EMC ANALYSIS OF POWERLINE SYSTEMS

FINAL REPORT

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1 EXECUTIVE SUMMARY

The main goal of this project is to analyse:

- The PLC (powerline communication) market
  - Indoor
  - Outdoor (Access)
- The different standards
- The technologies
- The behaviour of the modems

PLC current situation:

- The Access PLC systems are not significantly present in Europe. This situation may be due to a strong penetration of the market by the ADSL and cable modem technologies.
- The Indoor PLC modem market is dominated by the Homeplug compliant devices. This standard has been established by a consortium of the biggest telecommunication companies. The HomePlug modem market is growing very quickly. Those modems can be bought in many stores in Switzerland.
- American standards (FCC part 15) are much more permissive than European Standards (EN55022)
- The performance of the HomePlug modems tested in the course of this project can be qualified as good.

The main conclusion of our report is that:

- HomePlug modems tested did not respect the EN55022 standard.
- They are at least <u>25 dB above the specified limit</u> for the HomePlug Frequency band.

2 TABLE OF CONTENT

3 INTRODUCTION

Powerline systems (also known as plc systems) have been in full evolution for several years. Numerous manufacturers have since begun studying and producing such systems.

Existing powerline systems offer lower data rates than Ethernet, ADSL and 802.11 wireless LAN systems but, in the future, they are likely to achieve comparable transmission speeds. Indeed, the current powerline rates of 2.5 and 14 Mbps are expected to increase up to 100 Mbps and there is talk of chipsets being developed for 200 Mbps, although these number need still to be confirmed.

The great advantage of powerline communication is that it uses the existing mains network and it does not need any new wiring to be deployed. The mains network exists currently in most parts of the world. In some countries, while very few homes have phone lines, the great majority has been wired for electric power. In those countries, ADSL is not a viable solution and powerline is an attractive alternative.

The fact that plc systems use the existing electric utility wiring is actually a mixed blessing since the power cables' low symmetry makes them good radiators. In fact, one of the main problems with plc modems is the radiated emission and electric field. The plc modems transmit information on frequencies between 1 MHz and 30 MHz. All countries specify standards in which limits for these emissions are set and must be respected. Although efforts are constantly underway to harmonise EMC and EMI standards and regulations, there are still considerable differences between countries around the world.

Before equipment can be sold on the market, it must prove that it complies with the applicable standards. For each electric piece of equipment, a special homologation procedure must be used.

As part of this project, we will define a measurement setup to test plc modems and to compare our measurement with the European standards.

We will also analyse the current situation of the plc technology and its market share and potential.

We have organised this report in four parts dealing with both, American and European systems:

- PLC market analysis
- Modem analysis
- Comparison of standards
- Measurements

4 POWERLINE MODEM MARKET

The powerline market is separated in two distinct categories:

- Outdoor modems (Access) characterised by:
  - Special approvals
  - Low volume production
  - High cost
  - Currently: not available for the masses
- Indoor modems (Home) characterised by:
  - Standard EMC approvals (EN55022 in Europe)
  - High volume production
  - Low cost
  - Mass market usage

This chapter will provide a detailed analysis of this market.

4.1 OUTDOOR MODEMS (ACCESS)

The first observation is that the EU market seems to be dominated by cable and ADSL technology (maybe due to data-rate limitation for PLC technology). On the other hand, we find more PLC systems in developing countries and in the USA.

In Figure 1, we can see the main manufacturers and their operating regions

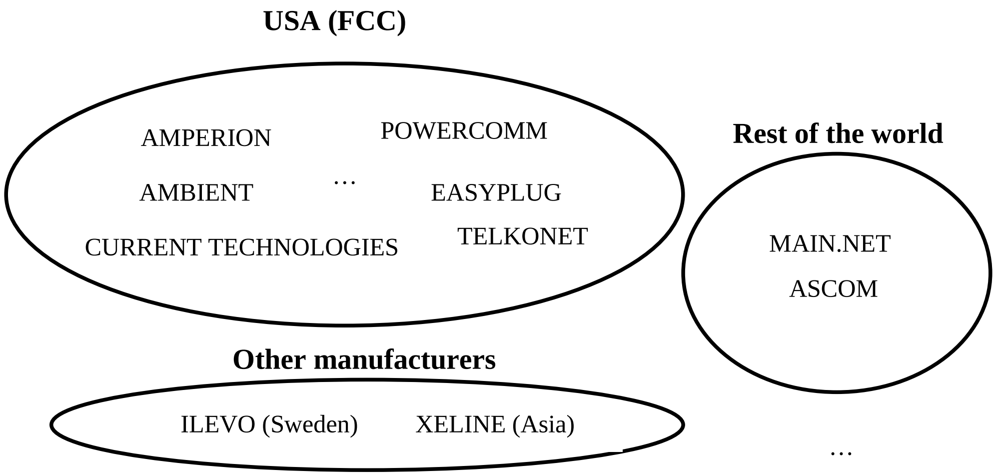

Figure 1: Access modem manufacturers

Although the majority of manufacturers do not easily furnish information about their systems, we still succeeded in collecting the following information:

Table 1: Access modem comparison

Manufacturers	Data rate [Mbps]	Chipset	Modulation
Amperion	45 / 6 (Wireless)	*	*
Powercomm	*	*	*
Ambient	45	DS2	*
Current Technologies	*	*	*
telkonet	14	*	*
Easyplug	45	DS2	*
Ilevo	45	*	*
Xeline	8	Samsung	*
Ascom	2.25 (indoor)/4.5 (outdoor)	*	GMSK
Main.net	2.5	Itran	ACSK

* Information not available

This market is clearly separated into two areas:

- USA
  - Several systems are available (PLC on high voltage lines and wireless LAN for the last few hundred meters
  - Push toward high data rates (45 Mbps) in the USA (only FCC compliance)
- Rest of the world except Europe
  - Non US units are concentrated in emerging regions like Russia, South America and Africa
  - Not distributed via mass market distribution channels, no detailed data-sheets are available.

Conclusion for the access modems:

- Hardly any operational systems in Europe. Only some trial tests.
- Viability only in developing countries (due to the lack of infrastructure for ADSL and cable network.)
- Not distributed through mass market distribution network
- Technical information unavailable

At present, there exists only one operational plc access system in Switzerland (Fribourg). On the other hand, Homeplug modems are widely available at electronics stores. Most perturbation problems are therefore not expected from the plc access modems produced by Ascom, but rather from the Homeplug certified modems that are being mass-produced and marketed in our country!

PLC access modems will not be studied further in the context of this project. However, measurements on access modems could be made if BAKOM requests it at a later point in time.

4.2 INDOOR MODEM (HOME)

In Figure 2, we separate the indoor market into three groups based on the specification on which they are based.

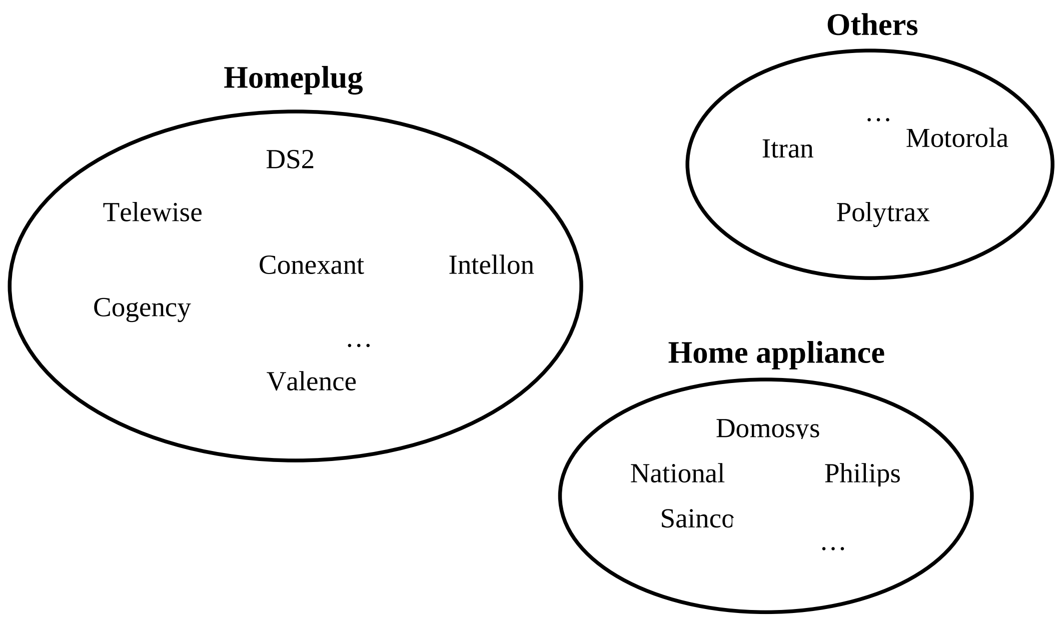

Figure 2: PLC indoor modem chipsets grouped by the specification on which they are based

Home appliance modems are outside the scope of the present study since they are not likely to generate disturbances due to the low bit rates used and to the fact that they are EN55022 compliant. Home appliance modems are characterised by:

- Low bit rate
- Very low cost
- Frequency band below 150kHz
- Low disturbance (EN55022 standard respected)

The group identified as "others" in Figure 2 refers to modems that represent a very small part of the plc market. Little or no information is available on them.

The third group is based on the Homeplug specification. The following observations can be made:

- Homeplug is an alliance of manufacturers founded in 2000. That year, they produced the Homeplug 1.0 specification, whose details will be explained later on in this report.
- Homeplug modems represent 99% of the market
- All indoor modems found on the market for this study are currently Homeplug certified

Above we saw that 99% of the market is Homeplug compliant. In Figure 3, we see that Intellon occupies 60% of the Homeplug chipset market. An explanation for this percentage could be that Intellon is one of the founding members of the Homeplug alliance.

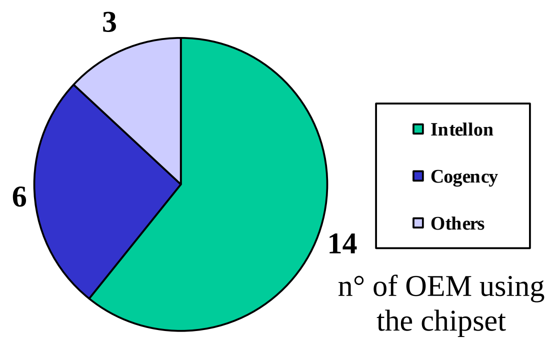

Figure 3: Leaders of the PLC chipset market

Conclusion for the indoor modems:

- Modems are available in the whole world.
- The market is dominated by Homeplug certified modems. More than 99% at present.
- Technical information for Homeplug modems is readily available. That is not the case for the other modems!

Due to the wide domination of the EU market by Homeplug modems, this study will focus on an in-depth analysis of those modems only!

In Switzeralnd al Homeplug modems use Intellon chipsets!

5 MODEM HARDWARE ANALYSIS

Two important observations can be made about PLC modems sold in Europe:

- They are CE compliant
- They are Homeplug certified

Table 2 shows the differences among the modems ordered to date.

Table 2: Modem ordered for our analysis and measurements

Trademark	Standard	Chipset	Analog Front End	Type	Ordered in	Unit price [CHF]
Corinex	FCC/CE	Intellon	Intellon	Bridge (ETH)	USA	200
Corinex	FCC/CE	Intellon	Intellon	Bridge (ETH)	USA/Switzerland	200
Niroda	FCC/CE	Intellon	Niroda	Bridge (ETH)	France	230
Devolo	CE	Intellon	Intellon	Wall mount (ETH)	Switzerland	170
Zeus	CE	Intellon	Zeus	Wall mount (USB)	Switzerland	140
Zeus	CE	Intellon	Zeus	Bridge (ETH)	Switzerland	180

For our analysis, we attacked the following three questions:

- What are the differences and similarities in the hardware?
  - All ordered modems use an Intellon chipset
  - The analog front-end (LNA + PA) is customized even if the Intellon front-end module (hybrid circuit) seems to be used by most manufacturers.
  - The printed circuit board design is different for each one of the manufacturers
  - The output transformer (important part of the harmonics filter) is different for each modem
- What standards are respected?
  - Modems available in Switzerland are CE compliant but not necessarily FCC compliant
  - Zeus and Devolo modems are not sold in the USA
- What is the difference between American and European modems?
  - The first remark to be made is that most American vendors reject orders coming from Europe. We could obtain modems from one of them only.
  - The Corinex modem we obtained is the same in the USA and in Europe. The only difference seems to be the marking on the device (CE label for the European and FCC for the American version)

6 HOMEPLUG SPECIFICATION

The Homeplug alliance is a partnership of companies active in powerline communication networks.

The Homeplug alliance produced Homeplug Specification version 1.0 in 2000. Work is currently in progress on the next version, called the Homeplug AV (Audio Video) specification.

6.1 HOMEPLUG AV

The release of this new specification is scheduled for July 2004. The only information that is currently available is the data rate:

- Data rate up to 100 Mbps
- Effective data rate up to 50 Mbps

6.2 HOMEPLUG 1.0

As mentioned above, the Homeplug 1.0 specification was released in 2000. Currently, most of the modems are Homeplug certified. The following discussion is based on the description of the Homeplug 1.0 protocol presented in [2].

Some of the salient characteristics of these modems are:

- Data rate up to 14 Mbps (Effective data rate up to 6 Mbps)
- 56-bit DES encryption for superior security and privacy
- Easy integration with all manufacturers compliant with Homeplug 1.0
- LAN connectivity anywhere a power outlet exists

6.2.1 FREQUENCY BAND

The Physical layer of Homeplug uses OFDM (Orthogonal Frequency Division Multiplexing) in a band from 4.49 MHz to 20.7 MHz. The band is used as follows:

- 0 – 25 MHz divided into 128 evenly spaced carriers
- 84 carriers (23-106) fall within the used band
- 8 carriers are permanently masked to avoid radio amateur bands.
- **=> 76 effective carriers available for data transmission**
- The bandwidth of the carrier is equal to **195.3 kHz**

Table 3: Carriers frequencies of the Homeplug specification

Carrier number	Carrier frequency [MHz]	Carrier number	Carrier frequency [MHz]	Carrier number	Carrier frequency [MHz]	Carrier number	Carrier frequency [MHz]
1	4.4922	22	8.5938	43	12.6953	64	16.7969
2	4.6875	23	8.7891	44	12.8906	65	16.9922
3	4.8828	24	8.9844	45	13.0859	66	17.1875
4	5.0781	25	9.1797	46	13.2813	67	17.3828
5	5.2734	26	9.375	47	13.4766	68	17.5781
6	5.4688	27	9.5703	48	13.6719	69	17.7734
7	5.6641	28	9.7656	49	13.8672	70	17.9688
8	5.8594	29	9.9609	50	14.0625	71	18.1641
9	6.0547	30	10.1563	51	14.2578	72	18.3594
10	6.25	31	10.3516	52	14.4531	73	18.5547
11	6.4453	32	10.5469	53	14.6484	74	18.75
12	6.6406	33	10.7422	54	14.8438	75	18.9453
13	6.8359	34	10.9375	55	15.0391	76	19.1406
14	7.0313	35	11.1328	56	15.2344	77	19.3359
15	7.2266	36	11.3281	57	15.4297	78	19.5313
16	7.4219	37	11.5234	58	15.625	79	19.7266
17	7.6172	38	11.7188	59	15.8203	80	19.9219
18	7.8125	39	11.9141	60	16.0156	81	20.1172
19	8.0078	40	12.1094	61	16.2109	82	20.3125
20	8.2031	41	12.3047	62	16.4063	83	20.5078
21	8.3984	42	12.5	63	16.6016	84	20.7031

The grey shading marks the radio bands which are not used by the Homeplug systems. The decametric frequency bands are in Table 28 (see the Appendix).

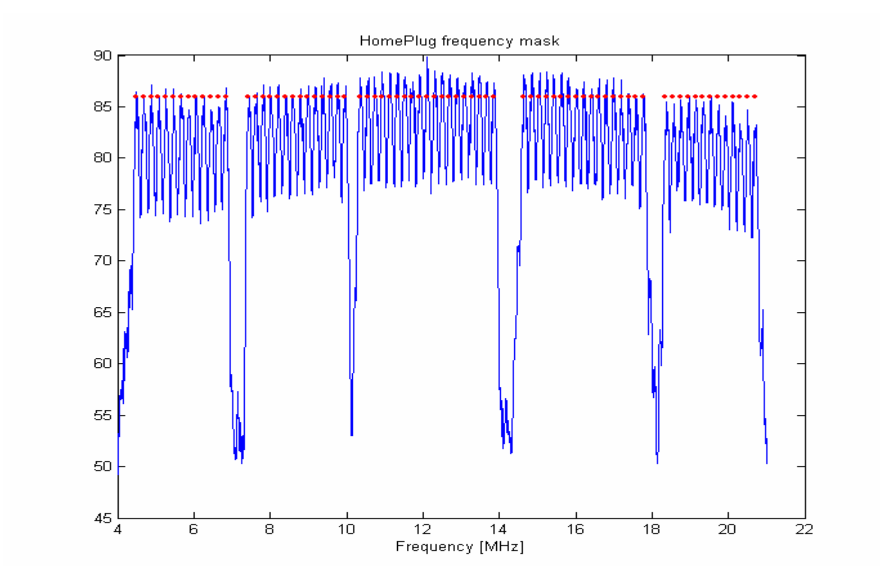

Figure 4: In red the carriers frequencies of the Homeplug specification and in blue the measured spectrum.

Figure 4 shows the PSD mask defined in the Homeplug specification (dashed red line) and the PSD measured on a Homeplug compliant modem model Zeus.

6.2.2 THE TRANCEIVER:

A block diagram of the OFDM transceiver is shown in Figure 5.

Let us look at the transmitter end first (top of Figure 5).

- The FEC (Forward Error Correction) block uses two levels of coding: A Reed-Solomon block encoder for burst disturbance error correction and a convolutional encoder for random disturbance error correction.
- The Tone Mapping block groups the data bits and maps them onto the constellation points of the modulation method (the modulation methods are addresses in the next section). It selects both, the type of modulation, and the OFDM carriers to be used.
- The Inverse Fast Fourier Transform (IFFT) block implements the IFFT used in OFDM to modulate the constellation points onto the carrier waveforms.
- The Analog front end (AFE) block provides final power amplification and low noise preamplification.

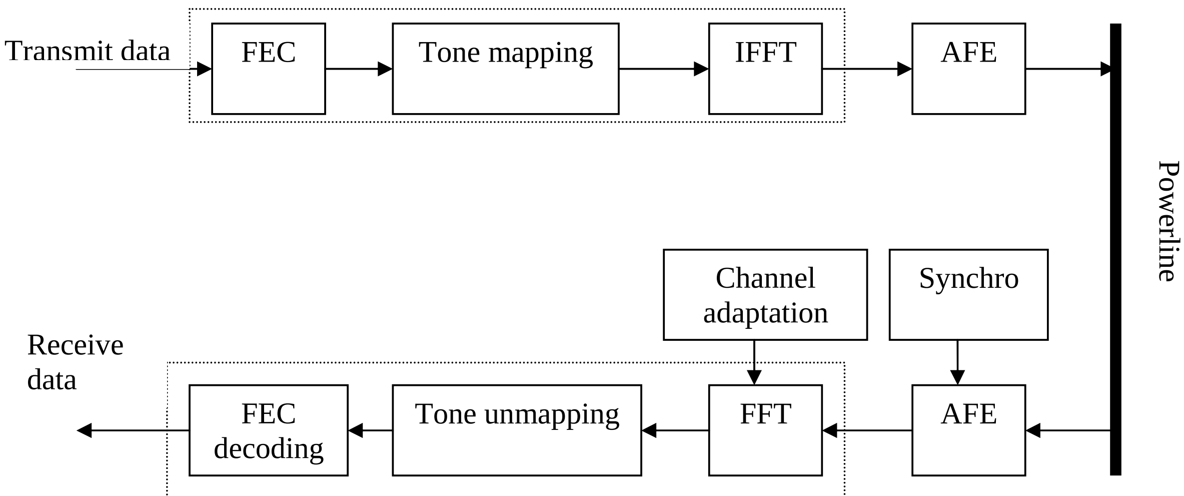

Figure 5: OFDM Transceiver

Let us now turn our attention to the receiver.

- The analog front end (AFE) block takes care of the analog signal processing and adaptation from the powerline.
- The Fast Fourier Transform (FFT) block performs the time to frequency-domain conversion needed for the detection of the OFDM signal. It demodulates the carrier waveforms onto constellation points using the tone map.
- The tone unmapping block uses the knowledge of the modulation method to unmap the constellation points onto data bits.
- The Forward Error Correction (FEC) block carries out Reed-Solomon decoding for burst disturbance error correction and it uses the Viterbi algorithm to decode the convolutional coding for random disturbance error correction.

6.2.3 TRANSMISSION MODE

Homeplug specifies two transmission modes:

- ROBO mode (Robust OFDM)
  - Used for Channel estimation
  - All carriers use the same modulation: Differential Binary Phase Shift Keying (DBPSK)
  - No channel adaptation
- OFDM mode
  - All carriers use the same modulation, either DBPSK or DQPSK
  - Channel adaptation

Homeplug uses channel adaptation (Channel estimation) to determine the carriers to be used and the modulation method to be applied.

Channel estimation occurs when transmission using the existing Tone map fails.

A tone map is considered to have expired if:

- the link is new
- it has not been used successfully for 30 seconds
- the sender had to revert to ROBO mode

The channel estimation is not performed more frequently than once every 4.5 seconds averaged over any 5 minutes interval.

Homepug defines 139 physical data rates available from 1 - 14.1 Mbps

6.2.4 PHYSICAL FRAME STRUCTURE

Figure 6 illustrates the structure of the physical frame. The PHY frame is separated into two parts: One of the parts contains the payload. It uses channel adaptation for transmission. The other one contains the delimiter transmitted without channel adaptation so that all receivers can decode the signal correctly.

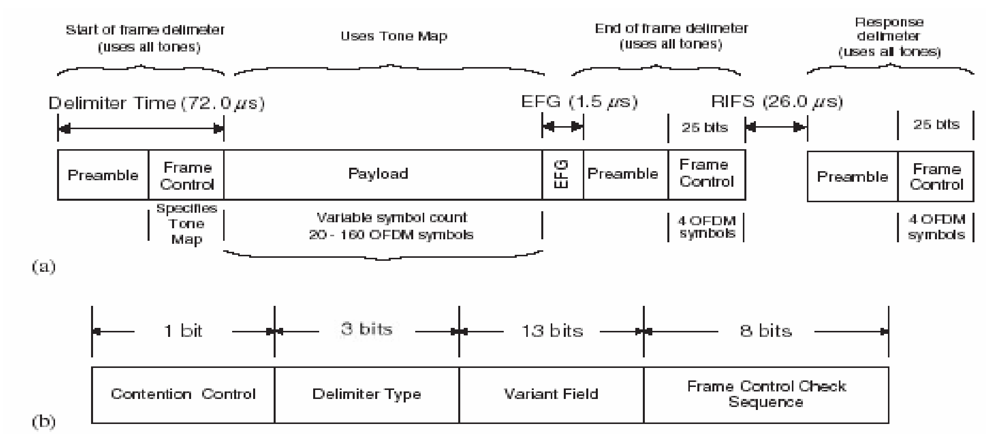

Figure 6: Homeplug 1.0 PHY frame format: (a) PHY frame format and (b) Frame Control (FC)

7 STANDARDS

In this chapter we present an overview of the different standards applied in the USA and Europe. We will begin with an introduction to the standards before giving a general comparison of the limits for conducted and radiated emission levels.

The setup currently used for plc modem testing will be explained in the next chapter.

All limits are given for class B equipment, which is intended primarily for use in the domestic environment

7.1 FCC (USA)

The Federal Communications Commission (FCC)[3] set principally radiated limits for the whole frequency band but it specifies also conducted limits below 1.705 MHz.

The radiated levels are very permissive and allow plc modems to attain higher data rates than the European standards do, as shown in Figure 9 (Section 7.5.3).

7.1.1 LIMITS

7.1.1.1 Conducted limits

For measurements on plc modems, we are not directly concerned by conducted limits because Homeplug specifies an operating frequency range above 1.705 MHz (see Table 4). The powerline will not be influenced by a Homeplug modem for all frequencies below that limit.

Table 4: FCC conducted limits

Frequency of emission [MHz]	Quasi-peak limits [µV]	Band [kHz]
0.535 -1.705	1000	9

7.1.1.2 Radiated emission limits

The radiated emission limit specified in the boldfaced line of Table 5, is important because it define the limit in the Homeplug frequency band (4 MHz to 20 MHz).

Table 5: FCC radiated emission limits

Frequency [MHz]	Quasi-peak limits [µV/m]	Measurement distance [m]
0.009 – 0.490	2400/f(kHz)	300
0.490 – 1.705	24000/f(kHz)	30
1.705 – 30.0	**30**	**30**
30 – 88	100	3
88 – 216	150	3
216 - 960	200	3
Above 960	500	3

7.1.2 MEASUREMENT SETUP

The FCC specifies conducted measurements with an artificial mains network (AMN) for frequencies below 1.705 MHz. Radiated emission measurements, on the other hand, are made for the whole frequency range with a dipole antenna at a distance of 30m.

For both measurements it is clearly specified that the modem must be in maximum emission mode with its accessories attached.

7.1.2.1 Conducted measurements

The main characteristics for conducted measurements are summarized in Table 6.

Table 6: FCC conducted measurements main characteristics

Frequency	**535kHz – 1.705 MHz**
Detector	Quasi-peak
Band	9 kHz
Antenna	AMN
Modem mode	Maximum emission and accessories attached

7.1.2.2 Radiated emission measurements

Table 7 contains information corresponding to radiated measurements as specified by the FCC.

Table 7: FCC radiated measurements main characteristics

Frequency	**– 1.705 MHz**	**1.705 MHz – 108 MHz**
Detector	Quasi-peak (peak)	Quasi-peak (peak)
Band	6 dB (CISPR16.1)	6 dB (CISPR16.1)
Antenna	Dipole	Dipole
Distance [m]	30	30
Maximum frequency [MHz]	30	1000
Site	Open field	Open field
Modem mode	Maximum emission and accessories attached	Maximum emission and accessories attached

Some details of the FCC testing are neglected here because of the focus on European approvals

7.2 EN 55022 (EUROPE)

The EN55022 [4] does not specify any limits for plc systems. It specifies mains port limits and telecommunication ports limits but no limits for multi-purpose ports. This standard requires conducted measurements below 30 MHz and radiated measurements for frequencies above 30 MHz.

7.2.1 LIMITS

7.2.1.1 Conducted limits

In Table 8 we see the conducted limits for the mains ports. They are given in quasi-peak and in average levels.

Table 8: EN55022 limits for conducted disturbance at the mains ports of class B equipment

Frequency range [MHz]	Limits [dB(µV)]	
	Quasi-peak	Average
0.15 – 0.5	66 – 56	56 – 46
0.5 - 5	56	46
5 – 30	60	50

The first observation we can make is that the conducted limits for telecommunications ports are higher than for the mains ports. These limits are also given in current levels.

Table 9: EN55022 limits of conducted common mode (asymmetric mode) disturbance for class B equipment at telecommunications ports

Frequency range [MHz]	Voltage limits [dB(µV)]		Current limits [dB(µA)]	
	Quasi-peak	Average	Quasi-peak	Average
0.15 – 0.5	84 – 74	74 - 64	40 – 30	30 – 20
5 – 30	74	64	30	20

7.2.1.2 Radiated emission limits

For the radiated limits it is important to note that the limits are given at a distance of 10m.

Table 10: EN55022 limits for radiated disturbance of class B ITE at a measuring distance of 10 m

Frequency [MHz]	Quasi-peak limits [dBµV/m]
30 - 230	30
230 - 1000	37

7.2.2 MEASUREMENT SETUP

An important point to stress is that the modem used in the measurement setup does not need to be forced to a "maximum emission mode".

We explain the general measurement setup below. It is not specific to plc modems because of the lack of specifications for the multi-purpose port in EN55022 as already mentioned at the beginning of this section. (see also Section 8.4)

7.2.2.1 Conducted measurement

Details of the measurements on the mains port and on the telecommunications port are given in Table 11. The only difference is the use, for the mains port, of an artificial mains network (AMN) and, for the communications port, of a line impedance stabilization network (LISN)

Table 11: EN55022 conducted measurements main characteristics

Frequency	**0.15 MHz – 30 MHz mains port**	**0.15 MHz – 30 MHz communications port**
Detector	Quasi-peak (peak)	Quasi-peak (peak)
Measurement band	At -6 dB (CISPR16.1) (recommended 9 kHz)	At -6 dB (CISPR16.1) (recommended 9 kHz)
Antenna	AMN	LISN
Modem mode	Normal operation mode with accessories attached	Normal operation mode with accessories attached

7.2.2.2 Radiated emission measurement

Table 12 describes radiated emission measurements.

Table 12: EN55022 radiated measurements main characteristics

Frequency	**30 MHz – 230 MHz**
Detector	Quasi-peak (peak)
Measurement band	At -6 dB (CISPR16.1) (recommended 9 kHz)
Antenna	Dipole
Distance	10m
Height	1m and 4m

7.3 NB30 (GERMANY)

The German Regulatory Authority for Telecommunications and Posts, Reg TP, established the NB30 limits which are based on radiated measurements. The measurement setup is described in reference [5].

7.3.1 LIMITS

Contrary to the two previously discussed standards, the limits are given in peak levels. It is difficult to make a direct comparison with other standards since the conversion factor depends on the measurement setup. The NB30 limits are given in Table 13. Some conversion factors are also given in reference [5].

Table 13: NB30 radiated emission limits at a measuring distance of 3 m

Frequency [MHz]	Peak limits [dBμV/m]	Band [kHz]
0.009 – 0.15	40 – 20 log(f/MHz)	0.2
0.15 – 1	40 – 20 log(f/MHz)	9
1 – 30	40 – 8.8 log(f/MHz)	9
30 - 1000	27	120
1000 – 3000	40	1000

7.3.2 MEASUREMENT SETUP

The salient characteristics of the NB30 radiated measurement setup are given in Table 14.

Table 14: NB30 radiated measurements main characteristics

Frequency [MHz]	0.009 – 30	30 - 3000
Antenna	Loop	Bi-log
Measurement distance [m]	3	3
Detector	Quasi-peak	Quasi-peak
Modem mode	Maximum emission	Maximum emission

The Regulatory Authority for Telecommunications and Posts specifies a correlation factor between Quasi-peak and peak levels since the measurement setup uses a quasi-peak detector and the radiated emission limits are given in peak levels. (Reg TP 322 MV 05 Part 1 [5])

7.4 MPT1570 (UNITED KINDOM)

The MPT1570 standard [6] specified limits up to 30 MHz up until January 2003. The current version specifies radiated limits below 1.6 MHz only. PLC modems do not need to be compliant with this standard since they operate in another frequency band. Table 15 contains the current MPT1570 limits and it is given for information only.

7.4.1 LIMITS

Table 15: MPT1570 radiated emission limits

Frequency [MHz]	Peak limits [dBμA/m]	Measurement distance [m]
0.009 – 0.15	49 – 20 log(f/kHz)	3
0.15 – 1.6	-1.5 – 20 log(f/MHz)	1

7.4.2 MEASUREMENT SETUP

Notice that this setup is the only one that specifies the use of a peak detector. This is coherent with the fact that the limits are given in terms of peak levels, as defined in Table 14. Some aspects of the measurement specification are given in Table 16.

Table 16: MPT1570 radiated measurements main characteristics

Frequency [MHz]	**9 kHz – 150 kHz**	**150 kHz – 1.6 MHz**
Detector	Peak	Peak
Measurement distance [m]	200 Hz	9 kHz
Antenna	Loop	Loop
Measurement distance [m]	3	1
Modem mode	Not specified	Not specified

7.5 COMPARISON OF THE STANDARDS

A comparison of the different standards is not straightforward since every standard uses its own limits and measurement setup.

- The **FCC** specifies conducted limits in μV and radiated emission limits in μV/m and uses quasi-peak levels at a distance of 30m.
- **EN55022** specifies conducted limits in dBμV and dBμA. It uses average or quasi-peak levels. Radiated limits are defined above 30 MHz in dBμV/m
- **NB30** specifies radiated emission limits in dBμV/m and it uses peak levels. The measurement detector is, however, a quasi-peak detector and the measurements are made at a distance of 3m
- **MPT1570** specifies radiated emission limits in dBμA/m and it uses peak levels at a distance of 1m or 3m

A further important difference is the mode of operation of the modem during the measurement. While FCC and NB30 specify a "maximum emission mode", EN55022 currently specifies a "normal operation mode".

7.5.1 CONDUCTED LIMITS

The FCC limit is between the communications and mains port limit of the EN55022 but out of the HomePlug frequency band. This comparison shows also that the mains port limit is much stricter than the communications port limits.

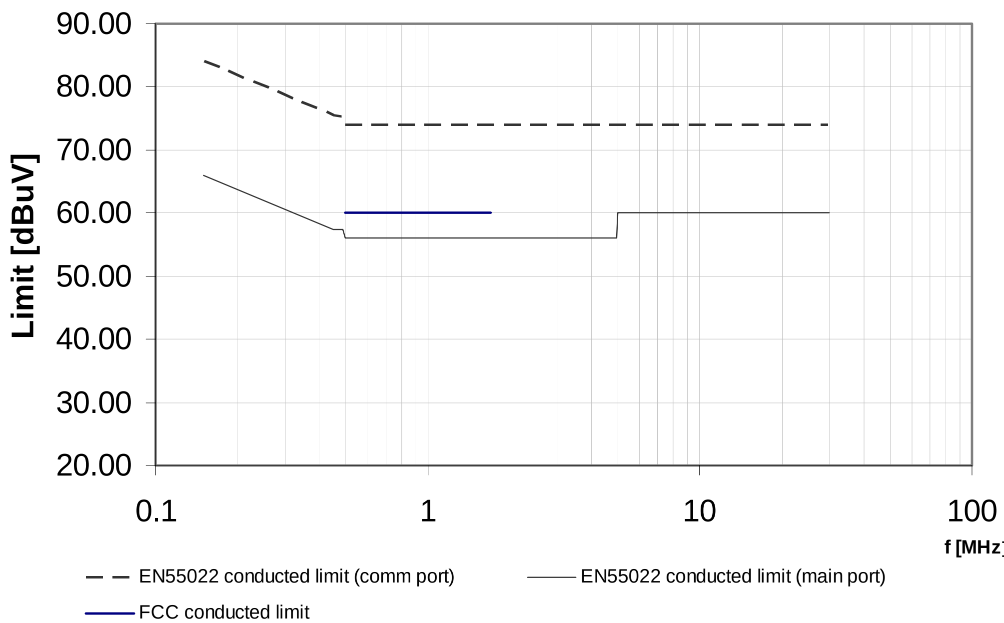

Figure 7: Standards limits comparison for conducted measurements

7.5.2 RADIATED LIMITS

This comparison shows a considerable difference between the FCC and NB30 limits within the Homeplug frequency band. Although EN55022 does not specify limits in the Homeplug frequency band, the specified limits above 30MHz are similar to those of the FCC.

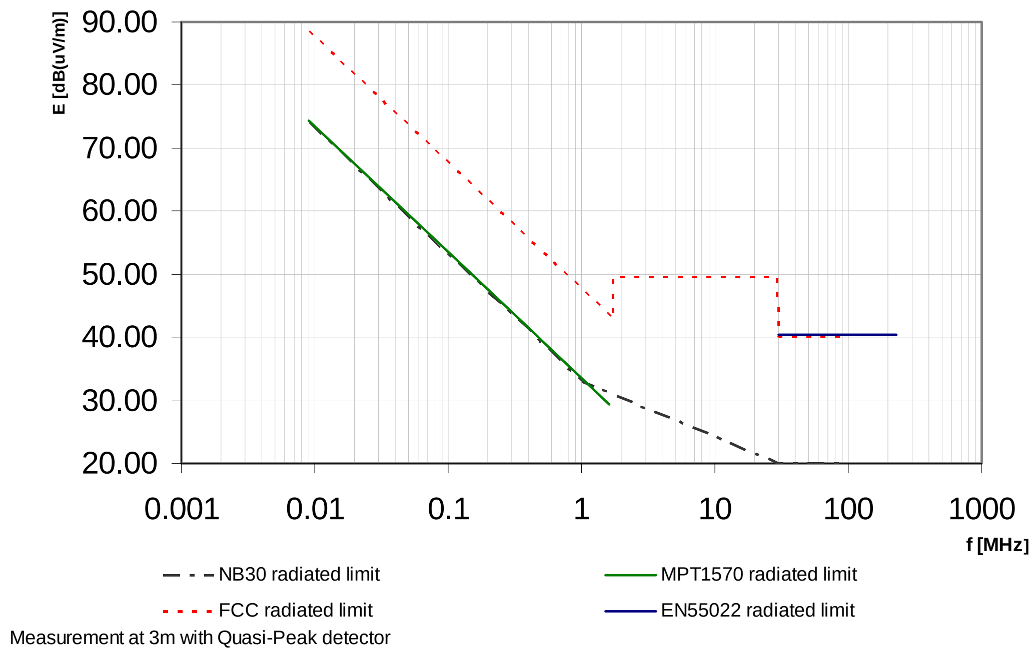

Figure 8: Standards limits comparison for radiated measurements

To allow a comparison, all of the values have been converted to 3m quasi-peak values of electric field strength dBμV/m.

7.5.3 RADIATED AND CONDUCTED LIMITS

To compare radiated and conducted measurements limits, we take into consideration the following factors:

- Conversion factor from Peak to Quasi-Peak limits (see Section 7.5.6)
- Distance correction factor (see Section 7.5.5)
- Conversion between conducted and radiated measurements (see Section 7.5.4)

In the following graph we compare only norms that define limits in the HomePlug frequency band.

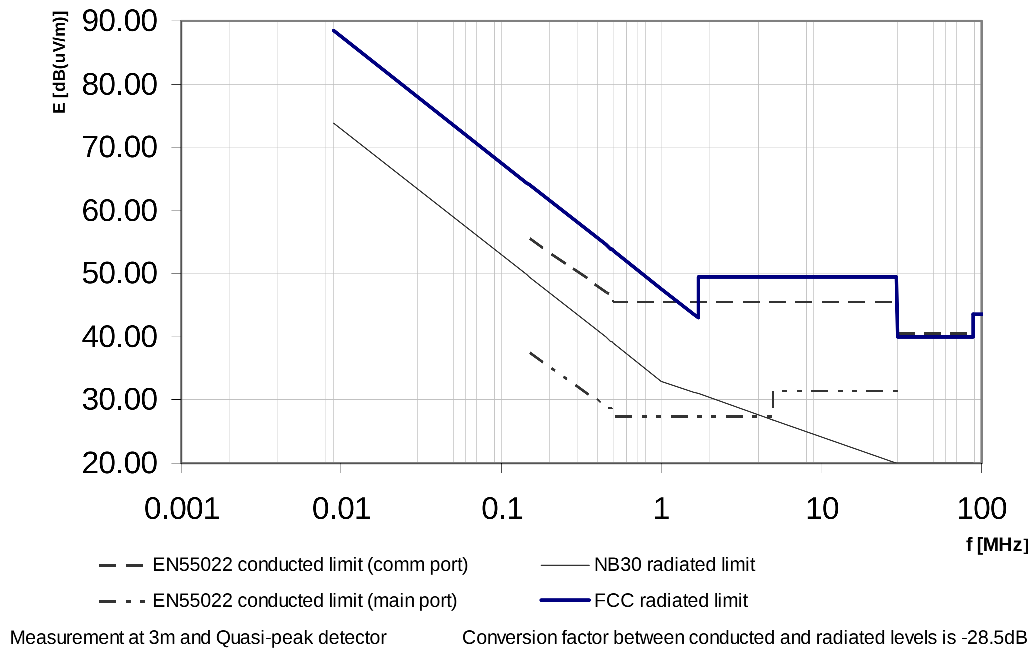

Figure 9: Standards comparison in radiated limits measurements in the HomePlug frequency band

7.5.4 CONVERSION FACTORS BETWEEN CONDUCTED AND RADIATED LEVELS

The relation between a current level and its associated radiated fields depends on many factors, including the symmetry of the cable, the geometry and the frequency. It is therefore difficult to establish this relation exactly. Although constant factors are an oversimplification in most cases, they are commonly used because they provide a way to make first order comparisons. France telecom has established the following conversion factors [9]

Table 17: Conversion factors from France Telecom R&D		
Conducted (power, 50Ω)	**Factors**	**Radiated**
dBm/Hz (10kHz EN55022)	**+ 67 dB**	**dBµA/m (3m EN55022)**
dBm/Hz (10kHz)	- 37 dB	dBµA/m (10m outdoor)
dBm/Hz (1Hz NB30)	+ 50 dB	dBµA/m (3m NB30)
dBm/Hz (10kHz comm CE)	+ 50 dB	dBµA/m (alim CE)
dBm/Hz (single)	+ 27 dB	dBµA/m (indoor)
dBm/Hz (single)	+ 10 dB	dBµA/m (3m)
dBm/Hz (single)	- 3 dB	dBµA/m (10m outdoor)

We selected the EN55022 factor +67dB (boldface in Table 17) and, after straightforward calculation, we obtained our correlation factor, given in Table 18, between conducted (in a T-ISN, according to current CE homologation) and radiated levels.

Table 18: Conversion factor between conducted and radiated limits		
dBµV	**-28.5 dB**	**dB(µV/m)**

This factor will be verified experimentally in a future project.

7.5.5 OTHER FACTORS

Some other conversion factors used for the standards comparison are given in tables 19 through 22 below.

Table 19: Conducted conversion between current and voltage levels		
µA	150 Ω	µV
dB(µA)	+ 44 dB	dB(µV)

Table 20: Radiated conversion between electric and magnetic field		
µA/m	377 Ω	µV/m
dB(µA/m)	+ 51.5 dB	dB(µV/m)

Table 21: Conversion between Voltage and power levels		
µV	u^2/Zc	mW
dB(µV)	-90-10*log(Zc)	dBm

Table 22: Distance correction		
Level at distance X [dB]	+20*log(X/Y)	Level at distance Y [dB]

7.5.6 CONVERSION BETWEEN PEAK AND QUASI-PEAK DETECTORS FOR HOMEPLUG MEASUREMENTS

To determine the conversion factor between Peak and Quasi-Peak detectors, we use the PMM8000Plus. This piece of equipment uses Peak, Quasi-Peak and Average hardware detectors.

To determine this factor we made several measurements whose results are illustrated in figures 10 and 11:

- Maximum transfer rate (14 Mbps) to obtain maximum disturbance.

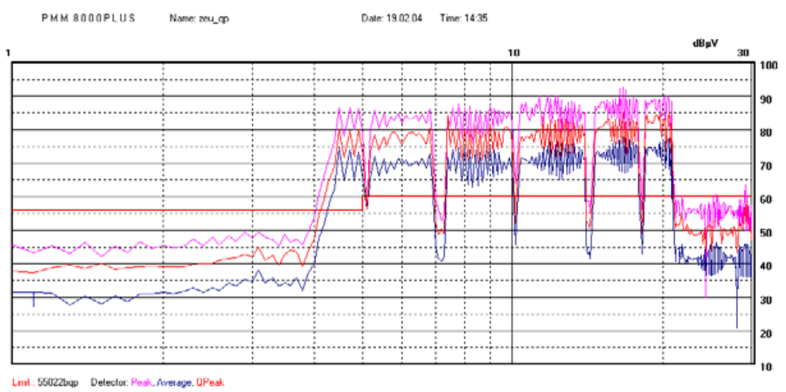

Figure 10: Conducted measurement of two modems Zeus in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

- Low transfer rate (1Mbps).

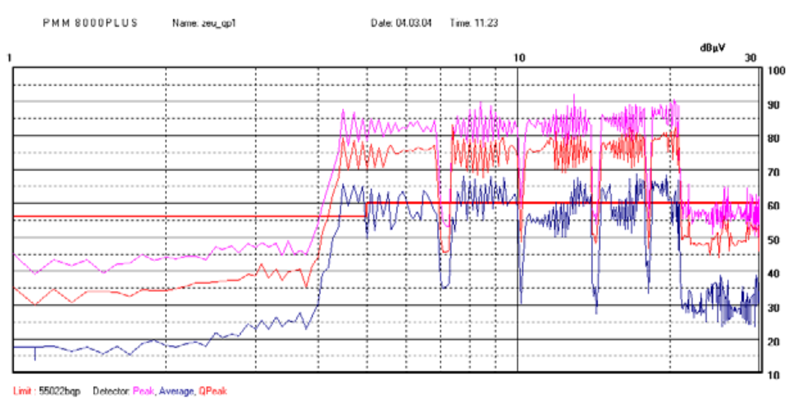

Figure 11: Conducted measurement of two modems Zeus in low transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

From the measured data, we calculated the conversion factor twice: The first one is the analysis on the full band (1 to 30 MHz) and the second one is the analysis in the HomePlug band only (4 to 20 MHz). The results are given in Table 23.

Table 23: Measurements of the conversion factor for several modems

		Average value for the modem				
		Corinex	Devolo	Niroda	Zeus	Zeus USB
Maximum rate (14 Mbps)	Difference Peak-Qpeak [dB] (1-30MHz)	-6.61	-6.74	-7.66	-6.38	-7.70
	Peak-Qpeak [dB] (4-20MHz)	-6.34	-6.19	-6.92	-6.33	-6.66
	Peak-Average [dB] (1-30MHz)	-14.06	-14.30	-15.49	-13.93	-16.57
	Peak-Average [dB] (4-20MHz)	-13.38	-13.25	-13.94	-13.58	-15.20
Rate of 1 Mbps	Peak-Qpeak [dB] (1-30MHz)	-8.60	-8.61	-8.76	-8.24	-8.35
	Peak-Qpeak [dB] (4-20MHz)	-8.18	-7.96	-8.15	-7.74	-7.79
	Peak-Average [dB] (1-30MHz)	-28.31	-28.44	-24.72	-24.90	-28.29
	Peak-Average [dB] (4-20MHz)	-27.56	-27.35	-23.62	-23.64	-27.41

Table 24 contains the mean values of the measurements given in Table 23.

Table 24: Conversion factor between Peak/Quasi-Peak and Peak/Average

		Mean		**Mean of the two measurement**
		1-30MHz	4-20MHz	
Maximum rate (14 Mbps)	Peak-Qpeak [dB]	-7.016	-6.49	**-6.75**
	Peak-Average [dB]	-14.87	-13.86	**-14.37**
Maximum rate 1 Mbps	Peak-Qpeak [dB]	-8.51	-7.96	**-8.24**
	Peak-Average [dB]	-26.93	-25.92	**-26.42**

The conversion factor between Peak and Quasi-Peak changes about 1.5 dB between the measurement with full and low bandwidth. But for the factor between Peak and Average the difference is approximately a factor of 2.

It is difficult to determine an exact value for this factor but if we round off the values for maximum rate and low rate, we obtain the following factor:

Table 25: Conversion factor between Peak and Quasi-Peak detectors		
Peak	**-7 dB**	**Quasi-Peak**

8 PLC MODEMS HOMOLOGATION

In this section, we will analyse the current and future approval procedure for the plc modems in the USA and in Europe.

8.1 CURRENT HOMOLOGATION IN THE USA

The FCC standard clearly specifies the measurement setup for PLC modems as shown below:

- Quasi-peak detector
- Modem in maximum emission mode with accessories attached. This means that the modem under test is connected to another device and that it is transferring data so that the radiated emission is maximum.
- Radiated measurement
    - Dipole antenna
    - Frequency: 9 kHz – 108 MHz
    - Open field test site
    - Distance of 30m
- Conducted measurement
    - LISN
    - Frequency: 535 kHz – 1.705 MHz

8.2 CURRENT HOMOLOGATION IN EUROPE

The European standard EN55022 does not currently contain any special specifications for PLC modems but the following arrangement has been used to certify them for the mass market:

- Conducted measurement with non standardized T-ISN at the mains port
- Telecommunications port limits used
- Frequency: 150 kHz – 30 MHz
- Quasi-peak detector
- Modem in normal operating mode (minimum emission) with accessories attached. Unlike the FCC specification, the European setup allows the measurement to be made in the standard operating mode.

In the following sections, we will compare the different ISN's specified in the European standard.

8.3 IMPEDANCE STABILISATION NETWORK (ISN AND T-ISN) FOR CONDUCTED MEASUREMENTS

The EN55022 standard specifies, for conducted measurements, the ISN whose schematic is given in Figure 12.

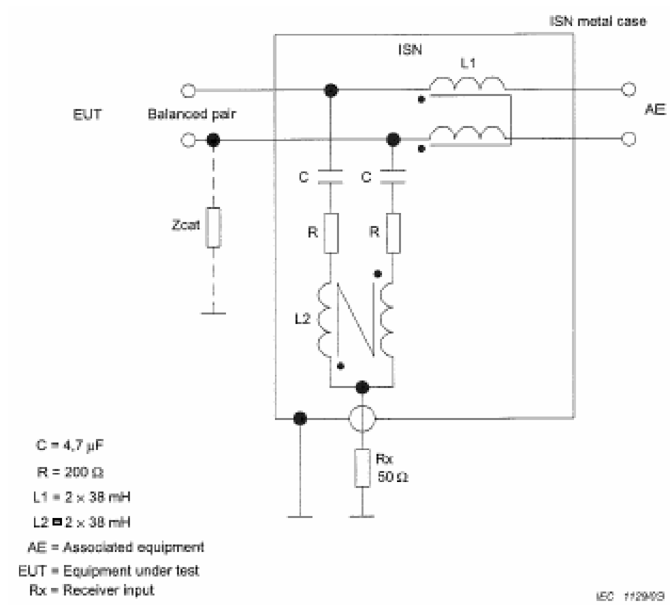

Figure 12: Impedance stabilisation network (ISN) specified in EN55022.

The current conducted measurement uses a non standardized ISN. The T-ISN is an ISN with a longitudinal conversion loss (LCL) of 30dB as shown in Figure 13 below. The modems currently on the EU market were certified using this T-ISN.

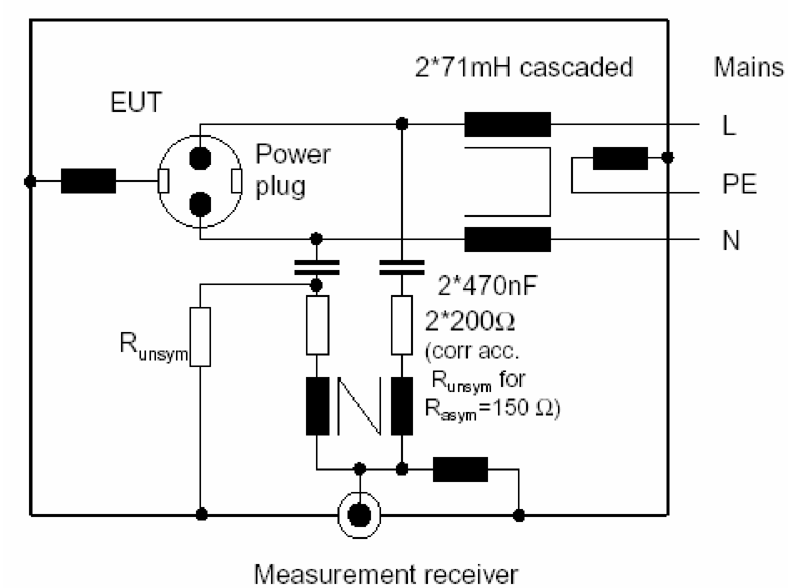

Figure 13: Impedance stabilisation network with an LCL factor of 30dB (T-ISN)

This non standard T-ISN was designed by professor Hirsch from the University of Dortmund (D) [7].

The T-ISN specified in the "future" EN55022 is similar to the currently used T-ISN but with an LCL of 36 dB as shown in Figure 9.

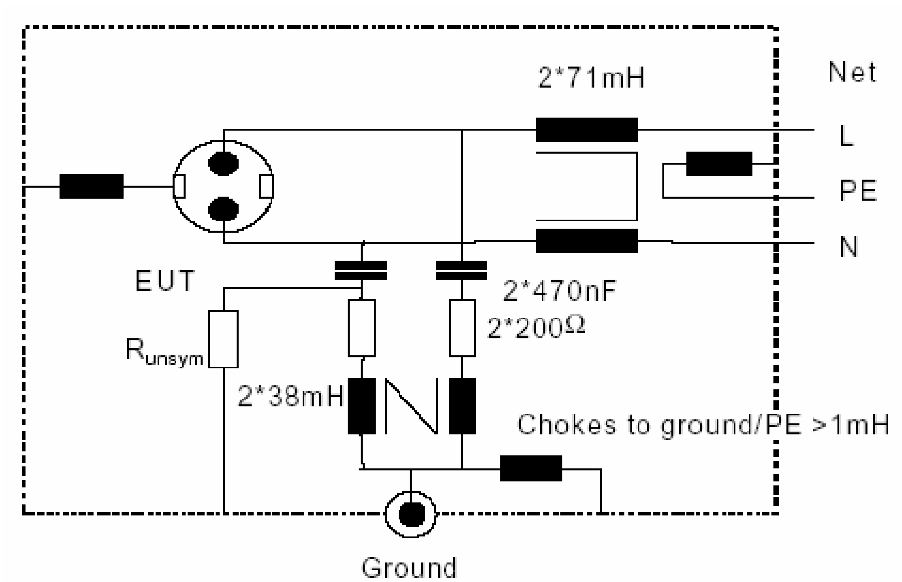

Figure 14: Impedance stabilisation network with an LCL factor of 36dB (T-ISN)

8.4 FUTUR HOMOLOGATION IN EUROPE

Although no one appears to know exactly how modems will be certified in the future, two solutions are the most likely candidates:

- The first one is presented in a CENELEC draft [8]:
  - Conducted measurement at the multi-purpose port
  - Communication function inactive using an AMN with mains port limits
  - Communication function active using a T-ISN (as shown above) with telecommunications port limits
- The second follows NB30:
  - Radiated measurement at a distance of 3m with NB30 limits and measurement setup.

9 TESTS & MEASUREMENTS

Our main goal was to determine whether or not the PLC modems currently on the European market are EN55022 compliant. We also investigated the factors that influence the emission level.

To do this, we separated our measurements in three parts, each with its own objective:

- General analysis: Analyse the difference of emission field with different modems in different emission modes.
- Conducted measurement according to EN55022: Qualify conducted emissions with the European standard for the modems currently on the market
- Radiated measurement according to EN55022: Check the harmonics above 30 MHz

9.1 GENERAL ANALYSIS

For all conducted measurements we used the same base configuration illustrated in Figure 15. The modems were connected to the LISN which was in turn connected to an EMC filter. The computer and measurement equipment was directly connected to the powerline.

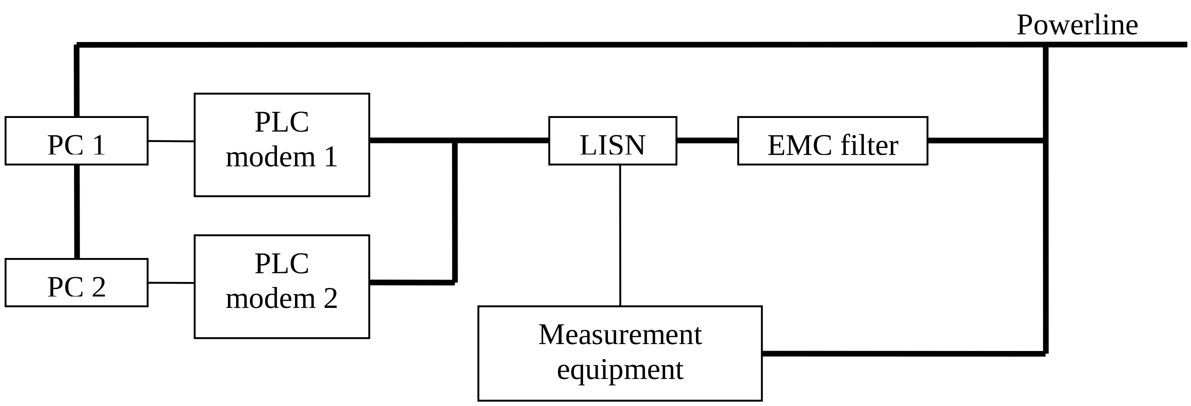

Figure 15: General measurement setup

A network with two different modems work equally well as with two identical modems. We observed the following points:

- The maximum rate is identical under all configurations (about 8 Mbps*) but we notice small instabilities in the transmission rate (of the order of 200 kbps) probably due to errored frames.
- The connection was always restored after an interruption if two identical modems were used.
- Sometimes the connexion could not be restored after a long interruption with two different modems.

* The transfer rate measurements were made with a program called *Analyser* and the transferred data were generated with *TfGen*. With this system we obtained a maximum transfer rate of 8 Mbps but with a file transfer program such as ftp we obtained half that rate (4 Mbps).

9.1.1 INTERACTION BETWEEN TWO HOMEPLUG NETWORKS ON THE SAME POWERLINE

It is possible to establish two separate networks at the same time on the same powerline as shown in Figure 16. We refer to each PC as PCi, where I is the number of the modem installed on it. To set up a network, for example between PC1 and PC2, the same network name is given to each modem using the modem's configuration utility.

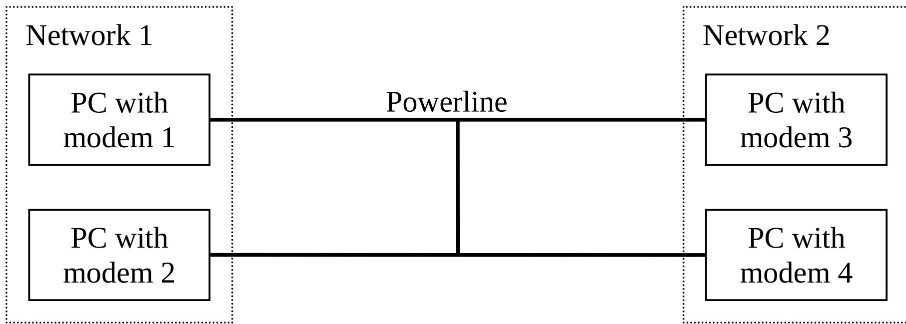

Figure 16: Measurement setup with two different networks

- All observations given in the previous section are valid for the case of two networks.
- Two networks work perfectly on the same powerline at the same time.
- To establish a connection between to modems, they must be in the same network. In Figure 16, PC1 could not reach PC3.
- The available bit rate is uniformly divided between the two connections.
    - If there is one transfer between PC1 and PC2 and a second between PC3 and PC4 the band rate is divided into two (about 4 Mbps for each connexion).
    - If the transfer between PC1 and PC2 is stopped, the band rate of the second transfer is doubled (to about 8 Mbps).
    - If we reactivate the first connexion, the rate is once again divided (about 4 Mbps for each connexion).
- It is also possible to establish two connections (transfer) between two PCs on the same network and the functionality is the same as the transfer in two separate networks.

The main remark is that the Homeplug system is very robust but sometimes it was difficult to establish a connection between two modems due to the modems' configuration.

9.2 FREQUENCY ANALYSIS

We made the general frequency analysis in conducted measurements with an LISN (Certifiate below 30 MHz). The measurements take into consideration the frequency response of the LISN below 100 MHz.

9.2.1 COMPARISON OF THE MODEMS

From Figure 17 we observe that the general apperance of the measured voltage spectrum is very similar for all of the modems. A difference can be noted at frequencies higher than 55 MHz for the Zeus wall mount modem (usb).

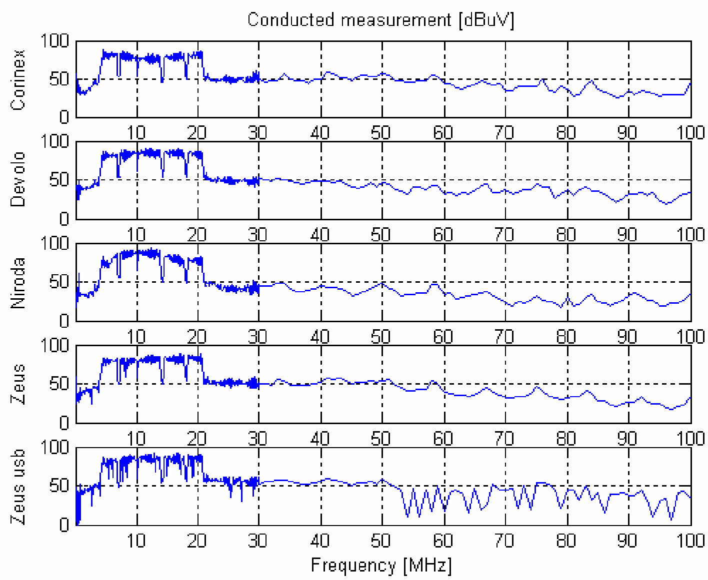

Figure 17: Conducted measurement below 100 MHz of all tested modems

The mean difference of all bridge modems is about **4.5 dB** in the range 150 kHz to 100 MHz. For this calculation, we chose to leave out the Zeus wall-mount modem because of the oscillatory behaviour of the measurement in the upper frequency band.

In Figure 7 all the measurements were made with identical at each end of the connection. We observed also that, even if two different modems are used, the mean difference remains essentially unchanged.

We tested the Corinex modems from the USA (110V and FCC compliant) and did not observe any difference when compared to their European counterparts (Corinex modem, 220V and CE compliant). The frequency behaviour of the amplitude spectrum was also observed to be identical.

9.2.2 HOMEPLUG FREQUENCY BAND CONDUCTED MEASUREMENTS

In the previous section, we saw that the HomePlug based modems were all very similar in the range 150 kHz to 30 MHz. For that reason, the analysis presented in this section is limited to the Zeus modem. However, measurements for all of the modems can be found in the Appendix.

In Figure 18, we show that the modem's conducted emissions are up to 25 dB above the EN55022 limit when the modem operates at maximum transfer.

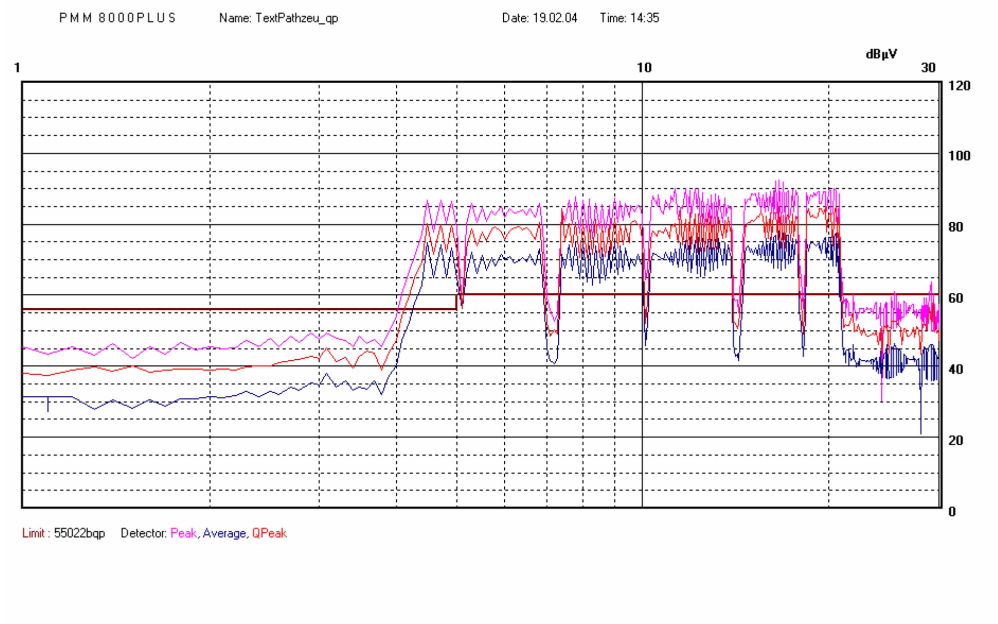

Figure 18: Conducted measurement of two modems Zeus in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

In the following figure, we show the emission level both, with the modem operating at a 1 Mbps transfer rate, and when it is operating at maximum transfer rate. Interestingly, although the measurements for the two transmission rates look different, the spectra are identical if max hold is used during the measurement.

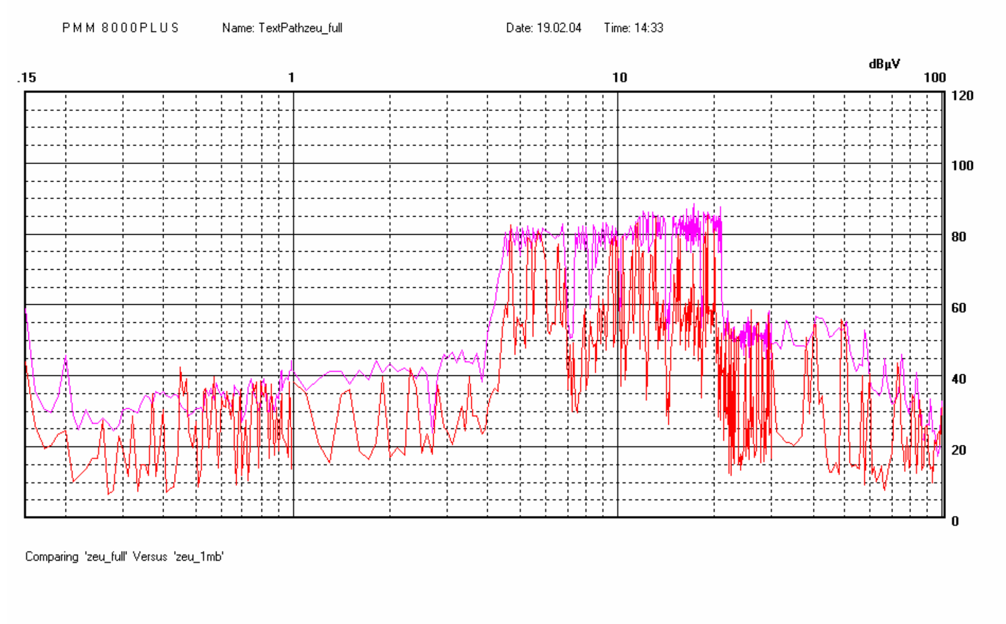

Figure 19: Conducted measurement of two modems Zeus. The red trace the modems are in a transfer rate mode of 1 Mbps and the violet trace in maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

In Figure 20, the modems are in standby mode and we observe that the modem is 25 dB under the EN55022 limit.

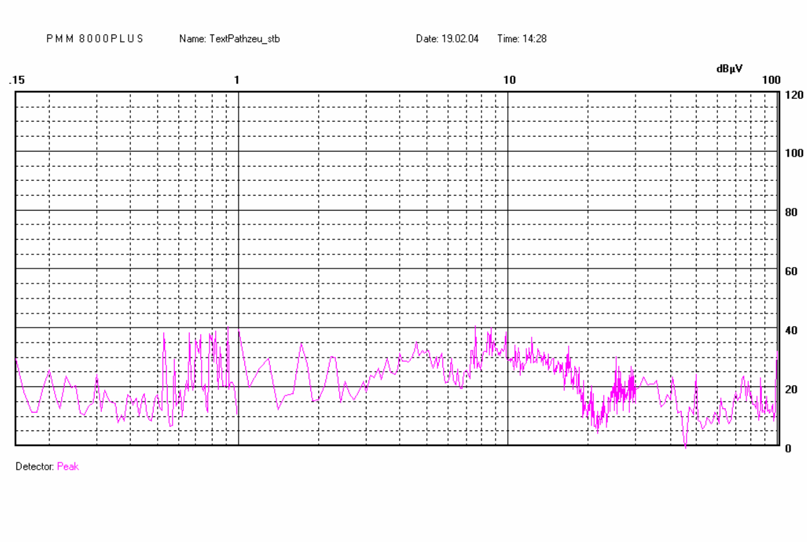

Figure 20: Conducted measurement of two Zeus modems in standby mode. (Peak time = 2ms and BW=9kHz)

9.2.3 HARMONIC ANALYSIS BELOW 100MHZ

In Figure 21, we show the harmonic disturbance of a HomePlug modem. We can consider that this electric field is under the EN55022 limit. The measurement setup and the complete radiated measurements are given in the Appendix.

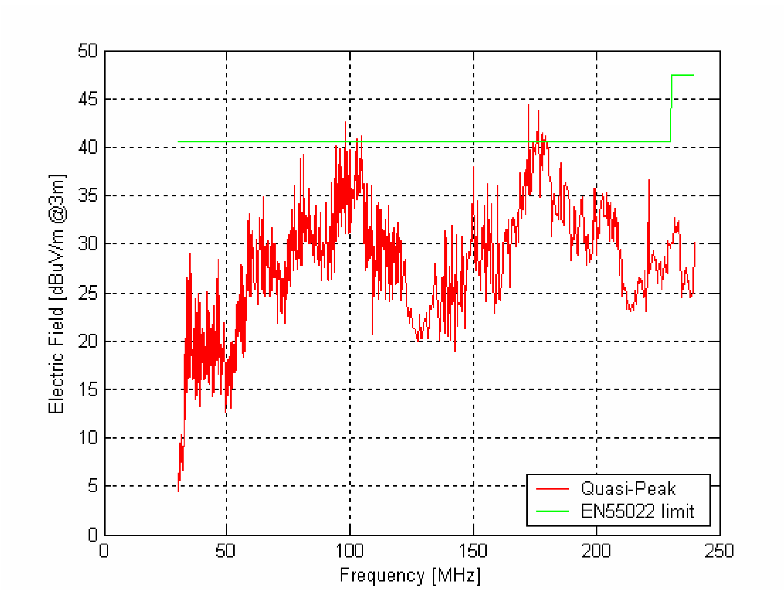

Figure 21: Radiated measurement of two Zeus modems in maximum transfer rate mode. (Peak time = 2 ms and BW=120kHz)

9.2.4 EMISSION COURRENT BEHAVIOR

To determine how the modem output current behaves as a function of the load, we changed the load of the powerline and measured the current on it. The schematic of the system that allowed us to change the load is shown in Figure 29 in the Appendix.

Figure 22 shows the current on the powerline from the Zeus bridge modem without additional load.

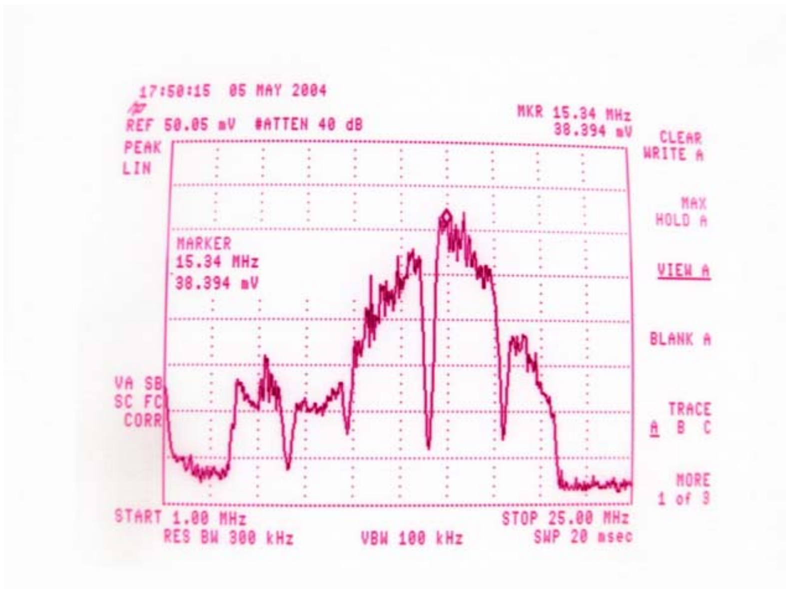

Figure 22: Current measurement without additional load

Figures 25, 26 and 27 in the Appendix show the current behaviour from 1 MHz to 25 MHz. We selected a single frequency, 15 MHz, to study the behaviour of the modems over the whole frequency band and we used that frequency as a basis for comparison of the different modems. The choice of that particular frequency was based on the following observations:

- The selected frequency is in the middle of the band.
- The current at that frequency exhibits a strong dependence on the load.
- The maximum current was measured at 15 MHz for a wide range of load impedances.

In Figure 23, we have plotted the "normalized" current at 15 MHz as a function of the load for 5 modems. Here, the term "normalized" indicates that all currents have been referenced to the current measured for a load of 150Ω. That load corresponds to the normalised load of an ISN according to EN55022 (CISPR16.1).

We can see form Figure 23 that the various modems exhibit different current behaviour characteristics. We observed that, while the Devolo modems have a 16 dB difference between 22Ω and 2,2kΩ, the difference is only 7 dB for the Niroda modems for the same load interval.

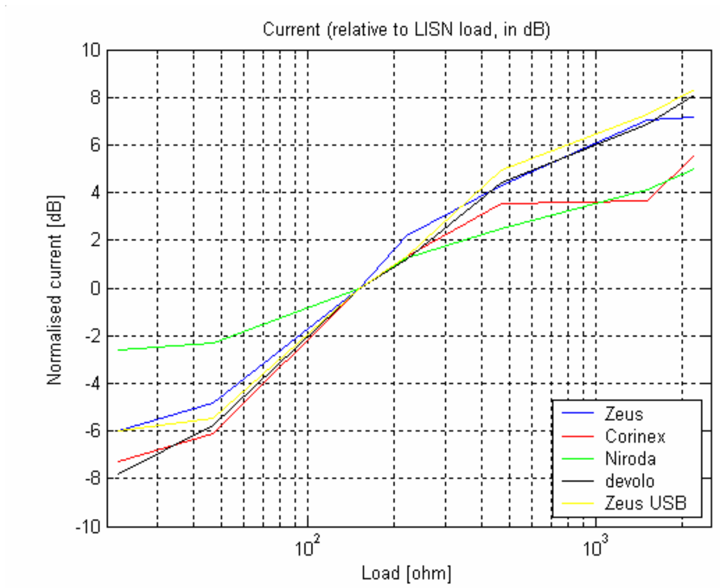

Figure 23: Comparison between the output stage from Homeplug modems

We can see that the current measured using an LISN (150Ω), is, on average, 6 dB smaller that the current measured under a 2,2kΩ load.

This suggests that **the HomePlug modems would radiate more on real installations** than on the EN55022 compliance setup (connected to an LISN).

We explained before that, almost all of the HomePlug modems use the same Intellon chipset, although the output stage may be different. This, however, should not influence the radiated field of the modems appreciably.

9.2.5 DISTURBANCE REACTION

9.2.5.1 Narrowband disturbance

To study the behaviour of the modems in the presence of narrow-band disturbances, we used a clamp to introduce a narrow-band signal whose width was equal to the bandwidth of a carrier, about 300 kHz.

9.2.5.1.1 Statique narrowband disturbance

We set the frequency of the narrow-band signal to different frequencies within the Homeplug frequency band and we increase its amplitude in an attempt to disturb the PLC connection. We were not able to disturb the connection even with a disturbance much higher than the PLC signal level.

Seeing that this disturbance has not effect we repeated the test, this time varying slowly the central frequency of the disturbance as explained in the next section.

9.2.5.1.2 Dynamic narrowband disturbance

For this measurement, we proceeded as follows: We set the frequency of the narrow-band signal to 10 MHz and changed its amplitude until the desired signal to noise ratio was reached (this is the value noted in the first column in Table 26). We then varied the central frequency of the narrowband disturbance slowly between 5 MHz and 15 MHz (Figure 24) and we observed the effect on the bandwidth of the PLC connection. The results were written in Table 26.

Interestingly, regardless of the central frequency of the narrowband signal, the bandwidth of the connection was not influenced until the SNR was much smaller than 0 dB.

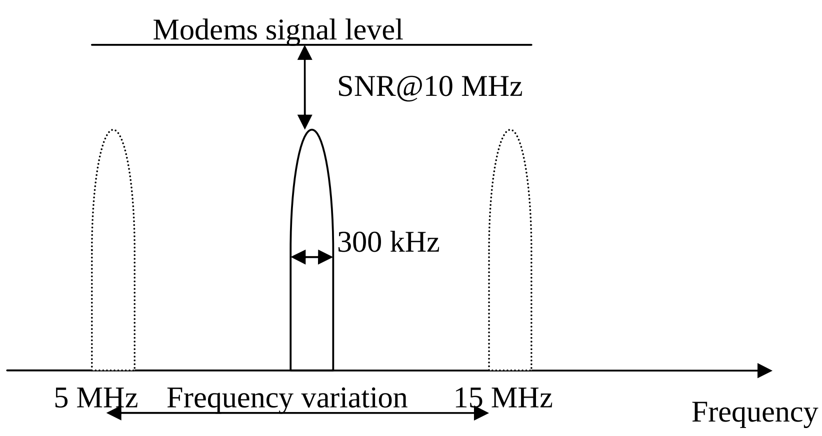

Figure 24: Narrowband disturbance with center frequency variation

Table 26: Measurement with variable frequency narrowband disturbance

SNR [dB] @10 MHz	Effect on the bandwidth of the connection
18	No effect on the bandwidth
1	Rate went down to 6 Mbps. Stayed most of the time at 7.3 Mbps
-8	Rate went down to 5 Mbps. Oscillated between 6.5 Mbps and 7 Mbps most of the time
-12	Rate went down to 2 Mbps. Oscillated most of the time between 4 Mbps and 6 Mbps (important disturbance)
-14	Rate went down to 1 Mbps. Oscillated most of the time between 3 Mbps and 6 Mbps (important disturbance)

The connection began to be disturbed by the narrowband disturbance when the signal to noise ratio got to SNR= -4dB and the bit rate fell to 5 Mbps.

The HomePlug modem was able to adapt its carriers very fast and, even in the presence of a considerable disturbance level and the transfer rate remained at a level that can be considered as acceptable for the user.

9.2.5.2 Wideband disturbance

A normalised burst disturbance was introduced to analyse its effect on the bandwidth of the PLC system.

Table 27 shows the signal to noise ratio due to the disturbance for several frequencies and the corresponding effect on the transfer rate.

Table 27: Transfer rate behaviour with wideband disturbance (Burst)

SNR [dB] @3 MHz	SNR [dB] @6 MHz	SNR [dB] @10 MHz	SNR [dB] @15 MHz	SNR [dB] @20 MHz	Effect on the transfer rate
-	-	-	-	-	No effect. 7.3 Mbps
25	16	4	14	18	Oscillation between 7.3 Mbps and 4.8 Mbps, most of the time at 7.3 Mbps
24	8	-2	8	12	Identical as before
17	7	-6	8	10	Oscillation with a lowest rate at about 3.8 Mbps
15	6	-8	8	10	Oscillation between 7.3 Mbps and 4.8 Mbps but most of the time remaining at 4.8 Mbps
15	6	-9	7	10	Identical as before

The transfer rate was disturbed lightly. Even with a SNR@10MHz of -9dB, the transfer rate stayed at 4.8Mbps.

9.2.5.3 Remark

We can make several remarks about the disturbance reaction:

- The Homeplug system is essentially undisturbed by static narrowband signals.
- Although dynamic narrowband signals disturb the Homeplug system by reducing the throughput, the communication does not be shut down.
- As with dynamic narrowband disturbances, wideband signals disturb the Homeplug system but not to kill the communication altogether.

In light of the results presented in this chapter, we can conclude that the HomePlug system is very robust.

10 SUMMARY AND CONCLUSION

At present, Homeplug compliant devices represent by far the biggest market share of the Indoor PLC modem market. The HomePlug specification was prepared by a consortium of some of the biggest telecommunications companies. The HomePlug modem market is developing rapidly. Compliant modems can be bought in many stores in Switzerland.

Most radiation problems in Europe are likely to come from the HomePlug modems since currently available Access systems are not attractive enough for the consumer due in part to the fact that the ADSL and cable modem technologies are very well established.

This project began last year, when the HomePlug modem market in Europe was in its early stages of development. While only a few stores carried HomePlug modems then, practically every computer store sells these products nowadays at prices half as high as last year's.

The standards are all different. Every state or continent specifies its own standards and it is therefore difficult to compare them correctly. American standards (FCC part 15) are much more permissive than European Standards (EN55022)

The European standard will be modified soon but it is not yet known whether or not HomePlug will become compliant with EN55022.

In Section 7, we presented the conversion factor between radiated and conducted measurements determined from a document from France Telecom [9]. We did not verify this factor in real measurements. Work is in the planning stages to carry out this verification using a special setup in an open area site in the near future.

The performance of the HomePlug modems tested in the course of this project can be qualified as good. A network can be established very fast in most cases and the network is resilient to narrowband interference.

All HomePlug modems are similar in the following points:

- The functionalities and performance in a Windows 2000 environment
- The current behaviour with under different load conditions on the line
- The radiated electrical field

The observed differences were small enough to be neglected.

Perhaps one of the most important conclusions of this study is that HomePlug modems did not respect the EN55022 standard. Their emissions are at least <u>25 dB above the specified limit</u> for the HomePlug Frequency band.

11 REFERENCES

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12 APPENDIX

12.1 CURRENT BEHAVIOUR MEASUREMENTS

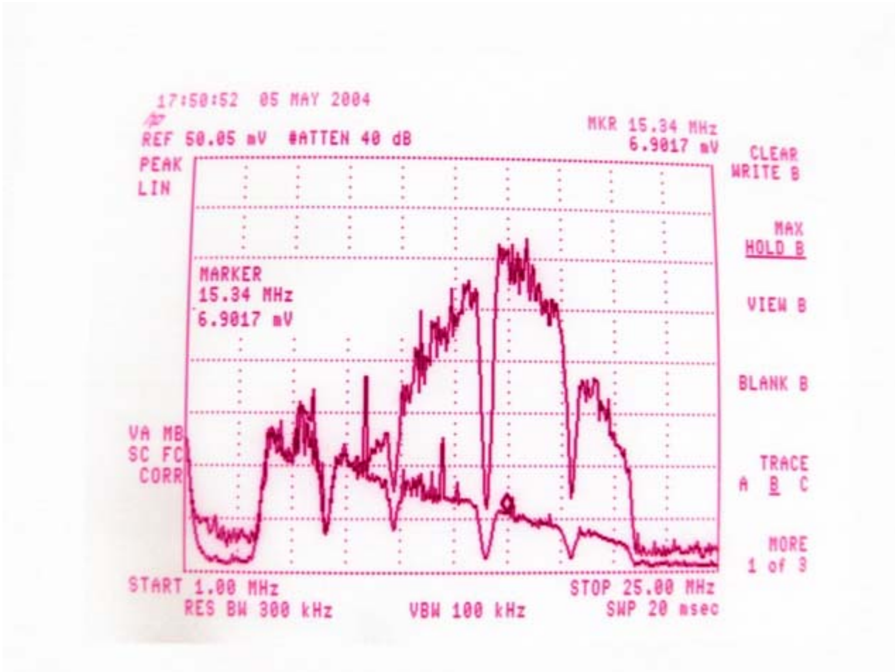


Figure 25: Current measurement: Top trace without load and bottom trace with 22Ω load

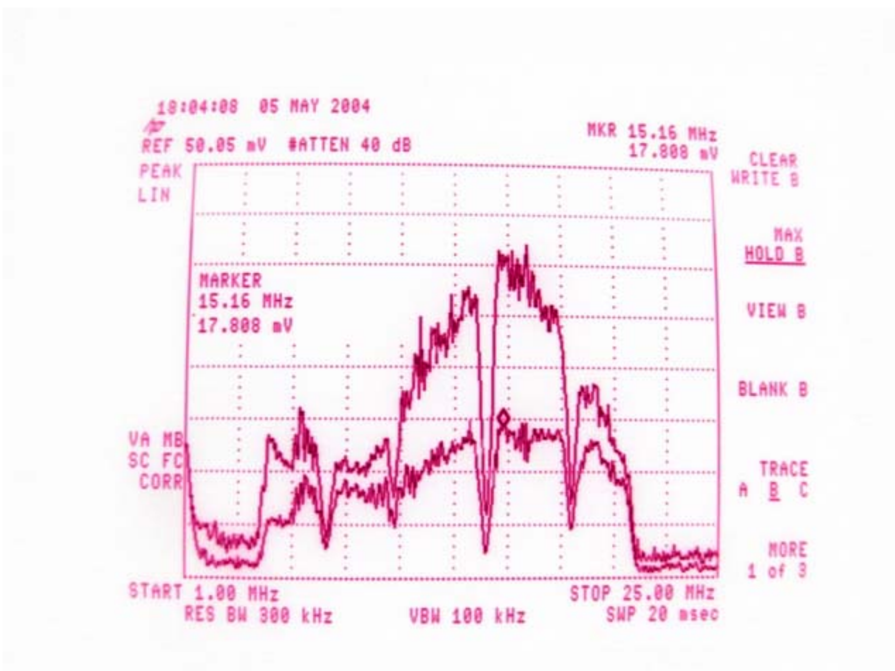


Figure 26: Current measurement: Top trace without additional load and bottom trace with 220Ω additional load

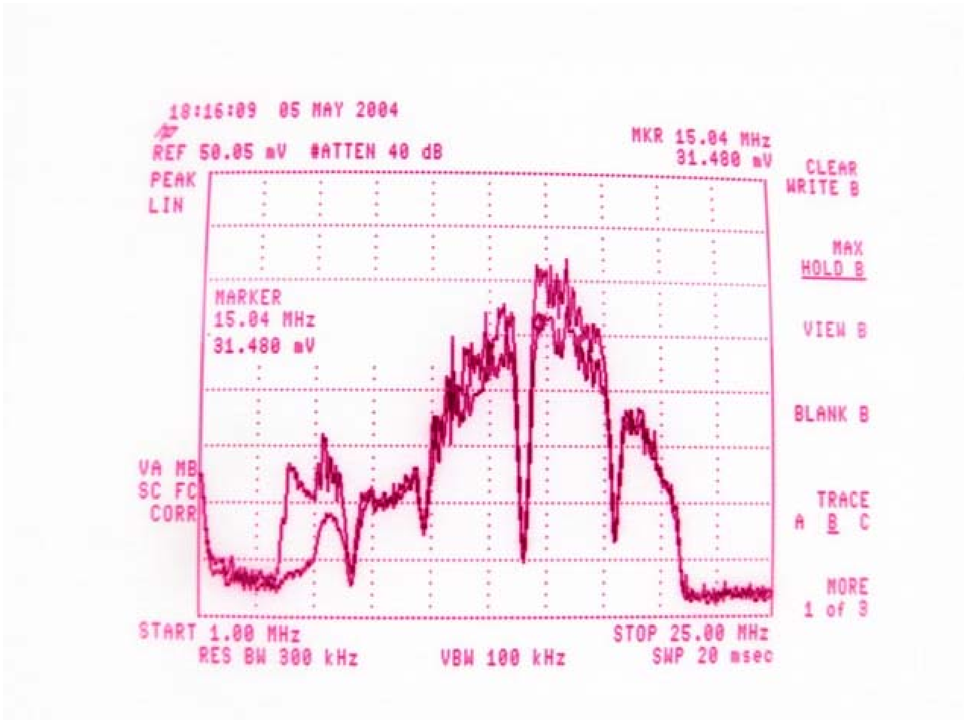


Figure 27: Current measurement: Top trace without additional load and bottom trace with a 2200Ω additional load

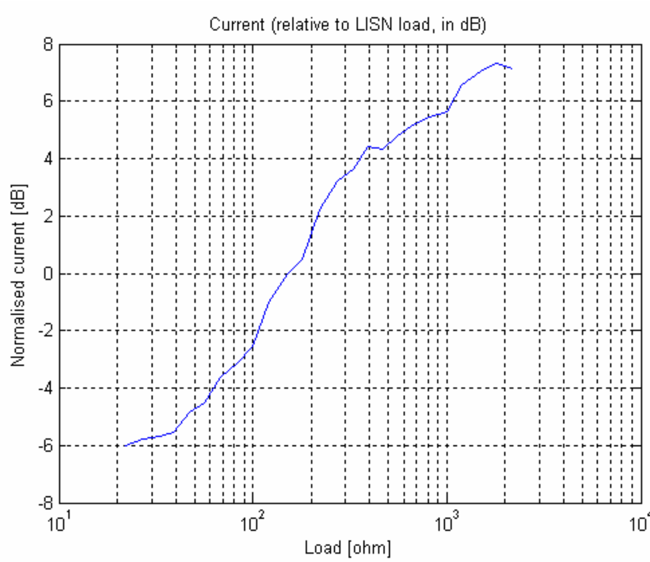


Figure 28: Detailed characteristic of the output stage from the Zeus bridge modem

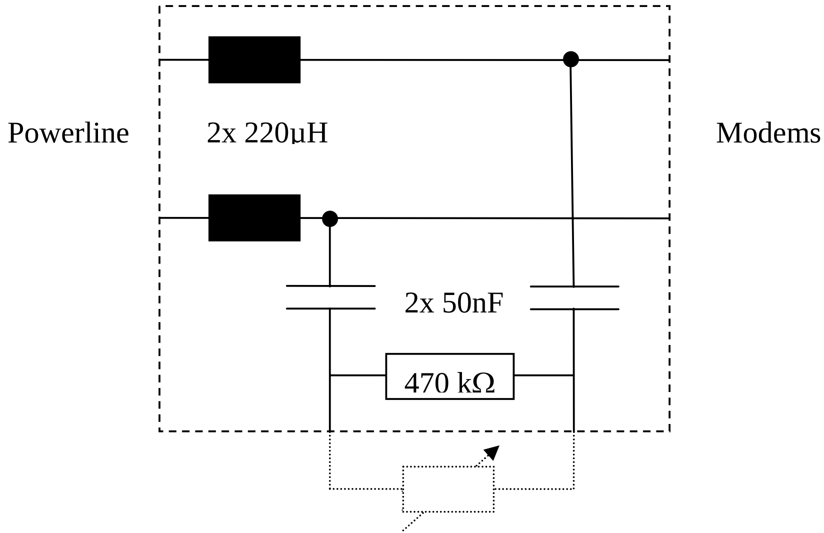


Figure 29: Schematic to change the load of the powerline to measure the current behaviour of the modems

12.2 CORINEX MODEM

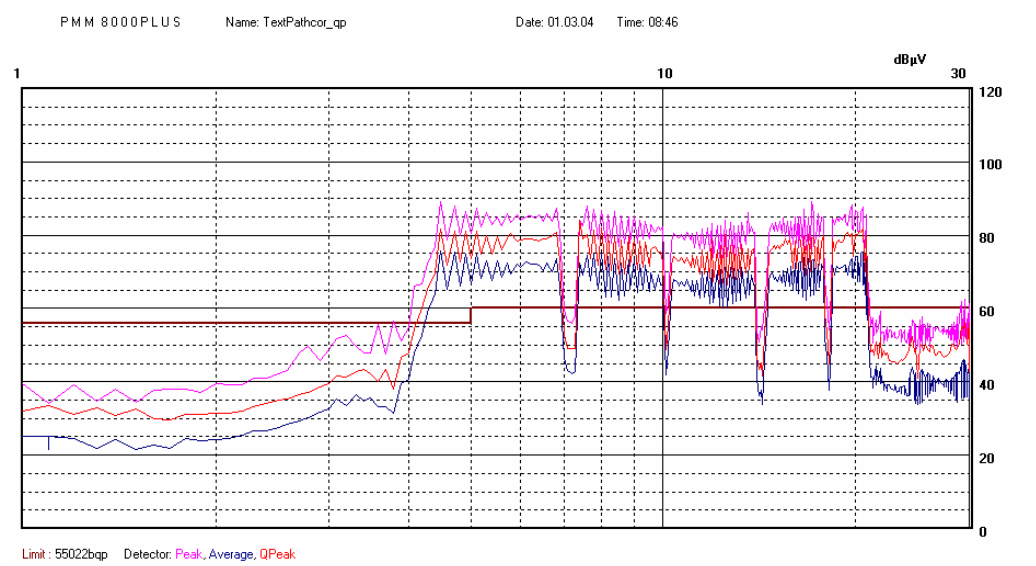


Figure 30: Conducted measurement of two Corinex modems in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

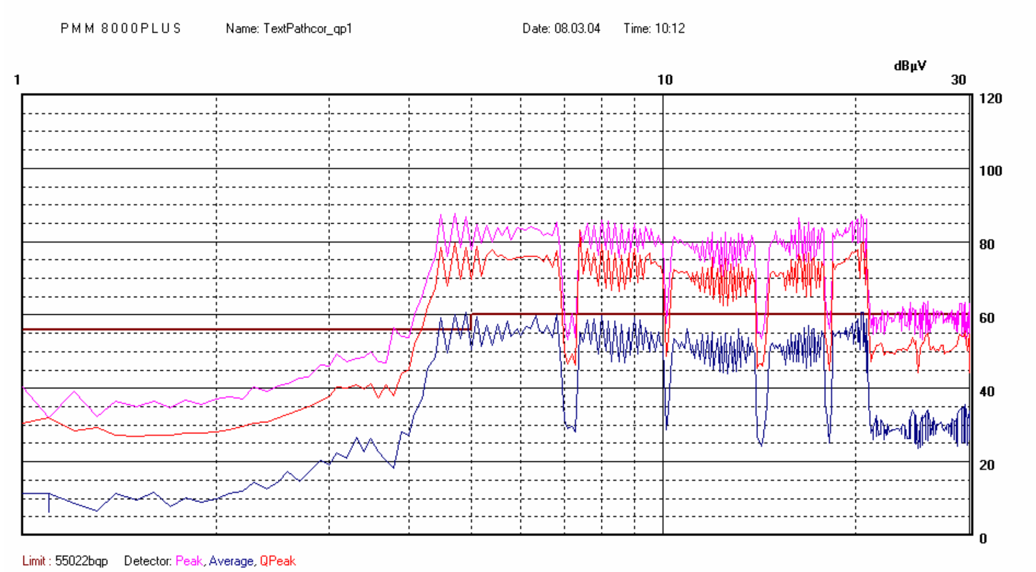


Figure 31: Conducted measurement of two Corinex modems in 1 Mbps transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

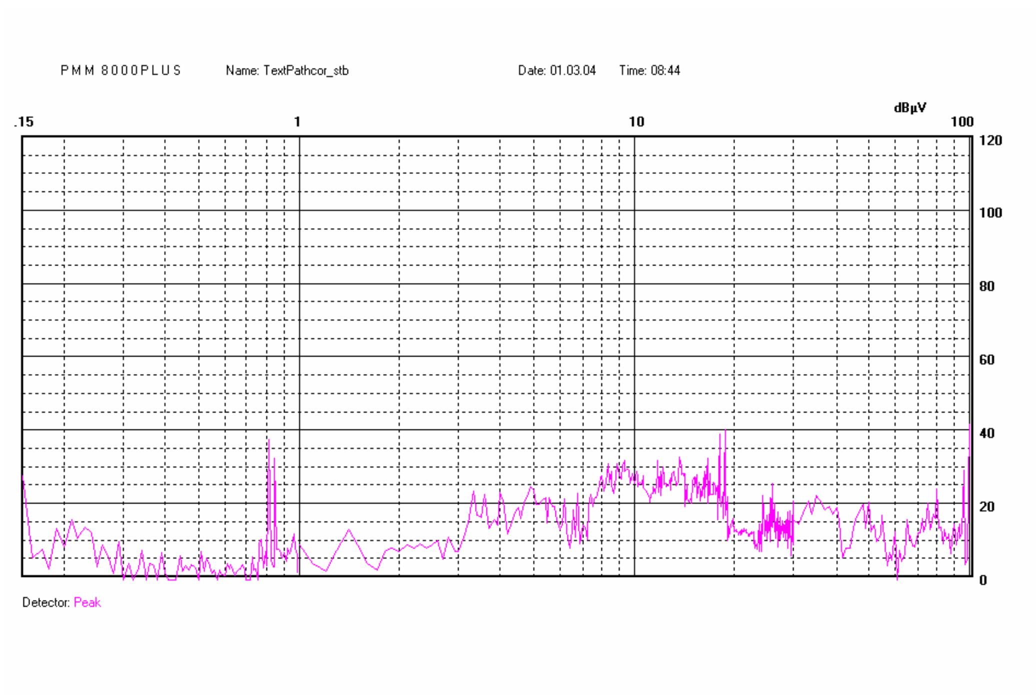


Figure 32: Conducted measurement of two Corinex modems in standby mode. (Peak time = 2 ms and BW=9kHz)

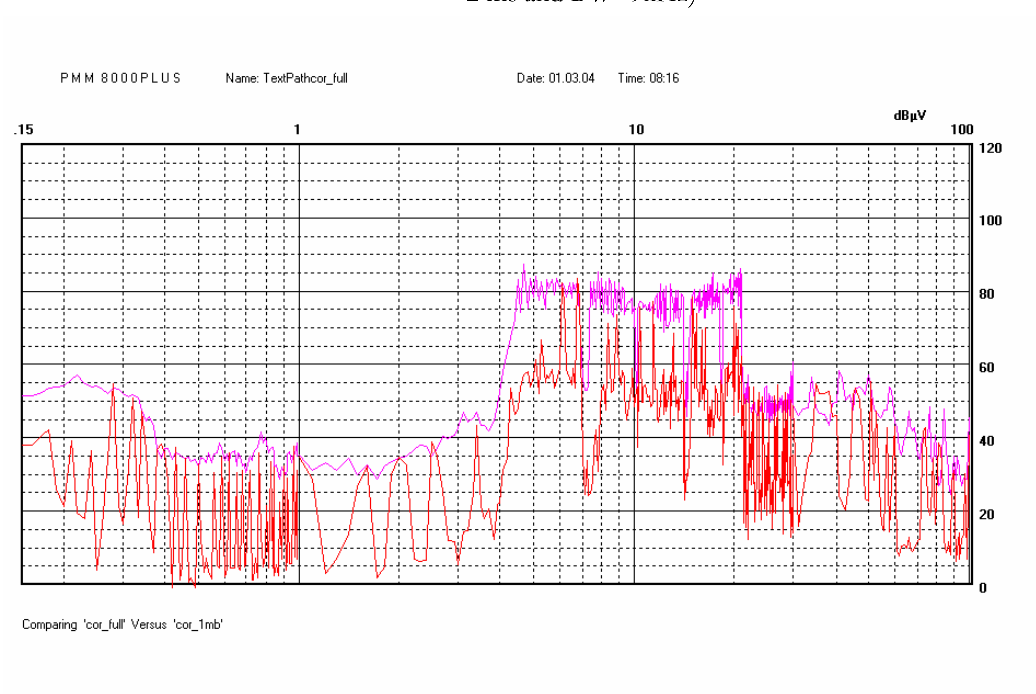


Figure 33: Conducted measurement of two Corinex modems. The red trace corresponds to the modems being in a transfer rate mode of 1 Mbps and the violet trace in maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

12.3 DEVOLO MODEM

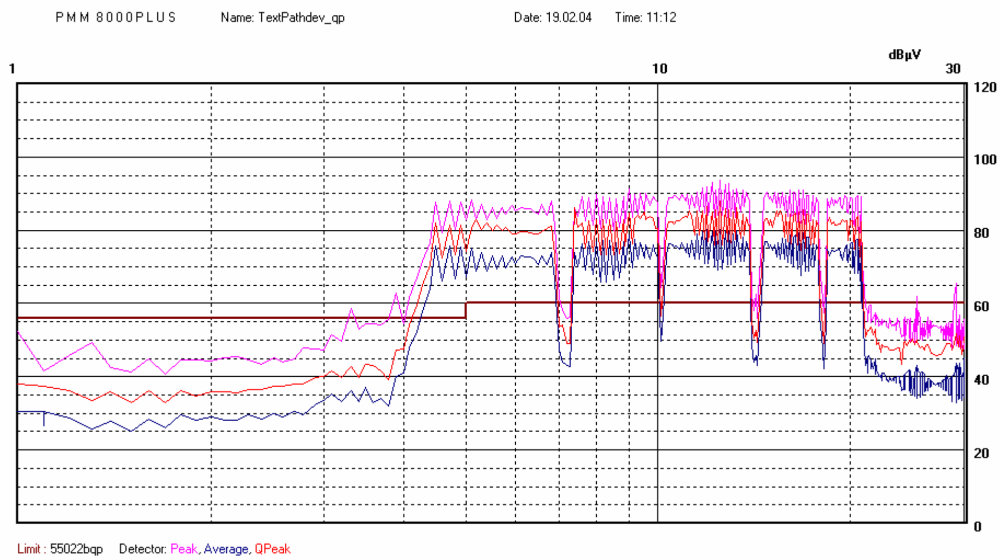


Figure 34: Conducted measurement of two Devolo modems in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

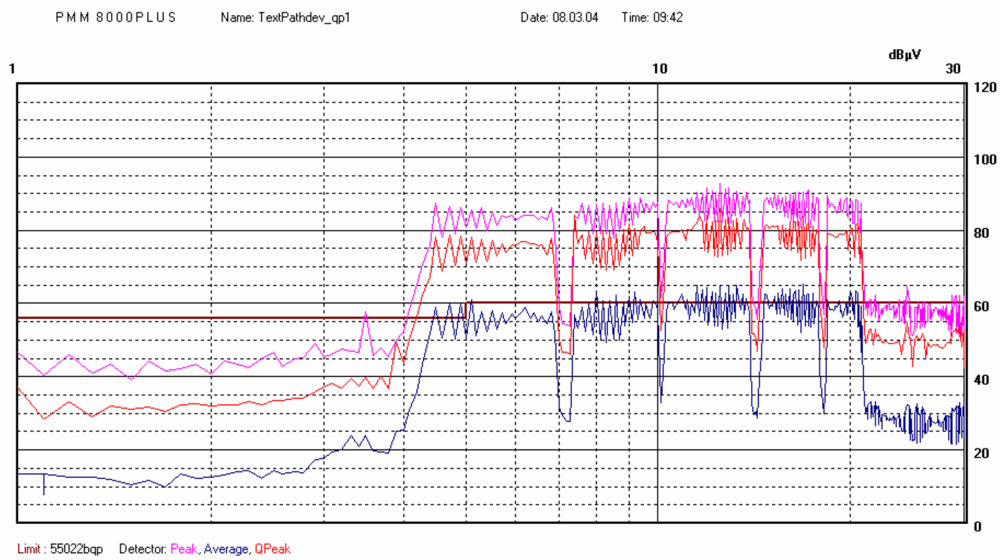


Figure 35: Conducted measurement of two Devolo modems in 1 Mbps transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

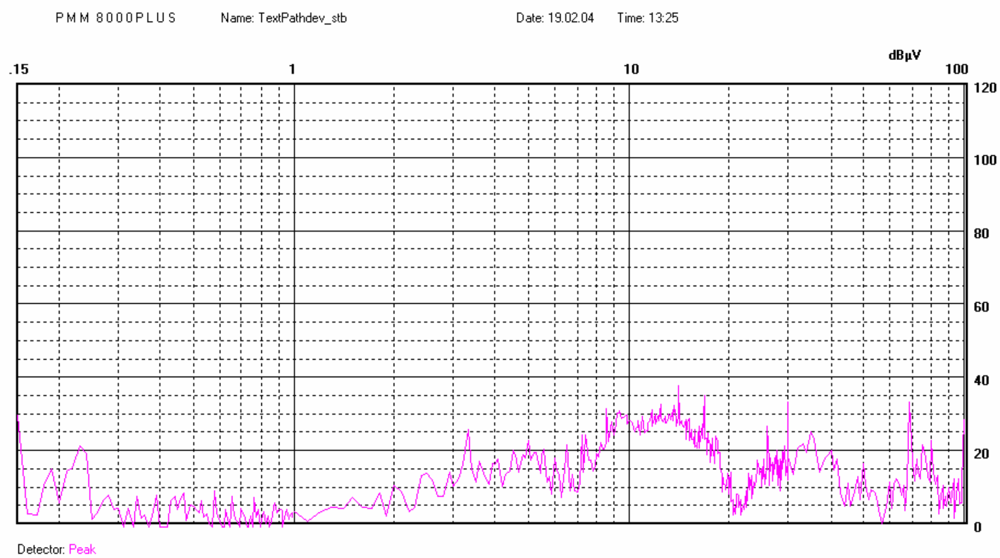


Figure 36: Conducted measurement of two Devolo modems in standby mode. (Peak time = 2 ms and BW=9kHz)

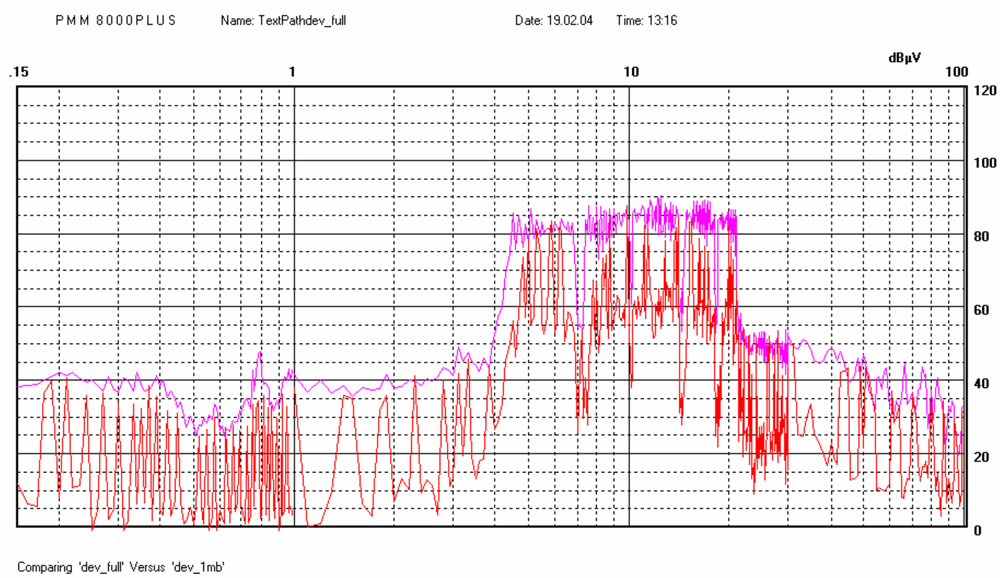


Figure 37: Conducted measurement of two Devolo modems. The red trace corresponds to the modems operating at a transfer rate mode of 1 Mbps and the violet trace corresponds to maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

12.4 NIRODA MODEM

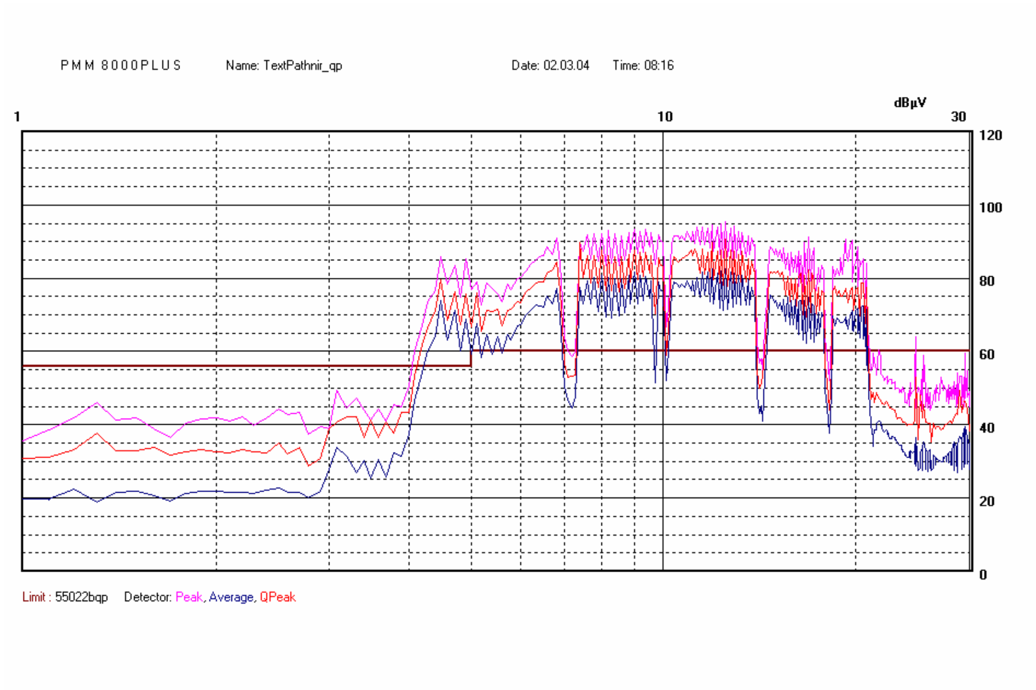


Figure 38: Conducted measurement of two Niroda modems in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

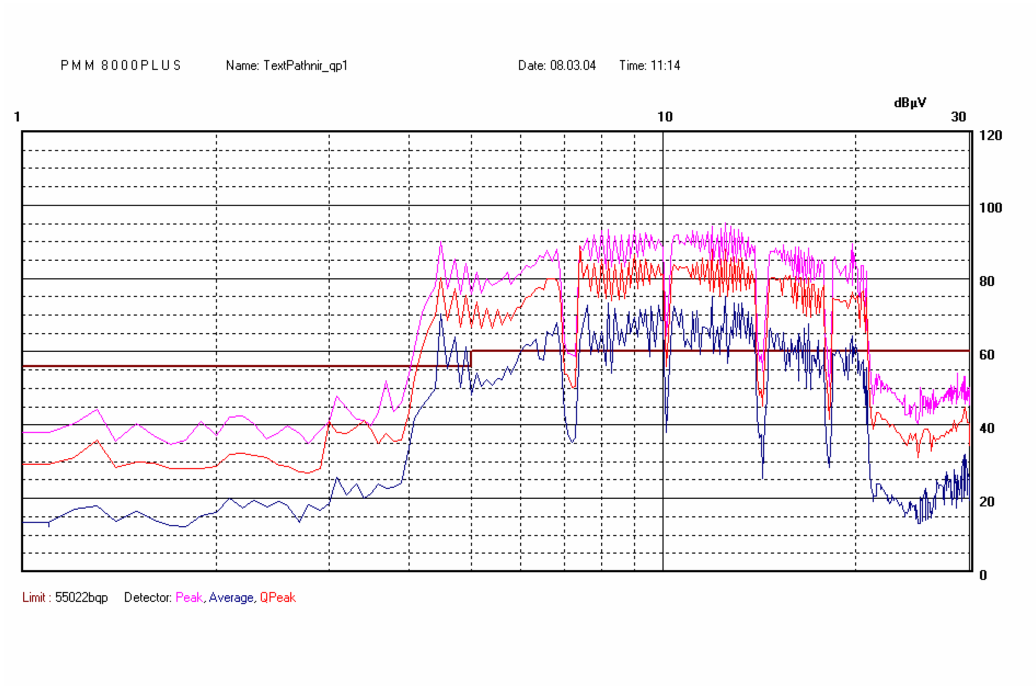


Figure 39: Conducted measurement of two Niroda modems in 1 Mbps transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

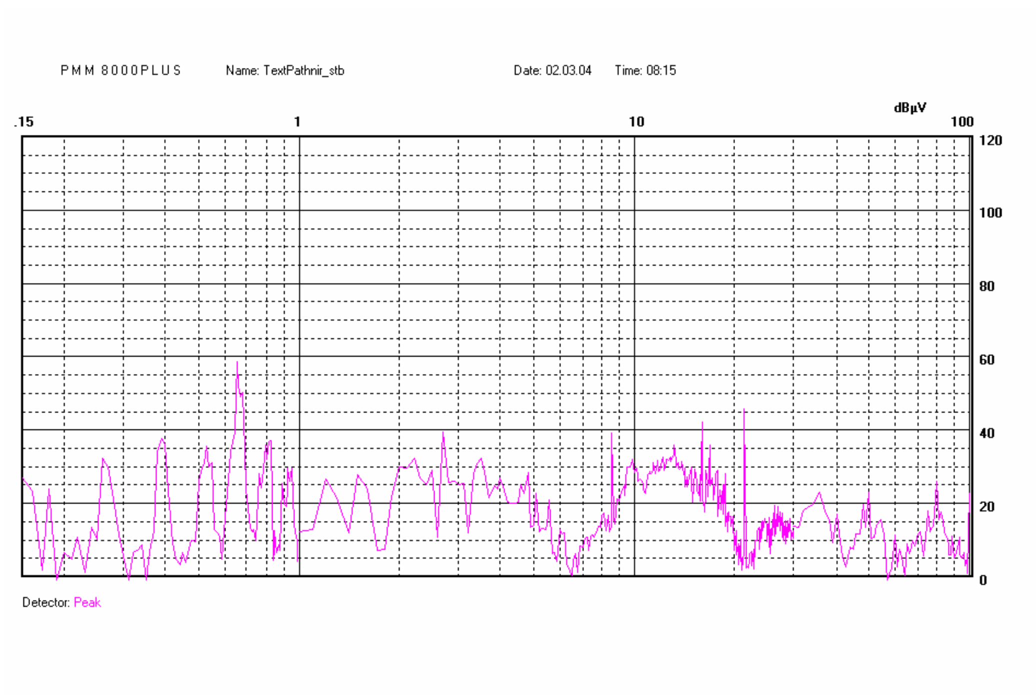


Figure 40: Conducted measurement of two Niroda modems in standby mode. (Peak time = 2 ms and BW=9kHz)

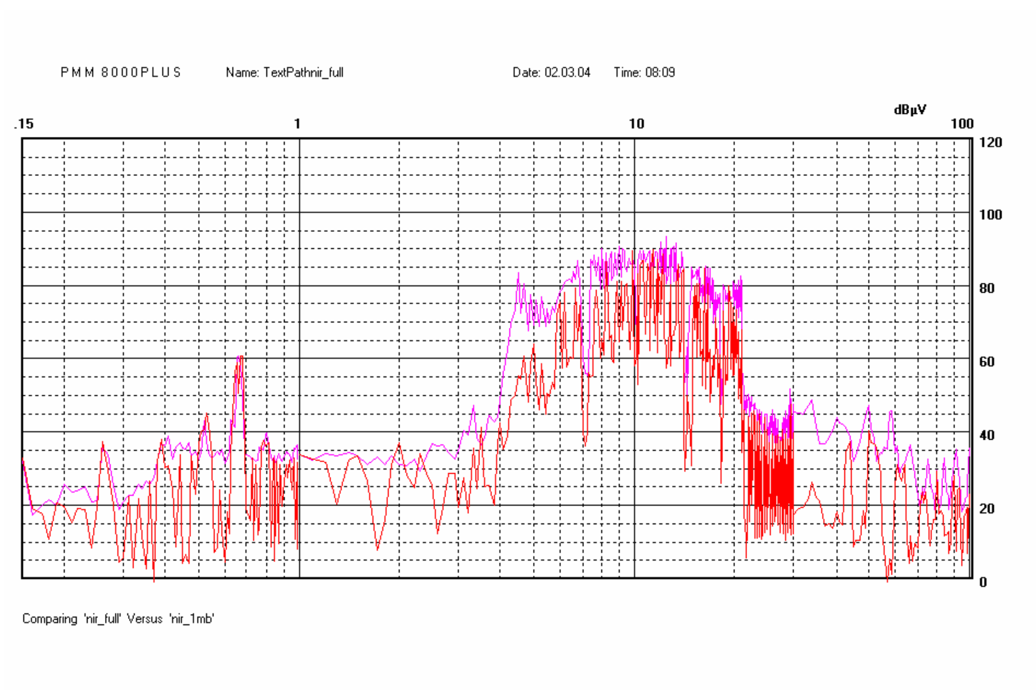


Figure 41: Conducted measurement of two Niroda modems. The red trace corresponds to the modems set to a transfer rate mode of 1 Mbps and the violet trace to the maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

12.5 MODEM ZEUS

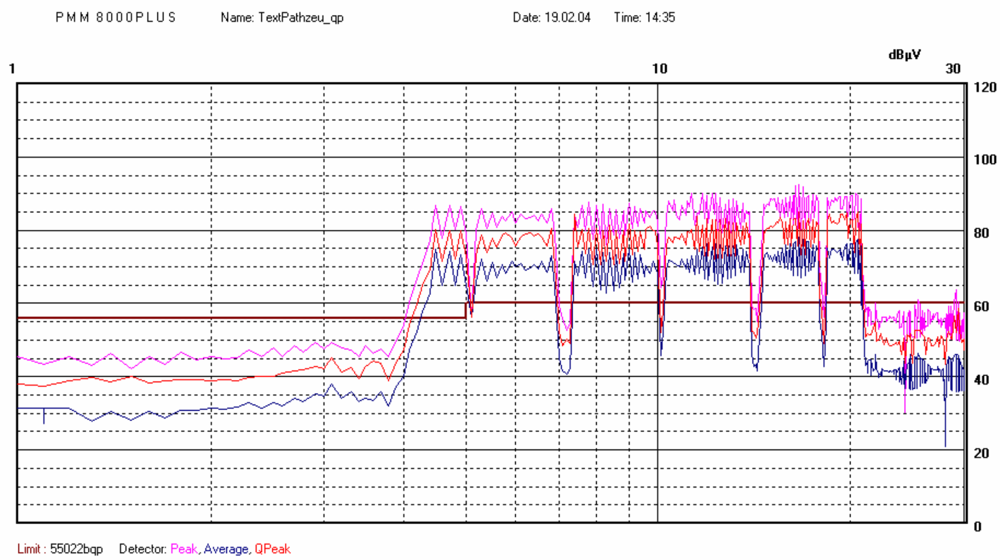


Figure 42: Conducted measurement of two Zeus modems in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

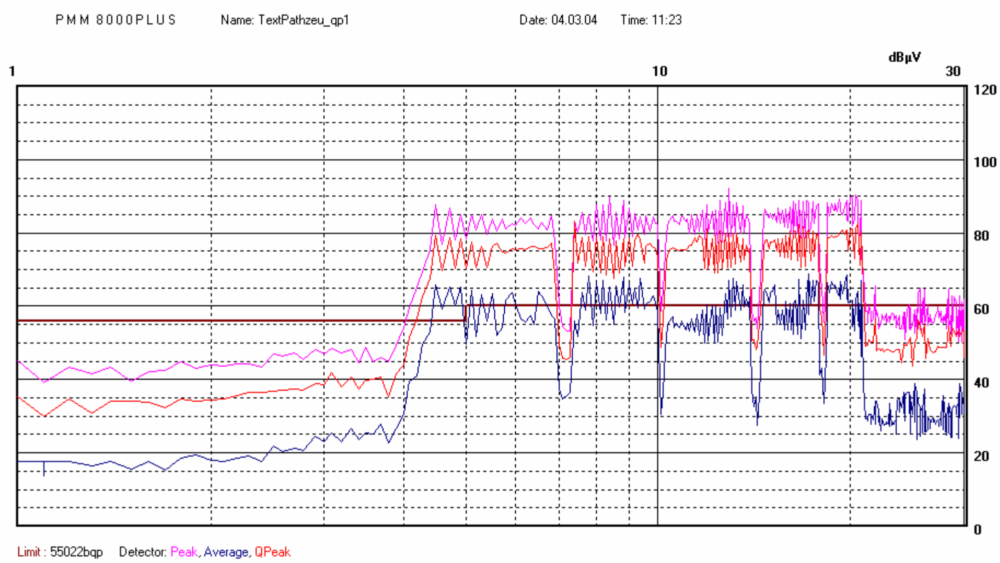


Figure 43: Conducted measurement of two Zeus modems in 1 Mbps transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

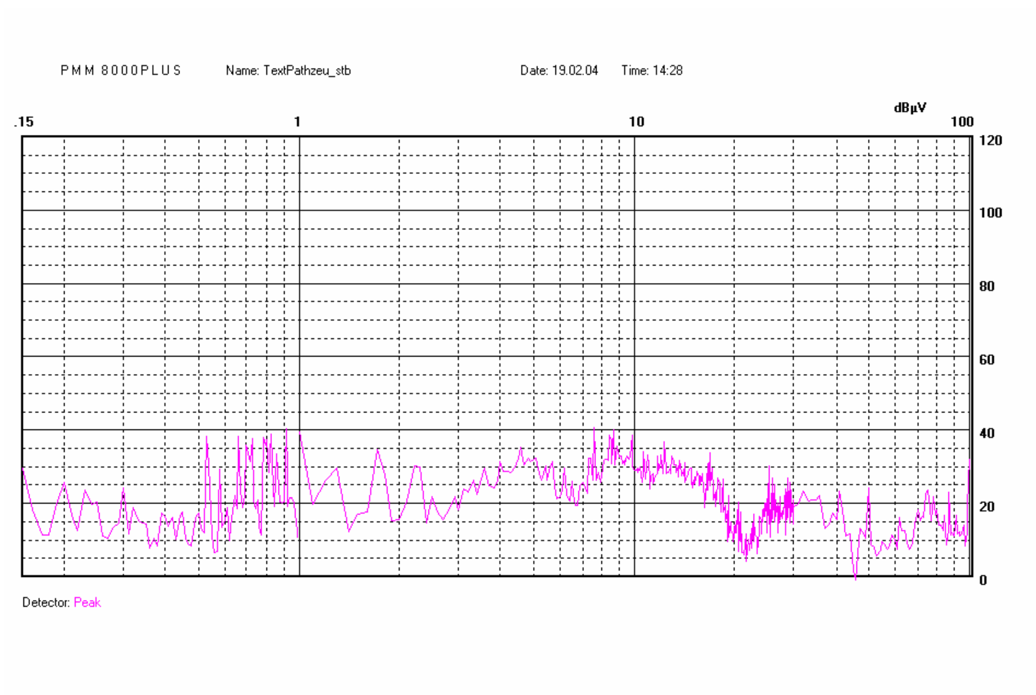


Figure 44: Conducted measurement of two Zeus modems in standby mode. (Peak time = 2 ms and BW=9kHz)

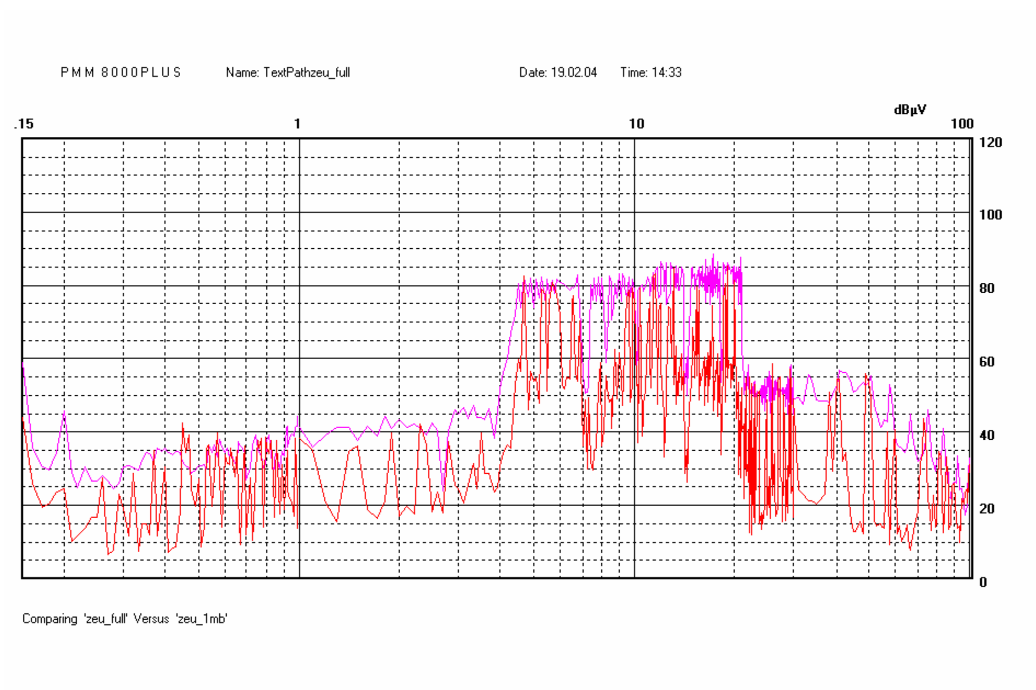


Figure 45: Conducted measurement of two Zeus modems. The red trace corresponds to the modems being in a transfer rate mode of 1 Mbps and the violet trace to maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

12.6 ZEUS MODEM (WALL MOUNT USB)

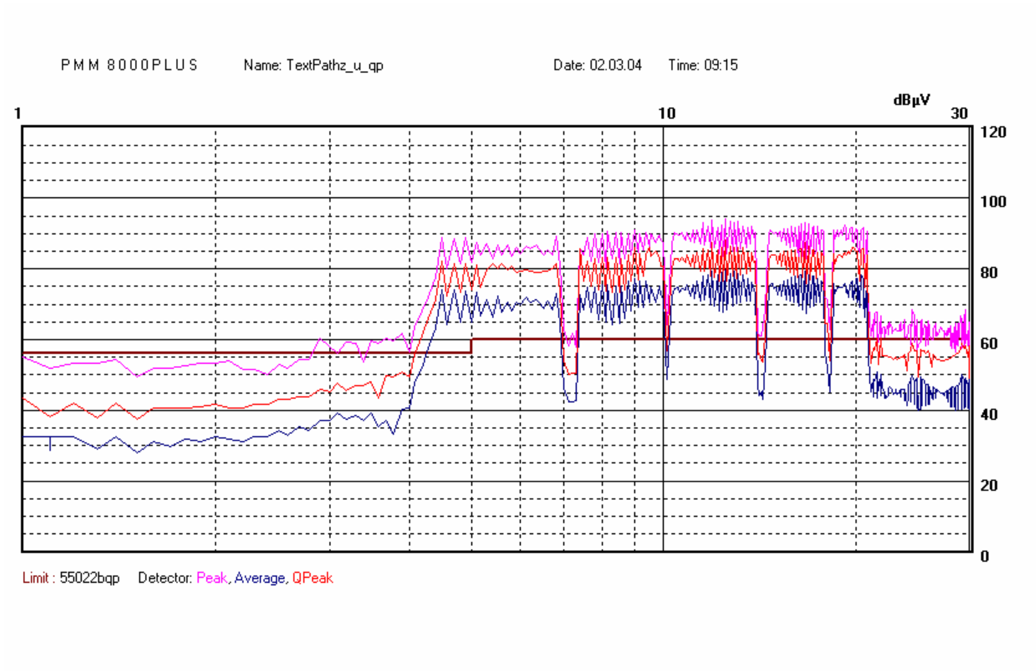


Figure 46: Conducted measurement of two Zeus modems (wall mount usb) in maximum transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

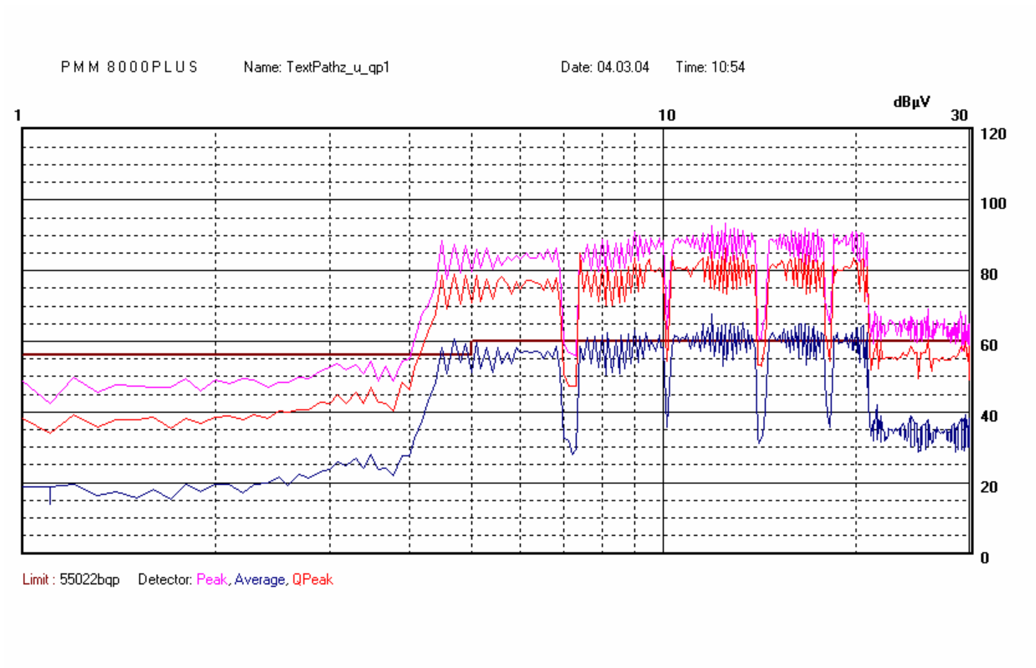


Figure 47: Conducted measurement of two Zeus modems (wall mount usb) in 1 Mbps transfer rate mode. (Quasi-Peak time = 500ms, Peak time = 2 ms, Average time = 10 ms and BW=9kHz)

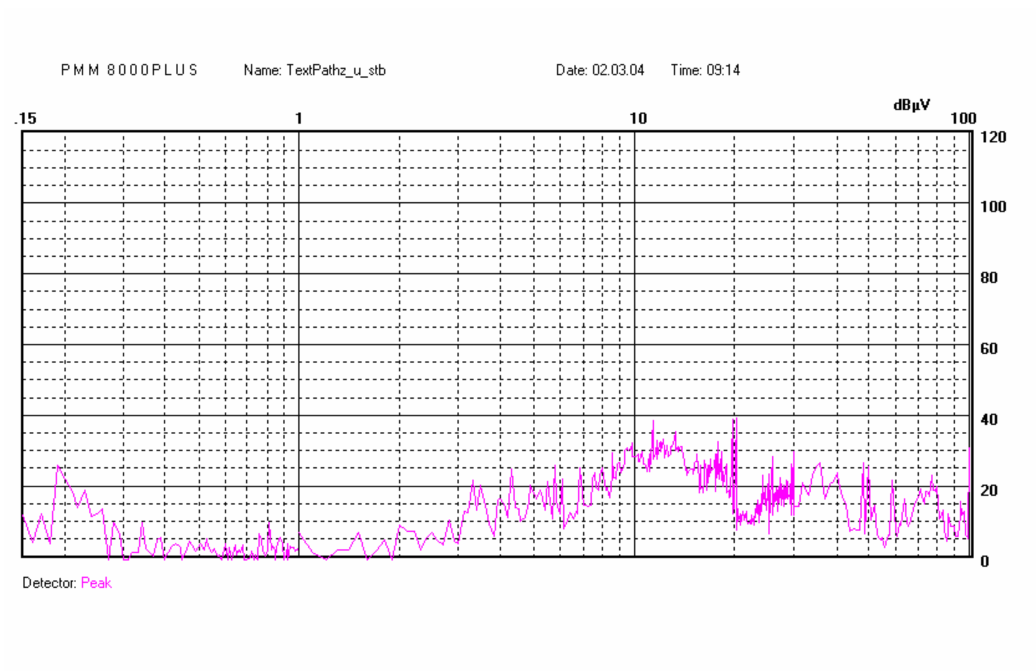


Figure 48: Conducted measurement of two Zeus modems (wall mount usb) in standby mode. (Peak time = 2 ms and BW=9kHz)

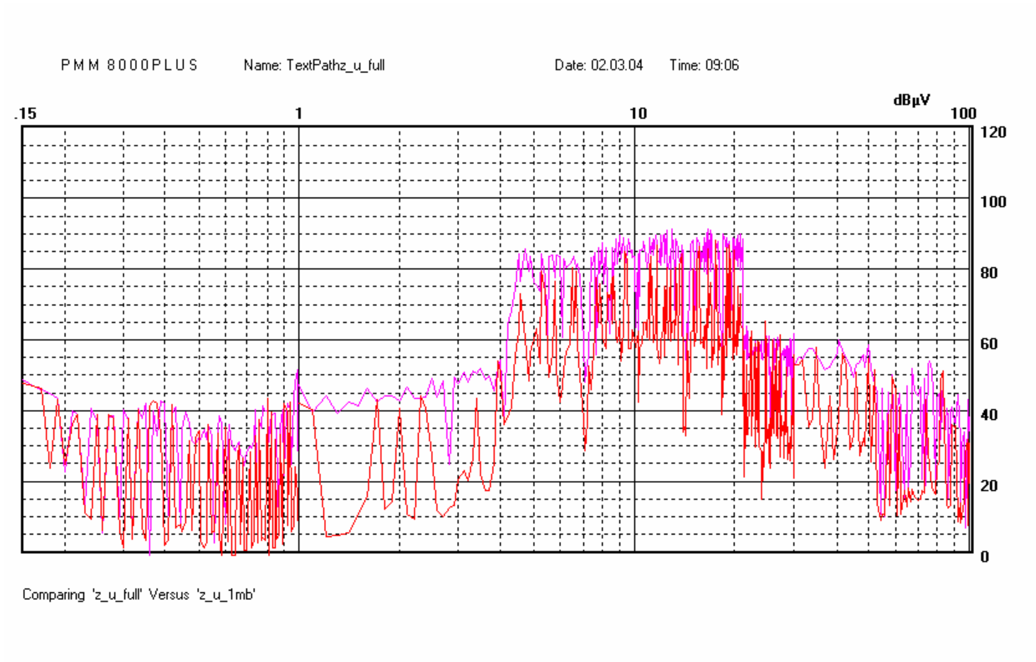


Figure 49: Conducted measurement of two Zeus modems (wall mount usb). The red trace corresponds to the modems being in a transfer rate mode of 1 Mbps and the violet trace to maximum transfer rate mode (Peak time = 2 ms and BW=9kHz)

12.7 DECAMETRIC RADIO AMATEUR FREQUENCY BANDS

Table 28: Decametric frequency bands

Meter Band	Frequency Band	Homeplug removed carriers [MHz]
1750 meters	165-190 kHz	
160 meters	1800-1950 kHz	
80 meters	3.50-3.90 MHz	
40 meters	7.00-7.30 MHz	7.03 MHz, 7.23 MHz
30 meters	10.10-10.15 MHz	10.2 MHz
20 meters	14.00-14.350 MHz	14.06 MHz 14.26 MHz 14.45 MHz
17 meters	18.068-18.168 MHz	17.97 MHz 18.16 MHz
15 meters	21.00-21.45 MHz	
12 meters	24.89-24.99 MHz	
11 meters	27.12 MHz	
10 meters	28.00-29.70 MHz	
6 meters	50.00-54.00 MHz	
2 meters	144.0-148.0 MHz	
0.7 meters	430-440 MHz	

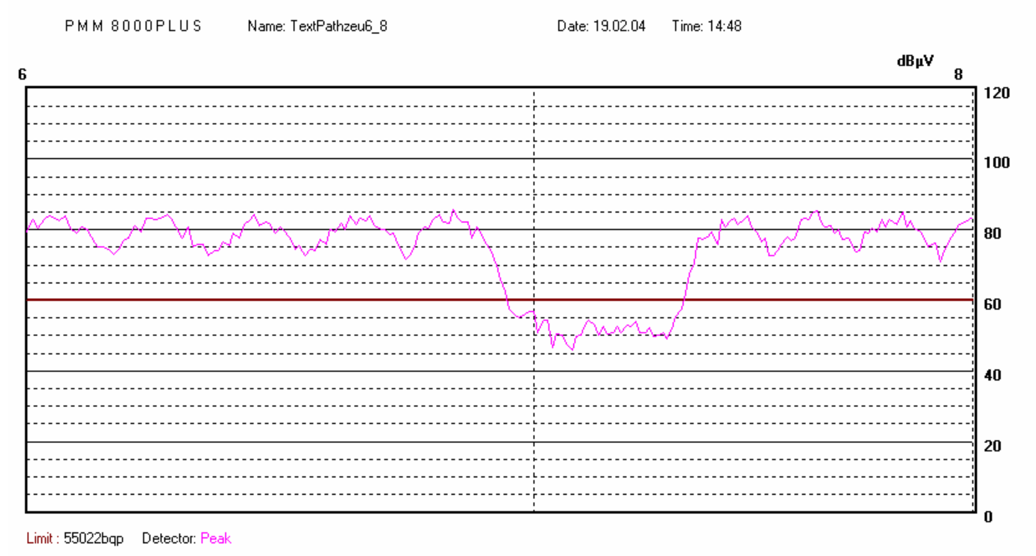


Figure 50: Conducted measurement of two Zeus modems in maximum transfer rate mode. (Peak time = 2 ms and BW=9kHz)

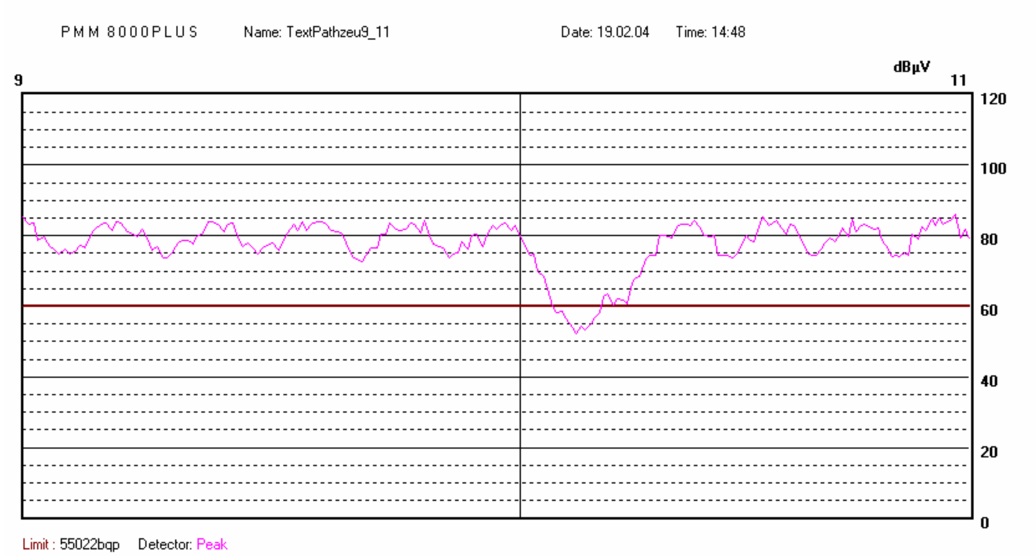


Figure 51: Conducted measurement of two Zeus modems in maximum transfer rate mode. (Peak time = 2 ms and BW=9kHz)

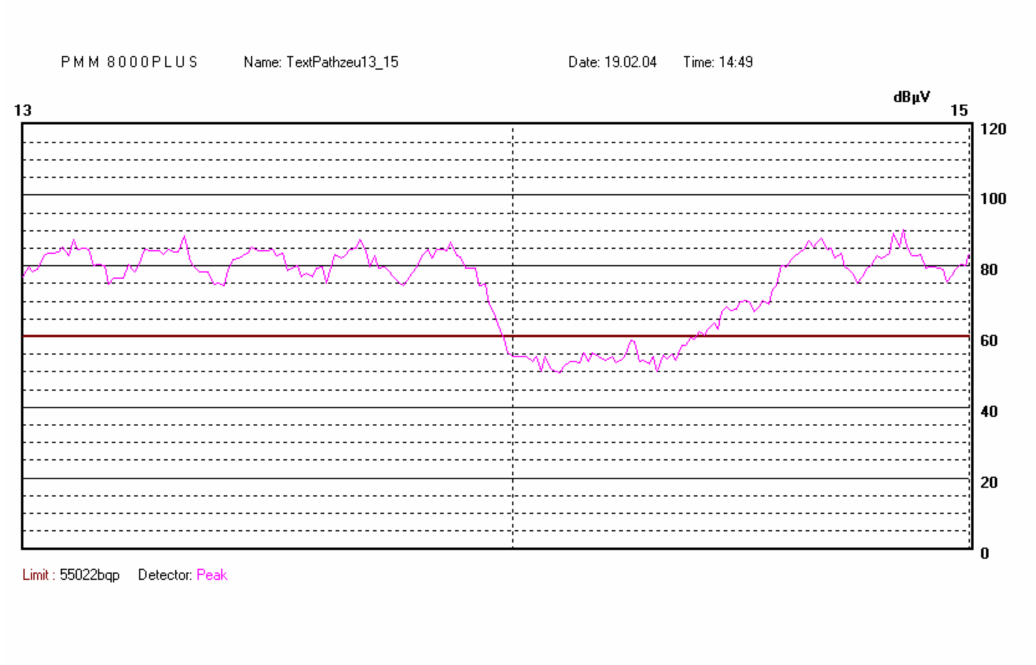


Figure 52: Conducted measurement of two Zeus modems in maximum transfer rate mode. (Peak time = 2 ms and BW=9kHz)

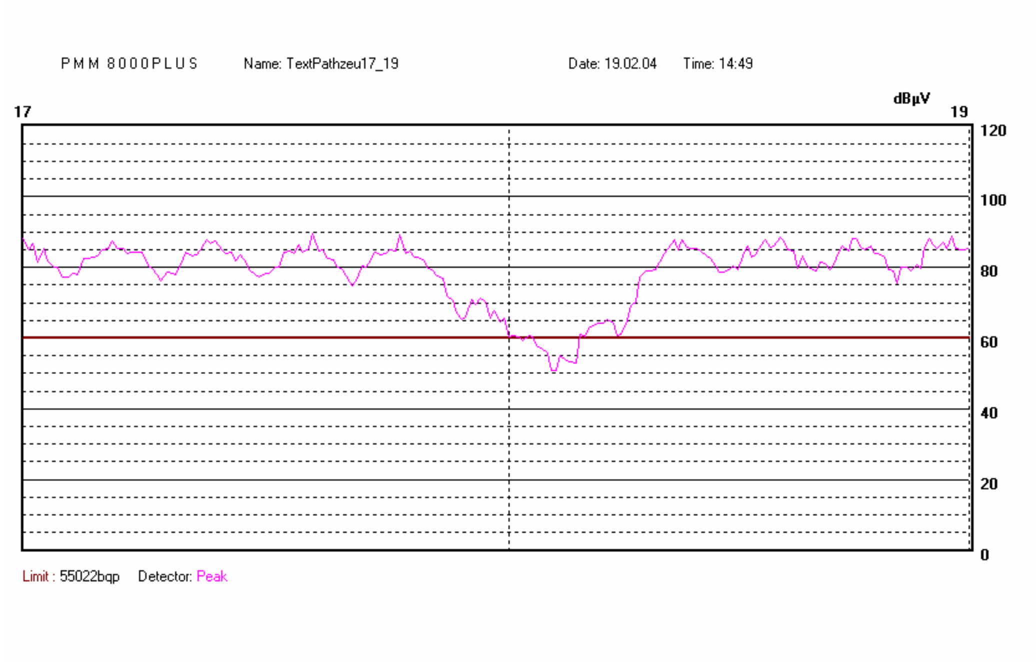


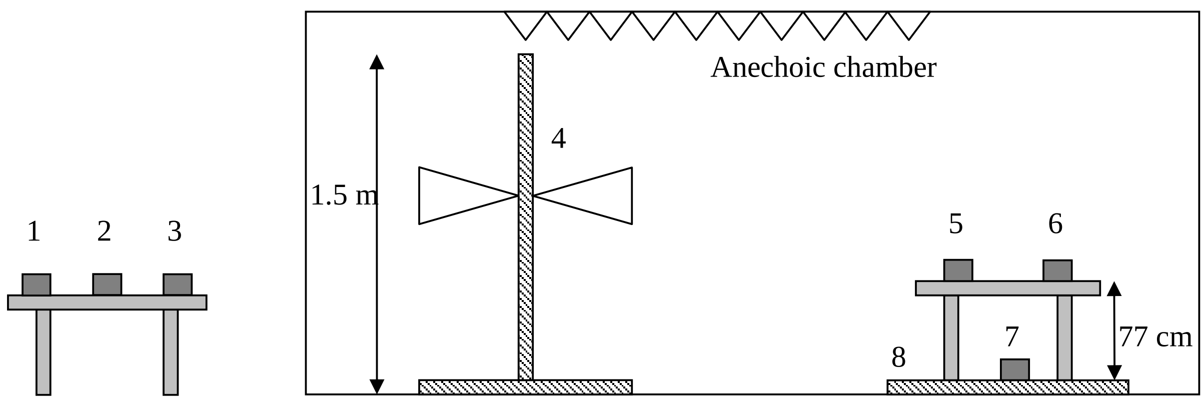
Figure 53: Conducted measurement of two Zeus modems in maximum transfer rate mode. (Peak time = 2 ms and BW=9kHz)

12.8 RADIATED MEASUREMENTS SETUP

- The radiated measurements according to the EN55022 / CISPR16 norms.
- Frequency measurements between 30 MHz and 240 MHz in tree parts

Table 29: PMM8000Pus measurement configuration			
Frequency [MHz]	**30 to 60**	**60 to 120**	**120 to 240**
Step [kHz]	100	100	100
BW [kHz]	120	120	120
Peak time [ms]	2	2	2
Quasi-Peak time [ms]	500	500	500

- Determine the maximum radiated field for horizontal and vertical polarisation:
  - Measurement with peak detector
  - Antenna height variation between 0.3m and 1.7m
  - 360° horizontal rotation of the modems under test with the turntable
- Final measurement for each orientation
  - Measurement with quasi-peak detector
  - Antenna height and turntable orientation according to the maximum radiated field
- Measurement configuration



1 Control computer
2 EMI Test signal analyser: PMM8000Plus
3 Amplifier: AR LM1000B
4 Bicone antenna: Schwarzbeck 9106
5 Powerline modems: Zeus bridge
6 Transfer and modem control computer
7 LISN: R&S ESH3-Z5
8 Turntable

Figure 54: Radiated measurements configuration

12.9 RADIATED MEASUREMENTS RESULTS WITH ZEUS BRIDGE MODEMS

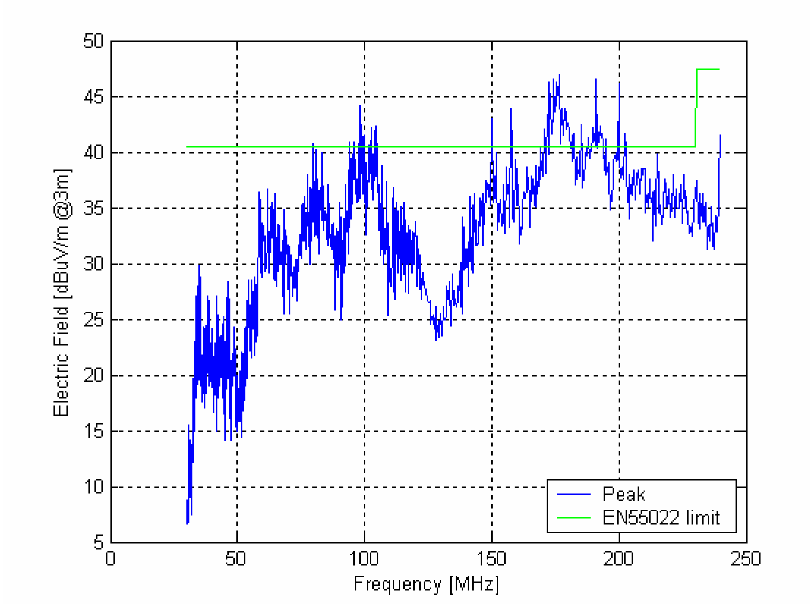


Figure 55: Radiated measurement, horizontal polarisation (modem in maximum emission mode)

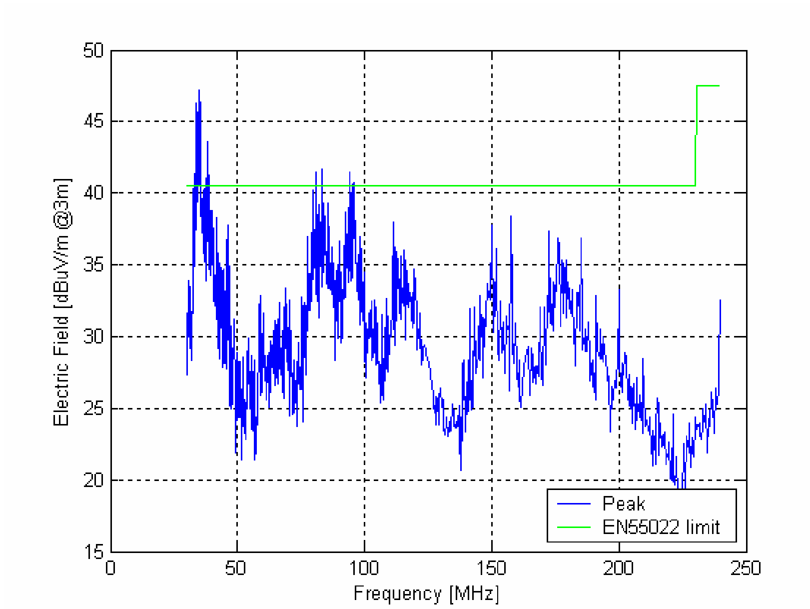


Figure 56: Radiated measurement at 3m, vertical polarisation (modem in maximum emission mode)

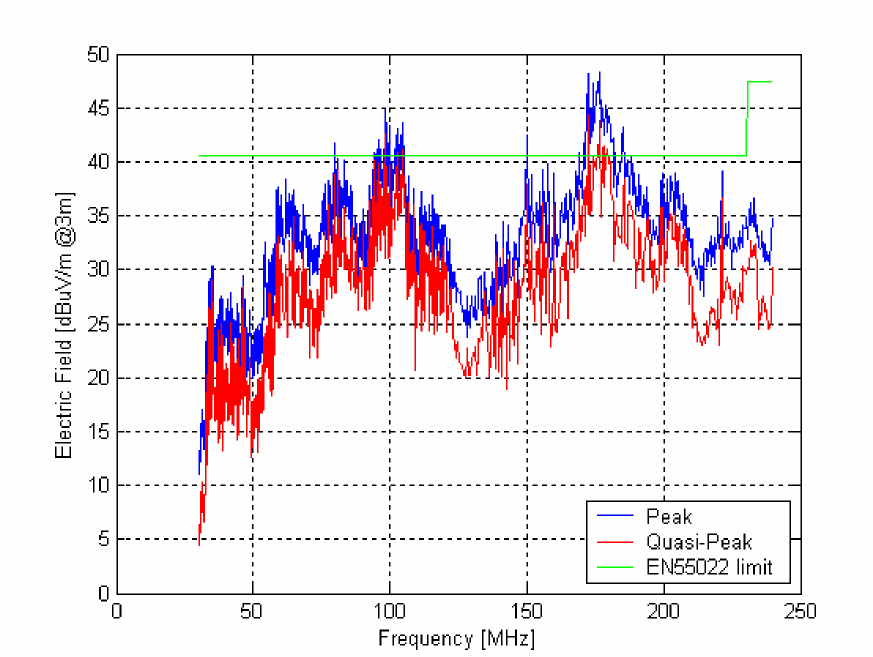


Figure 57: Radiated measurement at 3m, horizontal polarisation (modems in maximum emission mode)

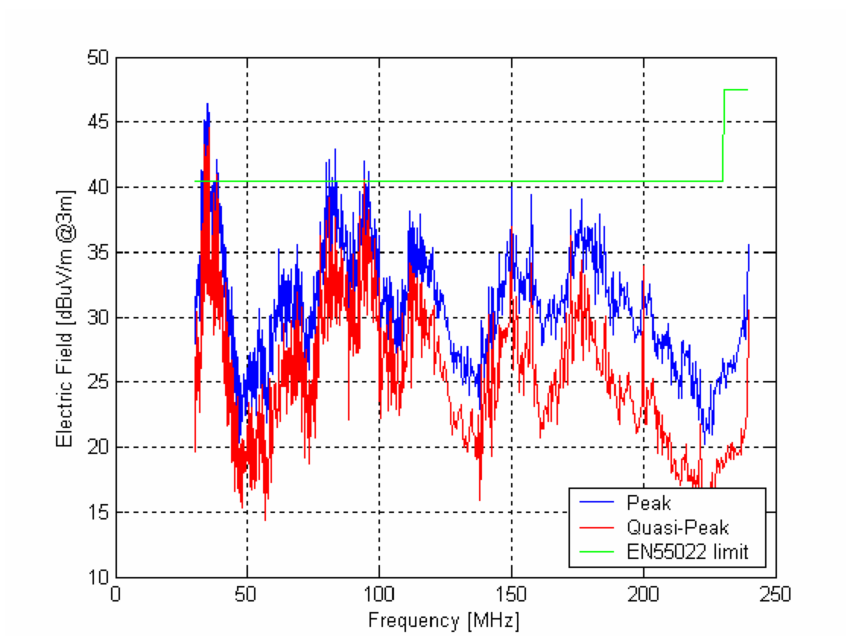


Figure 58: Radiated measurement at 3m, vertical polarisation (modems in maximum emission mode)

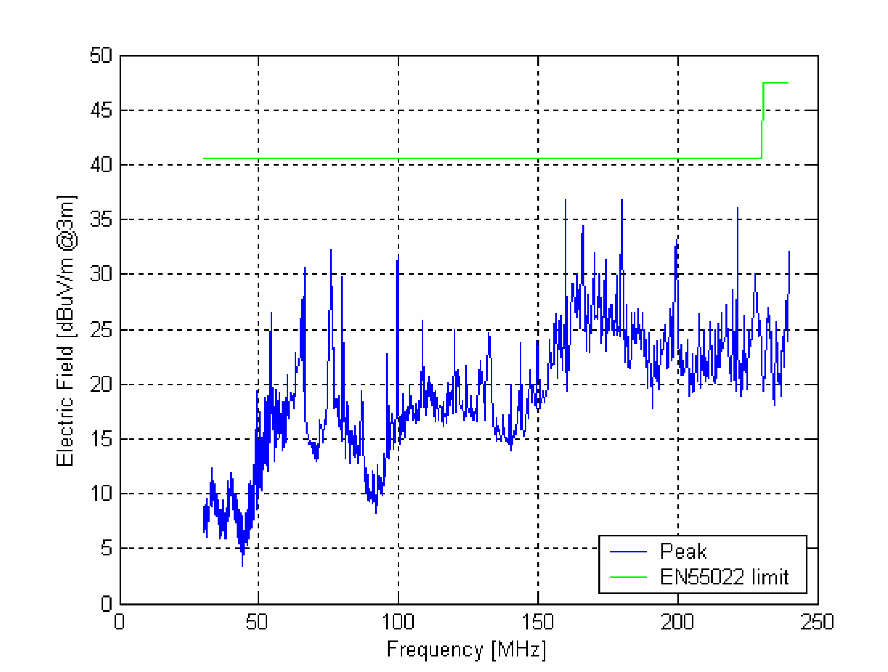


Figure 59: Radiated measurement at 3m, horizontal polarisation (Computers only without modems)

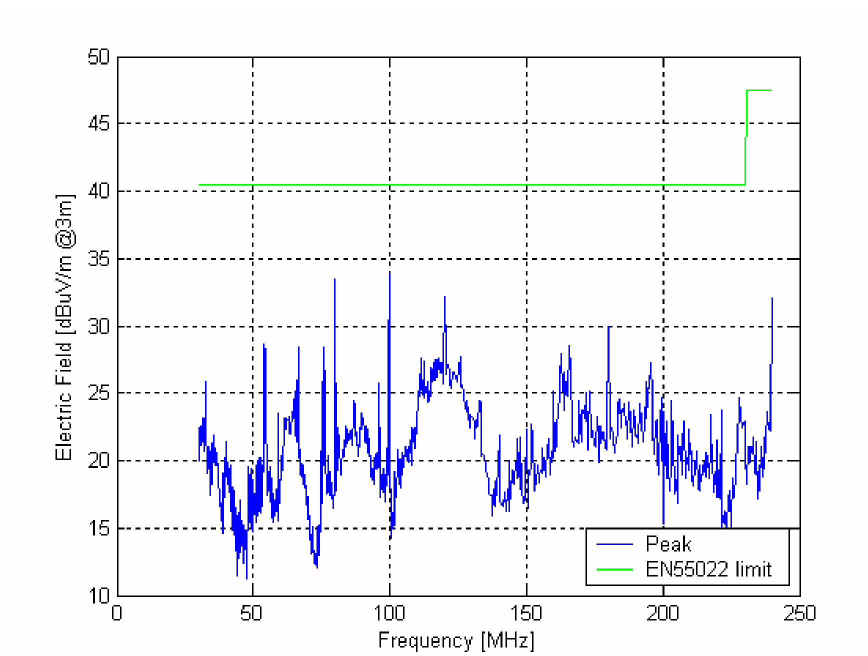


Figure 60: Radiated measurement at 3m, vertical polarisation (Computers only without modems)

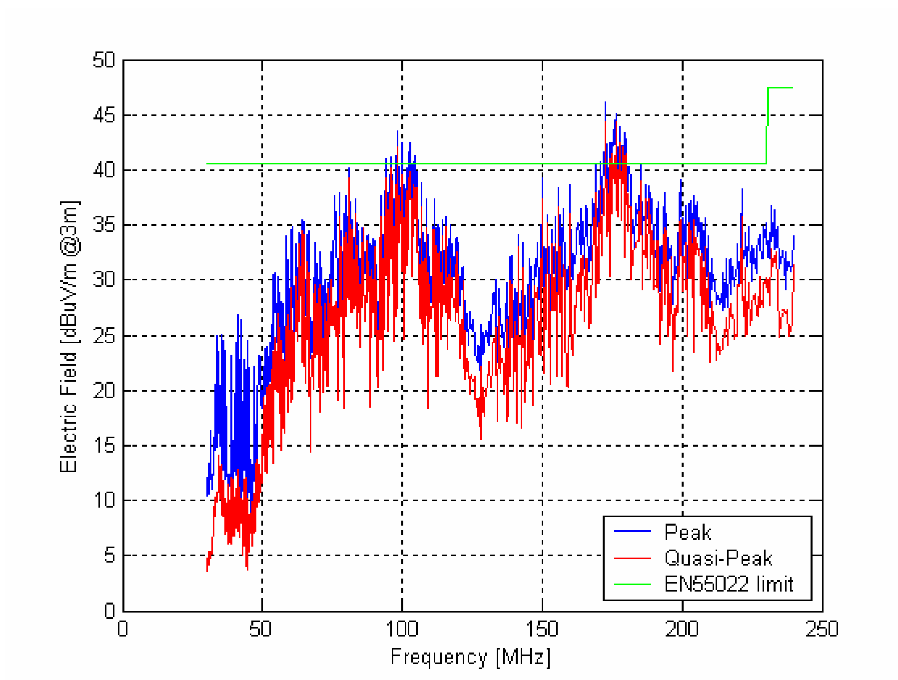


Figure 61: Radiated measurement at 3m, horizontal polarisation (modems in standby mode)

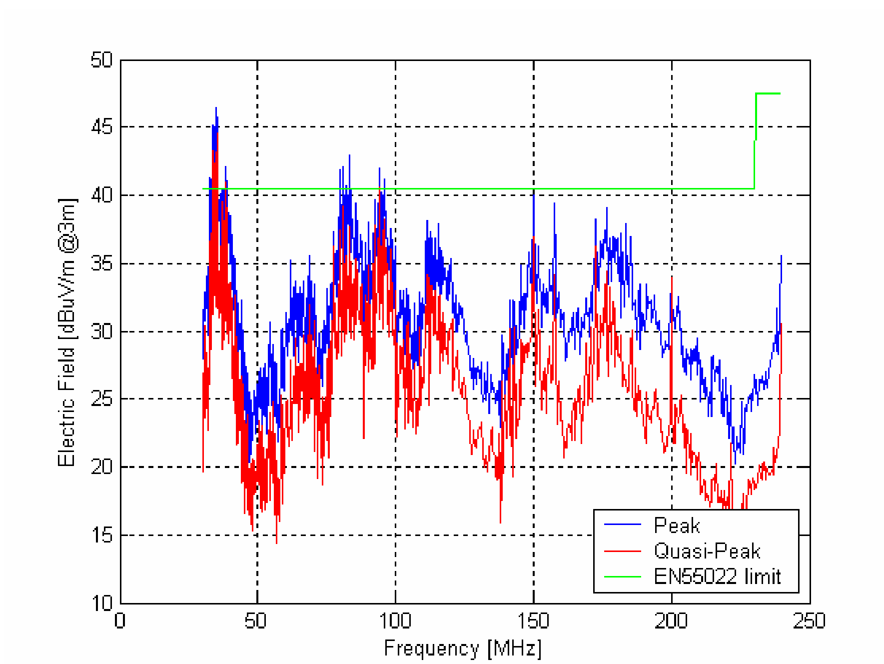


Figure 62: Radiated measurement at 3m, vertical polarisation (modems in standby mode)

12.10 COMPARISON BETWEEN INDOOR MODEMS

Table 30: Comparison between indoor modems

N°	Manufacturer	Port	Type	Homeplug	Chipset	Standards	Web
ATL60140	Archnet	USB/ETH					www.archnetco.com
102094	Conexant			1.0	CX11656		www.conexant.com
USB-Homeplug	Cogency	USB	Wall mount	1.0	Cogency	FCC	www.cogency.com
PL9720-ETH	Asoka	ETH	Wall mount	1.01	Intellon	FCC	www.asokausa.com
PL9720-USB	Asoka	USB	Wall mount	1.01	Intellon	FCC	www.asokausa.com
F5D4070	Belkin	ETH	Wall mount	yes	(Intellon)		www.belkin.com
F5D4050	Belkin	USB	Wall mount	yes	(Intellon)		www.belkin.com
PE-902-EB	Gigafast	ETH	Bridge	1.0	Cogency		www.gigafast.com
PE-909-UI	Gigafast	USB	Wall mount	1.0	Cogency		www.gigafast.com
PE-901-UI	Gigafast	USB	Bridge	1.0	Cogency		www.gigafast.com
PowerNet	Corinex	ETH/USB/PCI	Bridge/Wall mount	1.01	Intellon	FCC CE	www.corinex.com
Intelligent_PowerNet	Corinex	ETH	Bridge	1.01	Intellon	FCC CE	www.corinex.com
Wireless_PowerNet	Corinex	ETH/WLAN	Bridge	1.01	Intellon	FCC CE	www.corinex.com
	dima	ETH/USB	Wall mount	yes	Intellon	FCC CE EN NB30	www.power-surfer.com
DHP-100	D-link	ETH	Wall mount	1.0		FCC CE	www.d-link.com
P-LAN	Goldpfeil	ETH/USB	Bridge / Wall mount				www.elcon-system.de
RD51X1-USB	Intellon	USB	Wall mount	1.0	Intellon	FCC	www.intellon.com
GHPU21	IOGEAR	USB	Wall mount	1.0	Intellon		www.iogear.com
GHPU01	IOGEAR	USB	Bridge	1.0	Intellon		www.iogear.com
GHPB21	IOGEAR	ETH	Bridge	1.0	Intellon		www.iogear.com
Netplug Bridge	lanergy	ETH/USB	Bridge	yes	Cogency	FCC CE EN	www.lanergy.com
Netplug PCI	lanergy	ETH	PCI card	yes	Cogency	FCC CE EN	www.lanergy.com
PLUSB10	Linksys	USB	Wall mount	1.0	Intellon	FCC	www.linksys.com
PLEBR10	Linksys	ETH	Bridge	1.0	Intellon	FCC	www.linksys.com
XE602	Netgear	ETH	Bridge	1.0	Intellon	FCC	www.netgear.com

N°	Manufacturer	Port	Type	Homeplug	Chipset	Standards	Web
XA601	Netgear	USB	Bridge	1.0	Intellon	FCC	www.netgear.com
XE102	Netgear	USB	Wall mount	1.0	Intellon	FCC	www.netgear.com
NeverWire combo	Phonex	ETH/USB	Wall mount	1.0	Intellon		www.phonex.com
NeverWire 14	Phonex	ETH	Bridge	1.0	Intellon		www.phonex.com
SS2501	Siemens	USB	Wall mount	1.0	Cogency	FCC	www.speedstream.com
SS2502	Siemens	ETH	Wall mount	1.0	Cogency	FCC	www.speedstream.com
SS2521	Siemens	WLAN	Wall mount	1.0	Cogency	FCC	www.speedstream.com
SS2524	Siemens	ETH	Router	1.0	Cogency	FCC	www.speedstream.com
M51	STT	ETH	Bridge	1.0	Intellon	FCC CE	www.stt.com.tw
M53	STT	ETH	Wall mount	1.0	Intellon	FCC CE	www.stt.com.tw
U21	STT	USB	Bridge	1.0	Intellon	FCC CE	www.stt.com.tw
U22	STT	USB	Wall mount	1.0	Cogency	FCC CE	www.stt.com.tw
U23	STT	USB	Wall mount	1.0	Intellon	FCC CE	www.stt.com.tw
P11	STT	ETH	PCI card	1.0	Intellon	FCC CE	www.stt.com.tw
DPL100	VCOMM	ETH	Bridge	yes	Intellon		www.vcomm.com.au
DPL100-U	VCOMM	USB	Bridge	yes	Intellon		www.vcomm.com.au
3574	zeus	ETH	Bridge	1.0	Intellon	FCC CE	www.broadband.ch
3575	zeus	USB	Wall mount	1.0	Intellon	FCC CE	www.broadband.ch
	enikia	ETH	Bridge	yes	Enikia		www.enikia.com
	lugh	ETH/USB	Wall mount	oui	Cogency		
Microlink dlan	devolo	USB	Wall mount	yes	Intellon	CE EN	www.devolo.de
Microlink dlan	devolo	ETH	Wall mount	yes	Intellon	CE EN	www.devolo.de
MHP-21XX	Microlink	ETH/USB	Wall mount	1.0	Intellon	FCC	www.microlinkcomm.com
MHP-31XX	Microlink	ETH/USB	Bridge	1.01	Intellon	FCC CE EN	www.microlinkcomm.com
MHP-51XX	Microlink	ETH/USB	Bridge	1.01	Intellon	FCC CE EN	www.microlinkcomm.com
MHP-11XX	Microlink		Card	1.0	Intellon		www.microlinkcomm.com

Data as of November 2003

12.11 COMPARISON BETWEEN OUTDOOR MODEMS

Table 31: Comparison between outdoor modems

Manufacturer	Name	N°	Chipset	Distance	Max bit rate	Standards	Modulation	Frequency	Web
ILEVO	Central	TPE		400m	45 Mbps	**CE**			www.ilevo.com
	Répéteur	IR		400m	45 Mbps				
	Home	CPE		400m	45 Mbps				
ASCOM	Modem	APA-45i/o		100m (indoor) 300m (outdoor)	2.25Mbps (indoor) 4.5Mbps (outdoor)	**EN55022 NB30 CE**	GMSK	1.6MHz -12MHz (indoor) 15MHz -30MHz (outdoor)	www.ascom.com
	Gateway	APG-45B		100m (indoor) 300m (outdoor)	2.25Mbps (indoor) 4.5Mbps (outdoor)		GMSK	1.6MHz -12MHz (indoor) 15MHz -30MHz (outdoor)	
	Accès Point	APM-45ap		100m (indoor) 300m (outdoor)	4.5Mbps sym		GMSK	1.6MHz -12MHz (indoor) 15MHz -30MHz (outdoor)	
	Master	APM-45o/i		100m (indoor) 300m (outdoor)	2.25Mbps (indoor) 4.5Mbps (outdoor)		GMSK	1.6MHz -12MHz (indoor) 15MHz -30MHz (outdoor)	
Mainnet	Central	CuPlus	**Itran** (ds2 / Enikia)?		2.5Mbps	**NB30**	ACSK	4MHz-20MHz	www.mainnet-plc.com
	Modem	NtPlus			2.5Mbps		ACSK	4MHz-20MHz	
	Répéteur	RpPlus			2.5Mbps		ACSK	4MHz-20MHz	
	Management	NmPlus							
Ambient	Central	S-node	**DS2**						www.ambientcorp.com
	Transformateur	X-node							
	Répéteur	R-node							
	Gateway	GW-node							

Manufacturer	Name	N°	Chipset	Distance	Max bit rate	Standards	Modulation	Frequency	Web
Ambient	Modem	U-node							
Xeline	Gateway	SM-100	**samsung**	400m	8Mbps	**FCC**	OFDM		www.xeline.com
	Gateway	MM-100		400m	8Mbps		OFDM		
	Central	SU-100		400m	8Mbps		OFDM		
		CU-100		400m	8Mbps		OFDM		
	Management	ES-100							
CurrentTechnologies	Central	CT-Backhaul							www.currenttechnologies.com
	Bridge	CT-Bridge							
	Coupler	CT-Coupler							
	Modem	Modem				Homeplug 1.0			
Amperion		Falcon 1000MV			45Mbps / 6 Mbps WiFi	**(HomePlug)**			www.amperion.com
		Lynx 1000MV			45Mbps / 6 Mbps WiFi				
PowerComm		Modem							www.powercommsystems.com
		Coupler							
		Repeater							
	Management	SCADA							
Easyplug	indoor		**DS2**		**45Mbps**				www.easyplug.com
	outdoor								
Telkonet	Modem				14Mbps				www.telkonet.com
	Gateway				14Mbps				
	Coupler								
DS2									www.ds2.es

Data as of November 2003

12.12 COMPARISON BETWEEN POWERLINE CHIPSETS

Table 32: Comparison between powerline chipsets

N°	Manufacturer	Homeplug 1.0	Max bit rate	Modulation	Frequency band	Web
CS1102	Cogency	yes				www.cogency.com
Piranha	Cogency	yes	14Mbps			www.cogency.com
CX11656	Conexant	yes	14Mbps	OFDM		www.conexant.com
DSS4200	ds2	no	45Mbps	OFDM	1MHz-38MHz	www.ds2.es
INT5130	Intellon	yes		OFDM		www.intellon.com
ITM1-BIP	Itran	no	2.5Mbps	CDMA		www.itrancomm.com
VS6801	Telewise	yes		OFDM		www.telewisecomm.com
	Valence	yes				

Data as of November 2003