PLC and the Amateur Radio Service
A paper by the International Amateur Radio Union Region 1

Introduction

This paper is presented on behalf of the 3.5 million amateur radio members of the International Amateur Radio Union (IARU) worldwide, and more specifically on behalf of its members in Region 1, the Region which incorporates the EU. IARU Region 1 represents the interests of 89 national radio societies, the largest being in Germany and the UK.

Radio amateurs throughout Europe are concerned at the impact the mass roll-out of PLC would have on the HF radio spectrum; a precious resource which is of such vital importance to those who rely on it for their communication needs. The comments in this paper refer principally to the Amateur Radio Service but the technical issues and arguments apply equally to other users of the HF spectrum.

The Amateur Radio Service

Article 1.56 of the ITU Radio Regulation defines the amateur radio service as "*A radiocommunications service for the purpose of self training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorised persons interested in radio technique solely with a personal aim and without pecuniary interest*". The ITU also recognises the role of the amateur radio service in the event of natural or man-made disaster or emergencies. The ITU-R allocated frequencies are available not only for use by amateurs but by the emergency services in times of need.

The EU policy on PLC

The IARU fully understands that liberalisation of the telecommunications market is desirable, that the unbundling of the local loop and the encouraging of competition is healthy and advantageous and that the EU should become "the most competitive and dynamic knowledge based economy in the world". This however should not be at ANY price, especially when it is detrimental to the spectrum which is so important to its existing users. Commercial and marketing pressures should not be allowed to influence the diminution of standards. It appears that the technical issues are now being set aside in favour of a push to enable deployment of PLC, which by its very nature, has the potential to destroy the HF spectrum as we know it. The choice therefore appears to be between HF radio or PLC.

The HF spectrum and those who use it

The HF spectrum, traditionally recognised as 3.0 – 30 MHz, is a valuable natural resource which provides the only medium for international communications without the use of satellite or any other telecommunications infrastructure. The HF radio spectrum is extensively used by many organisations, such as broadcasters, military including NATO, diplomatic services, NGOs, civil aviation, ports and docks authorities, short range devices, safety of life service, radio astronomers as well as radio amateurs and short wave listeners. The HF Spectrum enables usage of a wide dynamic range of signals, with some users operating with low level signals which are particularly susceptible to the slightest increase in the background noise level. The reliability of long range HF communication is variable, due to ever changing environmental factors. HF operation could be considered "opportunistic" inasmuch as time and frequency are selected to optimise communication over any desired path. Inonospheric variations influence the use of these bands as does the ambient noise in any given location [1]. There seems to be a myth being promulgated in Europe that HF is dead. Nothing could be further from the truth. New generations of equipment operating on HF are envisaged by the military and NATO, much effort is being put into the development of DRM for high quality HF broadcasting and the continuing use of HF in aviation is assured. With the relaxation of the requirement for a Morse qualification for access to the HF bands, the number of HF amateur radio operators is already growing fast. In the future the amateur frequencies will still be the last (or in many case the first) resort in cases of emergency and disaster.

For may decades all countries who are members of the ITU have worked together to protect the radio spectrum from interference and to allocate frequencies that allow all users of the spectrum to co-exist. All this is at risk with the prospect of PLC rollout without satisfactory emission limits.

Comparison of cable technologies

The characteristics of data transmission over wired media are determined by several factors:

- the degree of screening
- the degree of balance
- the nature of the transmission
- the power used
- frequency
- mitigating measures available

These are compared in the following table:

Nature	Coaxial Cable	DSL	PLC
Suitability of the transmission medium to carry wideband data	Very Good	Medium	Poor
Features of the cable system	Screened	Balanced	Unscreened and unbalanced
Available bandwidth and potential for expansion	Very Good	Fair	Poor
Practicality of applying mitigating measures	Good	Medium	Very poor

Table 1 : Comparison of the cable technologies

Coaxial cable

Traditional cable (cable TV etc) is generally of very high quality, and when leakage occurs, remedial measures are put in place quickly.

DSL (ADSL)

ADSL uses low RF frequencies and radio interference problems are negligible for two reasons. Firstly the deviation of the twisted pair from a perfect transmission line is less significant at lower frequencies, and secondly the long/medium wave broadcast signals are very strong, so any RF leakage is unlikely to be noticed. DSL services are supplied only on-request. There are expected to be over 20 million subscribers in Europe by the end of 2003. There have been no reported cases of interference to amateur radio, but this may be due to the fact that current ADSL systems operate at frequencies below the lowest amateur band (apart from 136 kHz). However it is believed that some interference to aeronautical navigation beacons has been reported.

DSL (VDSL)

Because of the frequencies used, expected interference to the amateur frequencies will be relatively high. Nevertheless, the cable balance is much better than for powerline networks, and the transmitted power required is lower. ETSI standards require that systems shall be capable of being notched for the international amateur bands.

PLC

Variable launch power, variable frequencies, launched over unshielded relatively unbalanced lines, all lead to high interference potential to amateur frequencies in the domestic environment. In many cases interference is capable of destroying communications completely.

Radio and satellite

Use of higher power radio-LANs (community radio networks) for high speed internet access is growing fast in many smaller communities around the world. As volume increases the price drops, and these systems offer a viable and economic alternative to cable based systems for the “final mile”.

Uni-directional satellite links are available for remote sites, and the price is dropping. Bi-directional systems are still expensive.

All these systems create very few interference problems for HF radio

Why PLC is different

PLC does not compete on an equal footing with other broadband technologies in the following ways:

- **Interference levels are high**. The laws of physics come into play here. Applying a high frequency signal to unshielded copper wire which is the same as, or longer than a quarter wavelength at the frequencies being used will result in a high level of radiated emissions. [2] The higher the frequency, the shorter the cable needed to make a good radiator. Unshielded or unbalanced lines will radiate even when buried. A ground of average conductivity provides minimal shielding at frequencies up to 30 MHz for cables buried at typically 0.5m depth. This is because the skin depth in average ground up to 30 MHz is several metres. The cable is buried at a small fraction of this skin depth. As far as emissions are concerned, the cable may as well be lying on the surface. Tests during trials in Europe have shown the interference levels from PLC systems to be unacceptable [3]

- **Mains not designed for RF**. Mains cables are “lossy” at HF and also suffer significant levels of mains-borne interference from electrical equipment. So if PLC is to work at all, relatively high injection powers will have to be used, inevitably leading to high emission levels. Repeaters will have to be used at additional cost [4]

- **Capacity is shared**. The capacity of an “Access” PLC system is shared between all users in a street, and is therefore severely limited. For example if a total PLC data rate of 2Mbps is shared between 20 users, each user has an average of only 100 kbps. By comparison, ADSL can provide “downstream” data rates of 2-6 Mbps for each user individually.

- **Always on**. This is a selling point, according to PLC proponents. However, the presence of interference within the home and outside, 24 hours a day is one of the greatest concerns. This could mean that an amateur radio operator living next door to a PLC installation will suffer unacceptable levels of interference and in some cases the blocking of all signals continuously.

- **Appliances**. Many household appliance will affect the performance of PLC with surges and spikes on the mains triggering serious signal to noise ratio problems affecting data rates.

- **Country variations**. There are big variations in cable coupling factors in houses, depending on national installation specifications.

- **Overhead wiring**. In many countries, mains power is distributed via overhead wiring on poles, especially in rural areas. The emissions from these cables will be extreme, as there is no question whatsoever of balance between the cables, and so they will act as very effective antennas.

- **Mitigating measures**. It is suggested that it may be possible to isolate a house from PLC but this would prove to be both expensive and difficult to achieve. Filters designed to block HF PLC signals have their own inherent problems. Filter which handle mains current may give some attenuation, however they may prove too costly and may have to be retrofitted rather than be part of the system as deployed. Relying on software filtering again may not be sufficient. It is believed that the householder would be expected to bear the responsibility of "fixing" any interference problems that arise.

- **Human rights**. PLC signals will be present in households whether wanted or not, directly or indirectly preventing the reception of HF signals (amateur radio and broadcast) thus violating Article 10 of the European Convention on Human Rights

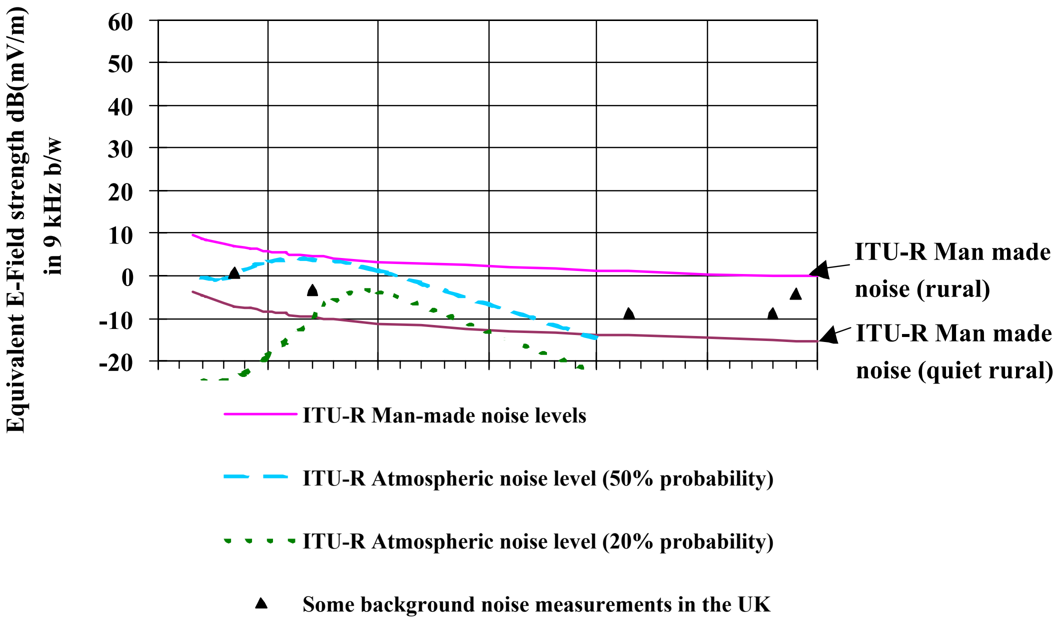
- **Compliance with NB30**. Although NB30 does not fully protect radio services, PLC trials have shown that in the majority of cases, the emission levels from PLC systems have been some 20-40 dB higher than the NB30 limit, confirming that the laws of physics have not changed !

Threats to radio

The threats to HF reception in the amateur bands is real. Those responsible for EMC in IARU national societies in Europe, as well as in the US and Japan, have incontrovertible evidence that if PLC is allowed to be rolled out without tight standards being applied, operation on certain HF bands will be severely affected [5]. The long term damage to the spectrum is incalculable, but the raising of the noise floor, even by a small amount, would seriously affect the HF users' ability to operate as intended.

It is important to identify the true noise floor when taking measurements. It is in reality a lot lower than commonly assumed.[1]

As can be seen in the graph below, background noise measured in the UK falls well below the ITU-R Man-made noise (rural) level in typical suburban areas.



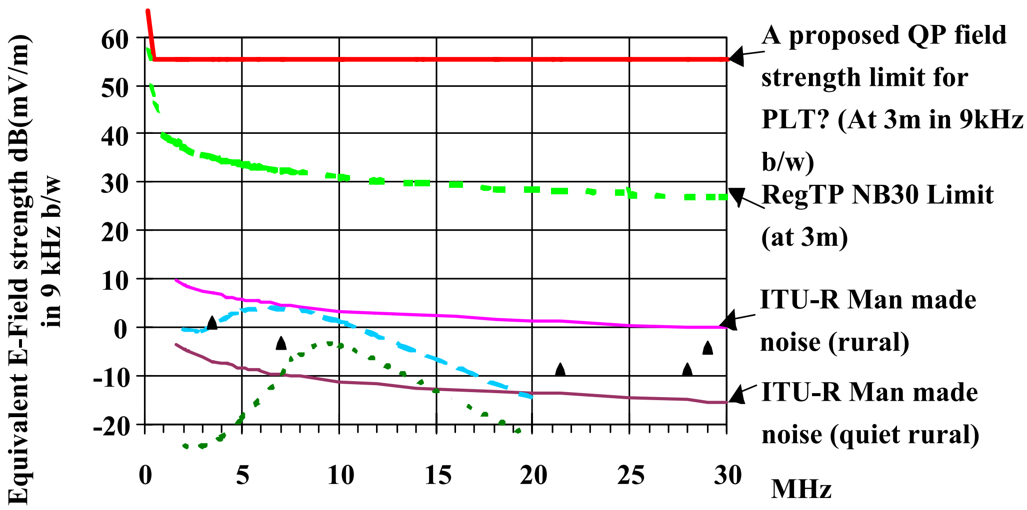
Radio signals in the HF spectrum propagate through reflection & refraction from the ionosphere. There is no reason to suppose that radio emissions from PLC installations would behave any differently. Cumulative effects would undoubtedly be evident in the long term [6] Trials in Germany, Switzerland, UK, Netherlands and Austria have shown that levels of interference are unacceptably high. Complaints have been lodged with administrations. Limited trialing does not present a “real world” situation as small numbers of installations running low data traffic volume give deceptively good results, and provide no basis for statements that “there have been no interference problems”. Should the EU think in terms of larger scale trials, then the IARU believes very strongly that these should be carried out under a common code of practice and has produced a draft document for this purpose.

To protect the Amateur Radio Service a standard should be put in place which requires tight emission limits. The SE35 task group worked for over two years to establish what would be a reasonable limit to allow all radio services to operate as intended in a PLC environment. For total protection of the amateur service, a limit 40dB below the NB30 level would be required. During discussions in the ETSI/CENELEC JWG it became obvious that HF radio users would have to compromise, with NB30 being the very maximum limit considered. NB30 does not protect small signal services, but it is better than any other proposed limit in the Draft Standard.

Standardisation

Following the stakeholders meeting, the JWG was instructed to devise a standard based on EN55022. EN55022 is a standard developed to address narrow band signals, transients and other time-based phenomena, not broadband and other quasi-permanent unwanted emissions. This standard does not protect small signal services – it simply provides a tolerable EM environment without imposing an intolerable burden on manufacturing industry. Most products do not approach the maximum permissible emission limit except on very specific frequency bands, or for a small period of time. In the domestic environment, where most radio amateurs operate, broadband interference at levels near the limit are rare, and can be dealt with by applying mitigating measures.

Setting a standard for broadband systems, which is based on an existing narrow band product standard is fraught with problems. Radiation limits for networks must be set tighter than those for single pieces of equipment as, in contrast to equipment which can be regarded as a point source of interference, a network covers a wide geographical area, is a source of continuous radiation, and produces unwanted emissions covering many tens or hundreds of Megahertz with high spectrum density. The statistical probability of interference to an amateur station caused by a network such as PLC is much higher than from a single piece of equipment. The NB 30 limit for network systems is about 30dB tighter than a proposed radiated limit that has been derived from the EN55022 conducted limits, although not tight enough for total protection.



Summary

The radiated limit (option 2) as presented in the Questionnaire relating to the "Draft Product Family Emission Standard for Telecommunication Networks" and extrapolated from the EN55022 conducted limit, equates to some 55.5 dBuV/m, which is too high to protect ANY radio service, including MF broadcasting. The basic principles of the EMC Directive should be uppermost in the minds of those setting the standards for wired systems. PLC systems are considered as installations in the terms of the EMC Directive, therefore to quote from Annex 1 of the Directive:

"Equipment shall be so designed and manufactured……to ensure that:

a) The electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended".

This basic principle must be reflected in any standard relating to cable networks.

> "Like the smog that fouls the air in many cities, electronic smog fouls the radio spectrum as a consequence of human activity and, like toxic haze, radio smog is an economic rather than a technical issue. We know how to control it, the debate is over whether it is worth the price to do so, and who should pay." - *David Sumner, QST October 2002*

References:

[1] Submission to the UK Radiocommunications Agency Technical Working Group on the compatibility of VDSL and PLC with radio services in the range 1.6 – 30 MHz * See http://www.radio.gov.uk/topics/interference/documents/dslPLC.htm

[2] Radiated Emission of Domestic Main Wiring Caused by Powerline Communications Systems – *Vick, Technical University of Dresden, Germany **

[3] http://www.qsl.net/rsgb_emc/#PLC

[4] EMC Aspects of Powerline Communication – *Stecher, Rhode & Schwarz, Germany **

[5] http://www.arrl.org/tis/info/HTML/plc/#Video Video and audio clips of PLC interference from around the world

[6] http://www.bbc.co.uk/rd/pubs/whp/whp004.html - Cumulative effects of distributed interferers – *Stott, BBC, England*

* Attached

Appendix 1

Submission to the Radiocommunications Agency Technical Working Group on the compatibility of VDSL and PLT with radio services in the range 1.6 – 30 MHz

4.2 The Current Radio Environment

This section considers the general environment for radio communications in the band 1.6 to 30 MHz. The operational environment for individual services is discussed later in chapter 5.

4.2.1 Ambient Noise

In general the sensitivity of a radio receiver is determined by the noise in the receiver "front end". It is generated by the action of the components such as transistors and is predictable from basic physics.

Communications in the 1.6 to 30 MHz band differs from that in the VHF, UHF and SHF (microwave) bands in that the external (ambient) noise entering via the antenna exceeds the noise generated in the receiver by a large margin. This is partly due to the nature of the natural sources of noise and the effects of the ionosphere. It is also significant that in the 1.6 to 30 MHz frequency range, quite modest sized resonant antennas are very effective in extracting energy from electromagnetic fields. (The "capture area" of a resonant antenna is proportional to the square of the wavelength.) The *ambient noise*[7] consists of an irreducible level of noise analogous to the white noise in receiving circuits, and "incidental" noise from localised sources of interference. There are, of course some, situations where this simple picture is open to question, but it has nevertheless proved a very useful concept for dealing with noise in residential areas.

4.2.2.1 *Ambient Noise floor*

The term *ambient noise floor* refers to the irreducible noise that exists at any location when there is no additional noise from specific sources. This noise floor varies somewhat from place to place and also with the time of day and season of the year. Reliable information on the factors constituting the noise floor is scarce, but it seems probable that it consists of a mixture of man-made noise from a large number of relatively distant sources, cosmic noise, and noise from distant atmospheric electrical activity, arriving by ionospheric propagation.

Measurements of the ambient noise floor in the HF band are complicated by the large number of wanted signals. At night the situation is further complicated, particularly towards the lower end of the band, by very strong wanted signals and by intermodulation products generated either in the measuring equipment or outside by non-linear effects in the vicinity. The TWG has not undertaken any measurements specifically intended to determine the

[7] For the purposes of this report, the TWG agreed a definition of ambient noise as the irreducible background noise entering a radio antenna to which other incidental noise sources are added to form the ambient noise environment.

ambient noise floor, but has recognised the work of BBC, DERA (later QinetiQ) and RSGB all of whom have carried out independent measurements. See **Appendices N & O**. The conditions of measurement varied slightly but all confirmed that the typical day-time ambient noise floor is below 0dBuV/m, measured as quasi-peak, in a 9kHz bandwidth. Most measurements gave figures very significantly lower than 0dBuV/m; the lowest level reported being -29dBuV/m. This was measured by DERA (as an average value in a 3kHz bandwidth and converted to 9kHz) at a quiet receiving location in Southern England using a horizontal dipole. Measurement was made at a frequency in the lower end of the band, and relates to the specific propagation conditions at the time. The availability of such locations is of significance to military and similar communications systems, since the necessary use of low power and inefficient antennas in some mobiles are partly offset by the use of quiet anchor stations at the other end of the link.

It is interesting to note that at the higher end of the band, the noise floor is somewhat lower when measured late at night when there is no ionospheric propagation in that part of the band. This is confirmation that some component of the day-time noise floor arrives by sky wave. It is generally believed that this noise is from far distant thunderstorm activity, but other sources could be relevant.

4.2.2.2 *Incidental Noise*

This term is used to describe localised noise that adds to the *ambient noise floor* to form the *ambient noise environment*[8]. In residential areas most *incidental noise*[9] has at least some of the following characteristics:

- It occurs for only a limited time;
- It affects a limited frequency range;
- The interference does not extend far from the source;
- It is technically possible to remedy the interference, even though this may not always be practical.

Situations where interference from a local source is continuous 24 hours a day do occur in residential areas, and not all are remediable, but fortunately such cases are rare. There is very little information on the propagation of incidental noise. At the lower HF frequencies the victim will be within the near field.

It is generally accepted that incidental interference on HF frequencies has a significant vertically polarised component. This is borne out by the widely held view that vertical antennas pick up more local noise than horizontal ones. This being so, it is reasonable to assume that at least a proportion of the received

[8] For the purposes of this report, the TWG agreed a definition of ambient noise environment as the total noise entering a radio antenna in any particular location. It is the sum of the ambient noise floor and the incidental noise.

[9] For the purposes of this report, the TWG agreed a definition of incidental noise as the noise entering a radio antenna from localised sources of interference. It adds to the ambient noise floor to form the ambient noise environment.

signal will be propagated by surface wave. This would account for the relatively rapid fall off of incidental interference with distance. This, of course, would not apply to interference radiated at high angles of elevation, which would suffer much less attenuation.

The effect of incidental interference is statistical. The probability of severe interference occurring for protracted periods across a wide range of frequencies in a residential location is small. When it does, the regulatory authority may, when appropriately notified, investigate, often resulting in the interference being remedied at the source. In most residential locations the limitation to HF communications is the ambient noise floor rather than incidental interference.

Appendix 2

Radiated emission of domestic main wiring caused by powerline communications systems

– Vick, Dresden, Germany

RADIATED EMISSION OF DOMESTIC MAIN WIRING CAUSED BY POWER-LINE COMMUNICATION SYSTEMS

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Abstract - *This paper shows the results of magnetic field strength measurement in the case of power-line carrier systems. The measurements were performed when RF signals in a frequency range of 150 kHz to 30 MHz were coupled into the 230 V main wiring of buildings. A relation between the unbalance of the power network and radiated fields is shown. However, applied models fail to predict the fields at frequencies below 4 MHz. The results show, that it is necessary to regulate power-line communication in order to protect the broadcast frequency band.*

1 INTRODUCTION

Transmission of data through a 230 V electric power line, called Power-line Communication (PLC), could find a intensified application within the next few years in households and industry. In a typical low-voltage system, several hundred households are connected star-like from a transformer station. Several new services could be operated without the installation of additional transmission mediums.

Data transmission through electric power-lines have already been installed in buildings to control functions, e.g. the brightness of lightning systems or the movement of shades etc.. Functioning systems based on the EIP protocol are still being commercialized. Transmission of data with a broader bandwidth is opening up new opportunities for communication technology. In US markets, systems are available which can transmit audio, television and Local Area Network signals at different carrier frequencies. This equipment right now is not allowed to be used in Europe, according to legal regulations, which also include existing restrictions of the carrier-frequency range.

In order to increase bandwidth, the transmission of signals in a frequency range above 150 kHz is necessary. With it comes a danger of radiated emission, since power lines act as an antenna at higher frequencies. This paper shows results of magnetic field measurements in case of PLC.

2 RADIATION BY UNBALANCED SYSTEMS

To transmit data through the power-lines, a modulated signal will be symmetrically coupled between the outer conductor and neutral or between two outer conductors of the three-phased system. The signal can be coupled to the power-line using a balun and coupling capacitors. More advanced systems adopt the output impedance of the transmitter to the power-system's impedance.

2.1 Unbalance of the system

It is known that the attenuation of symmetric signals along power-lines is much higher than the attenuation of asymmetric signals. On the other hand, asymmetric signals will be more efficiently radiated than symmetric signals, thus the real danger when doing PLC lies in generated asymmetrical signals along the lines.

Even if the signal is intentionally coupled symmetrically into the wiring, asymmetric voltages and currents will be generated along the line due to the system's unbalance, especially, at points with a high unbalance, i.e. electronic devices.

When a symmetrical voltage is feed into the power system one needs an appropriate method to estimate the generated asymmetrical voltage. The Longitudinal Conversion Loss (LCL) and the Transversal Conversion Loss (TCL) are defined in the ITU recommendations. They are ratios between the asymmetric and symmetric components at a specific test point, i.e. a power outlet.

The LCL of a specific test point is determined by coupling a asymmetrical voltage (longitudinal signal) into the system and measuring the resulting symmetrical voltage (transversal signal). The LCL is a logarithmic ratio between the asymmetrical (E_L) and the resulting symmetrical voltage (V_T).

$$LCL = 20 * \log_{10}(\frac{E_L}{V_T}) \quad dB \qquad (1)$$

The TCL is the ratio between the symmetrical and the asymmetrical voltage when a symmetrical voltage is feed into the system.

$$TCL = 20 * \log_{10}(\frac{E_T}{V_L}) \quad dB \qquad (2)$$

A probe can be used to measure the LCL or the TCL, [1].

Changing power-network conditions, especially the mismatch of the wave impedance between the measurement equipment and main wiring, lead to resonance in the TCL. This behavior requires the determination of the TCL at different test points within the building. Then an appropriate value, such as the minimum, should be used for interpretation of the TCL.

Once the TCL is known, one is able to calculate the asymmetrical voltage at a given amplitude of the symmetrical signal. This voltage can then be used to estimate the radiated emission with an appropriate model.

2.2 Measurement setup

Investigations were aimed to give an overview of the radiated fields during power-line communication. Furthermore, the relation between TCL and the radiated field should be shown. The setup was designed to measure the TCL and the radiated magnetic fields H ($0\ dB_{\mu A/m} = 51.5\ dB_{\mu V/m}$) without a change in the coupling conditions, Figure 1.

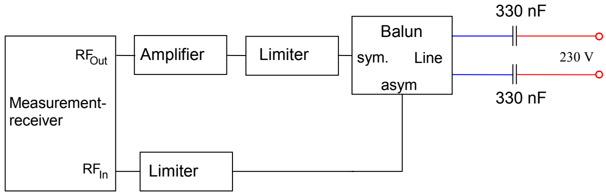

Figure 1 TCL measurement setup

An R&S ESHS30 measurement-receiver with an internal generator was used for the measurements. It allows the receiving frequency to be locked to the transmitting frequency. Using a balun, a symmetrical signal was coupled into the power-line system at specific power outlets. The resulting asymmetrical voltage was measured at the balun. Radiated magnetic fields within a range of approximately 30 m around the coupling point were measured by a magnetic loop antenna connected to the receiver.

3 MEASUREMENTS

Investigations were performed on five different buildings as well as an underground cable, but only the indoor measurements are mentioned in this paper. A symmetrical signal of $105\ dB_{\mu V}$ was coupled into different power outlets within the buildings and the radiated magnetic field was measured. The chosen buildings were an one family house, a rebuild villa, an office building, a two family house and a 12 story building from 1964.

3.1 Summarized magnetic field measurements

The magnetic field was measured at 192 field points within the buildings with at least two different coupling

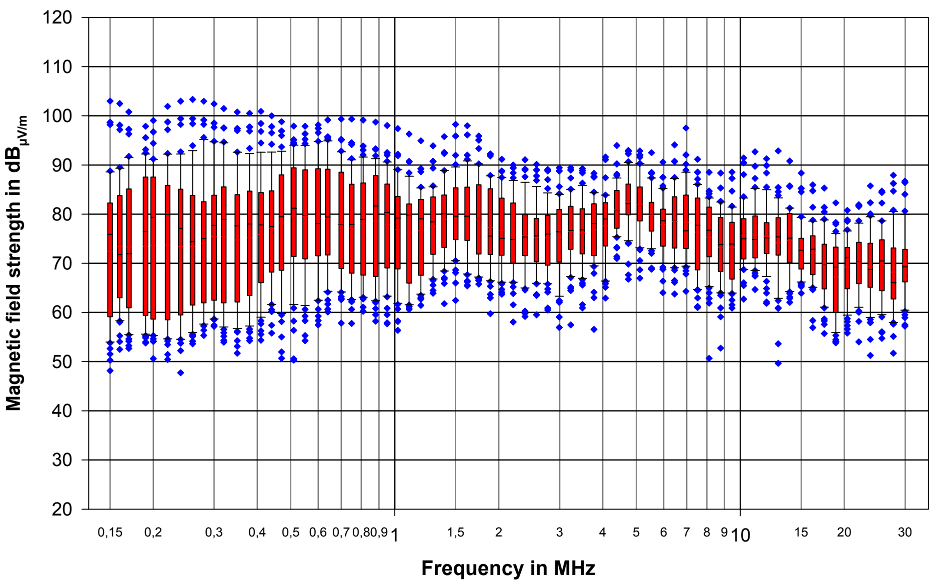

Figure 2 Measured field strength H in a distance up to 3 m of the coupling point when a symmetrical signal of $105\ dB_{\mu V}$ was coupled into the power-line

locations. The measurements were done at 70 pre-selected frequencies, which were chosen to have a low background noise. A high variability in the magnetic field was observed. In the case of resonance effects of the power-line system, the maximum measured magnetic field strength was 120 $dB_{\mu V/m}$. The results were grouped according to the distance, *d*, between the coupling and the measuring locations.

The following classes were chosen:

- measurements less than 3 m from the coupling point (48),
- measurements between 3 m and 5 m from the coupling point (57),
- measurements greater than 5 m from the coupling point (87).

The data are best displayed by Box-Plots. Box plots show the 25 % - 75 % interval of the values as a box, the median as a line within this box and the 10 % - 90 % values as a line interval. Additionally, all outliers are displayed as points. Thus, Box-plots give a good visual interpretation of the measured values, Figure 2 and Figure 3.

The variability in the magnetic field as well as the high resulting values are displayed in the figures.

One should use a specific value of the functions for interpretation. The demand, undisturbed reception for radio receivers should be possible in 90% of all cases, could be used to set this value.
Using this 90 % interval, it is possible to calculate a coupling factor for the magnetic field of approximately -15 $dB_{1/m}$ for frequencies lower 2 MHz, i.e. a symmetrical voltage of 105 $dB_{\mu V}$ would cause a magnetic field strength of lower than 90 $dB_{\mu V/m}$ in 90 % of the cases.

To show the dependence of the magnetic field on the frequency as well as on the distance between coupling and measurement points, the median for different distances is displayed in Figure 4.

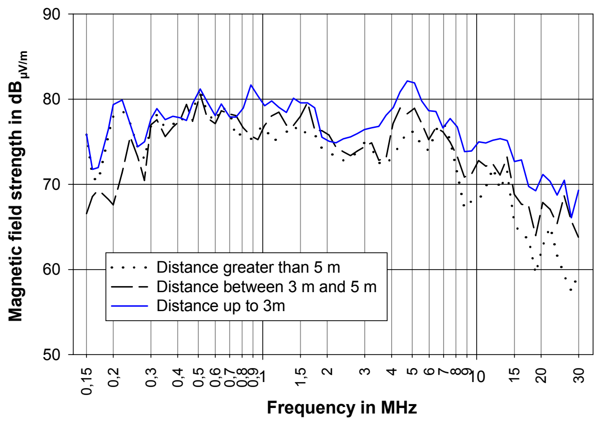

Figure 4 Median of the measured field when a symmetrical signal of 105 $dB_{\mu V}$ is coupled into the power-line

The curves may be interpreted as follows:

- *d* < 3 m:
  H remains around 79 $dB_{\mu V/m}$ up to 5 MHz, then falls by 15 dB per decade.
- 3 m ≤ *d* ≤ 5 m:
  H rises from 67 $dB_{\mu V/m}$ to 77 $dB_{\mu V/m}$ between 150 kHz to 500 kHz. Between 0.5 MHz to 5 MHz it remains around 77 $dB_{\mu V/m}$. Finally, it falls by 15 dB per decade for frequency greater than 5 MHz.
- *d* >5 m:
  H stays around 76 $dB_{\mu V/m}$ up to 5 MHz, then falls by 20 dB per decade.

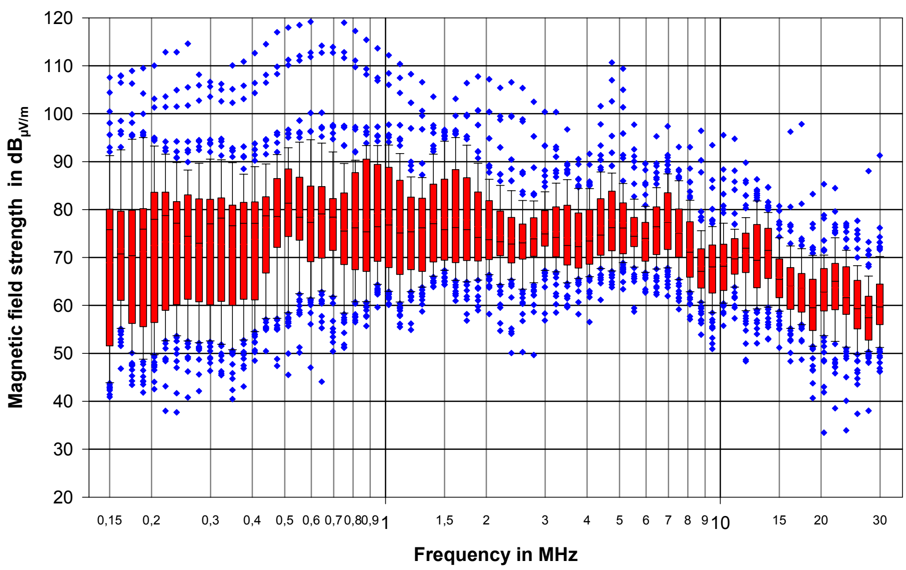

Figure 3 Measured field strength in a distance greater 5 m of the coupling point when a symmetrical signal of 105 $dB_{\mu V}$ was coupled into the power-line

A dependence on the distance of approximately 10 dB per decade is distinguishable at frequencies greater than 10 MHz.

3.2 Local distribution of the magnetic field

The local distribution of the magnetic field was measured in a single room of the one family house. The walls are situated at the coordinates (0,y), (x,0), (4m,y), (x,6m) and the power lines are installed along the walls and the ceiling (lamp outlet, z = 2.5 m).
For example, the local distribution of the magnetic field within the room at 30 MHz is shown in Figure 5.

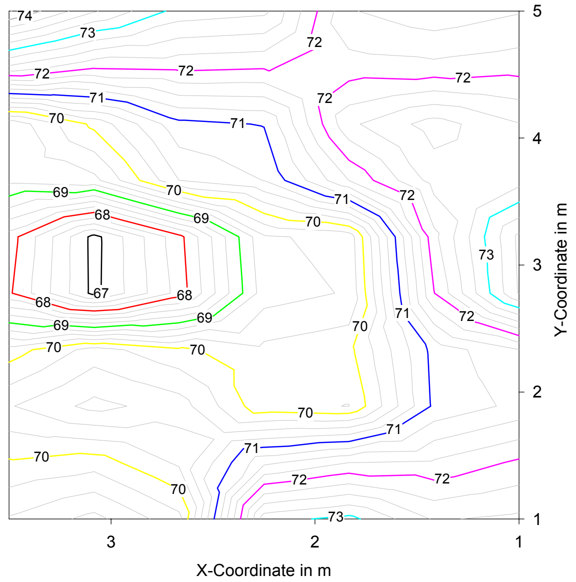

Figure 5 Local distribution of the magnetic field when a symmetrical voltage of 105 dB$_{\mu V}$ is coupled into the power line at (0,0), z = 1 m

It is obvious that the field varies only slightly within the room, which was already demonstrated in simulations. The maxima of the asymmetric current or voltage along the distributed lines leads to extended local maxima of the magnetic field within the room.
One will find the maxima of the field along the power line.

3.3 NB 30 related interpretation

The Regulation Authority of Post and Telecommunication in Germany set up limits for the magnetic field 3 m away from telecommunication equipment in the NB 30, Figure 6.
The symmetrical voltage that would cause a magnetic field according to these limits can be calculated,

$$U_{S,NB30} = U_{0,sym} \cdot \frac{H_{NB30}}{H_{ist}} \qquad \textbf{(3)}$$

where $U_{0,sym}$ is the symmetrical voltage used for the measurements, H_{NB30} is the limit according to the NB 30 and H_{ist} is the measured magnetic field.

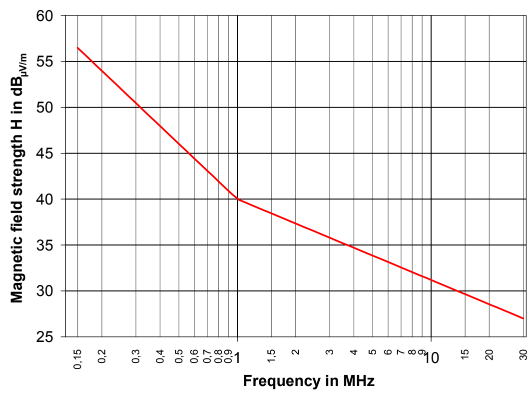

Figure 6 Limits for the magnetic field of telecommunication systems according to the specification NB 30 of the German Regulation Authority of Post and Telecommunication

This voltage, $U_{0,sym}$, is shown in Figure 7 for the 2 family house.

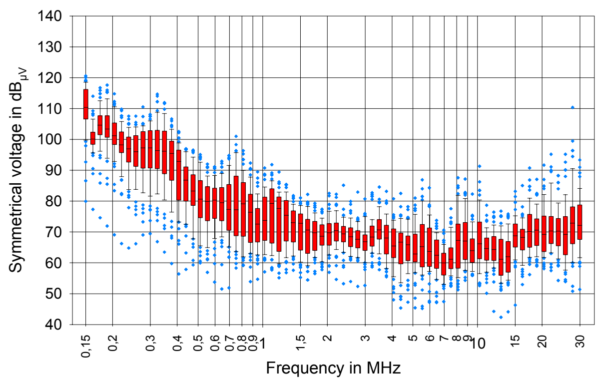

Figure 7 Symmetrical Voltage that leads to magnetic fields according to the German regulation NB 30

Using these voltages, one can limit the symmetrical or the unsymmetrical voltage. Therefore, it is a good assumption to assume the unsymmetrical voltage to be 6 dB less than the symmetrical voltage.

4 APPLYING SIMPLE MODEL

A have-wave dipole was applied to calculate the magnetic and electric field strength 10 m from the source. The amplitude of the source voltage was 105 dB$_{\mu V}$ and the dipole was in resonance for each selected frequency. The calculated field was reduced by the TCL of a specific test point in order to get an estimation for the magnetic or electric field. The median of the corresponding measurements was calculated. It is displayed along with the calculated approximation, Figure 8. The calculations were done for a number of test points and distances.
One can observe that there is a close correlation between TCL and the generated magnetic field. This simple Model underestimates the magnetic field. At 4 MHz the measured field is still around 20 dB higher

than the estimation. These discrepancy gets smaller at higher frequencies.

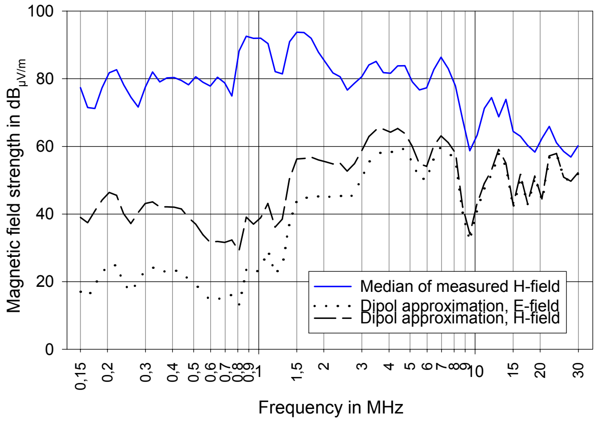

Figure 8 Comparison between modeled and measured magnetic field strength at one coupling point

At lower frequencies, estimation is not permitted. This is due to long wavelengths and the distributed power-lines. Even more advanced models of the wiring, which were used for numerical field calculations, are accurate in the frequency range below 1 MHz.

There are some effects that lead to these circumstances. One stems from the existence of single ended power lines. It was shown, [2], that the symmetrical signal can produce high electric fields even when the TCL, i.e. the balance of the system, is high. This is caused by unsymmetrical lines, e.g. single phased switched power-lines (lamp circuits). If the load is switched off, only one wire is connected to the load. That is why single ended line is driven as a antenna, with a source voltage equal to half of the symmetrical voltage (earth related). The result of this mode of operation is a high electric field.

There are additional undetected effects that lead to the mismatch between models and measurements in the lower frequency range. At this time, a statistical interpretation of the measurements should be used to overcome the inaccurate models. Therefore, limits of the symmetrical or the unsymmetrical voltages should be established. These limits should be related to the existing CISPR standards.

5 SUMMARY

The magnetic field radiated by power-lines was measured when a symmetrical signal was coupled into 230 V main wiring. The results show a potential danger related to unregulated power-line communications. The symmetrical voltage that may be coupled into the wiring is only in the order of 60 dB$_{\mu V}$ (1mV). This assumes that the generated field meets the German regulation NB 30 in 90 % of the invested cases. This is approximately valid for the entire frequency range of 150 kHz to 30 MHz. The generated fields within buildings are independent of the distance from the coupling point in the low frequency range, f < 10 MHz.

Simple models are not suitable to estimate the radiation due to PLC in the lower frequency range, especially below 4 MHz. There are some effects, related to the wiring of 230 V power networks that lead to high field strengths in the low frequency range, even when the balance of the system is still acceptable. One of the effects is a high electrical field, due to single ended wiring units, i.e. switched off lamps or loads. In this case the single ended conductor could be driven by half of the symmetrical voltage coupled into the power-line.

The results of the investigation showed the need for a regulation of the symmetrical or unsymmetrical voltage of power-line communication systems in order to protect broadcast services.

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BIOGRAPHICAL NOTES

Ralf Vick studied electrical engineering at Dresden University of Technology, Germany. After finishing his studies in 1991 he worked on the subject of immunity of microcontrollers to impulsive disturbances. He received his Ph.D. degree in 1995. Since 1995, he has been an EMC consultant in private practice. Projects he has involved with include the EMC of the German Frigate F124 and investigation of the radiation of power line carrier systems.

Appendix 3

EMC Aspects of Powerline Communication

– Stecher, Rhode & Schwarz, Germany

EMC ASPECTS OF POWERLINE COMMUNICATION

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Abstract - In order to provide broadband communication services using the low-voltage powerline distribution system as a network, the frequency range of 148,5 kHz to 30 MHz is taken into consideration by prospective operators. However in this frequency range broadcast, amateur, safety and other radio services are allocated. Since radio interference may be expected from PLC and wired telecommunication systems using high frequencies, some administrations have drafted rules with strict disturbance limits for radio frequency use on extended networks. These limits strongly reduce the chance for an easy realisation of PLC. As a way out of this situation, a reorganisation of the HF band has been proposed. This will need many years of phase-out time for existing radio systems. The paper discusses the EMC characteristics of the powerline network, available modulation schemes, a rationale for setting emission limits as well as conducted and radiated emission measurement procedures.

I. INTRODUCTION

The strong interest in quickly available information, the ever increasing power of personal computers and the thereby generated abundance of broadband information services cause an exponential growth of the amount of data transported over the Internet. Three different concepts are struggling to prevail on the last mile to the end user: the telecom line with ISDN, ADSL and VDSL (or xDSL), the broadband coaxial cable system and powerline communication (PLC, as the “Internet from the power outlet”). While EMC of the telecom lines and of broadband cable systems does not seem to pose unsurmountable problems, there is much discussion about the compatibility of PLC with radio reception in residential areas. Due to expected problems, some operators already stopped their activities and the remaining ones became extremely nervous. As a forum for the discussion of EMC issues, a working group has been formed in Germany. The author is secretary of that working group.

II. POWER PLUS COMMUNICATION

II.1 The Background of PLC

The idea of communication via the power line is not new. In the late 19th century the idea of using higher frequencies for the transmission of information came up [1]. It became a reality in the twenties with ripple control in the frequency range of 110 Hz to 1(3) kHz, in order to enable load control and other services on the side of electricity users by power utilities.

During the past 30 years twoway communication systems (mains signalling systems) were developed in the frequency range of 3 to 148,5 kHz acc. to EN 50065-1 [2] - in non-European countries even up to 525 kHz for tariff and load control on the side of electricity users as well as for data transmission from watt-hour meters (upstream). The EMC of this type of communicaton systems is handled in EN 50065-1 - regarding frequency management and emission limits and in EN 50082-1 regarding immunity to EMI (more detailed in future EN 50065-2-1, 2-2 and 2-3). Internationally EN 50065-1 corresponds to IEC 61000-3-8 [3]. The so-called CENELEC frequency range from 3 to 148,5 kHz is divided into ranges for power utilities (3 to 95 kHz) and for private use (95 to 148,5 kHz), e.g. for building automation under the term „Smart Home“. The levels injected are between 116 and 134 dBµV – enormously high levels from the viewpoint of radio reception. In these frequency ranges radio reception may be disturbed, e.g. of the German time transmitter DCF77 and of the German longwave radio transmitter Donebach. This is the reason why the regulatory authorities see a requirement to allocate frequencies for mains signalling independent of EN 50065-1. The frequency range above 135 kHz is not useable, since at 150 kHz radio disturbance voltage is limited to 66 dBµV, so the use of the upper frequency range is confined to 95 – 135 kHz.

For real broadband communication services, the frequency range 148,5 kHz to 30 MHz is taken into consideration. However this frequency range is allocated to broadcast, amateur radio, safety and other radio services. Before PLC can go into operation in wide areas of coverage, the compatibility with radio reception has be clarified. Some tentative systems have gone into operation in Germany (Berlin, Cologne and Herrenberg) in order to collect experience including EMC. The British company Nor.web [4] conducted field tests in 18 locations in 10 European countries.

II.2 RF and EMC Properties of the Power Supply Network

Most of the power utilities use broadband long-distance networks in fibre optic along high and medium voltage lines. The medium voltage cable network itself is used for broadband communication purposes [5]. The structure of the low voltage power supply network is suitable for electric transmission of information. The length of the individual lines is limited so that the RF attenuation is – at least for lower frequencies – within acceptable bounds. As a consequence, the lower frequencies can be used for the longer distances (e.g. from the transformer station to the homes) whereas within homes the higher frequencies can be used.

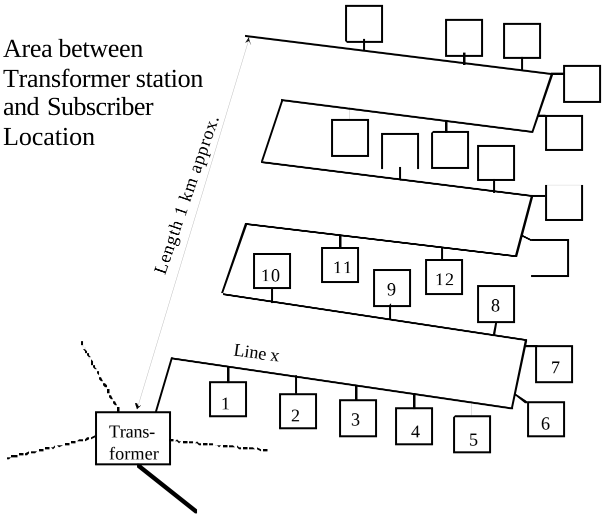

Fig 1: Structure of the low-voltage power supply network in dwelling areas

Power supply lines have a low pass character due to dielectric losses (PVC used for insulation) and due to the equipment connected to it. In addition notches occur due to reflections on open ended lines. Repeaters will therefore have to be foreseen, depending on transmit level, cable length and frequency.

Frequ/MHz Length	0,5	3	5	10	20
150 m	7 dB	18 dB	24 dB	36 dB	54 dB
200 m	10 dB	25 dB	40 dB	56 dB	75 dB
300 m	18 dB	52 dB	70 dB	-	-

Table 1: Average attenuation of underground cables acc. to various sources ([4], [6]). For comparison: usual telecom lines exhibit an attenuation of 12 dB, when used in the ADSL frequency range for a distance of 2 km.

Also disturbance levels are important for the layout of PLC systems: average values of 20-ms sweeps in the range of 3 to 16 MHz are acc. to [4] around 30 to 40 dBµV (for 100 kHz measurement bandwidth and peak detector, see fig. 2). Equipment connected to the network generates coloured noise, slowly time-variant disturbances, broadband disturbances generated by electric motors, periodic and asynchronous impulsive disturbances through switching operations in the network. In addition, the spectrum contains narrowband disturbance from radio transmitters (broadcast etc).

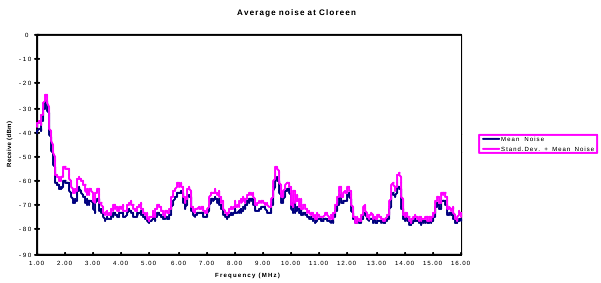

Fig 2: Mean values of disturbance from 20-ms sweeps at 9 locations of a British town [4] (100 kHz measurement bandwidth and peak detection). For 10 kHz bandwidth the level will therefore be 20 to 30 dBµV.

The **symmetry of the network** will be of decisive significance for its radiating properties and for the coupling of radiated emissions into the network. Even if a source would be perfectly balanced, the unbalance of the power supply network would cause a conversion of the differential mode signal into a common mode signal. A measure of the balance of the network is its longitudinal conversion loss (LCL). EMC specialists of Dresden Technical University conducted a study paid by the German Authorities on the radiation characteristics of PLC [7]. The LCL depends on the configuration of the network (TN system with PE connection of the neutral line N at the home access or separate routing of PE and N into the house). However also equipment connected to the network can cause an RF short-circuit of N and L with PE, whereby at any location of the network the LCL may be reduced to zero. The LCL is therefore also time dependent. An important quantity is the network impedance. It is in the order of 10 to 100 Ω. It is especially low when measured in proximity of the transformer. 50 Ω are regarded as a good compromise.

During the meetings of the a.m. German Working Group different digital modulation procedures were mentioned by the prospective operators (Nor.Web, Düne and Siemens). OFDM (Orthogonal Frequency Division Multiplexing), i.e. the procedure used for DAB (Digital Audio Broadcasting), which is especially resistant against narrowband disturbances and CDMA (Code Division Multiple Access) as well as combined solutions (multicarrier CDMA) have the highest chances. There is a hope for a camouflage solution using CDMA (spread spectrum) hidden in ambient noise. Due to the relatively high attenuation at high frequencies, a real camouflage solution would require many repeaters. Up to now, the proposed levels of the injected power are in the order of 0 dBm in 10 kHz bandwidth. This corresponds with an radio disturbance field strength of 50 dBuV/m in a distance of 10 m [4]; recent proposals from CENELEC SC205A/WG10 say 50 dBµV/m in 3 m distance. For an injected power of 0 dBm (= 107 dBµV) and an attenuation of 60 dB the minimum receive level is approx. 45 dBµV (in 10 kHz bandwidth). The median level will thus be in the order of 80 dBµV and the 90% value, which is important for radio planning, substantially higher. This corresponds to a field-strength median value of 50 dBµV in 3/10 m distance. Some prospective operators pretend to adapt the injection level to the ambient emission level. Only one operator [8] has announced lower injection levels and has indicated the transmit levels of table 2 for a useful bandwidth of 16 MHz, an interference level of 20 dBµV in 9 kHz bandwidth and an average signal attenuation von 50 dB in the frequency range of 5 bis 30 MHz:

Transmit level (B=9 kHz)	Useable Data Rate
60 dBµV	1 Mbit/s
75 dBµV	3 Mbit/s
80 dBµV	8 Mbit/s
87 dBµV	16 Mbit/s

Table 2: Relationship between transmit level and useable data rate according to [8].

II.3 Compatibility of PLC with Radio Reception

Up to now the frequency range of 148,5 kHz to 30 MHz is mainly used by AM radio. There are plans for digital modulation procedures in the AM broadcast bands using the available bandwidths and channel spacing [9]. Presently DRM (Digital Radio Mondial) runs in the test phase. Radio operators have indicated that they will insist on continuing use of the AM frequency bands. The radio amateurs too are struggling to retain their frequency bands. Worldwide radiocommunication at a low cost is a characteristic of shortwave radio. In addition this frequency range is used by safety services, flight and maritime navigation, air traffic control, embassy radio, mobile radio, standard frequency and time services, news services, maritime, military and general long distance radiocommunication.

Which disturbance levels are acceptable to radio reception? The problem of compatibility between radiocommunication and high data rate telecommunication services using the power supply or the telephone network is asked by an ITU-R Study Question [10]. Until now radiocommunication has survived with the help of CISPR emission limits. Now the question is asked whether CISPR conducted emission limits on power ports for e.g. house-hold or IT equipment can be used for PLC. Some PLC operators even propose to use the higher emission limits for telecom ports acc. to CISPR22/EN55022 [11]. For the definition of RFI limits, the minimum receive field strengths of radio planning are essential. From these values the protection ratio, e.g. 30 dB for AM radio is to be subtracted in order to obtain the ideal emission limit. However radio reception is possible with some compromise.

Which is the nature of radio disturbance emitted by PLC systems? For normal AM receivers, CDMA or OFDM signals are like Gaussian noise, i.e. the radio listener does not have the typical impression of interference, like clattering, buzzing, clicking, whistling or similar, in contrast there will be an impression of low sensitivity of the receiver, since the ambient noise is like increased Gaussian noise of the receiver frontend. Therefore the problem of searching and identifying the source of interference will be difficult. This problem would also arise when PLC systems were operated in dwelling areas due to their continuous presence everywhere.

The consequence of using the CISPR-22 emission limits on telecommunication ports as injection levels for PLC, can be illustrated by comparing the field strength, which results from using the permitted common-mode current on telecommunication lines, with the minimum field strengths in the short-wave frequency band (see fig. 3). Please keep in mind, that for the reception of the minimum field strength, a protection ratio of at least 26 dB (better 30 dB) is to be taken into account. It is therefore not sufficient to check whether the received radio spectrum changes significantly by the addition of PLC. It is necessary to check whether the PLC spectrum is 26 dB below the minimum field strength.

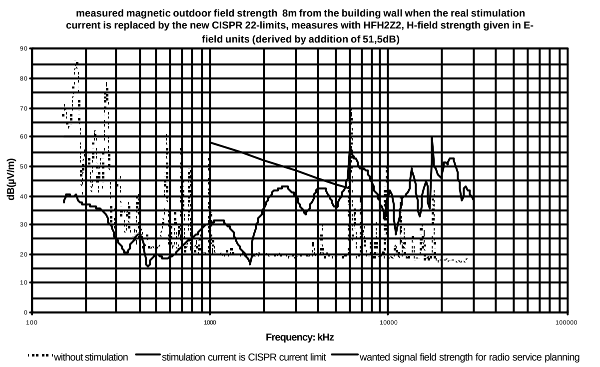

Fig 3: Values of field strength measured with a loop antenna at 8 m distance from a three-storey building. Dotted line: ambient emission; thin continuous line: field strength generated by injection of the common-mode current equivalent to the CISPR22/EN55022 emission limit into the telecommunication network of th building; bold line: minimum useable field strength for radio planning. HFH2-Z2: R&S active loop antenna 9 k to 30 MHz. (Measured data received from the RegTP)

III Emission limits for broadband communication on extended networks

III.1 Regulatory actions

There is a high probability of radio interference when unshielded twisted (UTP) pair cables area carrying a common mode current as in fig. 3. The probability is higher for PLC than for telecom that the emission limit is used to its full extent, since for PLC signal attenuation is so high, that a higher level will save cost.

In Europe, the EMC Directive (EMVG in Germany) serves for the protection of radio reception. In addition there are telecommunication laws (in Germany TKG) regulating frequency allocation. On the basis §45 of the TKG the German Ministery of Economics have drafted a decree on the frequency allocation plan (FreqBZPV) [12]. This FreqBZPV deals among others with the use of frequencies within and along leads, to be applied for broadband communication cables, telecommunication lines and PLC. Limits for the latter are in fig. 4.

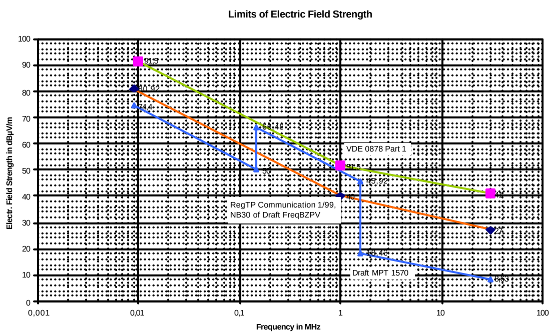

Fig. 4: Limits acc. to Requirements 30 (NB30) of the FreqBZPV [12], compared with the limit of VDE 0878 part 1/12.1986 class B up to 30 MHz. The diagram also contains the limits of Draft MPT 1570/Feb 2000 of the British Radiocommunication Agency [13]. The field strength is measured with a loop antenna in a distance of 3 m from the line (MPT 1570: 1 m from 9 k to 1,6 MHz). For comparison with the limit, the logarithm of the free-space wave impedance $20\log Z_0$ is added to the magnetic field strength. This is a reaction of the Ministery of economy on the increasing use of frequencies in networks. At the time of VDE0878 Part 1 there was ISDN with a frequency range below 148,5 kHz.

Comparison with ADSL and VDSL: Experience of th RegTP has shown that ADSL is within the limits of NB30. Members of the Deutsche Telekom expect that also VDSL will be within the limits. This means that VDSL will have to stay by far (30 dB!) below the limits of CISPR22. In order to avoid conflicts, the VDSL spectrum is reduced in broadcast and amateur frequency bands. Members of the RegTP say, in case of problems shielding is possible. Shielding of PLC is not possible. Theoretically PLC could work with the limits of NB30. This would however require to reduce the transmit power by 30 to 40 dB relative to the levels planned up to now. And this would require three times the number of repeaters! To comply with this draft decree, this would be **solution 1 for PLC** - probably too expensive.

III.2 Probability of Interference

Inspite of the low limits of NB30, many radio users and operators feel that they are not low enough, since using them to the full extent may still cause radio reception to suffer. The limits are not identical to the minimum useable field strength minus the protection ratio. A radio user would have to move to the country side in order to get the required protection distance.

Radio reception works inspite of the relatively high CISPR emission limits, because the statistical distribution of emissions is favourable. Basics on the definition of emission limits can be found in [14] and [15]. Conducted emission limits are in the order of 60 dBµV whereas mean values of the disturbance voltage in the actual installation are between 10 and 30 dBµV for 9 kHz bandwidth (see fig. 2). This is mainly due to the fact that emission limits of equipment are not used to the full extent over the whole frequency range, as in fig. 5.

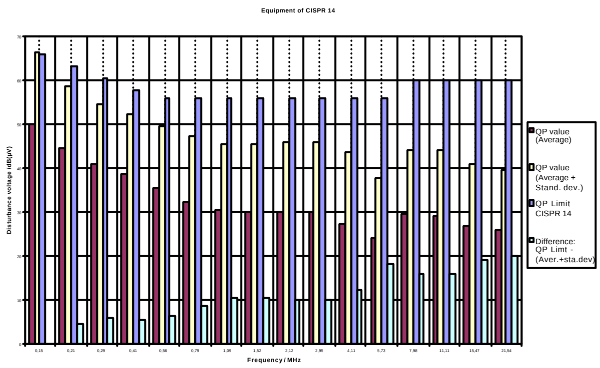

Fig. 5: Mean values of RFI QP voltage and mean + standard deviation of 35 different types (140 units) of household equipment and portable tools (CISPR 14 equipment). The frequency range was divided in 16 logarithmically equal subranges. In each subrange the maximum voltage relative to the limit was used for the statistical evaluation. The QP emission limit is added for comparison. (Data received from RegTP).

We have to differentiate between an emission limit and the field strength to be protected. The difference is due to the timing and spectral statistics of disturbances and due to the statistics of decoupling between source and sink [16]. Using an emission limit as a transmit level will totally change statistics (see fig. 6).

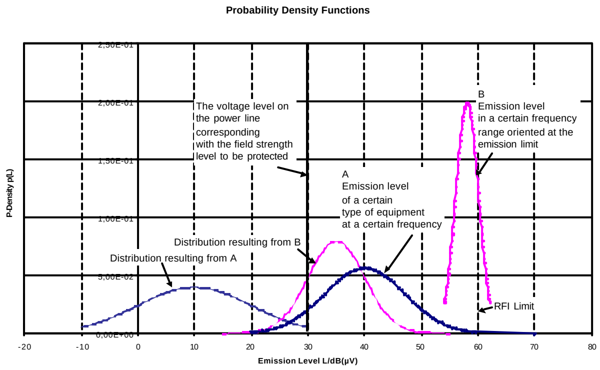

Fig. 5: Probability distributions for two cases:
A: Distribution of emission levels of an EUT type at a certain frequency. B: Possible distribution of PLC transmit levels, assuming that present limits are watched. This will result in an increased disturbance field strength at the receiver location. For good receiving conditions the 90% value of the distribution resulting from B should be below the level to be protected.

III.3 Further Considerations on Emission Limits

A common mode current of 0 dBµA on a line generates a field strength falling from 30 to 20 dBµV/m in the frequency range 1 to 30 MHz in a distance of 3 m, when measured with a loop antenna [17]. In order to remain within the limits of NB30, the injected current should be below 0 to 10 dBµA. Assuming a common mode impedance of 50 Ω will result in a common mode voltage limit of 34 to 44 dBµV from 1 to 30 MHz. The differential mode voltage may be higher depending on the network quality (see [7])

III.4 Frequency Allocation as a Way Out

According to RegTP, in the frequency range below 30 MHz at present a total amount of 7,759 MHz in elements of 2 to 30 kHz are unused in Germany. This may be typical for Europe. These frequencies are allocated to certain services but not assigned to certain users. It is however difficult and will probably take a decade to reorganize these elements so, that sufficient bandwidth is available for services like PLC.

Since the above described solution 1 is out of question due to cost reasons, for PLC only frequency allocation as **solution 2** can help. This is understood by most of the prospective PLC operators. In WG10 of CENELEC SC205A the so-called Chimney-Approach has been proposed with in total 8 frequency ranges between 2,2 and 24,0 MHz.

Access Bands	Bands for use in houses
2,2 ... 3,5 MHz	10,5 ... 11,5 MHz
4,2 ... 5,8 MHz	12,5 ... 13,0 MHz
7,4 ... 9,4 MHz	15,5 ... 17,5 MHz
	19,0 ... 21,0 MHz
	22,0 ... 24,0 MHz

Table 3: „Chimney Approach“ from CENELEC SC205A/WG10: 8 frequency bands

The Chimney Approach of Table 3 avoids operation of PLC in broadcast and amateur radio bands. The problem is however reallocation of bands in use. For bands in use, sufficient run-out time must be foreseen, before they can be reallocated. Also spectrum masks will have to be defined in order to assure that neighbouring services are not interfered. The advantage of frequency allocation for PLC would be that bands will be protected.

IV EMC MEASURING METHODS FOR PLC

IV.1 General

For the transposition of NB30, RegTP have developed a test procedure “MV05”. For the frequency range 9 kHz to 30 MHz a loop antenna is to be used. The closer the antenna is positioned to a line, the better a certain lead can be identified as the emission source. The field strength for a distance of 3 m can be extrapolated. A major problem is however the measurement of low noise signals (OFDM and CDMA) as inband interference to all kinds of radio signal. Measurement outside occupied radio bands would be needed. In addition, in bigger appartment stores there is a great amount of broadband disturbance so that the prescribed peak measurement will be difficult. For planning, development and production of PLC modems a test procedure will be required based on the principles of conducted emission measurement. For that purpose, limits of the radio disturbance voltage will be required.

IV.2 Definition of Impedance Stabilisation Networks (ISNs) for PLC similar to CISPR22

For unshielded telecommunication lines the interference effect is mainly determined by the common mode current. This is the basis for the limits of the common mode current and voltage on telecommunication ports in CISPR 22/EN 55022. The common mode impedance of symmetrical pairs of telecom wires is in the order of 150 Ω. In the case of PLC, Line (L) and Neutral (N) are assumed to form a wire pair and the common mode impedance will be in the order of 50 Ω. The longitudinal conversion loss LCL must be assumed as frequency dependant, will however be lower than for telecom lines. Experience of Nor.web says that the LCL is especially low in Germany: between 0 and 15 dB in the frequency range of 3 to 5 MHz. Further details are contained in [7]. ISNs will have to be defined accordingly.

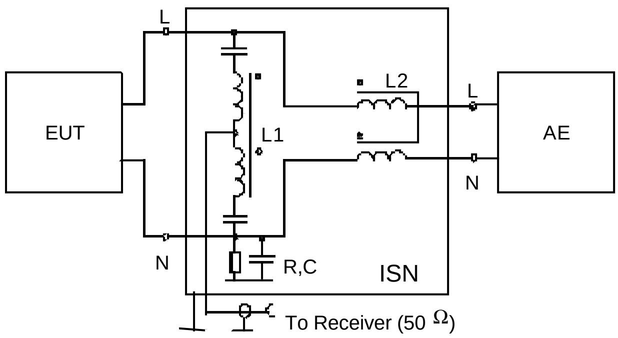

Fig. 6: An ISN (principle circuit diagram) for PLC interfaces is to be inserted between EUT (PLC Modem) and auxiliary equipment (AE, line). For emission measurements a test receiver will be connected as a common mode load to measure the common mode voltage generated by the EUT. Sufficient isolation (decoupling attenuation of e.g. 40 dB) must make sure that the common mode impedance is not influenced by the line and that disturbance from the line (AE side) does not influence the measurement results. An ISN has the following essential elements: a coupling choke L1, a decoupling choke L2 and an RC-element for a defined unsymmetry, which serves to simulate the unsymmetry of the powerline network. The common mode impedance of 50 Ω is determined by the test receiver connected.

Using an ISN a reproducible test setup can be formed. This can be used as an auxiliary test as long as limits of the magnetic field strength have to be met. Additional field strength measurements will have to be made on representative systems, since conducted emission measurements are only a substitute for radiated emission measurements.

IV.3 Measurement using a V-Network

In CISPR/G a proposal has been made to use the V-network as a voltage probe as defined in [18]. The disadvantage of this solution is obvious: the decoupling is missing and therefore the reproducibility of measurements will be low.

V CONCLUSION

The present report gives an overview over problems to be solved for the coexistence of power line communication (PLC) and radio services. The most important EMC parametes, proposed limits and test procedures for the measurement of emissions in extended networks are discussed. Two possible solutions are presented, where the first describes communication signal level near the ambient interference level – i.e. the original intention of spread spectrum communication on power lines – and the second describes communication on especially allocated frequency bands. Solution 1 requires high cost and solution 2 requires time. The author believes that we cannot expect a wide range of PLC systems operating in the near future.

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[17] Dunker, L.; Mosshammer, P.: “Erfassung der von Leitungen emittierten Feldgrößen.” (Determination of field quantities emitted from lines) – presented during a meeting of UAGr.3 PLC on 30.4.99 in Mainz.

[18] CISPR 16-2:1996 Amendment 1:1999-06