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Report on Electro Magnetic Compatibility of Power Line Communications

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Editor(s):	*Pascal PAGANI*
Author(s):	*Richard RAZAFFERSON, Pascal PAGANI, Ahmed ZEDDAM, Jean-Yves BAUDAIS, Ali MAIGA, Olivier ISSON*
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Abstract

This OMEGA deliverable presents a study of the EMC issues linked to PLC systems, in the context of a frequency bandwidth extension up to 100 MHz. The current status of EMC regulations for PLC is first recalled. An experimental study is then presented for the assessment of the effect of electromagnetic field radiation from an electrical network, in the 30 – 100 MHz band. Recommendations are given for the injected PSD levels to be used for future studies within the OMEGA project. From these results, the capacity of the PLC channel is evaluated in terms of outage probability. This analysis shows that an extended bandwidth up to 100 MHz provides capacities in excess of 1 Gbps, while satisfying the current emission limits.

Keyword list

Power Line Communication, Electro Magnetic Compatibility, regulation, electromagnetic emission, channel capacity

Executive Summary

Within the OMEGA Project, WP3 is particularly dedicated to the definition and design of the next generation of Power Line Communication (PLC) systems, allowing an increase of the offered throughputs, up to 1 Gbps. For this purpose, it is proposed to extend the frequency band of operation, currently defined as 2-30 MHz, up to 100 MHz. This OMEGA deliverable gives a thorough study of the Electro Magnetic Compatibility (EMC) issues associated this bandwidth extension, with a particular focus on the radiation problem that may occur in the [30-100] MHz band.

First, the current status of EMC regulations for PLC is recalled. A draft amendment of the CISPR 22 standard is currently under development for the assessment of PLC systems. Specific features are currently investigated to increase the protection of existing services against unintentional emissions: dynamic notching and transmit power management.

The effect of electromagnetic field radiation from an electrical network is then experimentally investigated. Several measurements were conducted, in an anechoic chamber and in an ideal open environment, by injecting different levels of Power Spectral Density (PSD) on different types of electrical cables. The network topology plays an important role on the measured radiated power, leading to different frequency peaks according to the network resonance frequency. We observed that an injection power of of -80 dBm/Hz leads to an acceptable fulfilment of the CISPR radiation limit above 30 MHz, even if the limit can be slightly exceeded for a small range of frequencies.

The definition of an adequate transmitted power level for PLC systems above 30 MHz is still debated within the EMC community, and this report discusses some of the main issues. From this discussion and according to our experimental observations, future OMEGA studies will use an injected power of -50 dBm/Hz below 30 MHz, and -80 dBm/Hz over the frequency band 30 – 100 MHz. This value will be refined, depending on the evolution of the EMC regulation for PLC.

Finally, we used the proposed power levels to conduct a statistical analysis of the PLC channel capacity in terms of outage probability. The report demonstrates that a capacity in excess 1 Gbps can be reached for most of the channel classes defined within the OMEGA project, with an overall outage probability around 33%. Hence, the bandwidth for PLC operation can be successfully enlarged to provide capacities in excess of 1 Gbps, while satisfying the emission limits currently defined by regulation bodies.

List of Authors

First name	Last name	Beneficiary	Email address
Richard	RAZAFFERSON	France Telecom	richard.razafferson@orange-ftgroup.com
Pascal	PAGANI	France Telecom	pascal.pagani@orange-ftgroup.com
Ahmed	ZEDDAM	France Telecom	ahmed.zeddam@orange-ftgroup.com
Jean-Yves	BAUDAIS	IETR	jean-yves.baudais@insa-rennes.fr
Ali	MAIGA	IETR	ali.maiga@insa-rennes.fr
Olivier	ISSON	Spidcom	olivier.isson@spidcom.com

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List of Acronyms

Acronym	Meaning
AMN	Artificial Mains Network
CB	Citizens' Band (unlicensed amateur radio)
CE	European Conformance mark
CISPR	Comité International Spécial des Perturbations Radioélectriques
CTF	Channel Transfer Function
EMC	Electro Magnetic Compatibility
FCC	Federal Communications Commission
FM	Frequency Modulation
HF	High Frequency
ISN	Impedance Stabilization Network
ITE	Information Technology Equipment
PE	Protective Earth
PLC	Power Line Communications
PLT	Power Line Transmission
PSD	Power Spectral Density
US	United States
VHF	Very High Frequency
WP	Work Package

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1 Introduction

One of the key goals of Work Package (WP) 3 of the OMEGA Project is to study and design the next generation of Power Line Communication (PLC) systems, allowing an increase of the offered throughputs, up to 1 Gbps. To reach this goal, an increase of frequency band of operation is necessary, extending the 2-30 MHz band currently used by deployed products. Different studies were thus held within WP3 of the OMEGA project for the characterization and modelling of the PLC transmission channel, up to 100 MHz [1]. The Electro Magnetic Compatibility (EMC) issues associated with the deployment of PLC systems, however, are not trivial. Above 30 MHz, regulation bodies consider the level of radiated emissions, and this aspect should be looked at carefully when extending the PLC operating frequency band.

In this context, this OMEGA deliverable provides an EMC analysis of the use of PLC systems up to 100 MHz. In particular, the deliverable gives the current state of art regarding EMC regulation standards, and provides an experimental study of the electromagnetic fields radiated by an electrical network.

Section 2 gives the status of the current EMC regulations for PLC, focusing on the work done within the organization CISPR, and recalling the regulation defined in the US by the Federal Communications Commission (FCC). In Section 3, a complete experimental study is provided, where the radiated emission is observed for different injected power levels and different electrical network topologies. From these observations, recommendations are made regarding the injected Power Spectral Density (PSD) for future OMEGA studies. Finally, a study of the PLC channel capacity is given in terms of outage probability, taking into consideration the proposed injection levels, and realistic Channel Transfer Function (CTF) and stationary noise realizations.

2 Status of the current EMC regulations for PLC

This section is an update of the status of EMC regulations for PLC that was initially described in the OMEGA deliverable D3.1 [2]. In particular, the situation at CISPR evolved with different proposals for an amendment of CISPR 22 for PLT systems, as described in the next section.

2.1 CISPR

The CISPR (*Comité International Spécial des Perturbations Radioélectriques*) is responsible for the elaboration and maintenance of several international EMC standards (emission and immunity) for large families of electric or electronic products which primary purpose is the protection of radio services in the frequency range 9 kHz to 400 GHz. Example standards are the European Standard EN 55022 [3], or the product standard CISPR 22. The CISPR is divided in several sub-committees among which the sub-committee "CISPR/I" is in charge of the development of measurement methods and establishment of emission limits for Information Technology Equipment (ITE).

Different measurement methods, measuring equipment and relevant limits are applicable depending on the access port and the frequency band being considered when testing a particular product. The ITE family product includes PLT systems for which the EMC requirements of the CISPR 22 standard apply.

The measurement procedure using an Artificial Mains Network (AMN) for compliance testing of PLT-modems with respect to the limits of Tables 1 and 2 given in CISPR 22 is not appropriate due to significant issues as explained hereafter.

PLT systems being telecommunication devices using the "mains network" as a physical support to transmit data, both the measurement methods and the emission limits for "Mains ports" and/or "Telecom ports" may be considered. Taking into account these particularities the decision was made by CISPR to establish a project team (CISPR/I _ PLT-PT) whose task is to prepare an amendment to CISPR 22 standard for the assessment of PLT systems. The goal for the development of a compliance testing method for PLT-modems is that this test gives the same protection level to radio services as current CISPR 22

Present situation:

Regarding the progress of the work, after two unsuccessful attempts to produce an amendment for PLT systems (specifying the criteria of tests in particular), a new project is again under discussion.

This amendment should define the measurement principles and the related limit values which allow appropriate operation of PLT systems and provide at the same time sufficient protection to sensible radio services by notching and/or other means, such as power management. The requirement to use such techniques to protect the broadcast services is considered a good way forward to reach a compromise. Hopefully, this work will allow publishing a new harmonized EMC standard that will be available for the CE marking of PLT equipment in a perennial way.

This new draft amendment takes two approaches:

- Type 1 PLT device is a category of PLT device that require the implementation of additional protection measures to reduce the probability of interference such as "Notching" and "Power management" described below.
- Type 2 PLT device is a category of all other PLT modems.

<u>Permanent Notching</u>: For certain parts of the radio spectrum (e.g. radio amateur bands, CB bands, selected safety services) permanent notches are applied which ensure that the expected emissions in these bands are well below the CISPR 22 limits.

<u>Dynamic Notching</u>: To protect the broadcast reception, a system called dynamic notching is proposed. In this case the PLT device detects the presence of broadcast signals which are strong enough to allow useful reception and protects them by means of notching. As for permanent notching, this will ensure that emissions of the PLT device are well below the limits in CISPR 22 and that shortwave broadcast reception even with in-door antennas is possible.

Transmit power management: The PLT system will be set up to detect the transmission losses and set the transmit power to the minimum level required to achieve data transfer at the required speed (present day PLT devices in general do not make use of transmit power management).

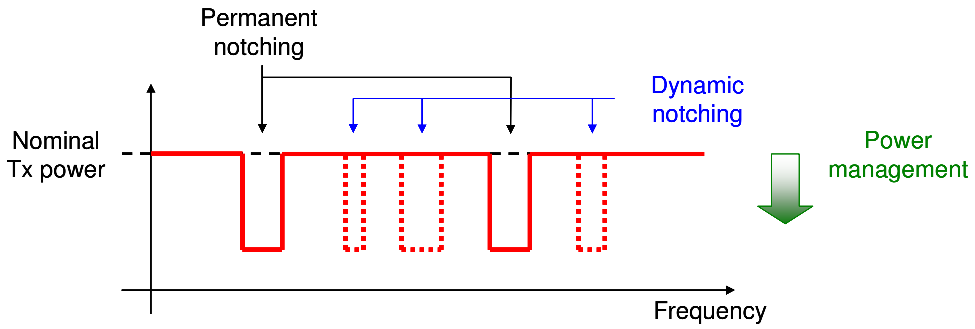


Figure 1: Illustration of dynamic notching and power management concepts

The Type 2 device approach transfers the CISPR 22 assessment of the disturbance potential of the telecommunication port to the case of a PLT port, using an ISN (Impedance Stabilization Network) to measure the common mode signal.

Proposed limits are as follows:

Frequency range MHz	**Limits** dB(µV)	
	Quasi-peak	**Average**
1,705 to 5	56	46
5 to 30	60	50

Table 1: Limits of conducted common mode (asymmetric mode) disturbance at PLT ports in the frequency range 1,705 MHz to 30 MHz with the communication function active for Class B In-Home Type 1 PLT Device

Frequency range (MHz)	**Voltage limits** (dBµV)		**Current limits** (dBµA)	
	Quasi-peak	**Average**	**Quasi-peak**	**Average**
1,705 to 30	58	48	30	20

Table 2: Limits of conducted common mode (asymmetric mode) disturbance at PLT ports in the frequency range 1,705 MHz to 30 MHz with the communication function active for Class B In-Home Type 2 PLT device

The radiated limits and measurement method in the frequency range above 30 MHz are those from CISPR 22.

Frequency range MHz	**Quasi-peak limits** dB(µV/m)
30 to 230	30
230 to 1 000	37

Table 3: Limits for radiated disturbance of class B ITE at a measuring distance of 10 m

2.2 FCC Part 15

The Federal Code Of Regulation FCC Part 15 [4] is a common testing standard for most electronic equipment. FCC Part 15 covers the regulations under which an intentional, unintentional, or incidental radiator that can be operated without an individual license. FCC Part 15 covers as well the technical specifications, administrative requirements and other conditions relating to the marketing of FCC Part 15 devices. Depending on the type of the equipment, verification, declaration of conformity, or certification is the process for FCC Part 15 compliance [5].

FCC Part 15 applies for In-home PLC. Present FCC rules say that carrier-current systems --this includes PLC-- need to meet the general radiated emission limits for unlicensed "intentional emitters." An intentional emitter is one that transmits a radio signal as a part of its normal operation. At HF, PLC systems are permitted a radiated field strength of 30 µV/meter measured at 30 meters from the signal source. At VHF, they are permitted radiated emissions of 100 µV/meter measured at 3 meters from the signal source. In most cases, the source will be the electrical wiring within a building or the electric-utility lines that pass close to residences and businesses in the US [6].

3 Characterization of the PLC electromagnetic emission

3.1 Context of the study and experimental setup

From the EMC point of view, PLC systems are required to comply with the standard EN 55022 class B, since these products will be deployed in the customer premises, in a residential environment. As a consequence, applicable EMC tests are conducted disturbance between 150 kHz and 30 MHz, and the radiated disturbance between 30 MHz and 1 GHz.

In this study, we observed the electrical field radiated by an electrical network at 3 m from the electrical wires. Note that the network under study was isolated from the mains network. As a function of the injected PSD, a direct measurement of the electrical field is taken, using a bi-conical antenna situated at a height of 1 m, and at a distance of 3 m from the centre of the electrical wire. The total length of the electrical wire is 15 m (see Figure 2). The experiment took place above a copper ground plane. A coaxial cable conveys the inducted signals toward the selective received.

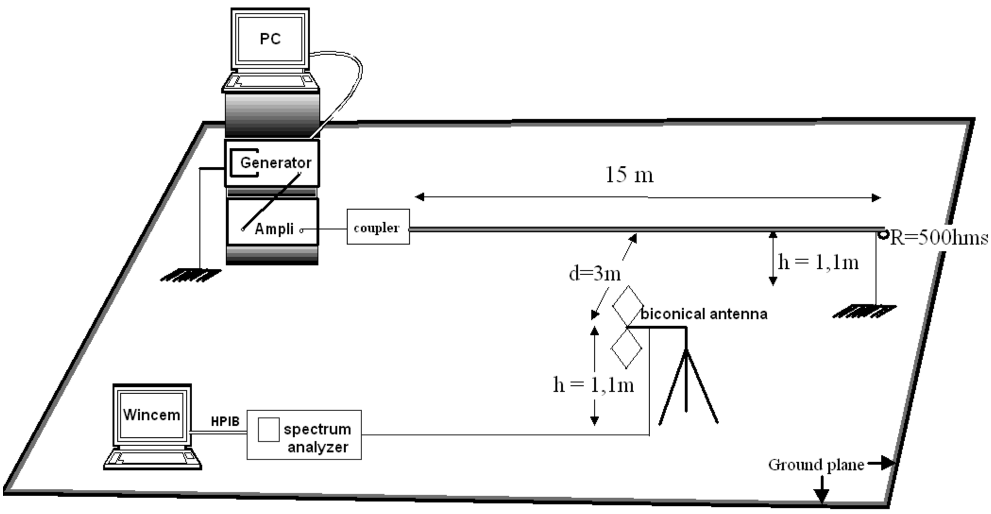


Figure 2: Experimental setup for the measurement of the radiated field for a 15 m cable.

In order to validate the selected measurement protocol, measurements were first taken in an anechoic chamber. In a second step, measurements were taken in a wide site, equivalent to free space conditions. During the experiment, we used two different electrical cables, with two different lengths, with a setup representative of a realistic residential environment. One of the cable extremities is connected to a 50 Ohm load. A computer-driven generator allowed injecting signals at one end of the cable using different power levels, in the 30-100 MHz band, using a passive coupler. Note that the measurements are done on a passive network, which is disconnected from the mains network. The injection of differential mode signal is thus realized using a simple wideband transformer, as depicted in Figure 3.

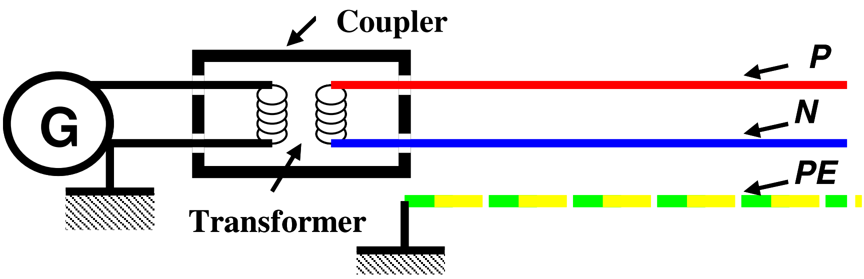


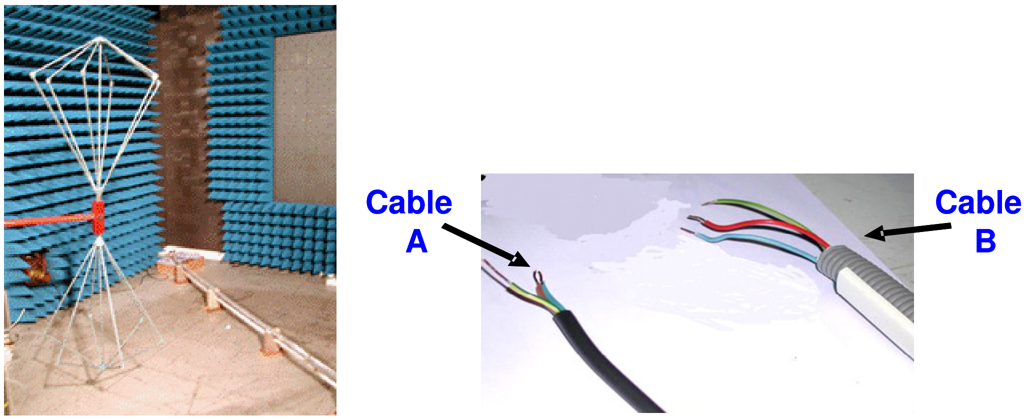
Figure 3: Wideband coupler.

It should be noted that the reference standard (EN 55022) defines the limits to take into account in a quasi-peak detection mode. For the sake of measurement rapidity, and in accordance with the EN 55022 measurement recommendations, all measurements are first realized in a peak detection mode, and the conversion to quasi-peak detection mode is done by post-processing. In the case of a narrowband signal, the difference between these two detection modes is negligible.

3.2 Measurements in an anechoic chamber

3.2.1 Experimental setup

Electrical lines are situated at 15 cm or 1 m from the floor in a shielded anechoic chamber, hence isolating the experiment from external disturbance. The pictures and schematics of Figure 4 and Figure 5 present the geometrical configuration of the measurement setup within the anechoic chamber. The termination load of the electrical line is 50 Ohm. For the first cable type, noted Cable A, the transversal positioning of the three wires is almost uniform, as the three wires are moulded in the cable. For the second cable type, noted Cable B, the transversal positioning of the wires is random.



(a) (b)

Figure 4: Anechoic chamber setup (a) and different types of cables (b).

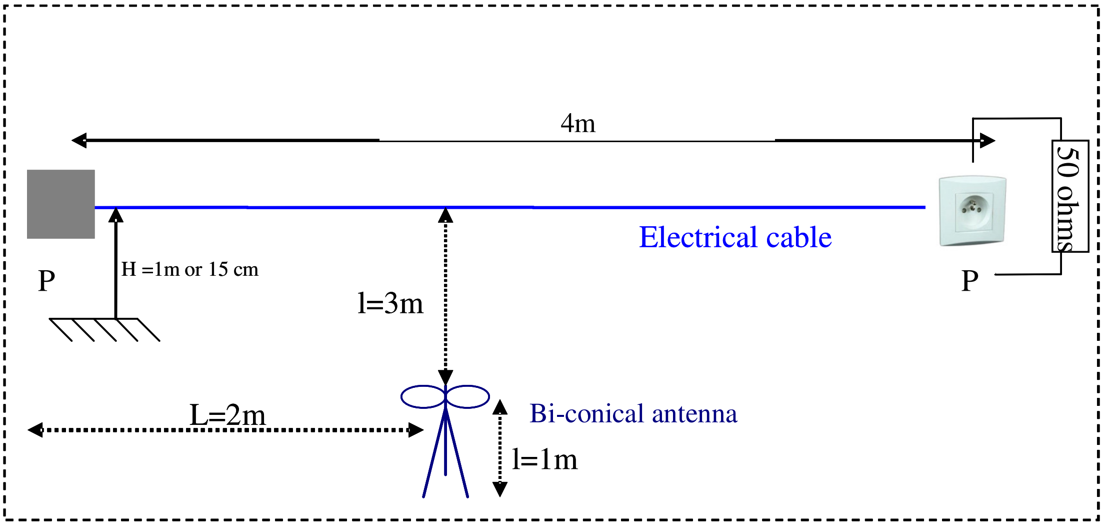


Figure 5: Experimental setup for the measurement of the radiated field in an anechoic chamber for a 4 m cable.

To evaluate the output power of the modems, on can use the following equation:

(1) $$P_{out} = 10 \cdot \log(R_{bw}) + PSD$$

where P_{out} is the output power in dBm, PSD is the observed power spectral density in dBm/Hz, and R_{bw} is the width of the analysis filter in Hz. In principle, the standardized filter width is 120 kHz for measurements above 30 MHz.

3.2.2 Measurement results

This experiment allows to analyse the influence of the type of cable (noted cable A and cable B, see Section 3.2.1) on the electromagnetic radiation, as a function of the cable length. Note that the Protective Earth (PE) wire is connected at the metallic ground at the injection point, and that the power was injected using varying levels.

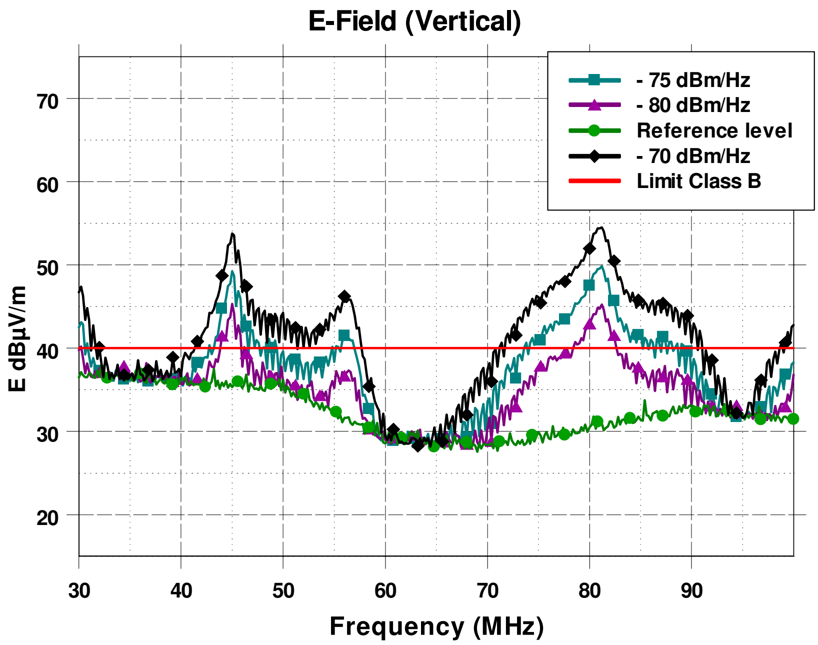


Figure 6: Comparison of the E_V field using cable B, with PE wire connected to the ground, at 1 m height.

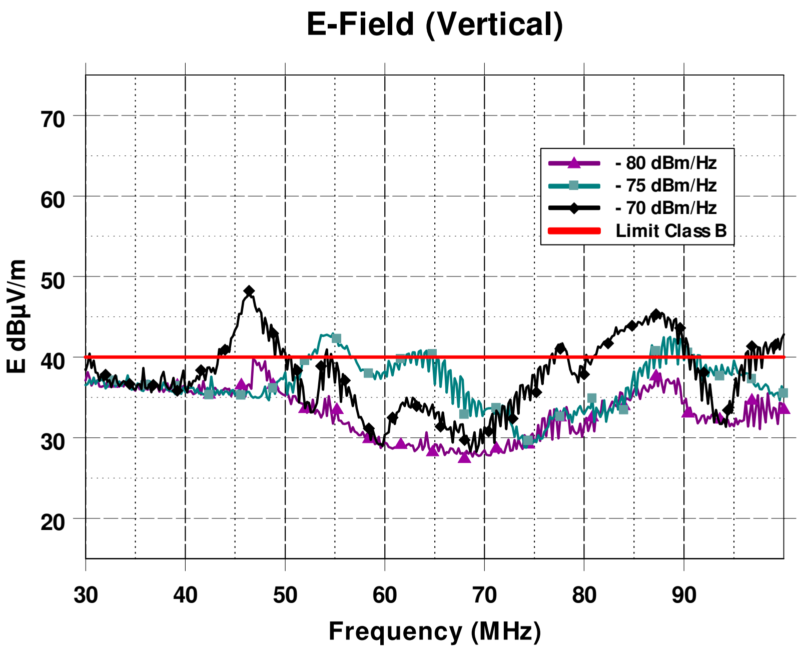


Figure 7: Comparison of the E_V field using cable A, with PE wire connected to the ground, at 1 m height.

Results presented in Figure 6 and Figure 7 show that the amplitude level of the measured field is higher when using cable B as compared to using cable A.

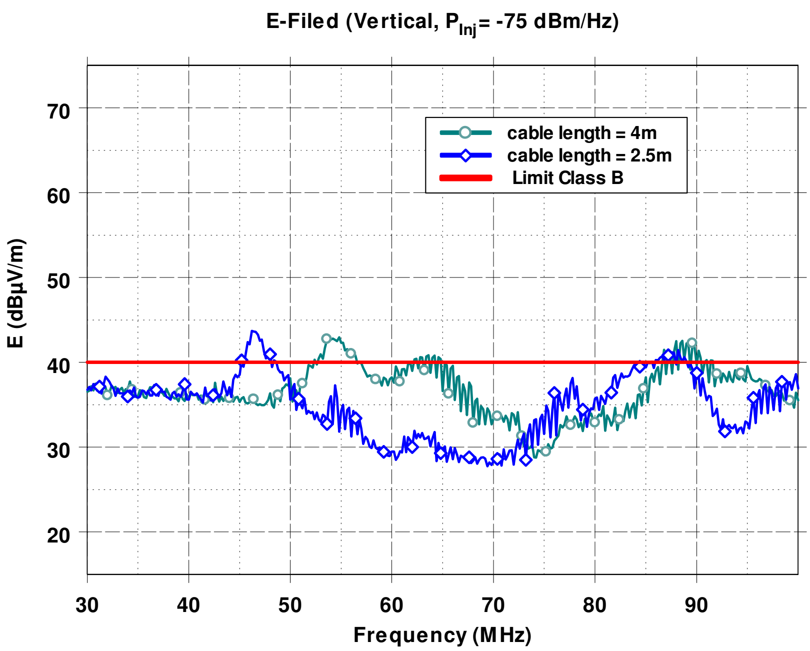


Figure 8: Comparison of the E_V field as a function of the cable length using cable A, with PE wire connected to the ground.

Results presented in Figure 8 show that there is very low divergence between the different cable lengths regarding the level of the radiated power. However, one can note that the cable length plays an important role on the resonance frequency.

3.3 Measurements in an ideal environment

This series of measurements was realized in a site similar to site in free space. We collected the measurements results regarding the electrical field as a function of the different types of cables and of the studies emission configurations.

3.3.1 Configuration 1: experimental setup and measurement results

The following figures represent the configuration 1 for field measurement, and the experimental setup. One can observe that cable B is placed at a height of 15 cm above the ground plane.

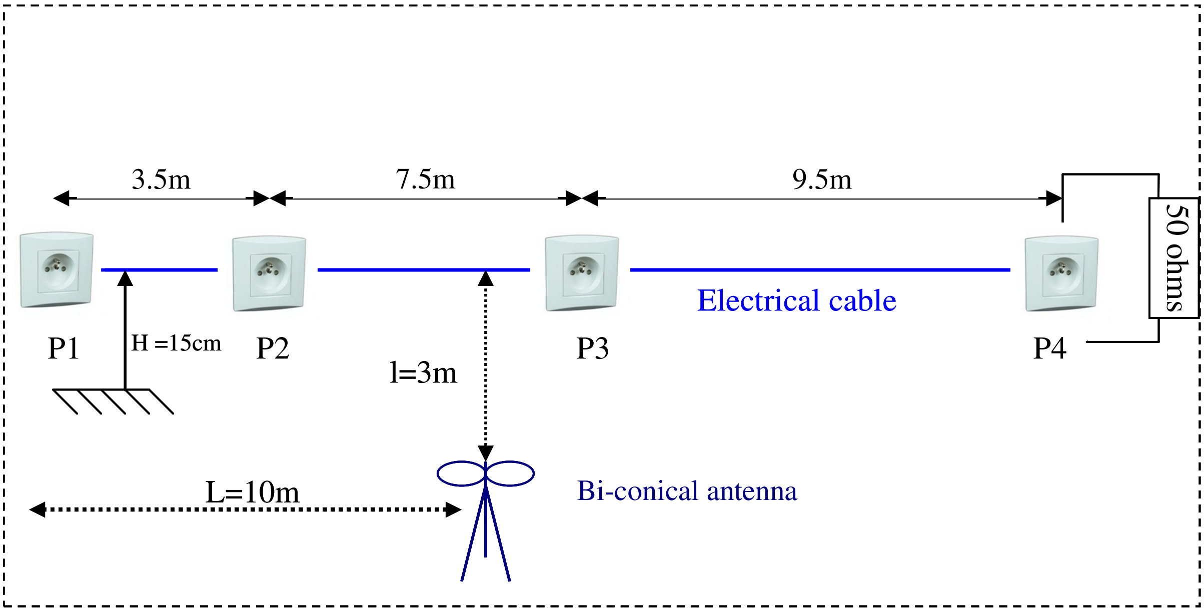


Figure 9: Configuration 1: experimental setup.

Figure 10: Setup picture taken from plug P2.

Figure 11 represents the comparison of different measurement results as a function of the injected power as well as the reference measurement. The reference measurement corresponds to a measurement taken without any power injection, and accounts for the local disturbance emitted by external sources and collected by the receiving antenna. On the same figure, we reported the limits given by the EN55022 class B standard, for the residential environment.

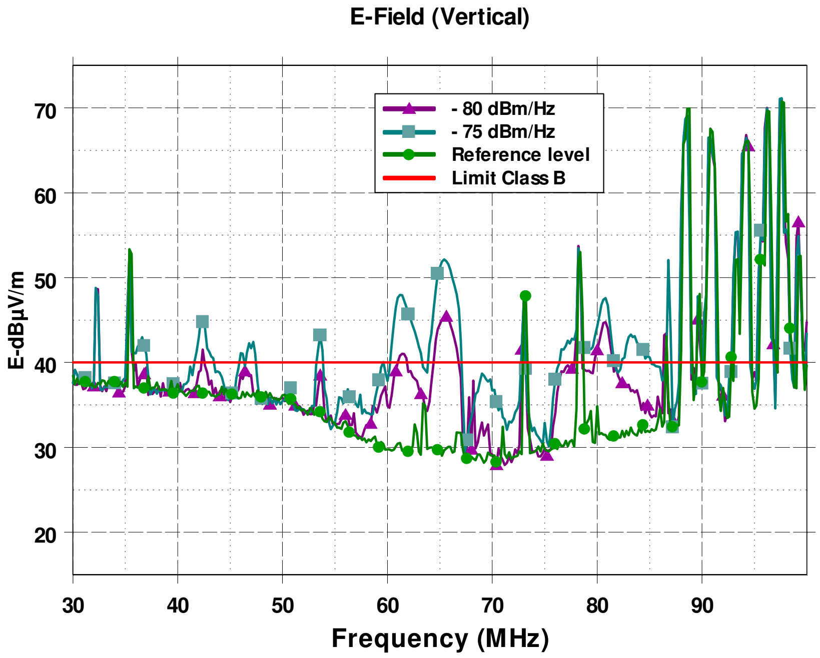


Figure 11: Evolution of the E_V field as a function of the injected power.

One can observe from this figure that the class B standard is respected for an injected power of – 80 dBm/Hz (except for a small range of frequencies around 66 MHz and 81 MHz in this particular observation). With a injected PSD of – 75 dBm/Hz, the level of the radiated power is in the range of 10 dB with respect to the class B EN 55022 standard. One can also notice a large number of radio signals between 87 MHz and 100 MHz (due to the FM band within 87 MHz – 107 MHz), as well as some external emissions between 70 MHz and 80 MHz.

3.3.2 Configuration 2: experimental setup and measurement results

Figure 12 below represents the configuration 2 for field measurement, and the experimental setup. One can observe that cable B and cable A are placed at a height of 1 m above the ground plane.

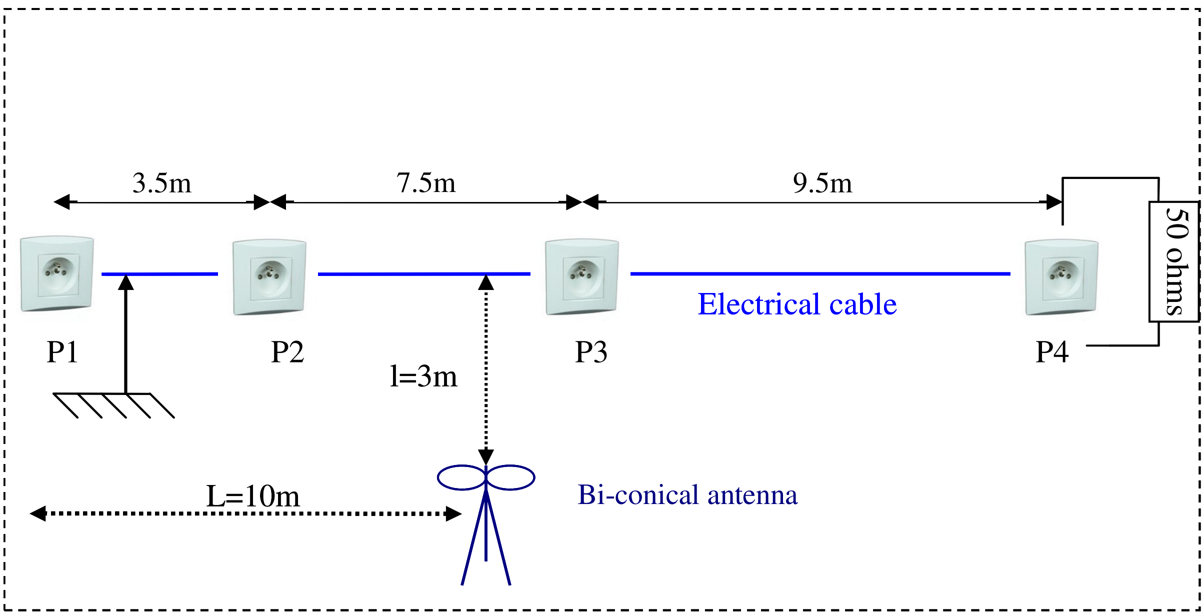


Figure 12: Configuration 2: experimental setup.

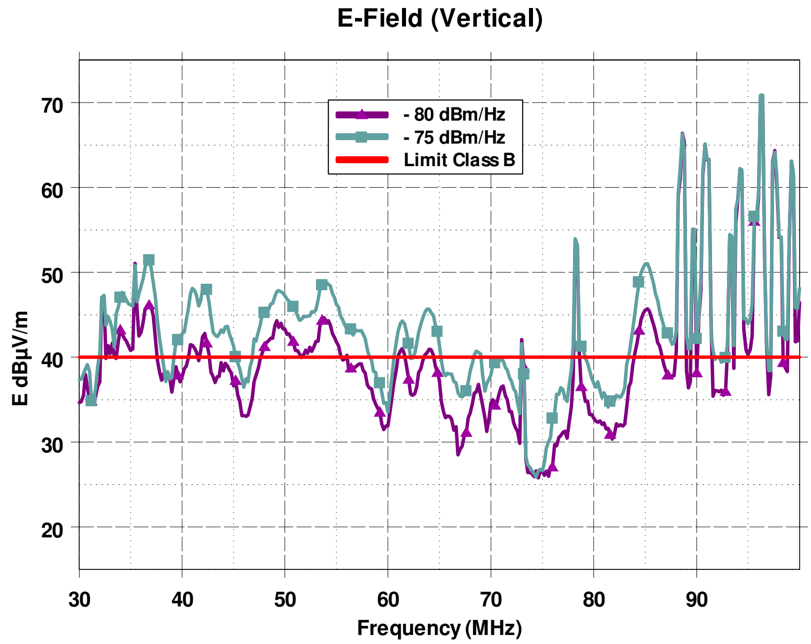


Figure 13: Evolution of the E_V field as a function of the injected power for cable B.

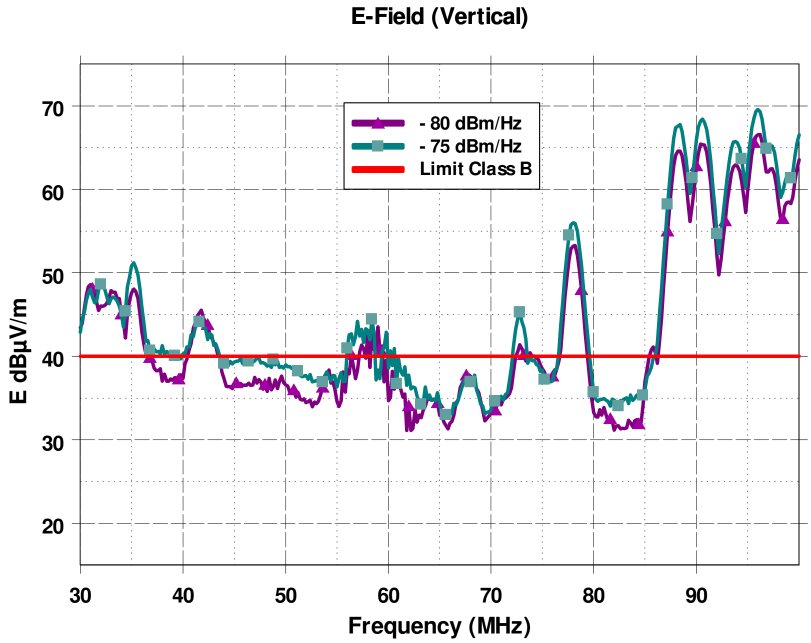


Figure 14: Evolution of the E_V field as a function of the injected power for cable A of length 15 m.

Figure 13 and Figure 14 represent the comparison of the radiated electrical field in configuration 2 as a function of the injected power. On the same figure, we reported the limits given by the EN55022 class B standard, for the residential environment. One can notice that the limit of the class B EN 55022 standard is respected when a PSD of – 80 dBm/Hz is injected, except for some frequencies, which can be due to ambient noise or measurement uncertainty.

3.3.3 Configuration 3: experimental setup and measurement results

Figure 15 below represents the configuration 3 for field measurement, and the experimental setup. Cable B is situated at 15 cm above the ground plane in the first section of the cable, and is then positioned vertically up to a height of 2.50 m, followed by a horizontal section a 2.50 m above the ground plane.

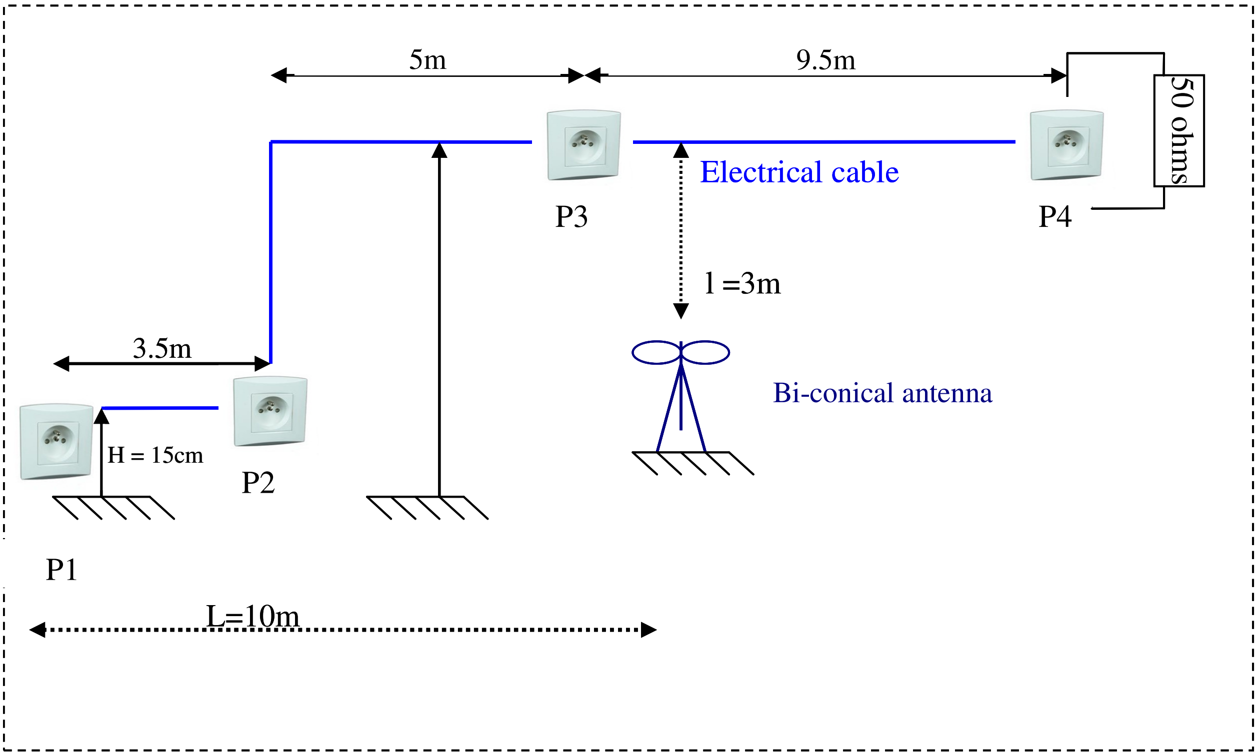


Figure 15: Configuration 3: experimental setup.

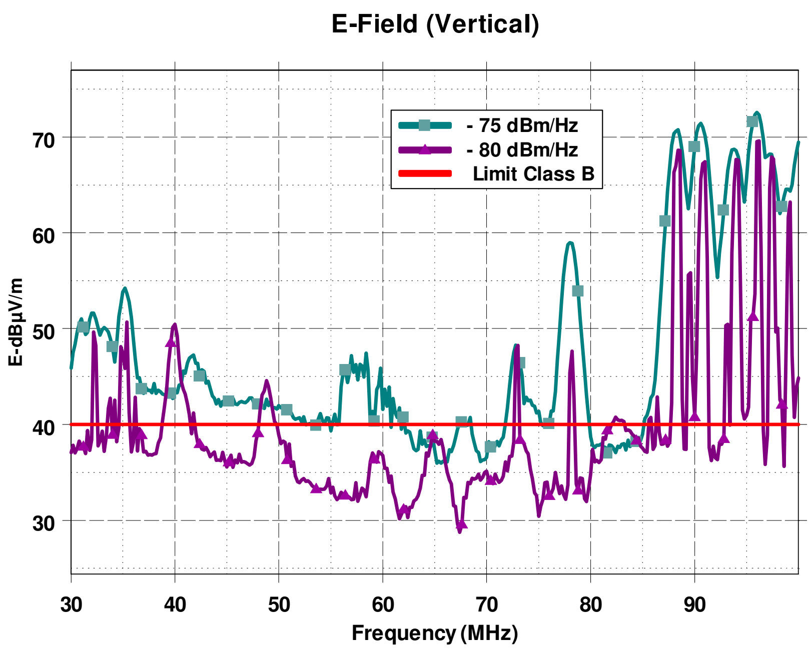


Figure 16: Evolution of the E_V field as a function of the injected power.

Again, the presence of external radio electric noise is observed above 70 MHz, and especially the FM band between 87 MHz and 100 MHz.

3.4 Evaluation of the transmitted power in the 0-100 MHz band

The experimental study presented above gives an idea of the radiated emission observed from a particular electrical network setup, with different levels of injected PSD. Before drawing conclusions on the transmitted power levels that are practical and realistic for an extension of the operating frequency for PLC systems, different points should be taken under consideration.

First, there is currently no regulation standard specifically addressing the problem of PLC transmission. Although a Project Team has been set up within CISPR/I in order to prepare an amendment to CISPR 22, the CISPR 22 regulation text in force addresses ITE in general. The described measurement process includes the device under test with its peripherals and connecting cables, but the equipment is connected to an AMN. This device is an artificial electrical network, providing the mains power and a given connection impedance, but without physical electrical wires. Hence, the power lines are not included in the current measurement setup. Whether or not a given topology of electrical network should be included in the radiation measurement setup has not been decided yet by regulation bodies.

This question raises several issues. As is demonstrated in Figure 8, for instance, a simple electrical cable will provide different resonance frequencies depending on the length of the cable. A more complex network topology will obviously generate a higher disparity in the possible measurement results. The line terminations, with different types of loads depending on the connected devices, may also influence the observed results.

Finally, it should be noted that the current CISPR 22 text, intended for the certification of ITE devices, recommends performing a series of test measurements, with a number of measurements generally comprised between 5 and 12. The recorded levels among all measurements are averaged. The experimental observations show that the radiated power presents some peaks with respect to the average level, the frequency of these peaks depending on the particular network topology (see for instance Figure 11 and Figure 13). If an averaging should be applied between measurements over different electrical network topologies, this would necessarily impact the level of injected power that should be considered as acceptable.

With all these comments in mind, and according to the observed experimental results, we will consider in the OMEGA project that an injected power of -80 dBm/Hz over the frequency band 30 MHz-100 MHz is an acceptable value. For all performed measurements, this level of injected power lead to a few peaks only above the CISPR radiation limit, with less than 5 dB overlapping for most cases, and with a high correlation with the actual network topology. The proposed value will need to be refined, depending on possible further results, and on the evolution of the EMC regulation for PLC.

For frequencies below 30 MHz, the OMEGA project will use an injected power of -50 dBm/Hz, as already used by deployed PLC products. Finally, the proposed injection power for future studies within the OMEGA project are recalled in Table 4.

Frequency range (MHz)	**Injected power (dBm/Hz)**
1.705 - 30	-50
30-100	-80

Table 4: Proposed injection power limits for future studies within the OMEGA project

3.5 Channel capacity under transmitted power limitations

Channel capacities are evaluated in terms of outage probabilities. Figure 17 to Figure 19 give examples of outage probabilities of channel class 2, 5 and 9, as described in deliverable D3.2 [1]. To evaluate the outage capacities the PSD noise is obtained with the noise model described in deliverable D3.2 [1]. This noise model takes into account the background noise floor level, the strong radio interference carriers within short-wave radio frequency bands, a frequency-dependent radio background noise and randomly distributed interference carriers.

Each outage probability curve is obtained using 1000 random draws for a couple of CTF realization and stationary noise realization according to the models described above.

For each figure, 3 transmitted power masks are used:

- case A: -50 dBm/Hz in the 1-100 MHz bandwidth plus notches in the 1-30 MHz bandwidth with a level of -80 dBm/Hz,
- case B: case A with a lower PSD of -80 dBm/Hz in the 30-100 MHz bandwidth,
- case C: case B without transmission within FM bands (87.5-100 MHz).

As it is shown in Figure 17 for channel class 2, the gigabit is never reached with the more tricky power mask. On the opposite side, 1 Gbps is all the time exceeded with channel class 9 and 2 Gbps is reachable with 94% of outage probability.

The FM band has low influence for class 2 (curve C versus curve B) whereas it is not the case for class 5 and 9. So, the better the channel (i.e. the number of the channel class) the more important is the FM bandwidth influence.

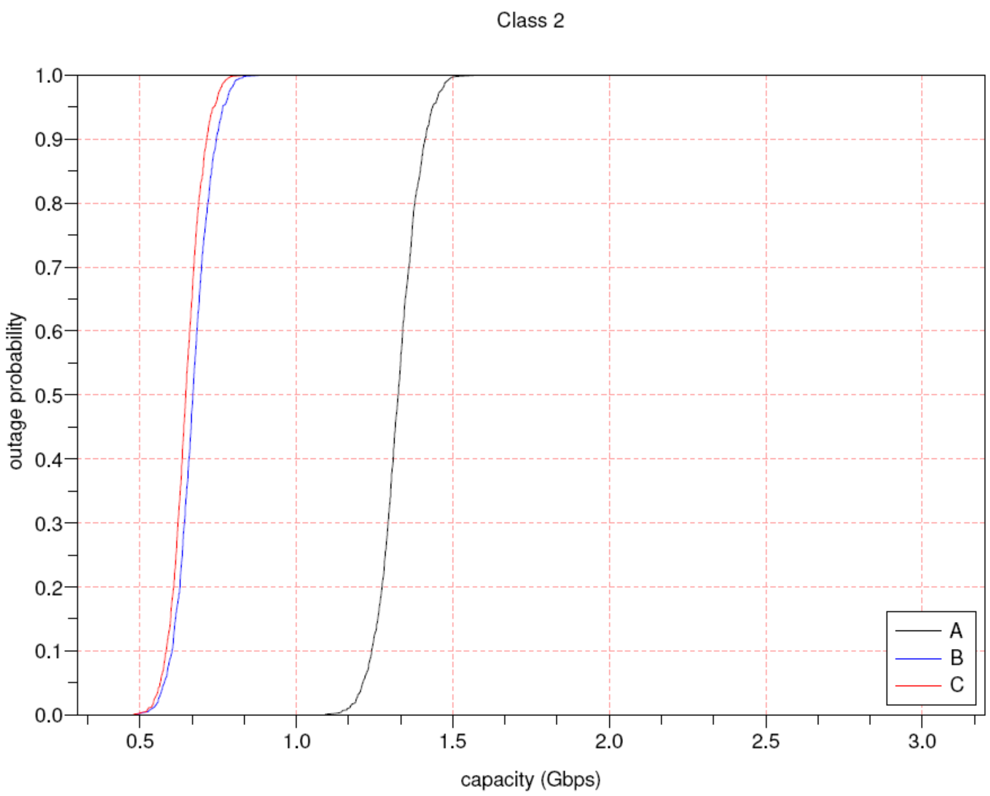


Figure 17: Outage probability of channel class 2.

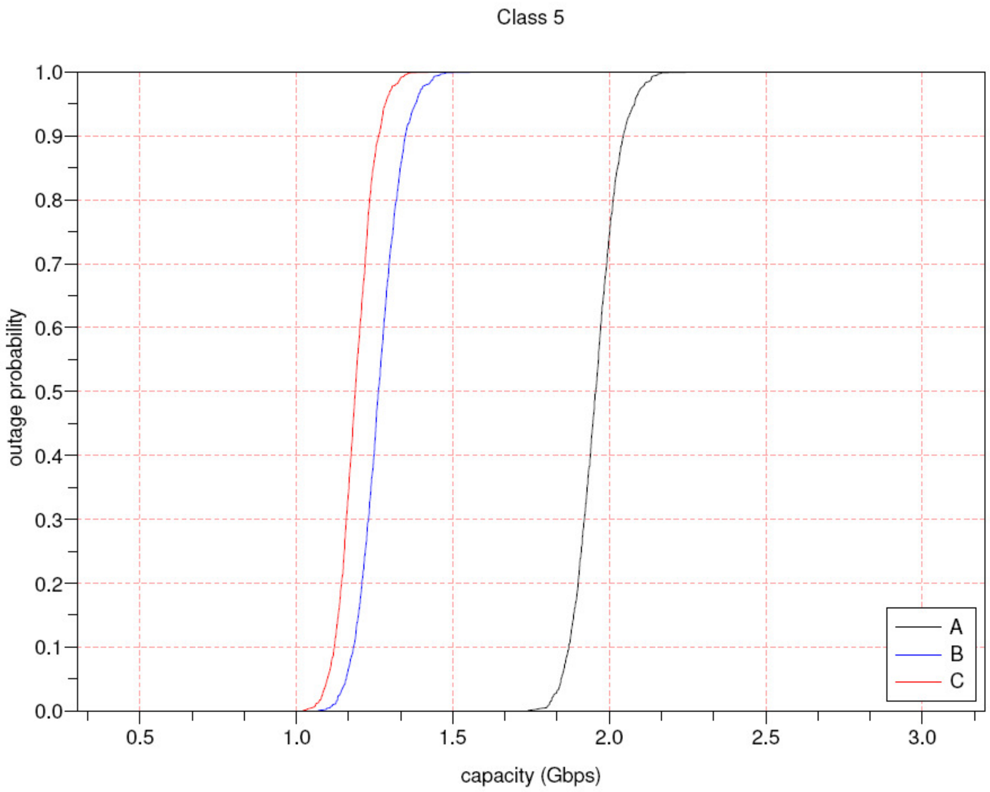


Figure 18: Outage probability of channel class 5.

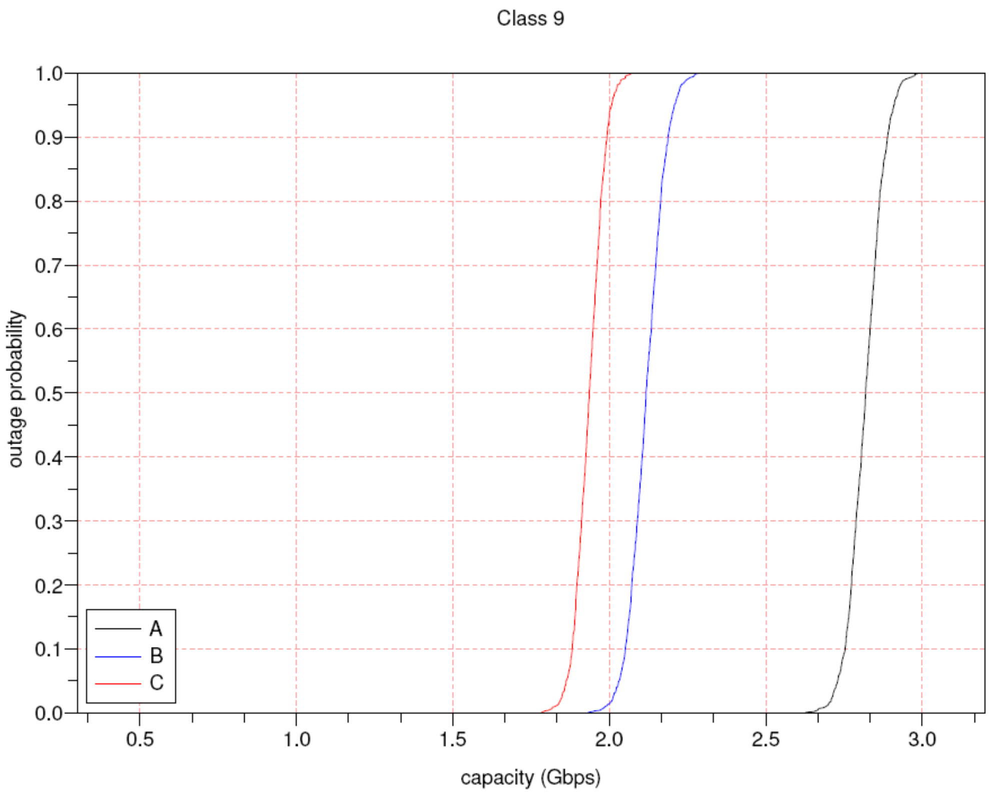


Figure 19: Outage probability of channel class 9.

Figure 20 shows the outage probabilities of channel classes 1 to 9 taking into account the repartition of the channel classes given in deliverable D3.2, table 32, page 102. To plot the curves, transmitted power masks in cases A, B and C are also considered. The gigabit is possible in case C with an outage probability around 33%.

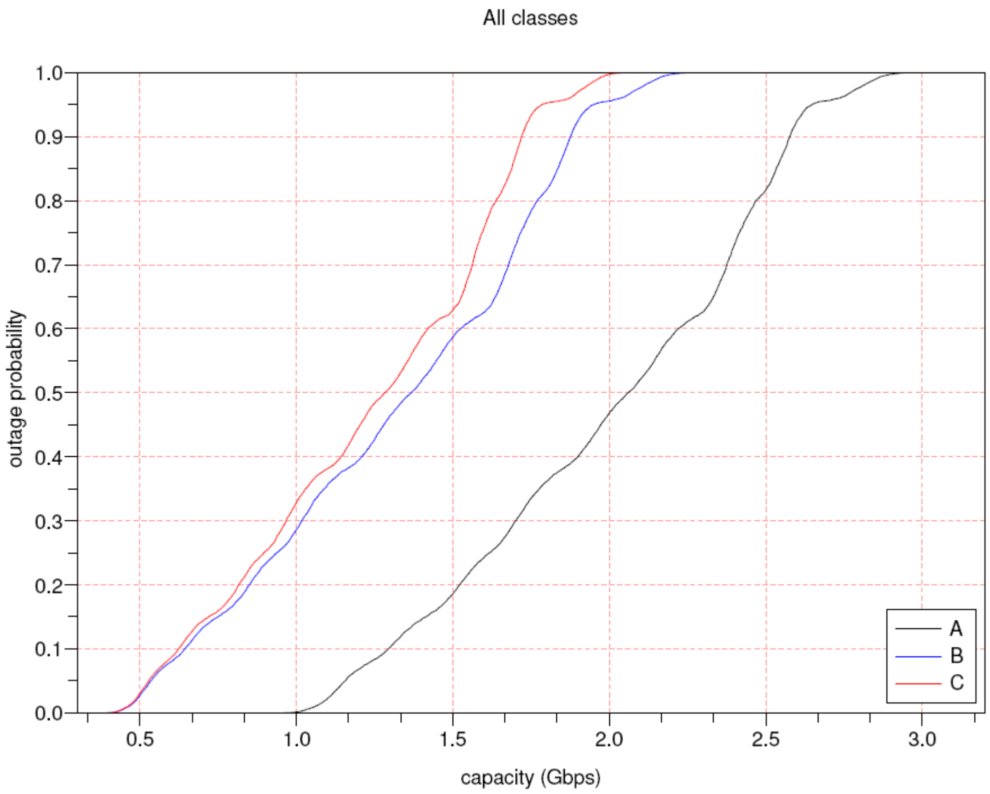


Figure 20: Outage probability of channel classes 1 to 9.

4 Conclusion

In this OMEGA deliverable, we presented a thorough study of the EMC issues associated to an extension of the frequency band for PLC up to 100 MHz.

The current status of EMC regulations for PLC is recalled, with a particular focus on the current activities conducted at CISPR 22. Specifically, a Project Team was established within CISPR/I to prepare an amendment to CISPR 22 for the assessment of PLT systems. The draft amendment is considering different additional protection measures to reduce the potential interference with other systems: dynamic notching and transmit power management. A particular level for conducted common mode disturbance is proposed for devices implementing these features. Further work is still needed within this committee in order to establish a specific standard amendment for PLC.

An experimental study was set up in order to evaluate the electromagnetic field radiated by an electrical network for different injected PSD levels. For this purpose, a complete experimental setup was realized, and experiments were conducted both in an anechoic chamber and in an ideal open environment. Two types of cables were studied, where the conductors are either moulded or loose. Results show that the recorded radiated level is strongly influenced by the cable length, and more generally by the network topology, with a weaker, but still observable, influence of the cable type. In general, an injection power of -80 dBm/Hz leads to an acceptable fulfilment of the CISPR radiation limit above 30 MHz. In most observed cases, the recorded radiation level exceeded the limit at a few frequency peaks only, with generally less than 5 dB overlap. In addition, the frequency of these peaks is strongly dependent on the network topology, which dictates the resonant frequency of the network.

Different questions need to be investigated before drawing conclusions on the transmitted power levels to be used by PLC systems above 30 MHz. In this deliverable, a few of them are examined: the current discussions on the measurement methods within EMC regulation bodies; the influence of the electrical network topology on the radiated fields; and the issue of measurement averaging in the EMC certification process. From these comments, and according to our observations, an injected power of -80 dBm/Hz over the frequency band 30 – 100 MHz will be used for future OMEGA studies. Below 30 MHz, we will consider the power level of -50 dBm/Hz already used by deployed products. The proposed value will need to be refined, depending on possible further results, and on the evolution of the EMC regulation for PLC.

Finally, we conducted a statistical analysis of the PLC channel capacity in terms of outage probability. For this purpose, the proposed injected power levels were taken into account, in conjunction with realistic models of CTF and stationary noise. Three power masks were considered, including a specific protection of the FM bands. In general, for the worst channel cases, a capacity of 1 Gbps is not reached unless releasing the EMC limitations constraints. On the other hand, our study shows that the average channels always achieve a capacity higher than 1 Gbps, with channel capacities above 2 Gbps for the best channel class. When considering all channel classes simultaneously along with their probability of appearance, a channel capacity of 1 Gbps is reached with an outage probability around 33%. This demonstrates that the bandwidth for PLC operation can be successfully enlarged to provide capacities in excess of 1 Gbps, while satisfying the emission limits currently defined by regulation bodies.

This report constitutes a first version of deliverable D3.1. An extended version with complementary studies will be provided within the course of the OMEGA project.

5 References

[1] Seventh Framework Programme: Theme 3 ICT-213311 OMEGA, Deliverable D3.2, "PLC Channel Characterization and Modelling", Dec. 2008.

[2] Seventh Framework Programme: Theme 3 ICT-213311 OMEGA, Deliverable D3.1, "State of the art, application scenario and specific requirements for PLC ", March 2008.

[3] European Standard EN 55022. Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement.

[4] Federal Communications Commission. Title 47 of the Code of Federal Regulations part 15. 2007.

[5] http://www.cclab.com/fcc-part-15.htm

[6] http://www.arrl.org/news/features/2003/06/19/2/