Broadband Power Line Communication

&

Electromagnetic Compatibility

A short overview of technology and problems

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Contents

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The INCASE project

Industry 4.0 (I4.0) is the next industrial revolution. Manufacturers are focussing on client-specific production and added-value products. In Germany 84% of the companies feel the pressure to digitize and 57% will significantly change their business model due to the digital revolution. Germany is world leader in this revolution. The project main objective is to **close the gap between the 2 Seas region and Germany & other leading countries**, by developing and demonstrating the necessary key technologies towards companies, in this way facilitating the conversion towards I4.0.

INCASE develops knowledge, innovative applications and pilots on key enabling automation technologies for the future I4.0. INCASE will deliver **10 thematic demonstration trajectories** on those key enabling automation technologies for smart factories and green technologies for smart homes and factories. The demonstration actions will inspire practicing engineers towards new products and new production methodologies. The intermediary organizations will actively create awareness on the future I4.0.

The project contains **three main workpackages**. **WP1** develops pilots on key enabling automation technologies for Industry 4.0, to achieve an early market uptake by and increased awareness of the manufacturing industries. Involved technologies are Industrial Communication (Profinet, Power Line Communication, ProfiCloud, Networked Control) and Integrated Design (Mobile robotics, Industrial Hardware Targets, Cosimulation). **WP2** develops pilots to reduce energy consumption in both home automation and industrial automation, and increase the awareness & knowledge for the automation and manufacturing industries. Involved technologies are Communication and HMI technologies for smart factories and smart houses (ProfiEnergy, Power Line Communication for smartgrids, Control & HMI for Smart Houses, energy monitoring devices connected to the Internet of Things). **WP3** develops demonstration tools, based on the pilots, to perform numerous demonstration actions for practicing engineers in industry. In this way the knowledge on new technologies is increased and an early market uptake of Industry 4.0's new automation technologies is achieved in the 2 Seas region.

The **main objective** of INCASE is preparing the industry (automation & manufacturing industry) for the future "Industry 4.0" (I4.0) and "Industrial Internet of Things" (IIoT). This is done by:

- Creating awareness of technical management and decision makers of companies on the possibilities of the new technologies.
- Preparing practicing engineers by demonstrating new technologies for the future smart interconnected factories, smart buildings and sustainable engineering.

The project **specific objectives** are:

- Pilots on ProfiCloud
- Pilots on Stress-testing on Profinet
- Feasibility study on PLC
- Pilots on Networked Control
- Pilots on Integrated Design
- Pilots for ProfiEnergy
- Pilots for smartgrids using PLC
- Pilots for Control&HMI for Smart homes
- Pilots for energy monitoring devices connected to IOT, IIOT and industrial networks
- Demonstration tools & actions

1. Introduction

This reports focusses on broadband power line communication (BB-PLC). The new reader is encouraged to read first the report on narrowband power line communication (NB-PLC), which contains basic information on power line communication.
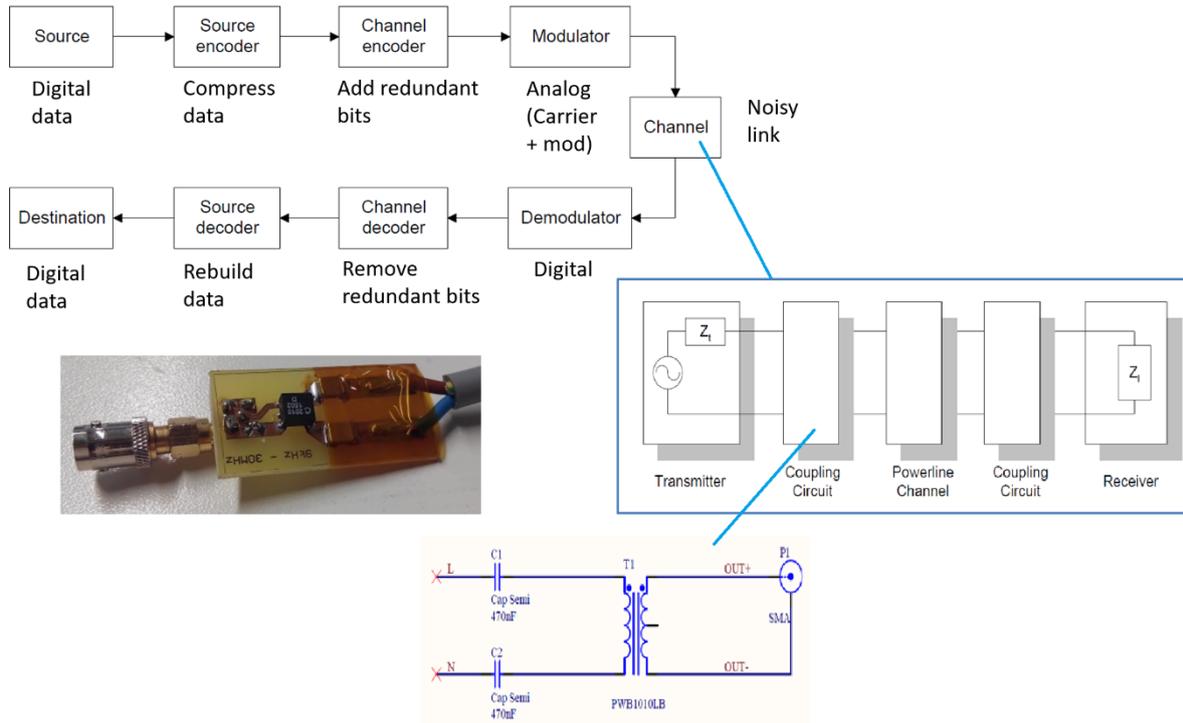

Figure 1. PLC basic schematics

A typical PLC system is illustrated in Figure 1. The digital data (source) is encoded and redundant bits are added. This redundancy is necessary as the signal has to cross the power cable, which is very noisy. The digital signal is converter to an analog signal. For modulation schemes, several are possible. Frequency shift keying (FSK) and phase shift keying with different levels (BPSK, QBPSK, 8BPSK and more) are typically used. For BB-PLC, frequency division multiplexing (OFDM) is used, including a multi carrier scheme. After transmission, at the receiver side, the same is done in the inverse way to reconstruct the data.

The main focus of Ghent University is the research on the power line channel. This includes the signal, modelled as a source and internal impedance Z_t, a coupling circuit and the power cables themselves. The coupling circuit consists of decoupling capacitors and a high frequency transformers. The capacitors decouple the transformer from the 230 V 50 Hz power supply, but are a short circuit for the high frequency communication signal. This makes it possible to use a small transformer, which will not saturate due to the 50 Hz components. The circuit is shown on the picture. With this circuit, signals from 10 kHz up to 100 MHz can be injected in the grid (Figure 2).
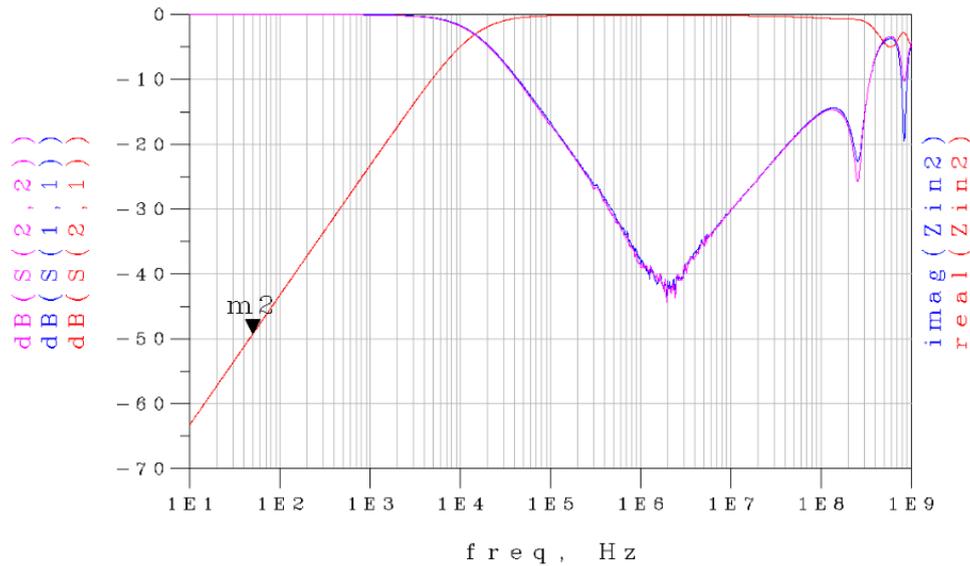
Figure 2. Transmission characteristic (red) of the coupling network

The power channel itself is the largest problem in PLC, as it is time variant, noisy and unpredictable.

Power supply cables are not intended to be used for communication. Figure 3 shows normal ethernet cables. These cables are intended for communication and are for this reason:
- Symmetric
- Twisted
- Shielded
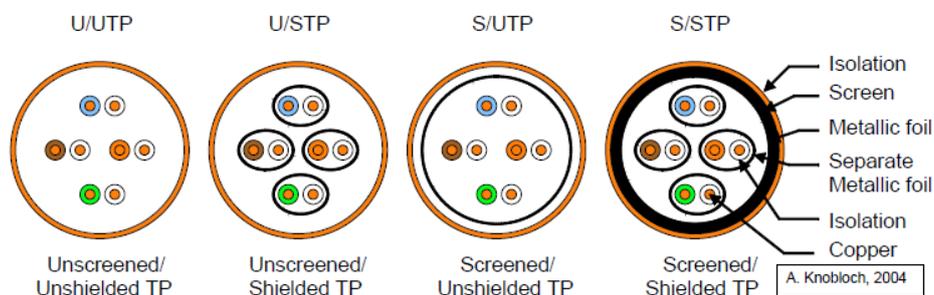- With low attenuation
- Terminated

Figure 3. Ethernet cables

Power supply cables are none of these. These cables are optimized for 50 or 60 Hz, not for MHz signals. The attenuation is high, as conductors as massive and not stranded, the lines are not twisted nor shielded. The termination of the line is not possible, as the characteristic line impedance is installation dependent.

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Figure 4. Power supply cables are not made for communication purposes

2. Broadband Power Line Communication
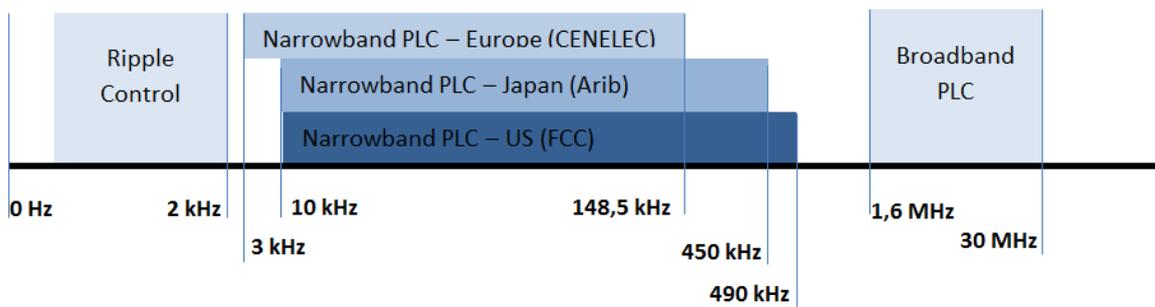
2.1. Broadband Frequency allocations

Figure 5. Frequency allocations for PLC

Figure 5 demonstrates the allowed frequency bands for PLC. As can be noticed, in Europe NB-PLC is limited to 148.5 kHz. In Japan, the US and China NB-PLC is allowed up to approximately 500 kHz for high data rate PLC. Broadband ranges from 1,6 MHz up to 30 MHz, but the latest standards allow PLC up to 100 MHz (according to IEEE) and even 300 MHz (ITU).
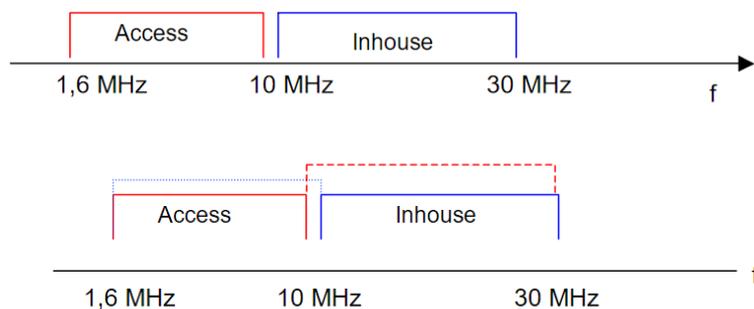

Figure 6. In-house versus access applications - first and second generation

A difference is made between 'access applications' and 'in-house applications'. In practice, frequencies between 1,6 MHz and 10 MHz are used by utilities (access applications). In the first PLC generation, the frequency allocation was separated. In the second generation a flexible allocation with priority is used (Figure 6).

2.2.   BB-PLC standards

The main standard for broadband PLC is the EN50561 series. EN50561-1 focusses on EMC requirements for PLC devices for in-house applications up to 30 MHz. EN50561-3 extends the carrier frequency up to 118 MHz. EN50561-2 is specific for utilities. For PLC communication, no license is required. The reason for this is mainly that PLC, and especially BB-PLC, can be kept very local. Due to the large attenuation in the grid, BB-PLC is limited to some tens of meters. The communication is only limited by EMC regulations. The mentioned standards refer to EN55022 (EN55032) and EN55016 known as EMC basic measurement standards. Specific frequencies are excluded in order to not disturb other communications channels (radio, traffic, ports).

The EN50561-1 describes the requirements for the dynamic frequency exclusion. When a radio broadcast is detected, the frequency will be excluded by the PLC modem, with a defined bandwidth and band-roll-off.

2.3.   BB-PLC protocols

The main protocols are Homeplug (up to 30 MHz), IEEE (up to 100 MHz) and ITU (up to 300 MHz). IEEE 1901 is the most important standard for vendors, to reach compatibility.

HomePlug 1.0 is fully compatible with IEEE 1901. It uses OFDM (orthogonal frequency division multiplexing) with 76 carriers between 4,4 and 20,7 MHz. As modulation scheme BPSK and QPSK is used, reaching 20 Mbps. This HomePlug version is typically used for in-house internet applications.

HomePlug AV uses OFDM with 917 carriers, with a 24,4 kHz spacing. Different modulation schemes can be used (PSK and xQAM) reaching 200 Mbps. In 8QAM is visualized Figure 7, depending on the noise of the signal up to 128QAM can be used. HomePlug AV is typically used for multimedia applications (internet, video, VoIP).

HomePlug AV Green PHY is specifically made for smart grid applications, as smart meters, electric vehicle chargers and in-house applications. Most applications need only limited bandwidth (10 Mbps). The communication modules use 75% less energy than the AV-systems.

HomePlug BPL is used by utilities for home access technologies.

ITU G.hn and ITU G.hn MIMO are used for smart applications and vehicle applications. IEEE 1901 finally can be used for all previous mentioned applications.
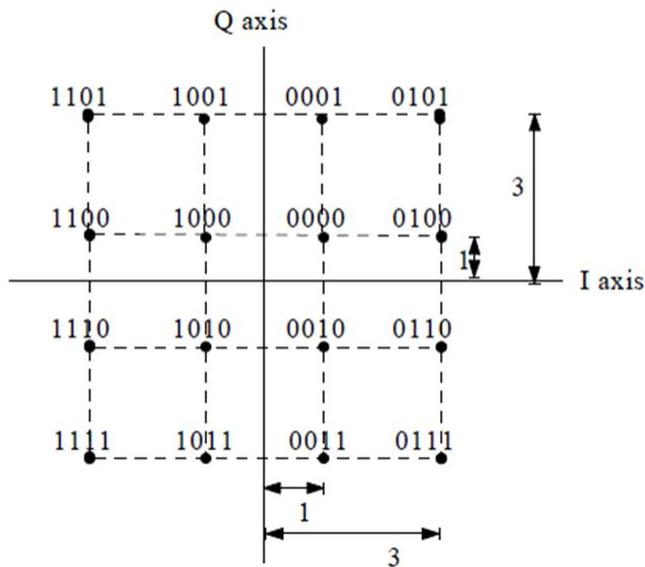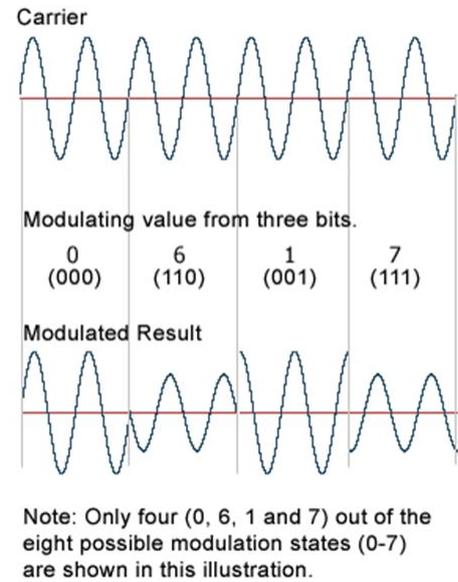
Figure 7. xQAM

3. EMC

For BB-PLC, the communication itself is mainly seen as a source of electromagnetic interference. When reading the standards, the only restrictions for communication are in fact EMC-related restrictions.

The standard EN 50561-1 defines emission limits for conducted and radiated emission. These limits are similar to other devices in domestic environments (so called class B limits). Radiated emission measurements are done according to EN55022 (which will be EN55032 in the next version). As radiated emission starts at 30 MHz and the communication stops at 30 MHz, the harmonics of the communication are measured and limited. For conducted emission, also the maximum emission is equal to normal devices. The difference in this standard is that the communication signal itself is allowed to be above the limit during communication. The emission limits are shown in .
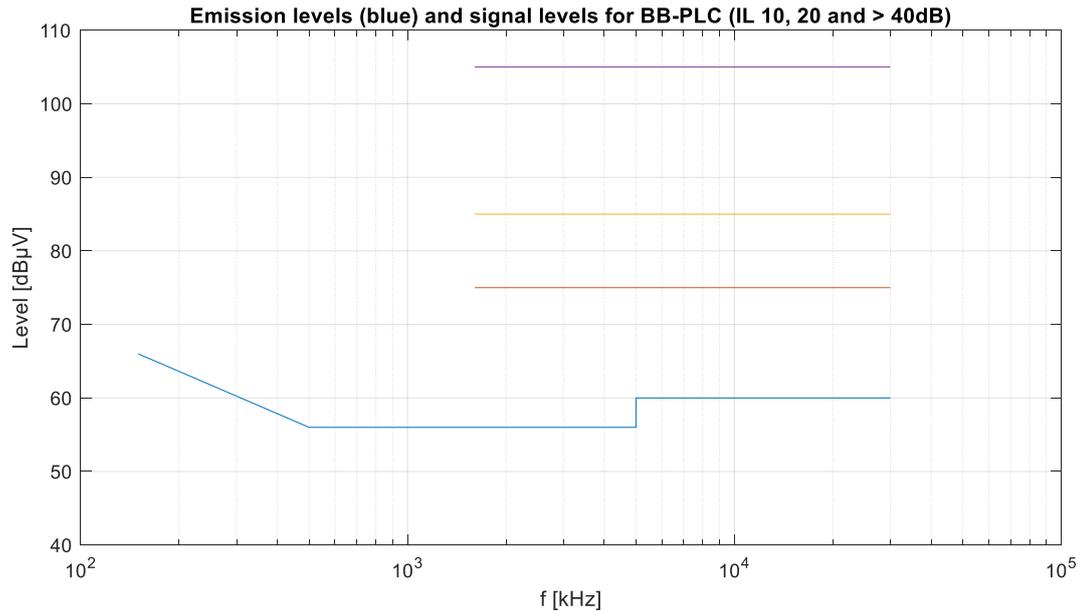
Figure 8. Emission limits EN50561-1

On Figure 8, the blue line shows the EMC limit similar to other devices. When communicating, the EMC limit can be exceeded between 1.6 – 30 MHz. The signal is measured unsymmetrically (as peak values). The values depend on the PLC modem to auxiliary equipment insertion loss (IL).

For the frequencies in table A.1[1], there is an exception. The EMC limits are always valid for these frequencies. Also for this, there is an exception. If dynamic frequency exclusion is used, the EMC limit can be exceeded for the frequencies in table A.2.

Table A.1 — Permanently excluded frequency ranges

Excluded frequency range MHz	Service
1,80 – 2,00	Amateur Radio Service
2,85 – 3,025	Aeronautical mobile
3,40 – 4,00	Aeronautical mobile (3,40-3,50) Amateur Radio Service (3,50-4,00)
4,65 – 4,70	Aeronautical mobile
5,25 – 5,45	Amateur Radio Service
5,48 – 5,68	Aeronautical mobile
6,525 – 6,685	Aeronautical mobile
7,00 – 7,30	Amateur Radio Service
8,815 – 8,965	Aeronautical mobile
10,005 – 10,15	Aeronautical mobile (10,005-10,10), Amateur Radio Service (10,10-10,15)
11,275 – 11,4	Aeronautical mobile
13,26 – 13,36	Aeronautical mobile
14,00 – 14,35	Amateur Radio Service
17,9 –17,97	Aeronautical mobile
18,068 – 18,168	Amateur Radio Service
21,00 – 21,45	Amateur Radio Service
21,924 – 22,00	Aeronautical mobile
24,89 – 24,99	Amateur Radio Service
26,96 – 27,41	CB radio
28,00 – 29,7	Amateur Radio Service

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[1] EN50561-1

Table A.2 — Permanent or dynamically excluded frequency ranges

Excluded frequency range MHz	Service
2,30 – 2,498	Broadcasting
3,20 – 3,40	Broadcasting
3,90 – 4,05	Broadcasting
4,75 – 5,11	Broadcasting
5,75 – 6,20	Broadcasting
7,20 – 7,70	Broadcasting
9,30 – 9,95	Broadcasting
11,55 – 12,10	Broadcasting
13,55 – 13,90	Broadcasting
15,05 – 15,85	Broadcasting
17,40 – 17,90	Broadcasting
18,90 – 19,02	Broadcasting
21,45 – 21,85	Broadcasting
25,65 – 26,10	Broadcasting
NOTE The bands in Table A.2 include frequency ranges allocated under Article 5 of the ITU Radio Regulations to the Broadcasting Service, plus a realistic appraisal of use for broadcasting under Article 4.4 of the ITU Radio Regulations.	

EN50561-3[2] gives limits for communication above 30 MHz. Figure 9 shows the maximum unsymmetrical measured signal when there is communication. As can be noticed, the emission is much more strict. This is normal, as the frequencies are relatively high. The length of the low voltage cables in a house are for these frequencies already long enough to act as ideal disturbing antennas. Several frequencies are excluded:
-   50 – 52 MHz Amateur Radio Service
-   70 – 70,5 MHz Amateur Radio Service
-   74,8 – 75,2 MHz Aeronautical Radio Navigation

Also the large drop at the FM radio band (87,5 MHz – 118 MHz) can be noticed.

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[2] EN50561-3: Power line communication apparatus used in low-voltage installations - radio disturbance characteristics - limits and methods of measurement - part 3: apparatus operating above 30 mhz
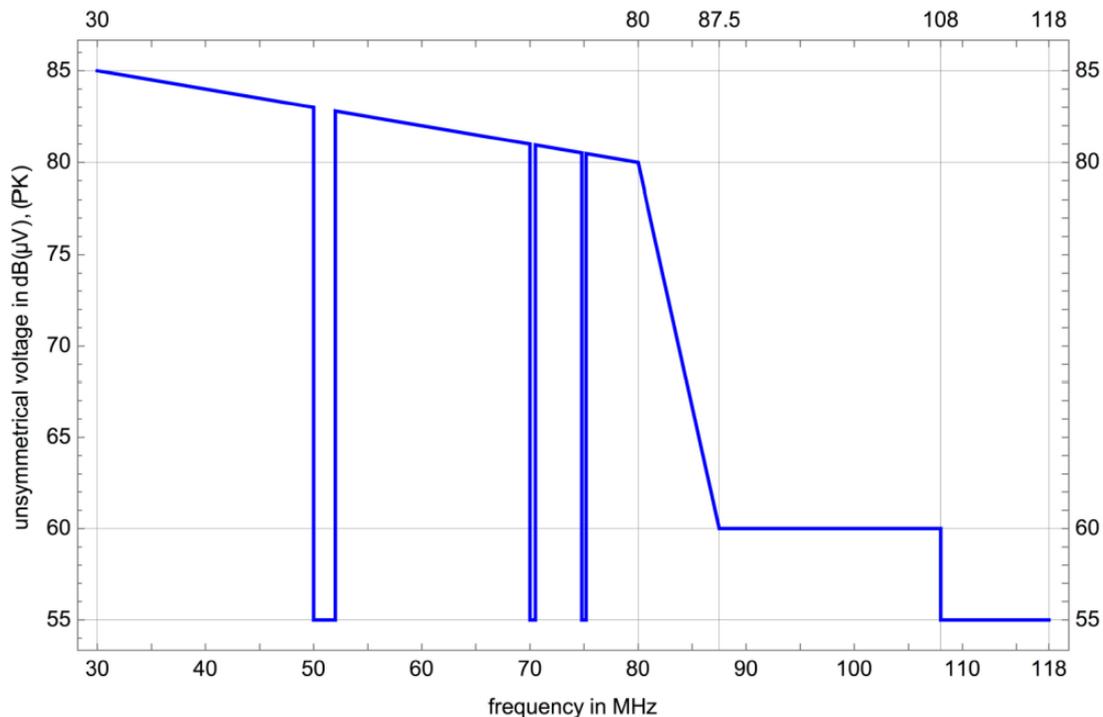
Figure 9. EN50561-3 unsymmetrically measured signal limits

For radiated emissions, the EN55032 class B apply. This is equal to the emission of multimedia equipment in domestic environments.

PLC-communication is normally done in a symmetrical way (between two phases or one phase and neutral), but the unsymmetric values are limited. In theory, communication is also allowed between phases and ground, as long as the limits are not passed. In practice this will not be done. The reason for this difference is the following.

Differential mode current (symmetric) is generally defined as the current that passes in one line, and returns in the other line (Figure 10). This is the normal functional current. The differential mode voltage is the normal supply voltage between two lines or in this case the PLC signal. The common mode current (unsymmetric) is a current that flows in both lines and returns to the source via parasitic elements and the common ground. For normal situations, the common-mode current can only be high-frequent, otherwise it cannot flow. In this case the PLC signal is applied between phase and ground or between all phases and ground. Also, with a symmetric voltage, an unsymmetric voltage and current can exist due to unbalances in the system. Notice that when a signal is placed between only one phase and ground, the signal is a combination of a symmetric and unsymmetric voltage.
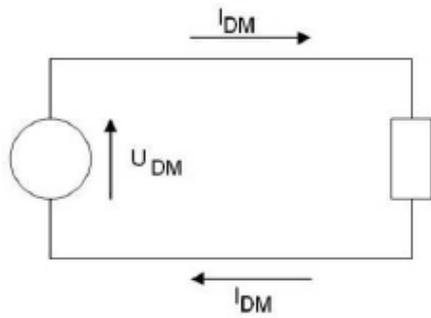
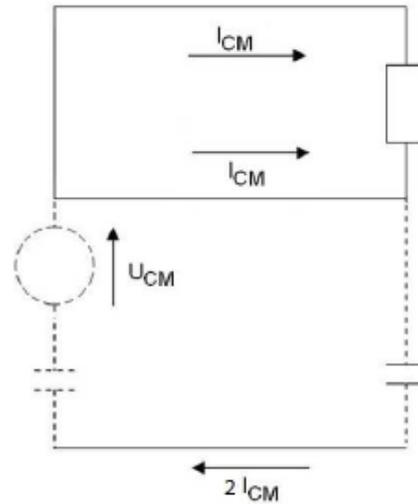*Figure 10. Differential mode current and common mode current*

Figure 11 geeft common mode en differential mode samen weer op één figuur.
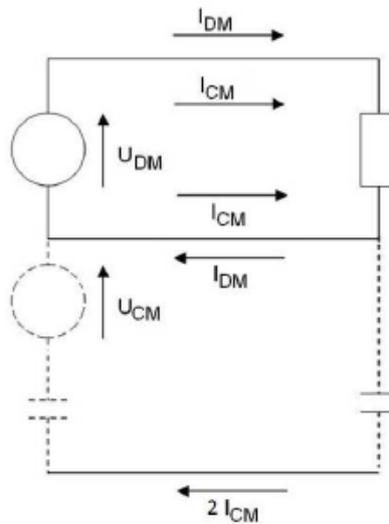

Figure 11. Differential and common mode current

It is assumed that the cables with a symmetric current are close to each other (). If the electric fields emitted are considered to be at a certain distance from the conductor, the fields will virtually cancel each other as a result of the differential mode current. This is in contrast to the fields of the common mode current. Because both common mode currents flow in the same direction, their electric field is also oriented in the same direction. Consequently, the resulting field is the sum of the two. This can cause (radiated) emission. It is therefore important that the common mode current flows back as close as possible to the continuous current. This is the principle of the shielded cable used in drives: the surface area within the current loop is minimized. For PLC, no shield cables are used and the signal can flow back

through every metal part in the house, causing large interference problems. For this reason, PLC signalling is done differential and not in common mode.
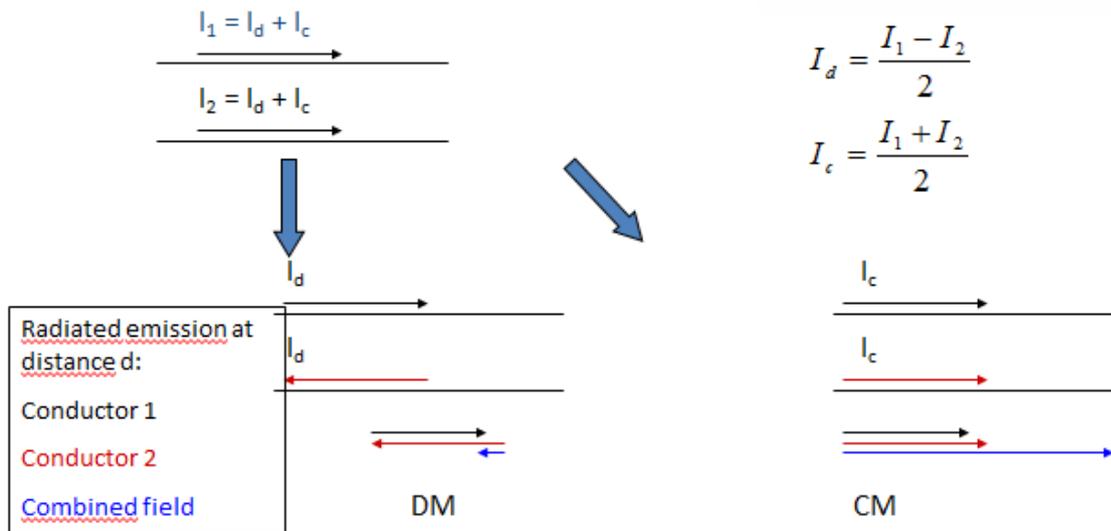
$$I_1 = I_d + I_c$$

$$I_2 = I_d + I_c$$

$$I_d = \frac{I_1 - I_2}{2}$$

$$I_c = \frac{I_1 + I_2}{2}$$

Radiated emission at distance d:
Conductor 1
Conductor 2
Combined field

DM

CM

Figure 12. Field generator by differential mode and common mode currents

4. Impedance and attenuation

BB-PLC is in general more feasible than NB-PLC due to several reasons. Where NB-PLC mainly suffers from the harsh environment due to switching harmonics from switched mode power supplies and grid connected photovoltaic inverters, BB-PLC mainly suffers from the attenuation. Where the attenuation is typical 1 to 3 dB/km voor NB-PLC, this increases to 150 dB/km and more for BB-PLC.
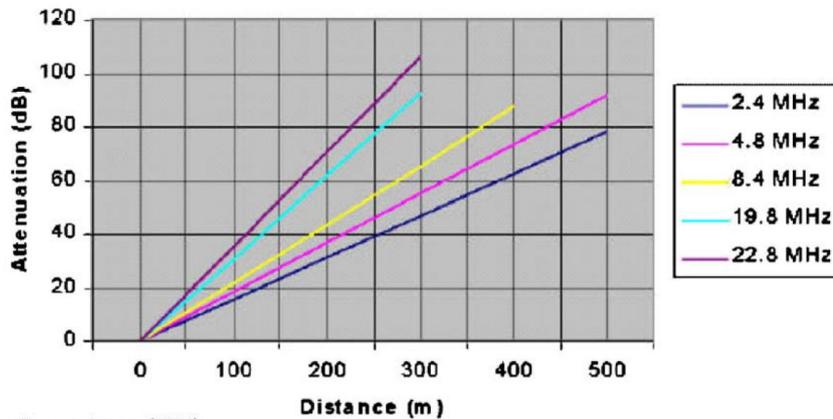
Source: Ascom (2001)

Typical path loss values for PLC in dB/km. Values may vary depending on cable type, loading conditions, weather, etc. OH: overhead; UG: underground.

	$f = 100$ kHz	$f = 10$ MHz
Low Voltage	1.5-3	160-200
Medium Voltage (OH)	0.5-1	30-50
Medium Voltage (UG)	1-2	50-80
High Voltage (OH)	0.01-0.09	2-4

Figure 13. Typical attenuation charactersitics[3]

A second reason for promoting BB-PLC is that the impedance is higher at those frequencies, resulting is less needed power and a more stable signal.

A third reason is that the disturbances below 100 kHz contain much energy, above 100 kHz not. This means that the quality of communication (indicated by the signal noise ratio) can be kept higher without a high output power for BB-PLC.

A fourth benefit is that BB-PLC can use crosstalk as an advantage in three phase networks. Figure 15 shows the crosstalk principle. When a signal is sent between phase L1 and N, a part of the signal will be measured between phase L2 and N. The reason for this is the parasitic capacitance between the lines L1, L2 and N. The larger the cable is or the higher the frequency is, the more capacitive coupling exists between L1 and L2. The characteristics show the result for three different cable lengths (1m, 11m, 23m) as function of frequency.
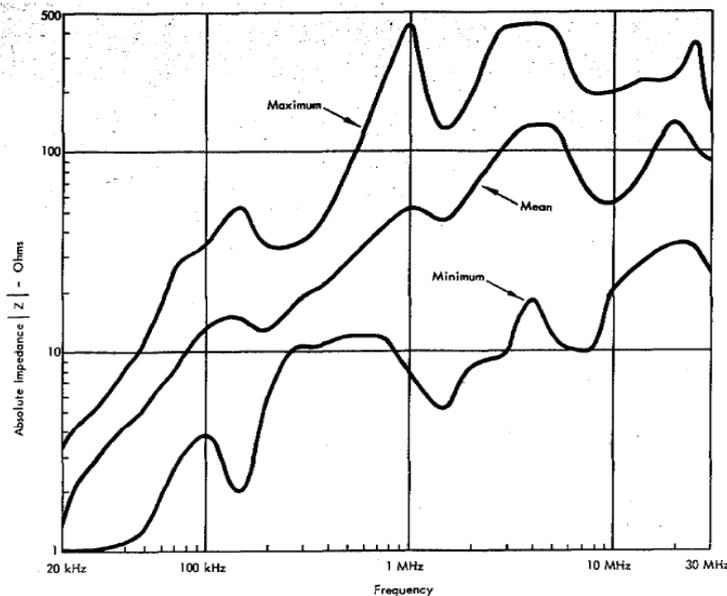

Figure 14. Grid impedance[4]

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[3] Computer desktop encyclopedia, 2007.
[4] R.M. Vines, H.J. Trussel, K.C. Shuey and J.B. O'Neal, "Impedance of the Residential Power-Distribution Circuit", IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-27, No. 1, pp6-12, February 1985.
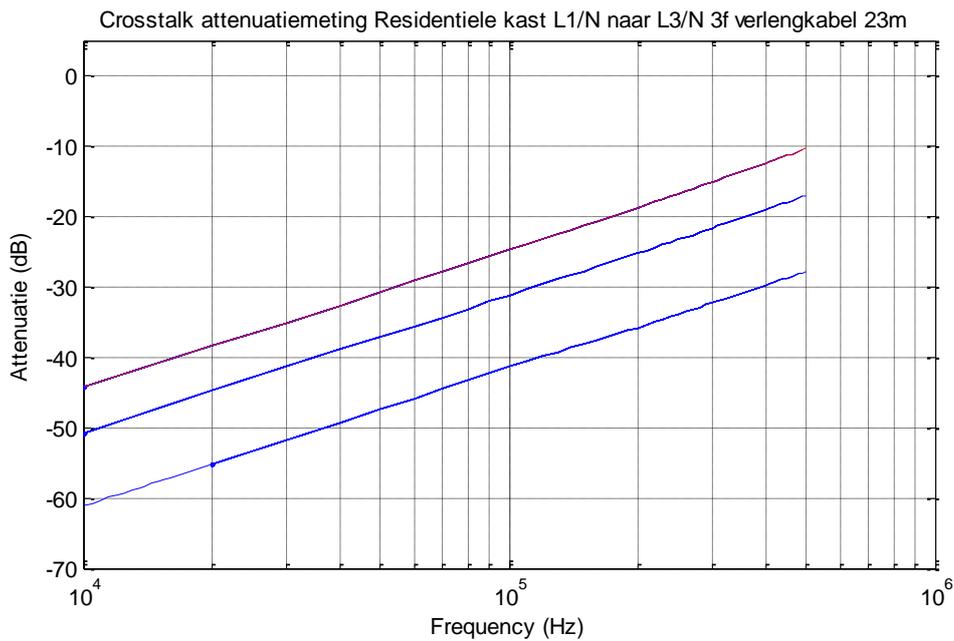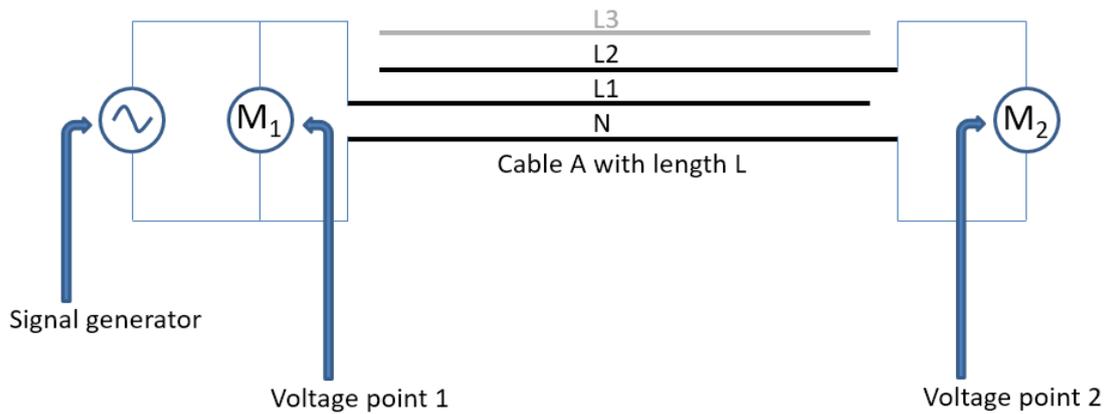
Figure 15. Crosstalk

One of the major problems in PLC is the fading problem. Consider Figure 16. When a signal is sent from point A to point B, the ideal path is path 1. This is the case when no other devices are connected. A practical example is medium voltage networks. In low voltage networks, path 2 is most of the time the case. The low voltage grid in-house contains a lot of paths as a normal house has tens of sockets and lights connected. This means that the signal starts in point A and arrives in point B, but simultaneously through different paths (path 1, path 2, …). Due to the different length, the signal arrives several times, with a small difference in time. The consequence is that a signal is stretched in time. This limits the maximum speed of communication. As solution for this OFDM with multicarrier schemes are used. This is out of scope of the report.
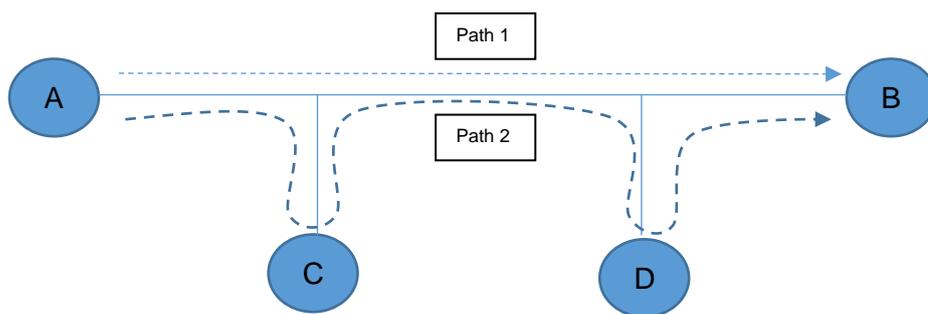
Figure 16. Fading due to multipath systems

5. Applications

PLC can be used in a wide variety of applications. The most obvious application for in-house is internet and multimedia applications. BB-PLC is used for smart grids and vehicle (car, boat, plane) applications. PLC has some interesting properties when f.i. weight can be important. As only one medium is used for both power and data, the used copper is limited.

Research[5] shows that PLC, as wired technology, is competitive to wireless technology. For automated meter reading and grid control, the use of PLC is mainly dependent on the presence (or absence) of a good mobile phone network. In countries like Finland and France, PLC is used by the utilities. These countries have typical regions with sparse population, leading to a limited coverage of the mobile phone network. Regions like Flanders did not choose for PLC as the GPRS network has an almost 100% coverage.

The application for BB-PLC typically asks higher bandwidths. For smart grids and smart metering, NB-PLC is more interesting. NB-PLC has a lower data rate, but can cover a larger distance. BB-PLC is typically made for in-house communication with large bandwidths. For smart grid applications and f.i. vehicle-to-grid applications, BB-PLC can be seen as an overkill. On the other hand, the frequency range of NB-PLC is filled with power conversion harmonics. In comparison to the NB-PLC frequency domain, BB-PLC is a quite area and gives lots of possibilities to avoid specific noise sources due to frequency shifting.

6. Industrial PLC

Broadband PLC in industrial applications is not widespread and commercially almost not available. Although industry is a harsh environment, BB-PLC has a certain potential to be used

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[5] For the grid and through the grid: the role of Power Line Communications in the Smart Grid, S. Galli, A. Scaglione, Z. Wang, IEEE Proceedings, Volume 99, June 2011.

as communication channel. It is proven[6], by testing PLC on a PWM motor cable. Consider the following setup:
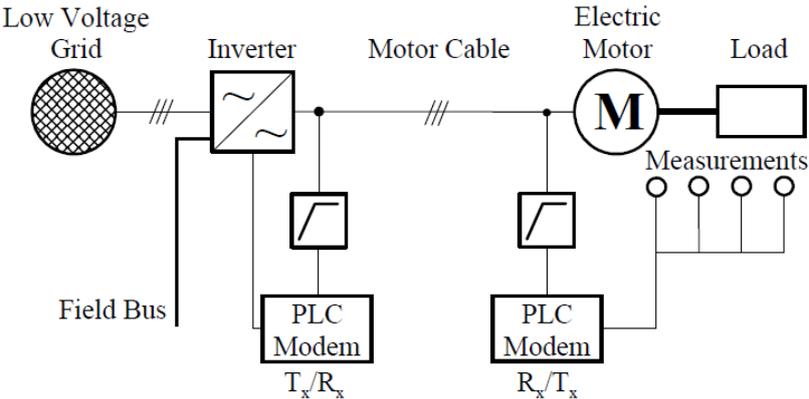

Figure 17. PLC communication on a motor-drive system

The system consists of a PWM-inverter, motor cable and motor. Different measurements are made on the motor. The sensor data is captured and sent from motor to drive with PLC. The used medium is the motor cable. The basics for testing the feasibility is by visualizing the noise spectrum. PWM contains a lot of energy below 500 kHz due to the fundamental and switching harmonics. Above 500 kHz, this energy is decreasing very rapidly. The contained power between 500 kHz and 15 MHz is only 24W and above 15 MHz only 5 µW. The emission is falling down very rapidly. This means communication is possible at MHz, making BB-PLC feasible. To choose an adequate frequency, the output signal of a normal PLC modem (typical 100 mW) is compared to noise signal. A signal-noise ratio of 0 dB is sufficient to make communication possible. As a result BB-PLC starting from 11 MHz is feasible (depending on the cable length and drive/motor impedance).

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[6] Selection of Optimal Frequency Band for Motor Cable Communication Jero Ahola, Antti Kosonen, Tero Ahonen, Jussi Tamminen, and Tuomo Lindh, EPE 2009
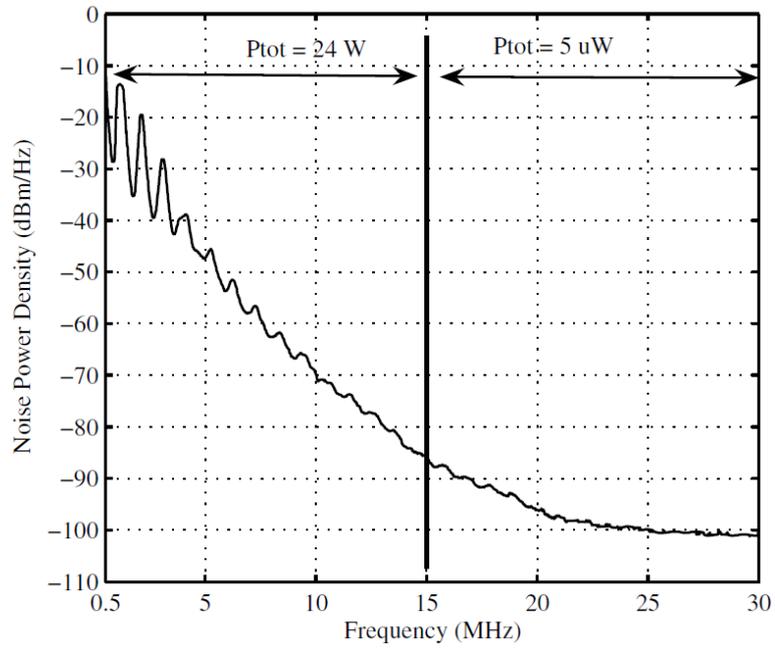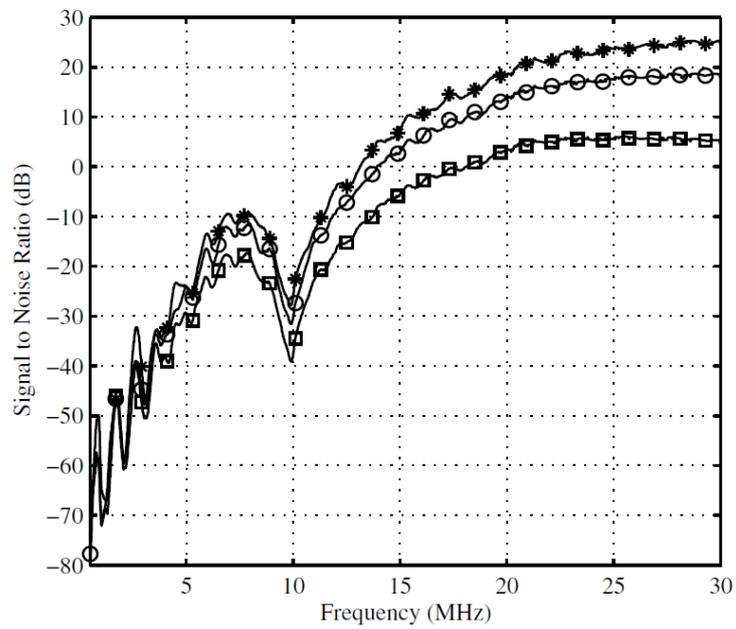
Figure 18. Spectral power density of PWM

Figure 19. SNR when taking into account a standard PLC modem

7. Testboards

7.1. Description to the system

UGent developed several demonstrators on BB-PLC.

Figure 20. I2SE XPL Rail demonstrator kits

To demonstrate the operation of broadband power line communication, demonstrator kits were made (Figure 20). The kit consists of several parts:

- a power supply
- switches
- 3 relays
- LED lamps
- PLC modem, the XPL Rail 4M – IO600
- RF transformer

The position of these parts in the case are shown in Figure 21.
A complete broadband demonstrator kit consists of two cases. Each suitcase is connected to the low-voltage grid, so communication is automatically established. The 12VDC power supply powers the relays which are switched by the PLC-modem digital outputs. The RF transformer

can be used to measure the communication signal on the power cable at the output of the case. The RF transformer has an operating range between 10kHz to about 30MHz.
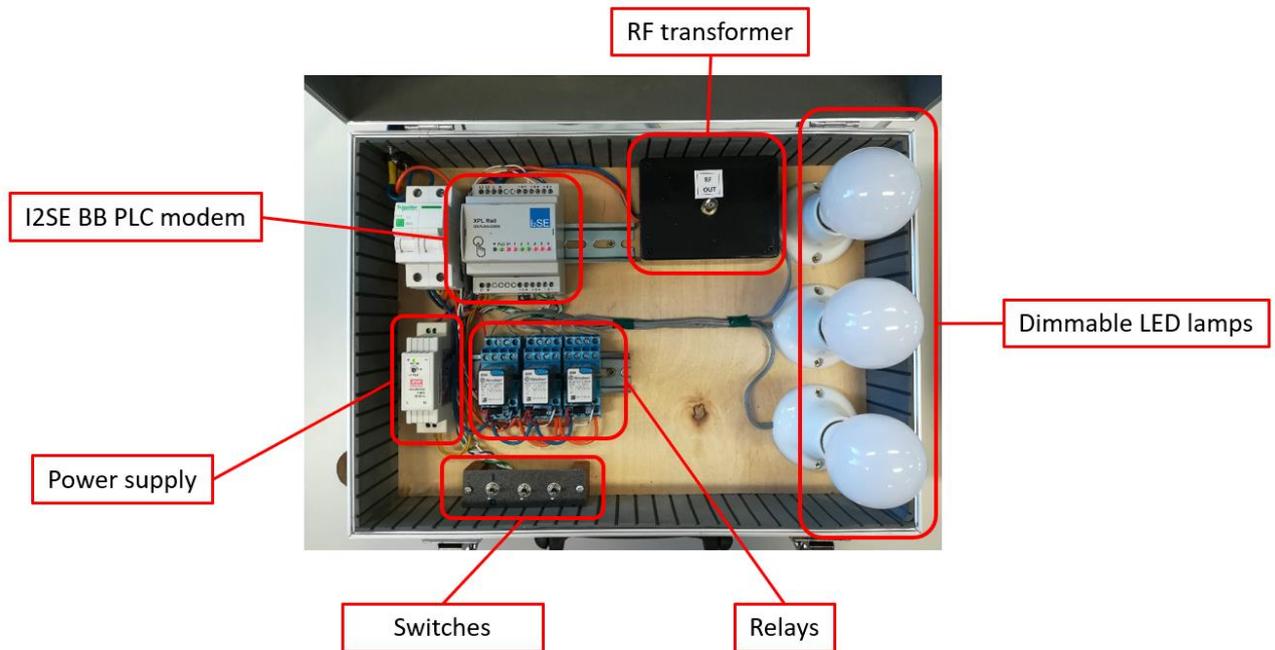

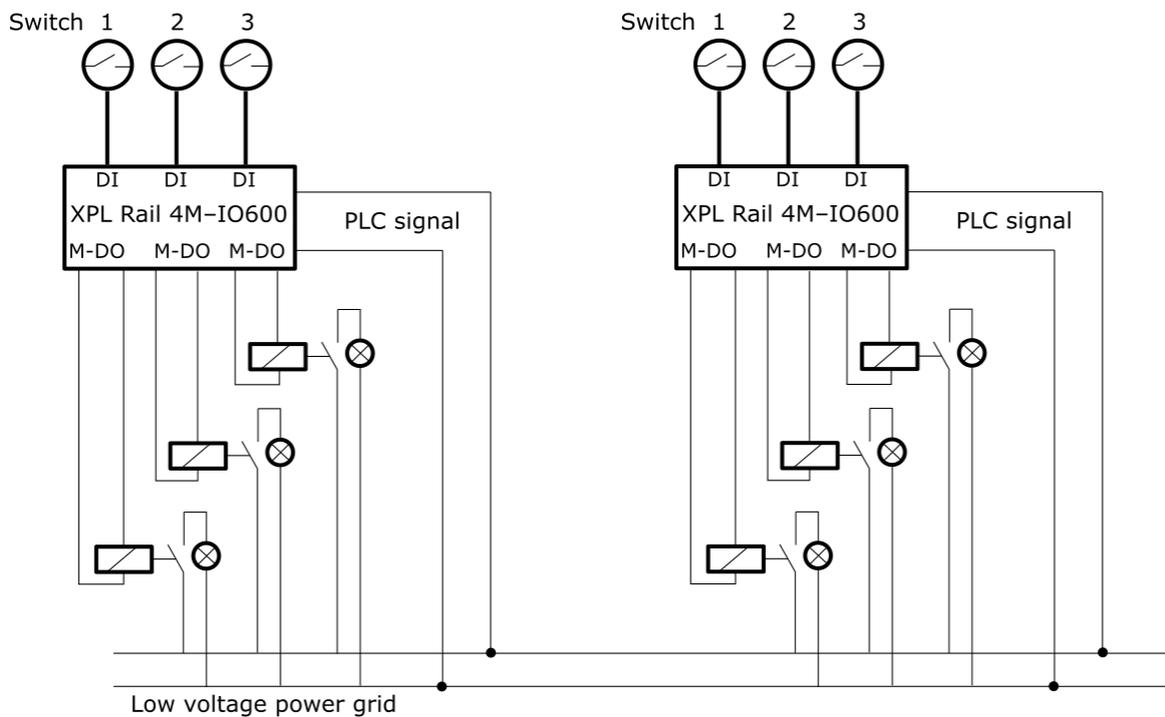*Figure 21. Demonstrator kit I2SE parts*

Figure 22. Block diagram demonstrator kit XPL Rail 4M-IO600

The block diagram of the setup is shown in Figure 22. The operation of the broadband demonstrator is as follows:
- with the switches of case 1, the LED lights in case 2 can be put on /off
- the LED lights in case 1 are switched on/off by the switches in case 2

Figure 23: PLC device XPL Rail 4M-IO600

The case uses a Powerline DIN rail device with 6 I/O channels. The XPL Rail 4M – IO600 powerline device (Figure 23) uses the HomePlug Green PHY® power line technology with reasonable CPU power by still having a minimal energy footprint. With the IO and due to the modularity it is possible to perform extensive control and automation functions in home or building automation and industrial environments.

The XPL Rail 4M – IO600 comes with the following features:
- 6 individually configurable physical channels
  - digital input (software-switchable pull-up resistor),
  - digital output (Open Collector) or
  - analog input (0 – 10 V)
  - S0 input (needs auxilary power supply)
- multiple configuration details for each physical channel
- support for multiple standard network protocols
  (DNS, DHCP, Auto-IP, TCP/IP, HTTP, IGMP, ICMP, IPv4-Multicast, UPnP)
- encrypted communication via powerline (HomePlug AV)

The embedded web server allows for easy configuration.

Powerline speed	10Mbit/s (max)
Powerline distance	Up to 300m
Configurable I/O channels	6
Configurable serial channels	0
Open collector outputs	24V (max) 1,3W (typical)
Temperature (operating)	0°C -+ 40°C
Humidity	15 – 85%
Mounting	DIN rail (EN 50022: 35mm x 7.5mm)

Size	4 HP (70mm x 110mm x 61mm)

The internal QCA7000/7005 is the latest PLC IC from Qualcomm. It is fully compliant with the HomePlug Green PHY specification. HomePlug's Green PHY specification was developed specifically for energy management applications. The QCA7000/7005 has been designed to meet specific industry requirements for a HomePlug AV interoperable device that offered lower power consumption. The QCA7000/7005 is fully interoperable with HomePlug AV and IEEE 1901 compliant products. The QCA7000/7005 features HomePlug Green PHY Distributed Bandwidth Control to ensure effective coexistence with HPAV equipment operating in close proximity on the same power line infrastructure. The IC also supports HPGP Power Save Mode, which enables the IC to enter and exit a low power state on a scheduled basis to maintain network synchronization.
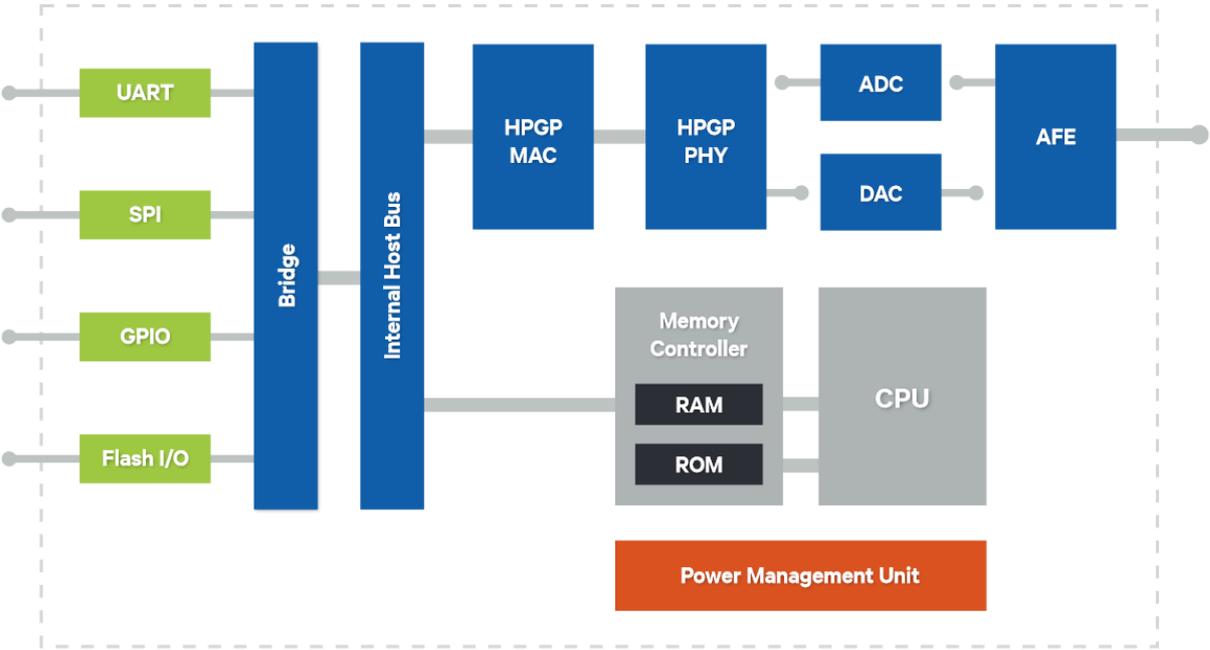

Figure 24: QCA7000/7005 System Architecture

The system is typically used for the following applications :

- Smart Meters
- Energy Management Systems
- Programmable Controlled Thermostats
- Remote Metering Devices
- Solar Panels
- Industrial Applications

7.2.   Initializing the system

Before an XPL Rail can be completely put into service, it may be necessary in most cases to parametrize the device or the terminals following the installation, depending on the customer

situation. For this purpose, a computer (or notebook) with browser (for example Mozilla Firefox, Google Chrome) is required for the configuration of the device. For this purpose, the computer must be capable of accessing the XPL Rail via the Powerline connection. It is recommended to use a standard-type Powerline Ethernet adapter. These adapters are available with different characteristics (for example only with LAN or with LAN and Wi-Fi, different speeds) at various providers. XPL Rail devices are compatible with any adapter manufactured as per HomePlug AV standard, i.e. they are compatible with any adapters designed for a speed of at least 200 MBit. It is a prerequisite for the next steps to successfully put into service such a Powerline Ethernet adapter. The easiest way is to connect the Powerline Ethernet adapter with a wall-mounted socket and to connect it to the existing router (see Figure 25) by means of a network cable. A direct connection between the computer and the Powerline Ethernet adapter can be established as well.
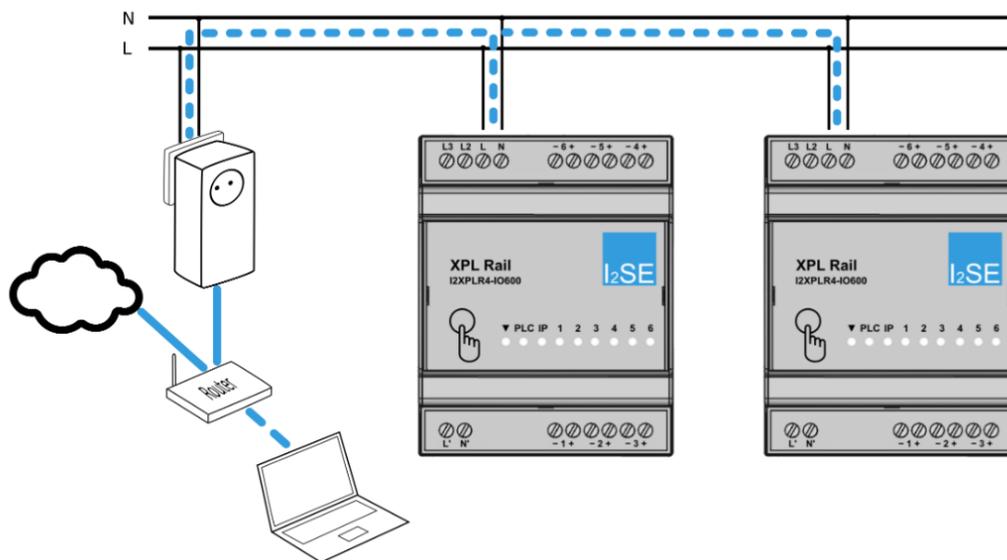

Figure 25. Connection with router

The system can now be configured according to the manual.

7.3. Measurements

The datasheet of XPL Rail 4M - IO600 shows that Homeplug AV power line communication is used. In the Homeplug AV specifications it is described that the frequency range starts at 1.8MHz and ends at 30MHz.

The measurement shown in Figure 26 and Figure 27 is a noise floor measurement. The measuring instrument used is the RSA306 (real time spectrum analyzer) coupled to the differential voltage probe. The probe is connected to the low voltage network over which the BB-PLC modems must communicate. In this measurement the BB-PLC modems are physically connected, but there is no voltage on the line. The PLCs are also not communicating.

The measurement result shows that we have a relatively clean spectrum. Note that a few frequency peaks can be observed in the frequency spectrum. One clear frequency can be observed. This at the frequency 650kHz. This frequency comes from the differential voltage probe. For the rest, there are no visible frequency peaks worth mentioning.
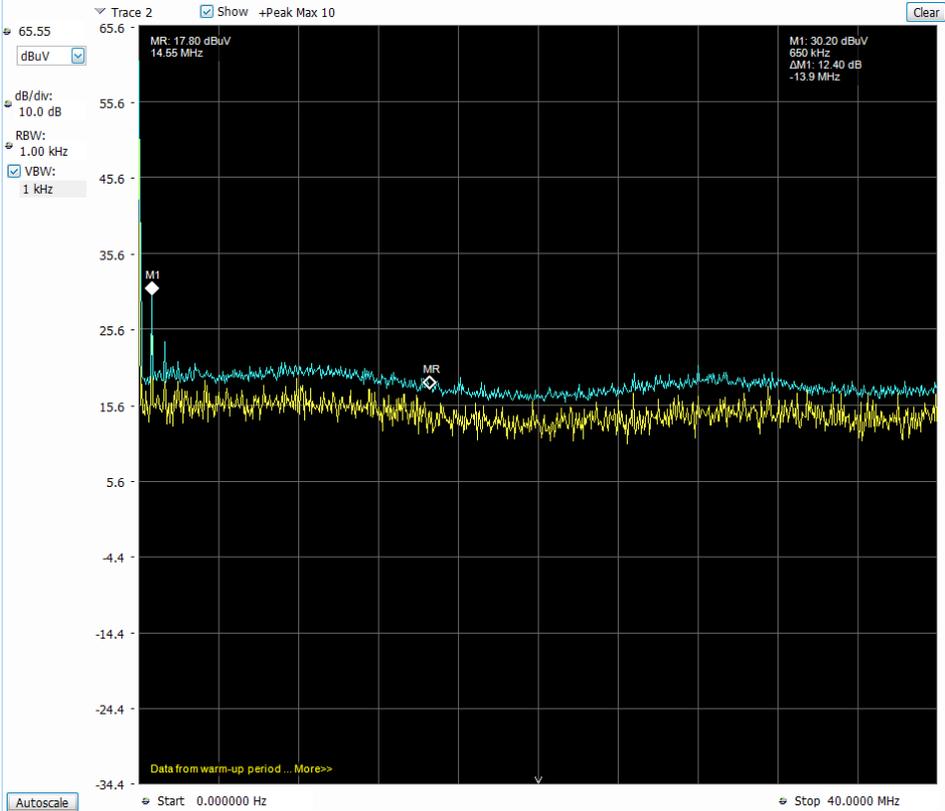

Figure 26: Real time frequency spectrum plot differential voltage probe
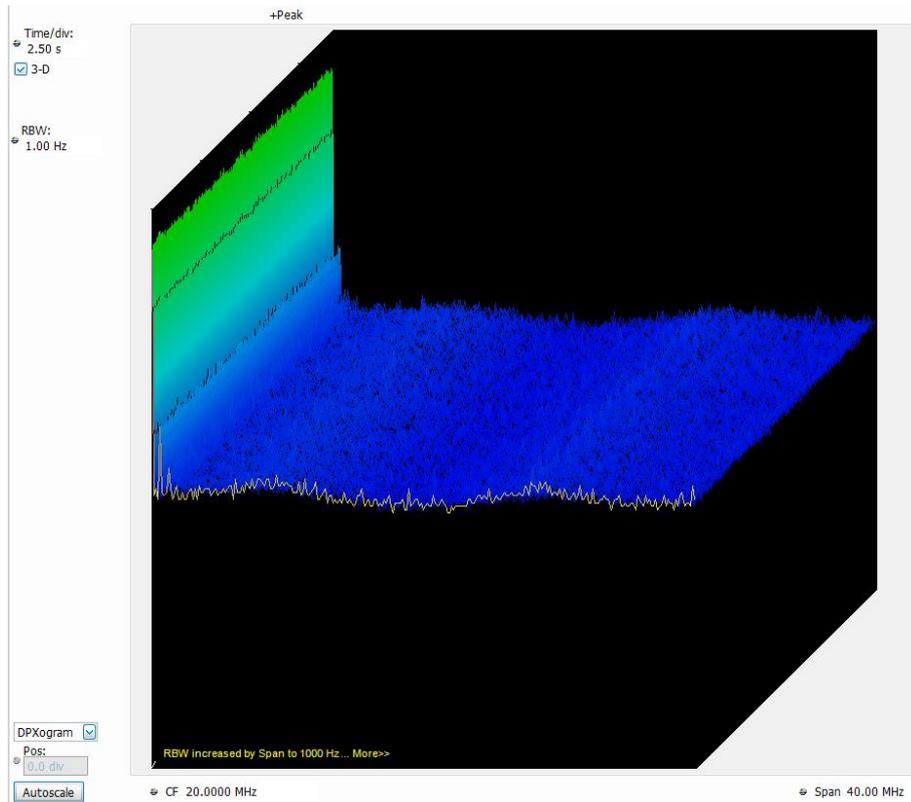
Figure 27. DPXogram Differential voltage probe

The figure below shows a measurement result of two BB-PLCs connected to the low-voltage grid. The B-PLCs are configured to communicate with each other over the low-voltage grid. As indicated earlier, these PLCs communicate in the frequency range 1.8MHz to 30MHz. This is also clearly visible in the figure.
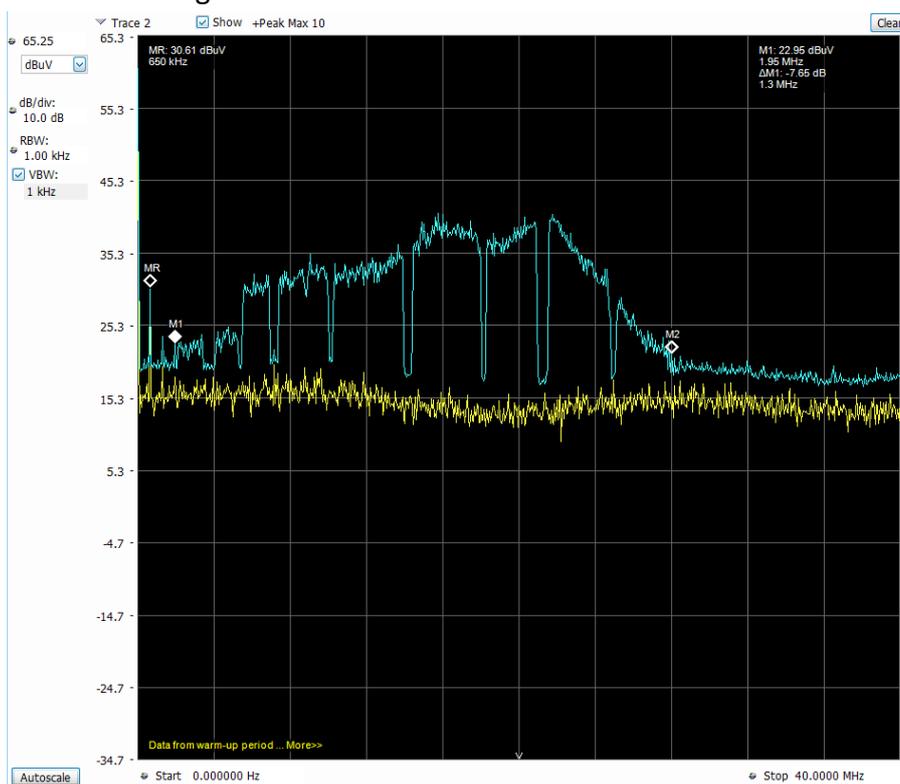

Figure 28. Real time frequency spectrum plot differential voltage probe and PLC signal
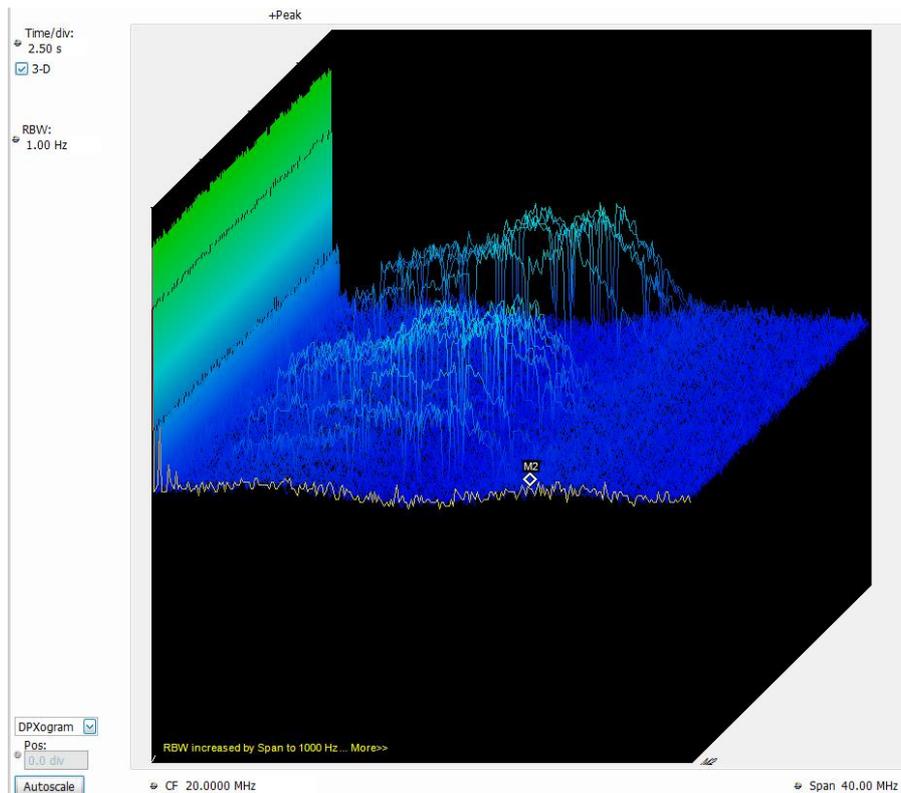
28

Figure 29. DPXogram Differential voltage probe and PLC signal

8. Feasibility and conclusion

BB-PLC is mainly used for in-house communication systems. Given the large attenuation in the low voltage grid, the application is typical in-house. For medium voltage lines, BB-PLC is also feasible as the attenuation and noise are lower.

In PLC power and data are combined in the same medium. A similar but complementary technique is Power-over-ethernet (PoE). In PoE an Ethernet cable, normally used for data transmission, is also used for DC power transmission. As currently 90W is allowed, this is interesting for a lot of applications (lighting, sensors, access points, …). In this way, the normal electricity grid and PLC can have a technological competitor.