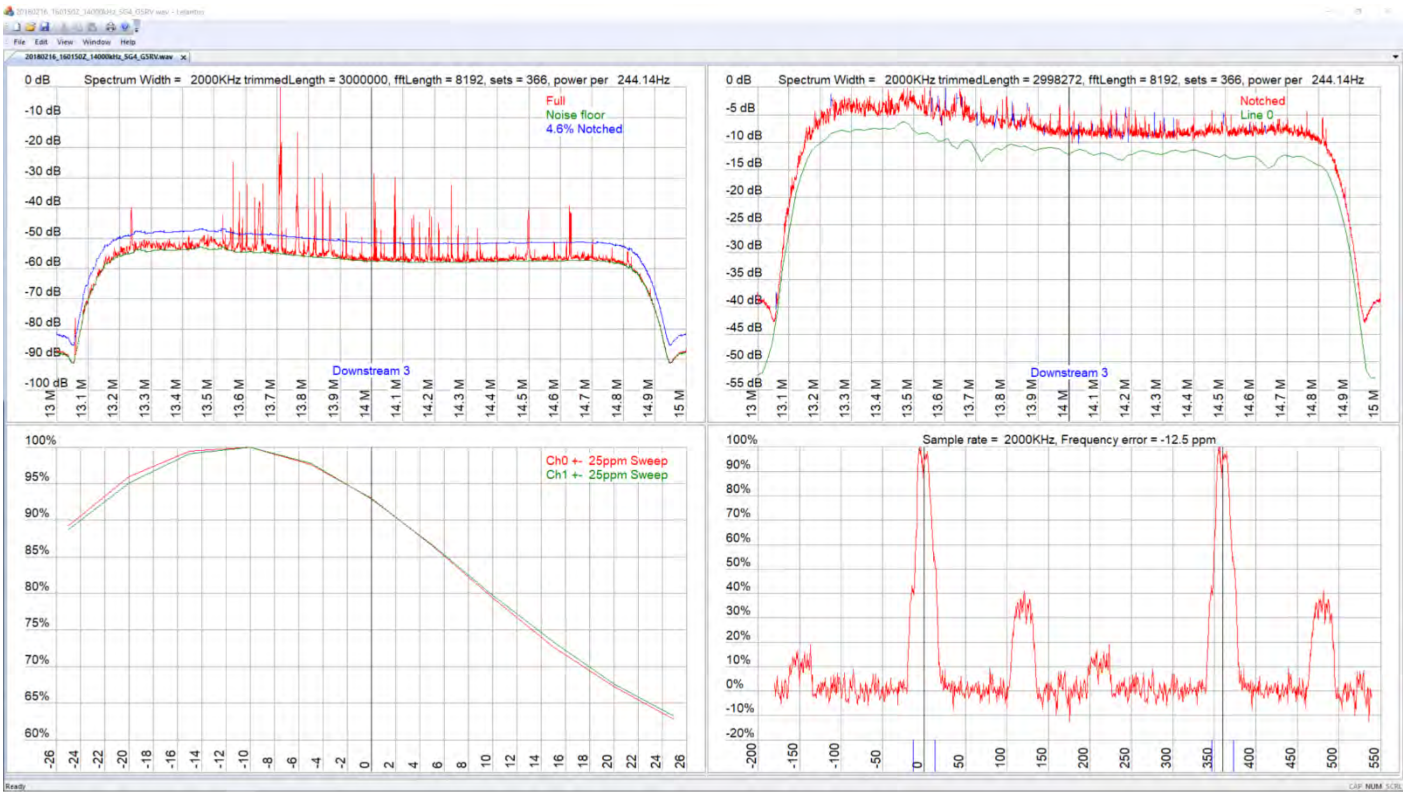
The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording. The measurements were made on 16/02/2018.



Lelantos 3.2 - 4.8 MHz showing significant VDSL noise



Lelantos 9.2 - 10.8 MHz showing significant VDSL noise



Lelantos 13.2 - 14.8 MHz showing significant VDSL noise

Appendix 5 VDSL measurements at PE28 location

A5.1 PE28 location - measurements with spectrum analyser

The following measurements are with Rohde & Schwarz FSC3 spectrum analyser and a temporary "Sotabeam" type portable wire dipole antenna on the 14 MHz setting with 24 dB external pre-amplifier and 1.8 MHz HPF. The pre-amplifier gain has been programmed in to the spectrum analyser. The amplitude units are dB(uV), the antenna factor has not been included but using short dipole antenna factors from EN55016-1-4:2010 Fig A.1 the antenna factor at 1.4 MHz would be approximately 20 dB higher (i.e. lower gain) compared to the antenna factor at 14 MHz.

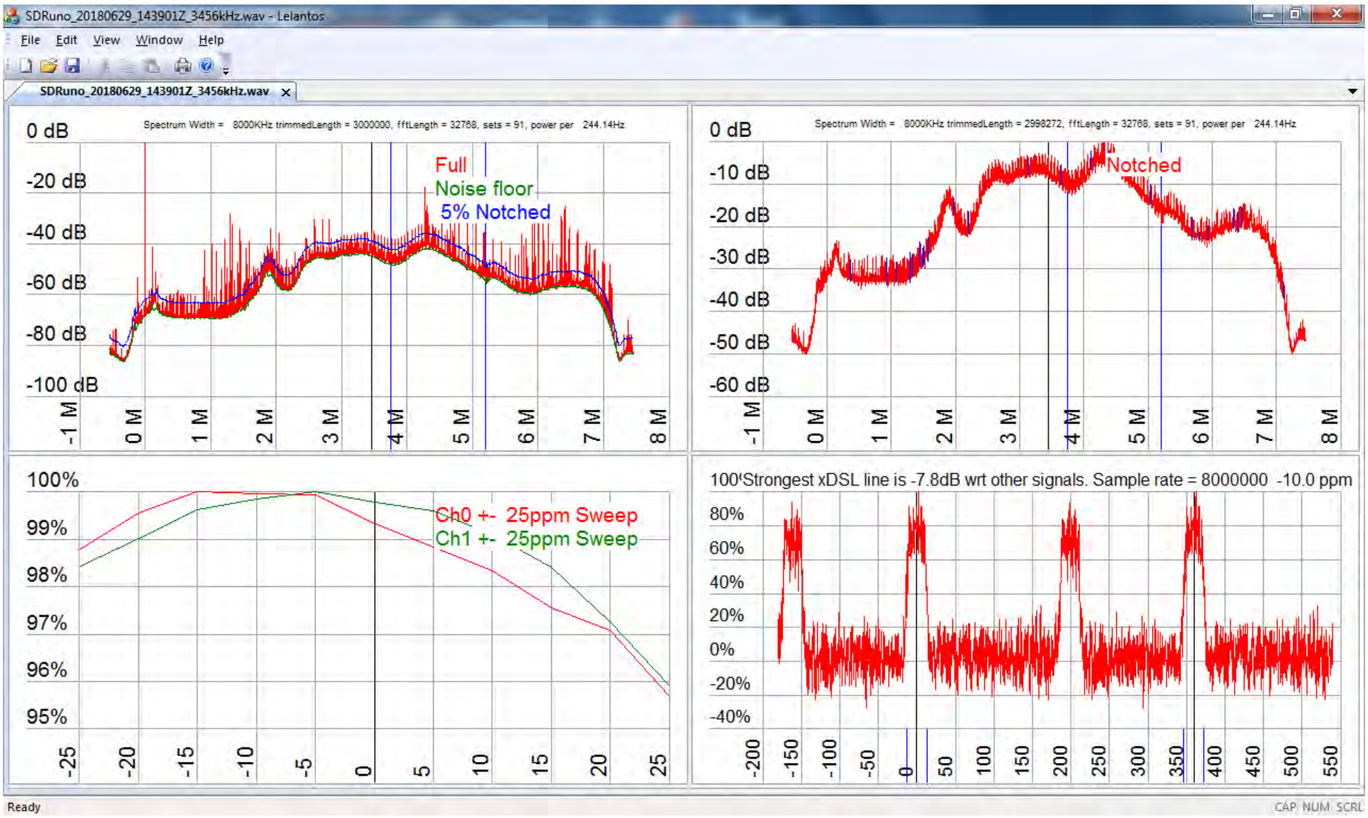
Screen2224 0 - 30 MHz, 14 MHz wire dipole 10 kHz RBW

A5.2 PE28 location - measurements with SDR recordings and Lelantos software

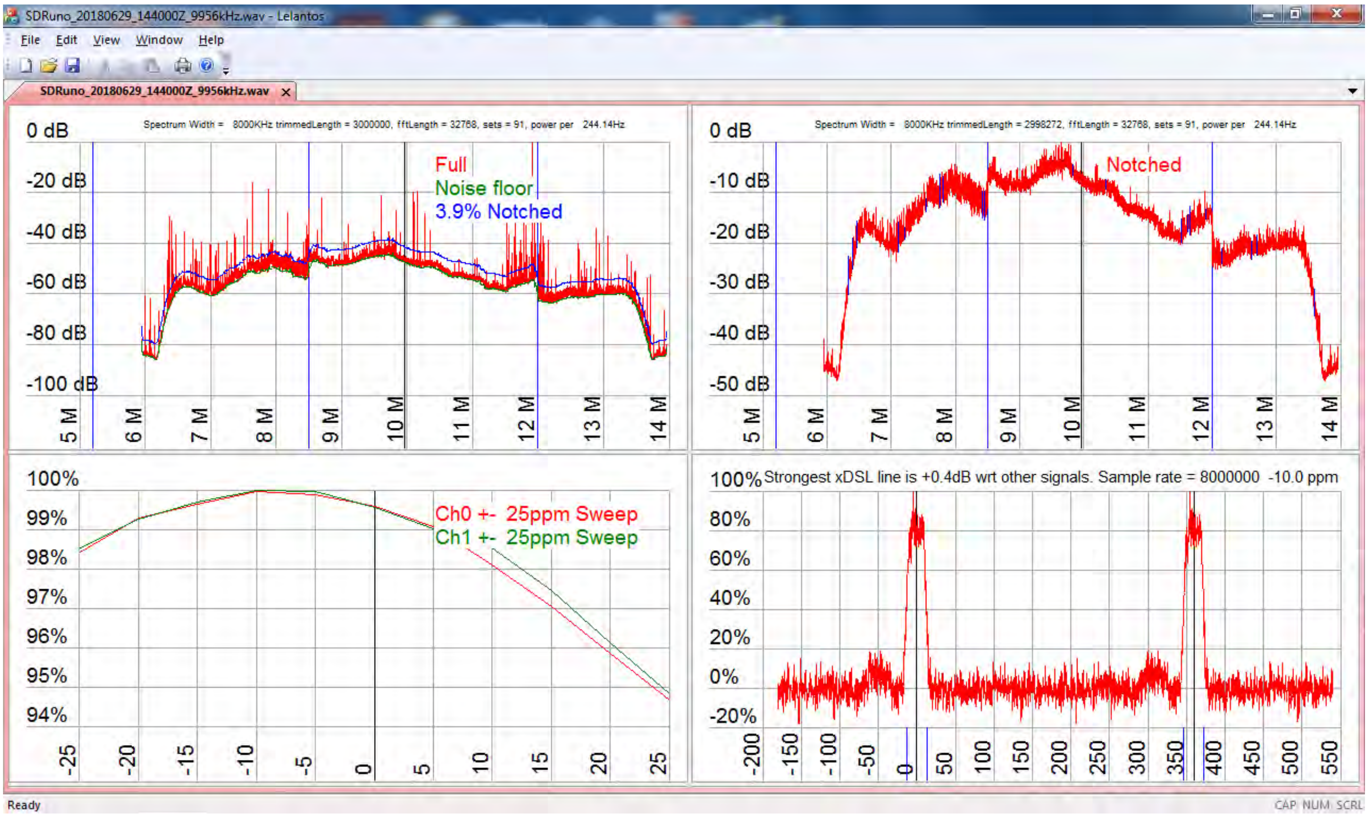
The following measurements are with .WAV file recordings made using an SDRplay RSP1 with 1.8 MHz HPF and SDRUno software. The antenna was a Wellbrook ALA1530 S/N 7000 and a 1.8 MHz HPF was also used. The maximum direction for all signals including non-VDSL sources was a bearing of 20°/200° (approx North-South) and the minimum direction is 110°/290° (Approx East-West).

.WAV files were analysed using Lelantos software release 1.2. The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording.

It can be seen there also appears to be a non-VDSL source up to 7 MHz.



Lelantos 1.8 - 7 MHz showing some VDSL noise



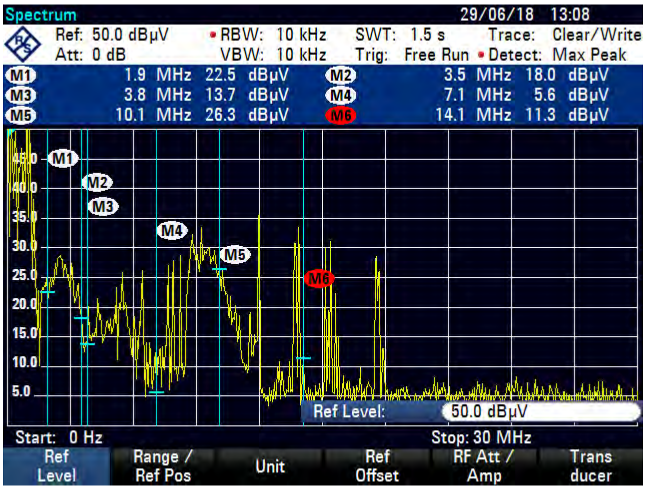
Lelantos 6.5 - 13.5 MHz showing significant VDSL noise

A5.3 PE28 location - common-mode current measurements with spectrum analyser

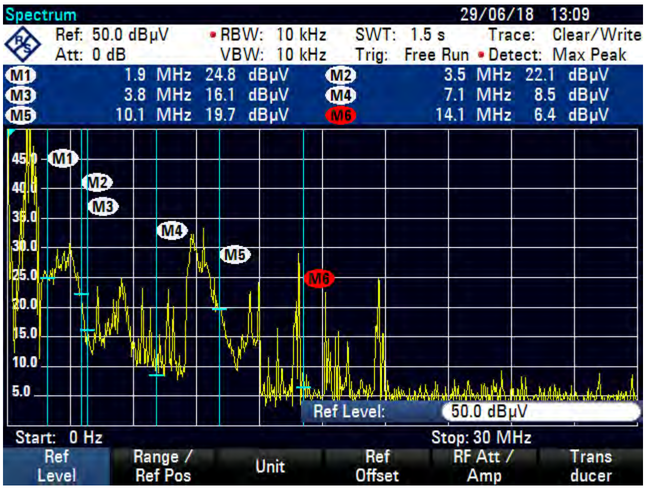
The following measurements are current measurements made on three overhead dropwires that pass over the radio amateur's premises and are connected to a DP adjacent to the boundary of the rear garden. The purpose of these measurements is to compare radiated field strength with common-mode current on the dropwires.

A Rohde & Schwarz FSC3 spectrum analyser was used without a pre-amplifier. A clip-on current probe was used consisting of 5 turns on a split ferrite bead with 12 mm internal diameter. This gives a nominal transducer factor of 14 dB with a 50Ω load. This corresponds to 0 dBS, i.e. 0dB relative to 1 Siemens which means that 1 μA of current gives 1 μV into the 50Ω load. Hence, using the nominal transducer factor, the amplitude scale in dB(μV) is numerically equal to the current in dB(μA).

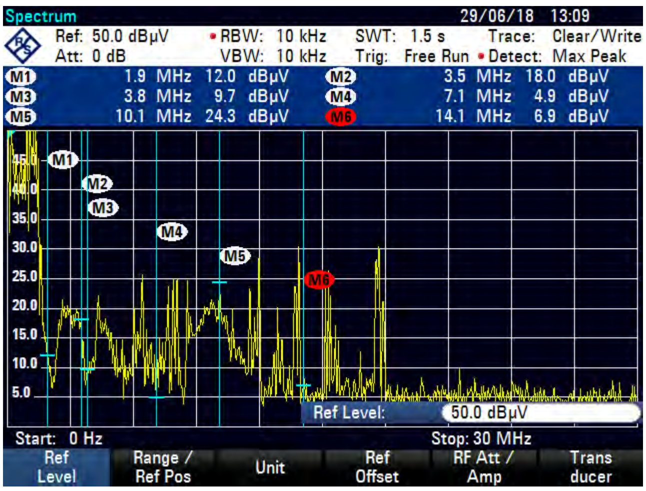
Overhead dropwires "A" and "B" go from DP 78 outside the front of the radio amateur's premises to another DP just outside the rear boundary of the radio amateur's premises. From there, dropwire "C" feeds the next door neighbour's house. Another dropwire (not accessible) feeds another house to the rear of the radio amateur's premises.



Screen2225, 0 - 30 MHz, current on dropwire 'A'



Screen2226, 0 - 30 MHz, current on dropwire 'B'



Screen2228, 0 - 30 MHz, current on dropwire 'C'

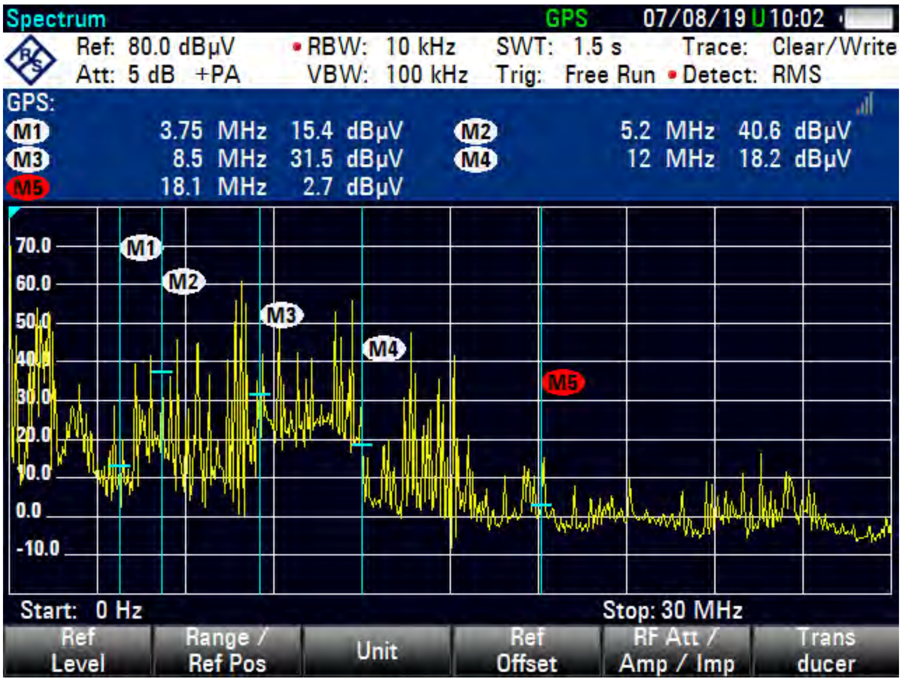
On all three dropwires, there is evidence of VDSL signals on the VDSL bands Downstream 1, Upstream 1 and Upstream 2. These are likely to be the source of the VDSL emissions measured using Lelantos above.

A5.4 PE28 location - second RSGB visit, measurements with spectrum analyser

A second visit to the PE28 location was made by RSGB on 07/08/2019, 9 days before the Ofcom second visit due to availability of RSGB EMC Committee members.

The following measurements are with Rohde & Schwarz FSH8 spectrum analyser powered from its internal battery. The antenna was the radio amateur's horizontal end-fed long wire antenna approx 46 m long and approx. 6 m above ground. The end of the wire antenna was fed directly into the spectrum analyser input. Although a local RF earth spike was used, the connecting wire was subsequently found to have a high resistance and the earth was therefore ineffective. As the RF earth path was due to the capacitance of the spectrum analyser to earth, this introduced a high pass filter response. A 1.8 MHz HPF was also used to reduce MF broadcast signals.

The amplitude units are dB(uV), the antenna factor has not been included as it is not well defined but the noise steps at upstream 2 VDSL band edges are clearly visible.



Trace0852, 0 - 30 MHz, 10 kHz RBW, peak detector

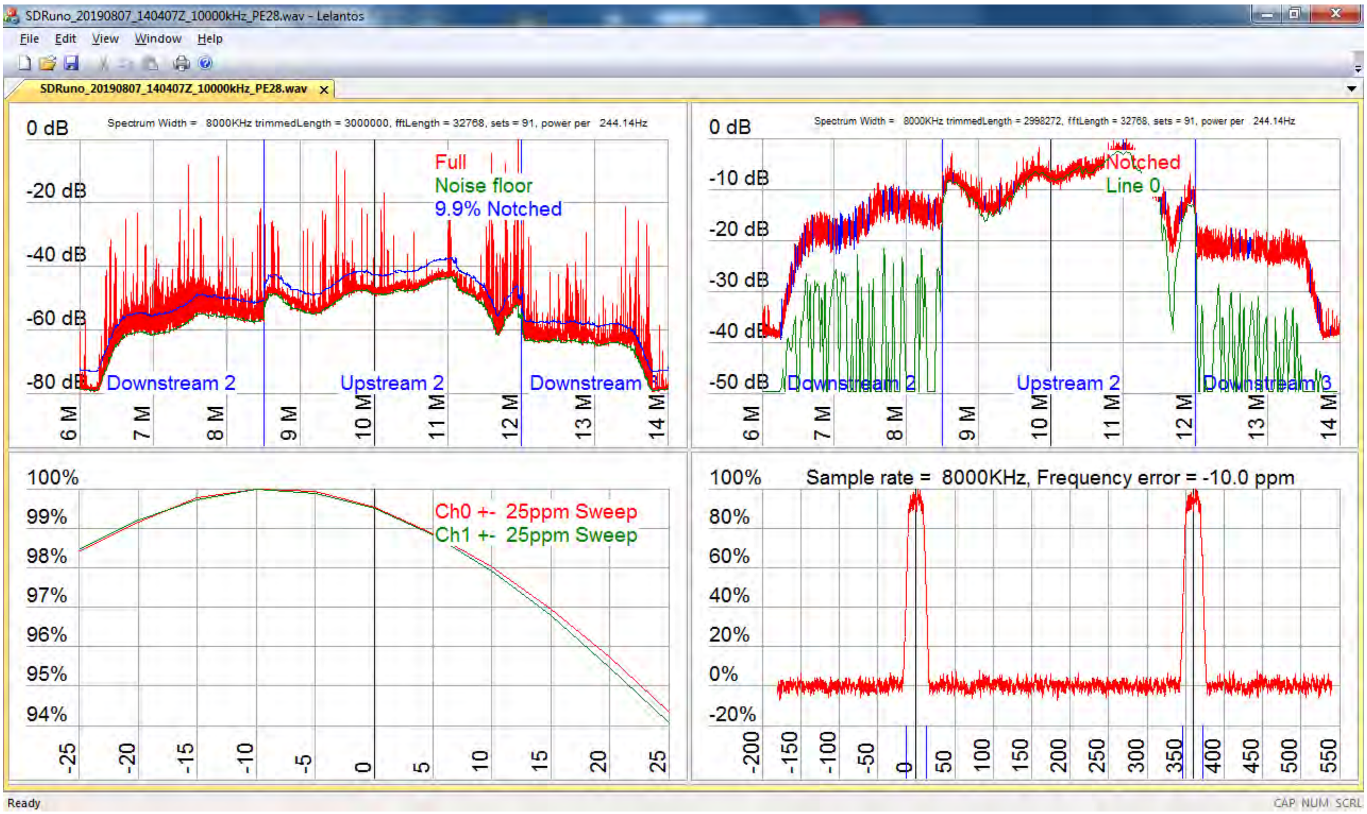
A5.5 PE28 location - second RSGB visit, measurements with SDR recordings and Lelantos software

The following measurements were made on a second visit to the PE28 location by RSGB on 07/08/2019, 9 days before the Ofcom second visit.

The measurements are with .WAV file recordings made using an SDRplay RSP1 with 1.8 MHz HPF and SDRUno software. The antenna was the radio amateur's horizontal end-fed long wire antenna approx 46 m long and approx. 6 m above ground. The end of the wire antenna was fed directly into the SDRplay RSP1 and a local RF earth spike was used. A 1.8 MHz HPF was also used.

.WAV files were analysed using Lelantos software release 1.18.10.0. The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording.

It can be seen there is also a non-VDSL source up to 8.5 MHz and above 12 MHz. On an HF receiver, this source or sources produces a buzzing noise up to at least 4 MHz, a popping noise 7.5 MHz to 8.5 MHz and above 12 MHz.



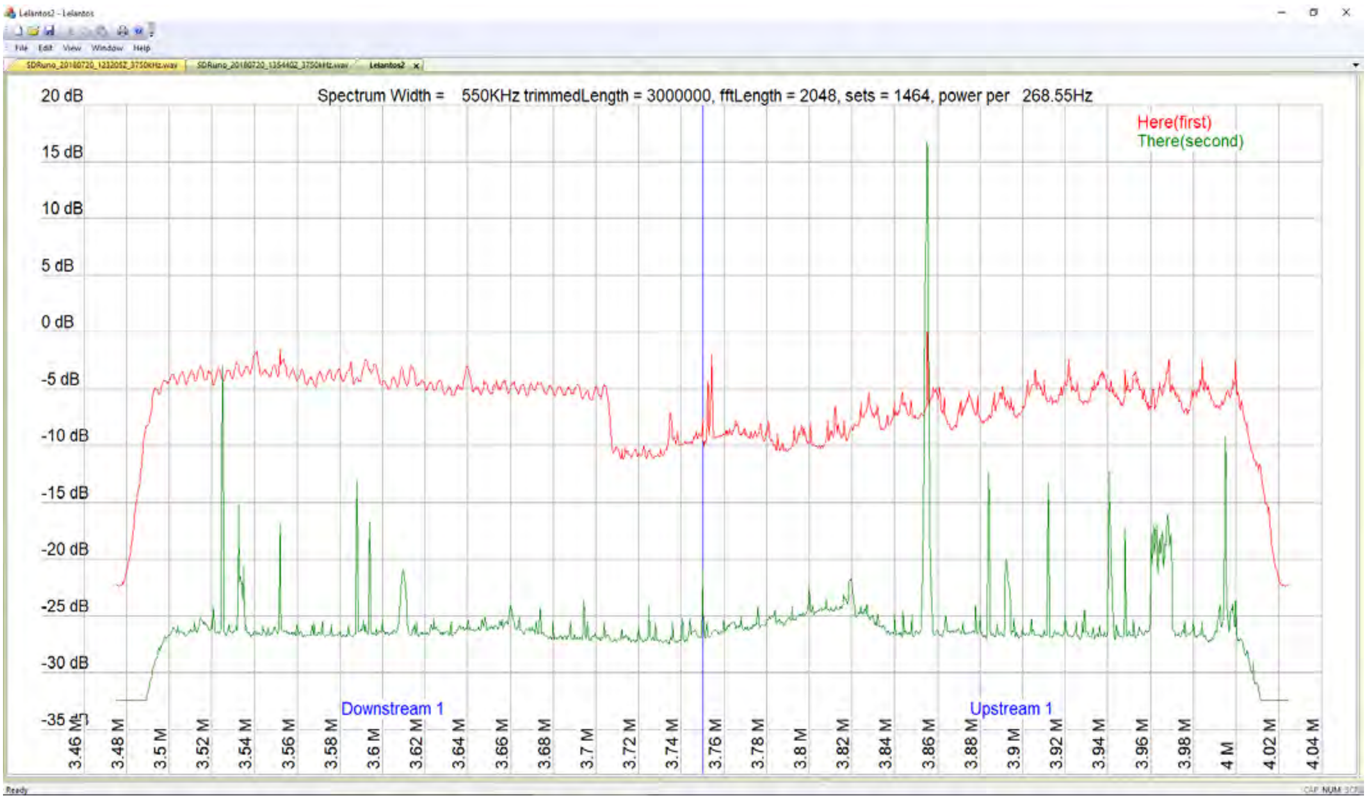
Lelantos 6.5 - 13.5 MHz showing significant VDSL noise from a single line

Appendix 6. CB8 location

A6.1 CB8 location - 'Here and there' measurements with SDR recordings and Lelantos software

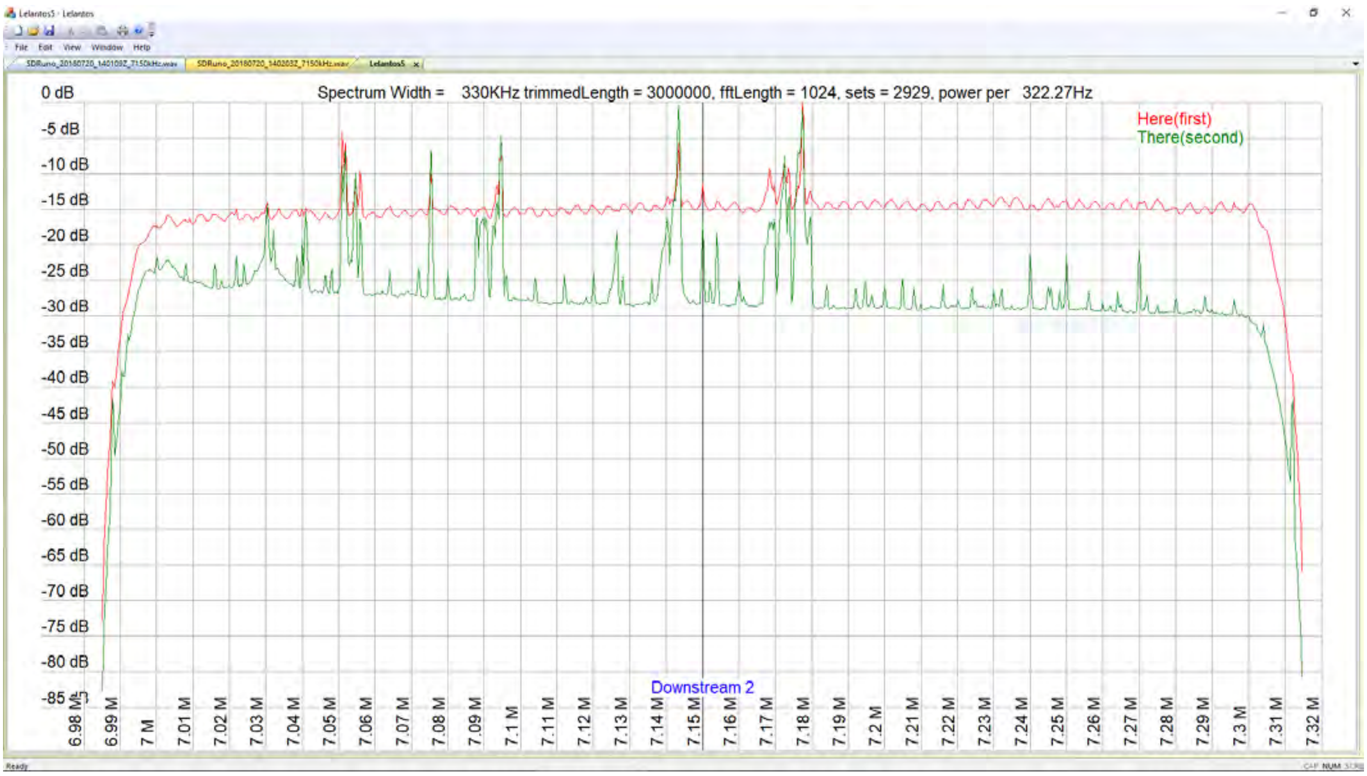
The 'Here' location was in the radio amateur's rear garden approx 10 m from the house. The 'There' location was a rural location by a country lane approx. 1 km away. Measurements at the two locations were simultaneous or near simultaneous.

All measurements are with .WAV file recordings made using a Wellbrook ALA1530 loop antenna with a 1.8 MHz HPF, an SDRplay RSP1 and SDRUno software. The .WAV files were analysed using Lelantos software release 111. The file names of the .WAV file recordings are displayed in the screen captures and these contain the date and time of the recording.



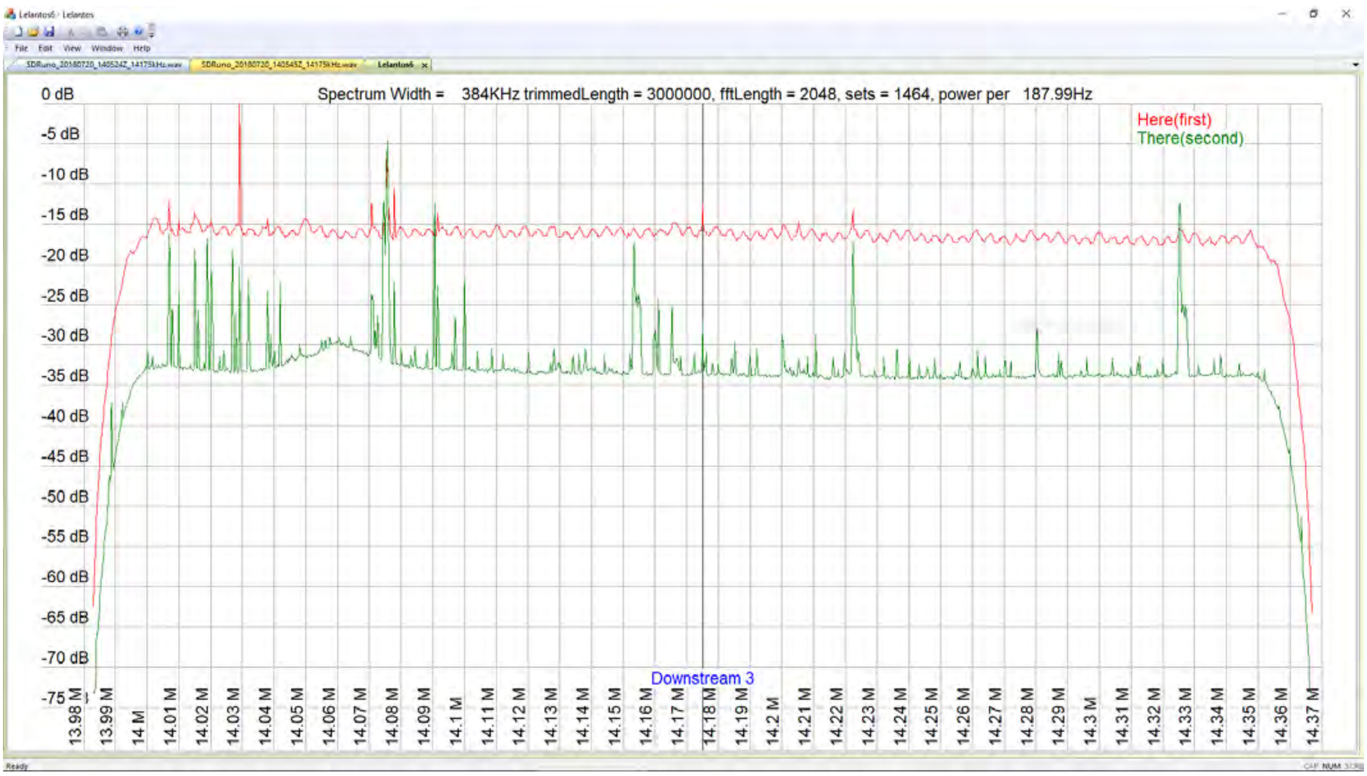
Lelantos 3.5 - 4 MHz.
Location 1 (here) showing very significant VDSL noise up to 3.7 MHz and a non-VDSL source above 3.8 MHz.
Location 2 (There) showing no evidence of VDSL noise.

Lelantos 5.25 - 5.405 MHz.
Location 1 (here) showing very significant VDSL noise. Location 2 (There) showing no evidence of VDSL noise.



Lelantos 7.0 - 7.3 MHz.
Location 1 (here) showing significant VDSL noise. Location 2 (There) showing no evidence of VDSL noise.

Lelantos 10.098 - 10.152 MHz.
Location 1 (here) showing very significant VDSL noise. Location 2 (There) showing no evidence of VDSL noise.

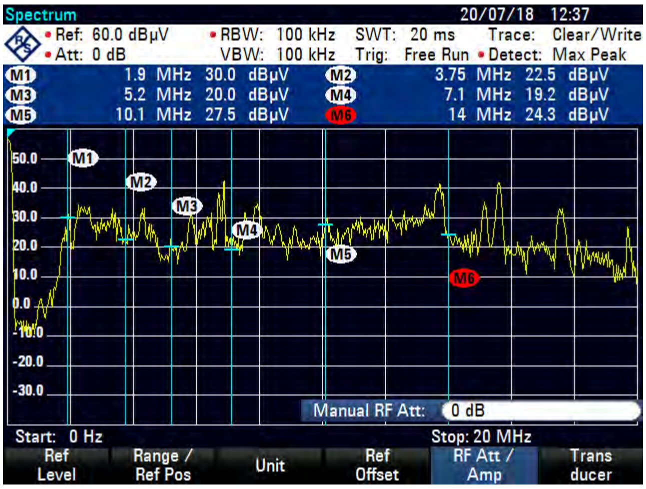


Lelantos 10.098 - 10.152 MHz.
Location 1 (here) showing very significant VDSL noise. Location 2 (There) showing no evidence of VDSL noise.

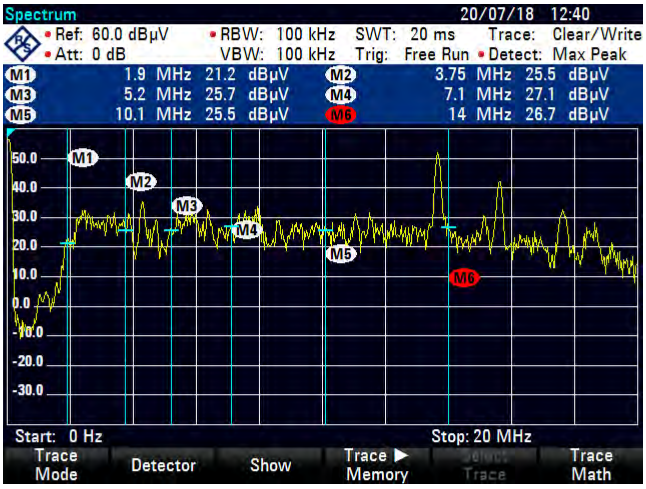
A6.2 CB8 location - measurements with spectrum analyser

The following measurements were made with Rohde & Schwarz FSC3 spectrum analyser and a Wellbrook ALA1530 loop antenna S/N 7000 with 1.8 MHz HPF. The amplitude units are dB(µV) and the antenna factor has not been included.

The measurement location was in the rear garden approx 10 m from the house.



Screen2232, 0 - 20 MHz, North/South



Screen2234, 0 - 20 MHz, East/West

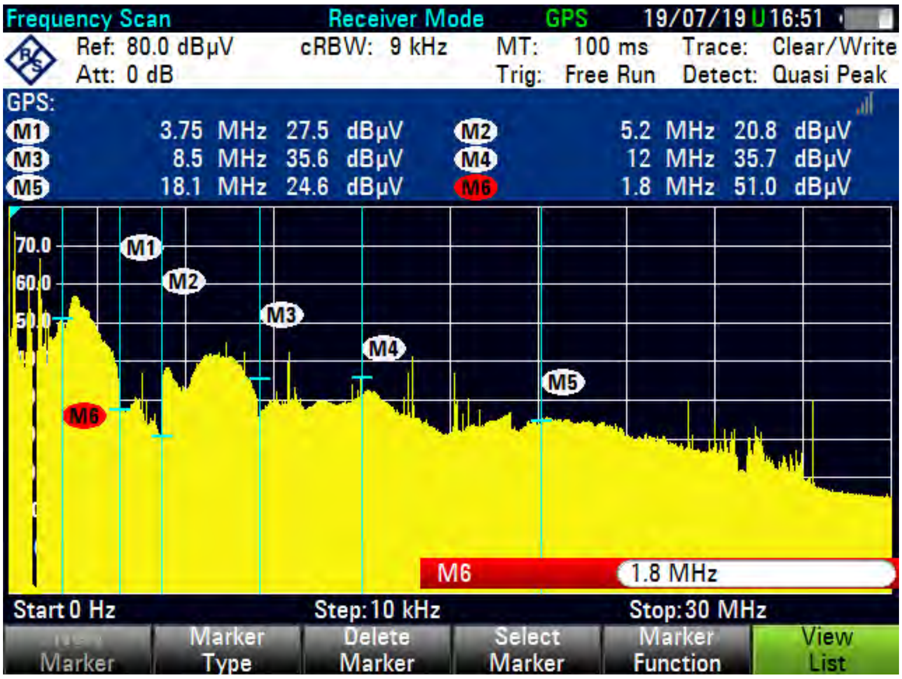
A6.3 CB8 location - Second visit, Spectrum Analyser measurements 3 m from dropwire

On 19 July 2019, the day of the Ofcom second visit, measurements also were made by RSGB to assess the level of disturbance emission generated by the telecommunications network using measurement procedures defined in CEPT ECC Recommendation (09)02 [2].

The following measurements are with Rohde & Schwarz FSH8 spectrum analyser in Receiver mode with Quasi-Peak (QP) detection and 9 kHz bandwidth. The frequency range was 0 - 30 MHz with 10 kHz receiver step size, giving a total of 3000 measurements. The measuring antenna was a Wellbrook ALA1530 loop antenna S/N 7474 and a separate 1.8 MHz High Pass Filter (HPF) was used.

The measuring antenna was mounted on a non-conductive tripod with the lowest part of the antenna 1 m above ground. The measuring location was outdoors near the rear of the house, 3 m horizontally from where the telecommunications network (overhead dropwire) enters the building under the eaves after passing along the outside of the building from the front. The location had not been selected as having the maximum disturbance field strength. The measuring antenna was rotated and tilted to give the maximum disturbance signal from the telecommunications network.

The amplitude units are dB(uV), the antenna factor has not been included. The purpose of the test is to evaluate the measurement procedures and limits defined in CEPT ECC Recommendation (09)02 [2].



Trace0850, 0 - 30 MHz, 10 kHz step, 9 kHz RBW, QP Detector