Why broadband PLT is bad for EMC

By Tim Williams, Elmac Services

Broadband internet communication is here to stay, but its method of delivery is still controversial. This paper looks at the technology of Power Line Telecommunications (PLT) through the lens of an EMC specialist, and attempts to explain why broadband through PLT is a dangerous and divisive issue.

Abstract

This paper first outlines the technology used in PLT systems, and the political support being offered to the technology, from the point of view of its effect on electromagnetic compatibility (EMC). The radio spectrum needs protection from other interferers, and there is a regime in place to provide this protection. Nevertheless, PLT has several features that mean that it is capable of creating such interference. These features are discussed, and some published field trial results are reviewed. Difficulties in achieving compatibility between the requirements for radio protection and the requirements for operation of the PLT system mean that there is no consensus as yet as to how PLT system components can be made compliant with EMC requirements. It is concluded that there is little prospect of an accommodation between the competing demands, so that if PLT is to become widespread it will be at the expense of the radio environment.

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The technology of PLT

Power Line Telecommunication (or PLC, Power Line Communications, or Broadband over Power Line, BPL, in the US) is a means of transmitting broadband data over the installed base of mains electricity supply cables. It can be used in two ways:

- Access to the home or campus, to deliver the data connection from the service provider;
- Networking within the individual home or larger building, for data interconnection between mains-connected devices.

Although an ETSI document (TS 101 867 [11]) exists to attempt to create co-existence between access and in-home systems, it has been largely ignored and there are several proprietary implementations using some or all of the frequency range between 1.6 and 30MHz. Coding schemes, spectral distribution and signal levels differ between systems and detailed data is not published. For a variety of reasons access systems are not widely implemented in Europe, although they are being actively pursued in other parts of the world.

On the other hand there is an established specification for the HomePlug network system which is in use in the US and elsewhere for in-home networking. The version 1 specification uses OFDM (Orthogonal Frequency-Domain Multiplexing) to modulate the data onto a series of carriers across the frequency range 4.5–21MHz, with notches at certain frequencies to protect the US amateur bands [12]. The delivered bit rate is about 14Mbps. A more recent specification is called HomePlug AV, which is stated to give an information rate of 150 Mbps. In the UK, BT is marketing its BT Vision package, which includes a mechanism similar but not identical to HomePlug for passing broadband data in the range 3–30MHz around the mains wiring.

In round numbers, and bearing in mind that the technology is now sophisticated enough that quoting a fixed level might be misleading, the generally accepted power level for adequate operation of a PLT system is –50 to –40dBm/Hz. Measured in a 9kHz bandwidth, as is standard for interference measurements at these frequencies, this implies a power level of around –10 to 0dBm, which across the differential 100 ohm impedance of the power network is 100–110dBμV (0.1–0.32V). This compares with the allowed levels for conducted emissions in the domestic environment, with which most if not all electronic product designers are familiar, of 60dBμV in a comparable frequency range between each phase and earth – one hundred times lower.

dBs and units

The deciBel (dB) is widely used to describe radio frequency parameters. For power, it is ten times the logarithm of the ratio of two powers:

$$dB = 10 \cdot \log(P1/P2)$$

For voltage or current, it is twenty times the logarithm of the ratio of two voltages:

$$dB = 20 \cdot \log(V1/V2)$$

Thus +20dB means that P1 is 100 times P2, or V1 is 10 times V2; –20dB means that P1 is 0.01 times P2, or V1 is 0.1 times V2; 0dB means that the two quantities are equal.

To express absolute units, the dB is given a suffix: thus 0dBm is 1 mW, +20dBμV is 10μV, and so on.

Electric field strengths are expressed in microvolts per metre (μV/m) or deciBels relative to a microvolt per metre (dBμV/m); magnetic field strengths are expressed in microamps per metre (μA/m) or deciBels relative to a microamp per metre (dBμA/m). Voltage limits are usually expressed as deciBels relative to a microvolt (dBμV).

Notching and power management

One capability which is potentially to PLT's advantage is that it can be programmed, possibly in real-time, to use only certain parts of the spectrum; notches can be applied to protect given frequency ranges, for instance the amateur or broadcast bands. However, the basic requirement is that data is transmitted at a bit-rate that is acceptable to the user (an expectation that is a core aspect of the attractiveness of broadband internet access) and there is a direct trade-off between the bandwidth required for acceptable bit-rate and that which is available to the system after all necessary notches have been applied. In other words, protection of spectrum allocations through notching can only be achieved by a reduction of the operational bit-rate. In the limit, you can't notch out the whole spectrum. So while notching could in theory afford protection to some spectrum users, such as broadcasters or radio amateurs [1], others could still expect to suffer. This issue, as we shall see later, is at the heart of the approach being taken by standards committees.

The technique of notching raises a further question, which is that of intermodulation. When multiple radio frequency signals are applied to a non-linear system – and the mains supply network, with all its connected electronic equipment, will certainly include non-linearities – they "intermodulate" to produce frequencies that were not present in the original spectrum. Thus although the PLT signal itself may be confined to certain parts of the spectrum and avoid others, at the victim receiver the system intermodulation effects may create interference signals within the supposedly protected bands. Although this phenomenon has been accepted as a possibility, there is little or no research into its likelihood or prevalence.

Another technique which can be applied in PLT modems is power management. Widely used in the GSM mobile phone context, it simply means that the system intelligently uses only the minimum power needed over a given part of the spectrum to achieve reliable communication. Thus although a figure can be quoted as above for the power level needed for adequate operation in all kinds of mains environments, in practice this can be adjusted downwards in any given spectrum sub-band depending on the noise level that the modem finds, in real time, in that sub-band.

The European politics of PLT

Because it provides a way to deliver domestic broadband access that is alternative to other providers such as cable and telephone companies, access PLT in particular has been viewed favourably by regulators on the grounds of extending competition. The "strategic goal" of the European Union, known as the "Lisbon Strategy", has been stated [10] to be

> *to become the most competitive and dynamic knowledge-based economy in the world*

and the broadband telecommunications infrastructure with cheap, high-speed Internet access is seen as a cornerstone of this policy. The local loop, or the "last mile" (delivery of the broadband data finally into the home or office) appears as a bottleneck in the process of liberalising the competitive environment for this infrastructure, particularly in breaking the perceived stranglehold of the "incumbents" (pre-existing telecom providers). Hence any technology which promises to unblock this bottleneck is regarded with encouragement by the European authorities. PLT is clearly such a technology.

Meanwhile, some European member states saw the potential RF interference dangers of this technology early [2], and implemented regulations which would allow them to control it if there was any threat of such interference becoming widespread. In Germany, the standard NB30 put down radiated emissions limits in the 1.6–30MHz range. In the UK, the former Radiocommunications Agency standard MPT1570 was also published, though it covered a lower frequency range. Naturally, this put a brake on PLT activity in these countries, since investors were wary of supporting systems which might quickly turn out to be illegal, and it also meant that there were differences in approach across the European Union. (The response of the UK's Federation of Electronic Industries, FEI, to MPT1570 was that it was "unacceptably parochial".)

Because the EMC implications of PLT have been a barrier to its widespread implementation, the European Commission has been, in a manner of speaking, champing at the bit to get this barrier resolved, if not lifted altogether. In 2001 it placed a mandate on the standard bodies ETSI and CENELEC (mandate M/313) to create a standard for the EMC of Telecommunications Networks. This has been addressed by a Joint Working Group of the two bodies but the difficulties involved, particularly that of finding agreement on a set of limits for radiated emissions from the network which would satisfy all participants, have meant that such a standard is a long time coming.

In early 2004 the EC appeared to lose patience with this process, and sent a letter [3] to CENELEC and ETSI which requested them to:

> *Define a technical specification providing test methods and limits for radiated disturbance (and possibly consistent conducted disturbances limits) compatible with state of the art powerline communication infrastructure. This technical specification should be made available by 31/03/2004.*

Such a deadline, considering that the letter was sent in January 2004, was clearly unrealistic, although the Joint Working Group responded quickly by offering a draft Technical Specification [4]. The Commission subsequently issued a Recommendation [5] which included the following uncompromising statement:

> *Member States should* ***remove any unjustified*** * ***regulatory obstacles,*** *in particular from utility companies, on the deployment of broadband powerline communications systems and the provision of electronic communications services over such systems. … Until standards to be used for gaining presumption of conformity for powerline communications systems have been harmonised under Directive 89/336/EEC, Member States should* ***consider as compliant with that Directive*** *a powerline communications network which is made up of equipment compliant with the Directive and used for its intended purpose … and which is installed and operated according to good engineering practices… (emphasis added)*

* An early version used the word "remaining"

The text goes on to talk about procedures for "If a system is deemed compliant but is nevertheless creating harmful interference, the competent authorities of the Member States should take special measures according to Article 6 of the EMC Directive, with a view to resolving such interference", but such procedures are bound to be time-consuming, and meanwhile the interference damage is being done. It is, though, interesting that the Commission clearly envisages a separation between "compliance" of a PLT system and its capacity to cause interference.

As it happens, the economics of access PLT systems have meant that the application of the Commission's Recommendation has been somewhat muted. But by comparison, in-home systems have quickly become popular, and it is to these that most attention is now given.

Protection of the radio spectrum

Man-made interference to radio services can come either from intentional radio transmissions, on the same or adjacent channels, or from unintentional sources, typically electrical or electronic equipment, that generates RF energy as a by-product of its operation.

Interference between radio stations

The first of these has been recognised since the early days of radio and has been controlled by international treaty, the Radio Regulations of the International Telecommunication Union. This allows for procedures for detailed planning of radio services throughout the spectrum, both within nation states and internationally. These procedures ensure that each service can establish a "protection ratio", that is the minimum ratio between wanted and interfering signals that ensures satisfactory reception of the wanted signal. Radio services are then planned to provide this ratio with a high probability.

The spectrum planning system results in complex frequency allocation tables, such as the UK's [7]. These show the range of services that have to be provided for; in the HF spectrum these include broadcasting, air, land and sea mobile voice and data communications, and radionavigation. Some of these services are safety-critical. An increasing number of short-range devices using for instance 13.56MHz, such as RFID readers and alarms, are installed in homes and offices. There are also "minority" users such as radio amateurs, radio astronomy, standard frequency and time transmissions and government monitoring stations who are concerned with receiving and analysing very low levels of radio signal. It is hardly surprising that many of these "stakeholders" have expressed grave misgivings about the spread of PLT [8].

One such stakeholder is the Radio Society of Great Britain (RSGB), which represents the UK's radio amateurs. A couple of years ago, the RSGB made a complaint regarding non-compliance of a PLT product that was declared compliant in Germany. Ofcom finally responded in 2008, implying that they would not take enforcement action in the UK. The RSGB's view, expressed in a public letter to Ofcom from its President, is that "this delay, attributed to restructuring, is frankly deplorable, unprofessional and certainly does not reflect well on the neutrality of the administration or the stated Statutory Duty of 'Ensuring the optimal use of the electro-magnetic spectrum'."[9] The evident frustration of radio amateurs at the lack of interest shown in the problem by some authorities is not limited to the UK.

Ofcom took over the duties of the disbanded Radiocommunications Agency at the beginning of 2004. Since their remit also includes "ensuring that a wide range of communications services – including high speed data services – is available throughout the UK", it may be thought that when it comes to enforcing regulations against a form of broadband delivery on behalf of radio users, there is more than a hint of conflict of interest in the air.

The use of the HF spectrum

The slice of spectrum from about 1 to 30MHz (MF and HF) is unique in that it can support long distance communication, and so it is particularly important to broadcasters. Sky-wave propagation in the HF bands enables an international broadcaster to reach a target country without having a transmitter within the target area. This has political consequences, since it means that an audience can be reached without the co-operation of that country's authorities – which cannot be said for other kinds of access, including any kind of internet delivery. The BBC's World Service, for instance, is broadcast on several HF frequencies and is heard by many people in countries that have no free media of their own.

To overcome some of the admitted reception quality issues with conventional AM broadcasting, a new digital service has been launched by a consortium of broadcasters, including the BBC and Deutsche Welle, known as DRM (Digital Radio Mondiale, see www.drm.org). An increase in the local HF noise floor due to PLT, with its continuous, broadband nature, would have the potential to seriously compromise the effectiveness of this service.

As well as broadcasting, aeronautical and marine communications use the HF band for long-distance communication, when the mobile station is out of reach of ground-based VHF stations, which can be a large proportion of their journeys.

Interference from other non-radio equipment

The second type of interference is caused by electrical and electronic equipment unintentionally creating RF noise in the vicinity of the receiver. This phenomenon has again been recognised for many years and a regulatory structure has been set up to deal with it. In Europe this structure is implemented by the EMC Directive (2004/108/EC), whose first essential requirement is that apparatus shall only be placed on the market or taken into service if

> *The electromagnetic disturbance it generates does not exceed a level above which radio and telecommunications equipment or other equipment cannot operate as intended.*

This means among other things that virtually all electrical and electronic equipment, especially that which connects to the mains supply, has to meet limits on the amount of noise it injects into connected cables. These limits are contained in standards which derive from CISPR, the IEC committee responsible for control of radio interference. They have been devised through a process which accounts for the protection ratio required by potential victim receivers, the likelihood of a source being in physical proximity and coupled to these receivers, and the probability of coincidence of operation of the source and the receiver. They apply within Europe through the operation of the EMC Directive to anything that is likely to cause such interference. Designers of mains-connected equipment are by now familiar with these requirements, which constitute an extra but necessary burden on their designs.

PLT's interference capability

Interference from PLT systems stands outside the general regime of interference control. The principal emissions are radiated from the supply wiring, onto which they have been deliberately injected, rather than unintentionally as is the case with other sources such as fluorescent light inverters or computer power supplies. From access-PLT systems, the interference could affect all households being supplied from a substation in a PLT-active zone, whether they are a subscriber or not. In-home systems can interfere with other parties connected to the same electricity supply point or in nearby properties; the electricity supply meter is not designed to attenuate HF signals.

The nature of the interference

Whatever the coding system, the interference signal will stretch across the whole of the spectrum occupied by the modem's output, and will be broadband in nature so that within a given region of spectrum it will be impossible to tune it out. In the quiescent state some systems will create a pulsing type of signal which may or may not be subjectively less annoying than the continuous noise which occurs when the system is actually passing data. Some systems may use low-frequency carriers such that a continuous audible tone is present across the frequency range. Several bodies, notably the BBC and RSGB, have audio recordings of actual PLT interference available on their websites.

One problem with determining the extent of actual interference problems is that non-technical radio users may have no idea that the interference they are experiencing is in fact due to a PLT source, since they will never have heard anything like it before. However the rapidly growing number of BT Vision installations, which appear to create a continuous signal even when not passing data, has already provoked a protest group which can be found via the YouTube website.

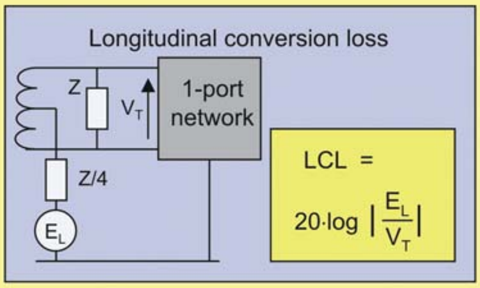
Dependence on quality of wiring

The mains supply wiring both to and within a domestic house was never intended to carry high frequencies. The connection between two points within a home looks like a complicated transmission line with many stubs terminated in unknown and changing impedances. At some frequencies the signal may be transmitted with little loss, but at others the attenuation can be severe, and this characteristic can change with time as users plug various appliances into the mains supply. This means that in order to work at all, the amplitude and frequency coverage of the signal must be enough to ride over any interference already present on the network, and must adapt to time-dependent changes in this interference and the network attenuation. Current-generation PLT systems are designed to do this.

A critical parameter which determines the degree of unintentional radiated emissions that a wired network creates is the "Longitudinal Conversion Loss" (LCL) of the cable. Simply put, this is the ratio between the signal level which appears across the wires, intentionally, due to the desired data transmission, and which to a first order should not radiate; and the signal level in common mode – all wires together – which represents the leakiness of the cable and which contributes the lion's share of the radiation. Data cables which carry broadband signals, of which Ethernet is the most typical example, are very tightly specified for a good LCL, which ensures that the RF leakage from the data signal is kept to a low, known value. This is also true to some extent for telephone cables that are used to feed ADSL and VDSL (phone-connected) broadband into the home.

Longitudinal Conversion Loss

LCL is the ratio of common mode (or "asymmetric") voltage in a network to the differential mode (or "symmetric") voltage that creates it. It is defined in ITU G.117 and measured as shown (the one-port network in this context is the cable, but note the reliance of the measurement on a meaningful ground connection):



It is not true of mains wiring. The most important aspect of cable design which affects LCL is the physical balance of the wire pairs which make up the cable. Each conductor must be tightly coupled to the other in the pair so that the interaction of each with the environment is identical. Then, provided the signal currents on the two wires are perfectly balanced, which can be ensured by suitable design of the terminal equipment, emissions from one wire exactly cancel the emissions from the other. Data cables are tightly twisted in a controlled way to achieve this. The interfaces at either end of the cable must be equally well specified.

Not only is mains wiring not controlled in this way, it is commonly installed in direct contravention of these principles. For instance, the live wire can easily be carried off to a light switch and back again, separating it from its neutral return by several metres. The conductors in the cables that make up the ring main wiring, typically flat twin and earth, are never twisted together. At each junction box in the ring main, there are large, uncontrolled deviations in the wiring configuration of the live-neutral pair. And in the connected appliances (TVs, cookers, computers, washing machines etc) there is every likelihood of unbalanced impedances between live, neutral and earth. None of this matters at the mains frequency of 50Hz, but at PLT frequencies of up to 30MHz it is critical. Even if the wiring is installed (as it should be in the UK) properly in accordance with the IEE Wiring Regulations, these are only meant to ensure electrical safety, and they have nothing to say regarding the high frequency properties. In fact, the UK's protective multiple earth (PME) wiring system is inherently unbalanced at the service entrance by the connection of Neutral and Earth conductors.

The IT emissions standard (CISPR 22 [6], published in Europe as EN 55022) gives a figure of 55dB for low-frequency LCL of Category 3 data cable (rarely used now in new installations) and 65dB for Category 5, degrading by 7dB at 10MHz. By contrast, work under the aegis of the COST 286 programme [14] has suggested a "mains symmetry factor" (comparable to, but not the same as, LCL) of around 7.5dB for same-phase measurements. In other words, mains cable could be up to 58dB or nearly a thousand times worse than the most commonly installed data cable at controlling unwanted radiation.

In fact, because of the inherently unbalanced nature of typical installations, it is arguable whether LCL is a suitable parameter with which to characterise mains wiring networks anyway. It is also the case that the specification of LCL depends on a knowledge of both common-mode and differential-mode impedances, and on a reference connection to an external earth. Since these are generally not available for mains networks, the use of a different measurement such as the mains symmetry factor proposed in the COST 286 paper appears to be a better way forward.

Is PLT the same as other interferers?

PLT supporters base their proposals for a relaxation of the emissions compliance requirements that a PLT system has to meet on those already applied to other devices, such as information technology, lighting, or household appliances. CISPR conducted limits, it is said, have been adequate to protect the HF spectrum so far and therefore any system limits should be no more onerous than levels derived from these. This argument overlooks a number of important points:

- A victim won't be able to get away from PLT interference. When a whole street or a whole building is wired for PLT, it will be pervasive and re-positioning the victim will not work. CISPR limits assume that mitigation by separation from a localised interferer is possible.

- PLT may be always on. CISPR limits incorporate a relaxation which takes into account the probability of non-coincidence in time of source and victim – for instance, no one uses a vacuum cleaner 24 hours a day. For PLT, this factor should be unity.

- EMC engineers know that the vast majority of products which comply with CISPR conducted limits do so with a good margin, often at least 20dB, in the frequency range above 2MHz. Such products are typically only near the limit at one or two frequencies; PLT covers the whole band as a matter of design. If CISPR limits do indeed protect HF reception, this factor should not be overlooked.

In fact, PLT modems seem to be unable to operate anywhere near the mains conducted emissions limits in force in CISPR at the moment.

Radiated or conducted?

It has been said that PLT is not intended to communicate via radiated signals. However, an elegant demonstration reported by Jonathan Stott [1] shows that even so, a PLT in-home system (using US HomePlug devices) does indeed do so. He describes the experiment as follows:

> *A HomePlug network was established. One terminal was a laptop PC using a USB-to-mains-PLT HomePlug device. The latter was plugged into a mains extension lead and thence into the mains wall socket. A set of Christmas-tree lights was also plugged into the same mains extension lead. The PLT network functioned as expected, communicating with a second terminal that was plugged in elsewhere. When the mains extension lead was then unplugged from the wall, so that the laptop PC's HomePlug device was no longer physically connected to the mains, the HomePlug network nevertheless continued to function. It was now functioning in effect as a Wireless LAN, using HF frequency spectrum. The lights acted as an antenna for the first terminal. This is possible since the particular USB-to-mains-PLT device draws its power supply from the USB connection and not from the mains and thus can still inject PLT signals. The mains wiring acted as the antenna for the second terminal. It could also be made to work (at lower capacity) with less obvious 'antennas' than the lights, e.g. by simply holding an exposed pin of the plug of the 'unplugged' HomePlug device.*

This suggests that a more appropriate response would be to regard the PLT system as an intentional radio transmitter and license it appropriately.

Cumulative effects

The foregoing discussion has concentrated on the emissions of PLT as they affect victim receivers in close proximity to the PLT system, generally within or near the subscriber's house. This is not the only threat that concerns radio administrations. If PLT were to be widely implemented within any country, the total radiated power would be sufficient to increase the radio noise floor at distances remote from the source, potentially in other countries. If, say, an entire city was to be wired for PLT, this could form an aggregate transmitter whose RF energy would be reflected from the ionosphere and illuminate a continent. In addition, an aircraft flying over such a city might find that its ability to receive HF signals was curtailed. The UK's Civil Aviation Authority has expressed its concern that "aeronautical services are under threat from cabled telecommunications services." Established HF propagation models exist for this phenomenon and a number of studies have been carried out to try and model the possible outcome.

The concern has focussed on several broadband technologies, including ADSL and VDSL. ERA report 2001-0333 [18] stated:

> *The study has found that the cumulative VDSL space wave emissions from a large city such as Greater London have the potential to increase the established ground level radio noise floor published by the ITU. In addition, considerable risk of interference is presented*

to Aeronautical mobile HF radio services sharing the frequency band.

VDSL uses similar frequencies to PLT, but the radiating efficiency of PLT systems, which use mains cables rather than telecom cables, is that much greater. A different study, York EMC Services AY3525 [17], said:

the only technology that is likely to significantly increase the established radio noise floor due to cumulative skywave propagation is PLT….

The problem with any such study is that for the time being it must remain theoretical, since it's impossible to validate the models used for prediction until there are sufficient installed systems to be statistically acceptable; but by then the roll out will be so advanced that it will be impossible to stop it. And the authors of these studies readily admit that their results are heavily dependent on the initial assumptions that they use, with regard particularly to the degree of market penetration and usage of the systems, and the figures that are assumed for the radiation efficiency of the cabling. For instance, the ERA report estimated that there was a 40dB "window" between the effects of pessimistic and optimistic assumptions for the various parameters. Even so, if the situation is likely to be bad for VDSL, it can only be worse for PLT.

Field trial results

Many field trials have been carried out on various systems in various European countries. Several of these were reported at the EC PLT Workshop in Brussels on 16th October 2003. Some significant points were [13]:

- Finland: from results of three installations, PLC is not compatible with HF radio services if the proposed emission limit is set to 55dBμV/m at 3m; this is about 40dB too high.

- Austria: put forward a proposal for a field strength limit of 14dBμV/m at 10m.

- Germany: initial findings about PLC applications suggest that, despite contrary assurances by the manufacturers, the ceilings in force nationally (NB30) cannot be adhered to.

- Netherlands: believes cumulative effects have been underestimated.

- Switzerland: conclusion from a trial in Fribourg is that PLC emissions exceed the German NB30 limit by up to 24dB near points of data injection and up to 18dB in urban areas.

- Spain: from trials in Madrid, Zaragoza and Sevilla, "There have not been any complaints from telecommunication users which could be caused by the operation of the PLT networks".

UK trial at Crieff

In the UK, Scottish and Southern Energy held trials with a total of three systems, from Main.net, Ascom and DS2, in Crieff in Scotland. The former Radiocommunications Agency, the BBC, and the RSGB were all invited to make measurements on these trials, and all three have put their reports in the public domain, with the exception of the DS2 trial which was held later. The RA measurements were made only outdoors, in roadside locations, over 21st-25th October 2002. The BBC [15] and RSGB [16] reports are more comprehensive, giving details of both indoor and outdoor measurements and an assessment of whether interference due to the PLT systems was actually noticeable. Their visits were concurrent and occurred on 12th-13th November 2002. Both parties concluded that, within the houses, both the Main.net and Ascom systems had the potential to deny the use of the broadcast and amateur bands to the occupants of the subscriber's house, and probably also to neighbours. The systems had different characteristics and used different frequency ranges, so that it might be possible to select PLT frequencies that were sufficiently separated from the desired reception frequencies that these latter would still be useable. But the actual amplitude of interference was substantially greater than any level that would render co-channel interference harmless. The measurements made by the BBC team showed levels that were sometimes in excess of the NB30 limits by 20dB, thus confirming the German and Swiss findings reported above; and the fact that even the NB30 limits are too high to protect broadcasting and amateur radio, as quoted by Austria and Finland, was also confirmed.

Reading all three reports, one is struck more than anything by the manifold difficulties involved in making reliable and repeatable on-site measurements of this type of interference, especially in situations where a baseline cannot be obtained because the PLT operation cannot be fully switched off. This is no surprise to an experienced EMC test engineer, but it does not bode well for a compliance regime which relies entirely on investigation and resolution of interference issues on a case-by-case basis after a PLT system is installed, as is envisaged by the European Commission.

Compliance status of PLT devices

The EC's Recommendation on PLT quoted above refers to a system being "made up of equipment compliant with the Directive". Here is the nub of the question: how can PLT modems be made compliant with the EMC Directive? It is the case that some PLT modems are already on the market in Europe and are CE Marked, which means that their manufacturers believe that they meet the essential requirements of the EMC Directive. But there are no standards specifically for such devices and for now, no such device could actually meet the general standard for RF emissions from IT equipment [6]. This is because the level of RF voltage that is put onto the mains connection is far in excess of the levels which are allowed for conducted emissions from all such products.

If these products can't comply with their applicable standards, how could they be CE marked? Until recently, the only alternative available to their manufacturers was the Technical Construction File (TCF) route, according to Article 10.2 of the first edition EMC Directive. This required the case for compliance to be submitted to a Competent Body, who provided a certificate stating that compliance with the essential requirements was actually achieved without recourse to standards. It is understood that all PLT modems on the EU market in the early days did actually use such a TCF route for their CE marking, implying that there was a Competent Body somewhere in Europe who believed that such a case could be made.

Because of the difficulty in justifying it, both the EC Association of Competent Bodies and the UK EMC Test Laboratories Association drafted guidance urging caution:

> *The basic question for a Competent Body when reviewing this or any other TCF is "Does this equipment meet the essential requirement of the EMC Directive". Given that a PLT requires a good signal to noise ratio to operate it must inherently generate emissions that may be in excess of the current limits allowed in EN 55022 and may therefore cause interference to some receiving equipment. It is the responsibility of the manufacturer to demonstrate in their TCF that the equipment does not generate such emissions and hence does meet the essential requirements. If the CB is not satisfied that the TCF accomplishes this then it should not provide a positive report or test certificate. (EMCTLA [19])*

> *As the topic of PLC is very controversial and developments and activities are on-going at several levels, Competent Bodies when asked to carry out a TCF assessment on a PLC system, should take all the latest developments and activities into account. … Although the situation with regard to these systems is still constantly changing, CBs should keep in mind that the systems must meet the requirements of Article 4 of the EMC Directive. (ECACB [20])*

The sensitivity of both of these documents can be gauged from the fact that neither of them were finally published in this form. Their sub-text was that there was very considerable doubt that any PLT system could meet the essential requirements embodied in Article 4. So any Competent Body which provided a positive report or certificate was, to put it mildly, adopting an exposed position.

The position changed with the adoption of the second edition of the EMC Directive, and the publication of a new guidance note from the ECANB [21]. This advises the use of the emissions measurement and limits according to the draft document CISPR/I/257/CD (see later), along with mitigation measures as proposed in the companion CISPR document (adaptive notching, also discussed later). But CISPR/I has already (within a few months of its circulation) rejected the method of CISPR/I/257/CD. This leaves the unsatisfactory position that EU Notified Bodies are being advised in the ECANB guidance to use an inadequate method for giving a compliance opinion.

The alternative, now available to manufacturers under the second edition EMC Directive, is to perform their own "EMC Assessment" without seeking the opinion of a Notified Body and without fully applying EN 55022. This leaves them open to a greater risk of challenge to their compliance statement; but given the lengthy process and uncertain outcome of such a challenge, some manufacturers might opt for this approach.
The fifth edition of CISPR 22/EN 55022, published in 2006 and harmonised with a date of withdrawal of older editions of 1st October 2009, has caused further upset to PLT manufacturers. This is because it includes a flowchart (Figure C.10) which determines the appropriate method for testing a telecommunication port. If this port is defined as a "mains" type (i.e., a PLT modem) then it insists that the test should be done according to the standard method applied to all types of mains-powered equipment. This has removed any lingering hopes that an alternative procedure that allowed the device to pass, could be applied – unless and until CISPR 22 is amended further.

Opening the floodgates

The EMCTLA guidance quoted above touches on a consequence of PLT which has caused concern to many in the relevant administrations. It must be assumed that the mains supply already carries noise from other apparatus which may approach the limits of EN 55022, even if everything connected is in full compliance with the Directive. For PLT to operate, its signals must be greater than this minimum noise level, and so it must breach these limits, almost by definition. As we have seen, this is indeed so, by several tens of dB. Yet all other mains-connected equipment, such as ITE, medical and household appliances, lighting and so forth – is subject to the standard mains conducted emissions limits.

What is to prevent the manufacturers of such equipment, which after all forms the vast bulk of products placed on the market within the EU, from demanding to know why PLT has received such special treatment? Why, they would want to know, do we have to comply with these limits, at considerable extra cost to our industries, when this technology alone is granted exemption? If PLT can flagrantly flout the limits and still protect the radio spectrum, they would say, so can we. But of course, were they to do that, it would open the floodgates to an uncontrolled escalation of interference on the mains wires. To mix metaphors more bluntly, it would drive a horse and cart through the principles of interference control established over decades.

Nevertheless, this exposes a contradiction at the core of the case for PLT. It can only operate if it is indeed granted special status to apply RF disturbances to the mains lines. It must, in fact, be regarded as a special case in the context of the EMC Directive. It cannot possibly comply with the requirement not to generate an electromagnetic disturbance exceeding "a level allowing radio and telecommunications equipment and other apparatus to operate as intended"; because, since the limits are set to achieve this requirement, it must itself exceed those limits and therefore breach the requirement.

Attempts to write a PLT equipment standard

Mindful of this contradiction, and parallel to other standards activities on PLT, CISPR/I is looking at ways to adapt CISPR 22 to apply in a meaningful way to PLT. The PLT project team has produced a succession of drafts, each of which seems to have provoked more controversy than the last, in defiance of the established method of standards production in which consensus is reached by an iterative process of comment and refinement.

The approach they have taken has been to re-define the mains connection for a PLT modem as "A port connecting to power lines supporting data transfer and telecommunications". It is measured once in the conventional way, with the established limits, with the communications function inactive; and it is then measured again, in a different way, with the communications function active. The second way relies upon treating the live and neutral wires as a balanced pair, and measuring only the common mode signal through a network (not the standard mains LISN – a decision which has itself provoked controversy) which applies a defined degree of longitudinal conversion loss (LCL).

Clearly, the LCL figure is crucial for this approach. The higher the value, the less interference is converted to common mode and so the easier the limits are to meet; or, the higher the level of differential signal that can be transmitted and just stay within the limits. The figure mooted in an early draft (CISPR/I/89/CD) was 30dB across the whole frequency range. But this figure was decidedly optimistic, and it was revised down to 24dB in the later draft, CISPR/I/257/CD [22]. Even this is too high to be acceptable to the majority of CISPR, and 6dB was to be the next proposal, tying in with the 7.5dB mains symmetry factor offered by the COST 286 work. But it appears that there is a practical difficulty in constructing a network that would both create a 6dB LCL and pass the wanted data signal – the standard CISPR mains LISN, used for conducted emissions tests for many years, actually gives an effective 6dB conversion between differential and common mode, since it measures half the differential signal on each line with respect to earth, but it deliberately blocks the wanted signal.

So, having gone around in several circles, the project team is now heading back towards specifying a higher LCL but with a different set of limits. In doing that, as a result of a higher-level decision within CISPR, it will have to verify that any new set of limits it comes up with are adequate to protect the radio spectrum.

Notching to the rescue

Having repeatedly run into the buffers on the question of measurement and limits, the CISPR/I project team has turned its attention to other technical fixes. The one that is causing most interest is adaptive notching. The way this works is described in CISPR/I/258/CD [23] as follows:

> *Adaptive Notching is a new technique in an advanced state of development in industry and in ETSI. It aims to protect in-house short wave broadcast reception and avoids static notching of all broadcast bands at all times, which would result in substantial permanent performance loss. Laboratory and field tests jointly with the EBU have successfully demonstrated this technique. Adaptive Notching is a powerful mitigation technique for PLT devices.*
>
> *Adaptive notching operates autonomously. The modems sense the radio frequency spectrum, detect the broadcast channels received* ***with usable quality*** *at the site and at the time and notch out these channels in the transmitted signal. The loss of throughput of a PLT system due to adaptive notching is very low.* ***Only the few broadcast channels which offer useful indoor reception at a given time are notched.*** *(my emphasis)*

The status of CISPR/I/258/CD is not entirely clear; it seems to be meant as no more than a report, but there is pressure to implement it as a standard requirement, and as said earlier, it is already viewed in this light by the ECANB guidance. This would be an entirely new development in the history of radio spectrum protection. It is clearly intended to address the powerful broadcasting lobby which has been a major stumbling block to the acceptance of PLT within CISPR, and there is every likelihood that if the technique is made mandatory within CISPR 22, it will neuter the objections of this group. What are the implications of this?

Note the emphasis in the above quotation. It is *the PLT modem itself* which judges what broadcast signals are received "with usable quality" and only these frequencies are notched – the rest of the spectrum is blotted out. So what becomes of the specialist user of the HF bands: the short-wave listener, the seeker of interesting but low-level broadcasts, the DX-er, the radio astronomer, and other uses such as long-distance aircraft communications? Such users clearly do not have any influence on the PLT modem to represent their interests. This is possibly the first time that an interference control agency has proposed to cede its authority so comprehensively not just to a third party, and not even to another authority, but to the whim of an autonomous piece of electronics in somebody's home. The phrase "driving a horse and cart through the principles of interference control" has already been used in this article. If CISPR/I actively votes this amendment into being, those principles are clearly being re-invented wholesale.

Aside from the issue of principle, some unanswered questions remain. Firstly, will it work even within its own remit? There appears to be no acknowledgement within CISPR that intermodulation could undo the effect of the notches and "fill in" the holes carefully left in the spectrum for the few privileged broadcast frequencies that are deemed to be usable. Laboratory and field trials will not answer this question – only experience.

Secondly, how would the operation of a modem using adaptive notching be tested and verified? Accurate standardized EMC emissions measurements are notoriously difficult to achieve even assuming a static interference source. How long would it take to develop and validate a new test method for such a device within CISPR, and what would the PLT industry be doing meanwhile?

Third, where does it leave the mainstream of electronic products that are not PLT modems? If an enterprising switchmode power supply designer were to create a power supply that was able to dynamically and adaptively notch its switching frequency emissions (admittedly unlikely with the present state of the art), would it benefit from the same waiver in emissions limits? If not, why not? More importantly, if the principle of uniform emissions limits is breached in this special case, there will surely be many other special cases to follow. CISPR must realise the nature of the Pandora's box it seems intent on opening.

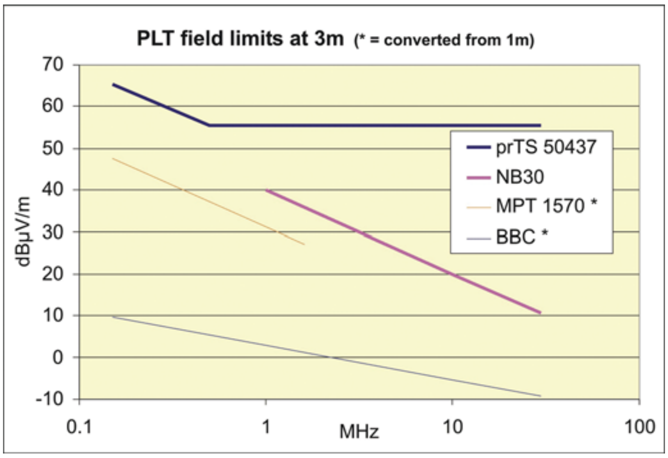
Another mitigation technique that could prove more beneficial is adaptive power management, briefly mentioned at the beginning of this paper. Reducing the power output to the minimum necessary to communicate might, in favourable circumstances, allow a PLT modem to operate at levels compatible with existing limits. But as with notching, this would be at the expense of delivered bit-rate; and it would limit the possible size of installations that the technology could address, since a large distributed system (think of a hotel, for instance) would still need high power levels just to cover the required distance.

Attempts to write a PLT systems standard

Meanwhile, acting in parallel, the CENELEC/ETSI Joint Working Group (JWG) produced in 2004 a draft of its Technical Specification (NB: not a standard) for the measurement of emissions from an operating PLT *network* [4]. This was restricted to limits and methods of measurement for electromagnetic emissions emanating from access powerline communications networks; in other words it didn't apply to in-home networks. Over the frequency range from 0.5 to 30MHz, it applied a limit of 4dBμA/m, which is taken as equivalent to 55.5dBμV/m, at a distance of 3m. As has been observed earlier, some national administrations thought that such a value was about 40dB too high.

In a presentation to the EC's October 2003 workshop on PLC, the chairman of the JWG wryly observed the dilemma that was facing him regarding the question of limits:

1. Radio users and some administrations: Tighten existing limits by 30 dB
2. Telecom suppliers and operators and some administrations: Continue to apply existing limits
3. PLT suppliers and operators: Relax existing limits by 30 dB



Or, as has also been observed, the spectrum users and PLT operators do actually agree on the values. They just disagree on whether they should take a negative or positive polarity.) The TS was never published, and in the end, in 2006 the JWG agreed to stop work on the project. It fell short of returning its Mandate to the European Commission, which would effectively have been an admission that PLT networks were incompatible with radio reception; it carried on work in other areas, in the hope that the networks standard could "resume some time in the future when new technology was in place". Because the EC Mandate was still active, this had the effect of preventing national authorities from introducing national regulations on their own initiative for the conformance of networks. In fact, with the advent of the mitigation methods referred to earlier, work has indeed resumed, but at the time of writing there is still no published specification.

Meanwhile, an Australian radio amateur has developed a prediction program [24] for determining the level of local interference that can be expected from a system which just meets the limits that were suggested in the original TS, at a given distance and frequency.

The graph above shows some of the limits that have been proposed, and demonstrates the wide variation between the values felt to provide protection for radio users (BBC) and the values that might be acceptable to PLT operators (prTS 50437).

Conclusions

A number of broad conclusions follow from the discussion outlined in this paper:

- PLT technology has the capability to create widespread interference, amounting to a denial of use, to users of the HF radio spectrum;
- This interference capability is inherent in the technology, particularly because of its use of standard mains wiring;
- Proposed technical fixes, such as frequency selective and adaptive notches, have limitations and cannot satisfy all users of the HF spectrum;
- Attempts to find a compromise set of system radiated emissions limits which will satisfy both HF users and PLT operators are bound to fail, since there is 50–60dB between them;
- Similarly, attempts to create a product related emissions standard for PLT equipment involve unmanageable technical contortions or a re-definition of what is meant by protection of the radio spectrum;
- Nevertheless, the political imperative behind the expansion of broadband over PLT is sufficiently strong that in some countries it is likely to outweigh any imperative for radio protection.

From the point of view of radio users, PLT is a technology too far.

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