Potential threats to radio services from PLT systems

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Power-Line Transmission (PLT) is a means of transmitting data along an existing, ubiquitous infrastructure: mains-electricity wiring. You might be forgiven for thinking "So what? What has this to do with broadcasting?" The answer is: "More than you might wish!", since PLT systems have a demonstrated ability to interfere with radio reception, which of course includes traditional over-the-air broadcasting.

This article tries to explain some of how this comes about, what the threats are and what is or isn't being done about it.

The occurrence of this interference is contrary to the general principles of regulating radio systems, but many of the detailed regulations in force, or proposed, do not provide adequate protection for broadcasting. "Notching" the PLT signals has been offered as a palliative measure but many requirements must be met for this to become a "cure". One promising possible extension to the notching technique is described here. If it were properly adopted, it might provide a constructive solution to the inevitable stalemate in the standards process.

PLT systems – what are they for?

PLT systems [1] provide a mains-borne method of communication that can be used for two distinct purposes:

- ***access*** – connecting the home to the outside world
- ***home networking*** – interconnecting apparatus within the home

In practice, access-PLT systems commonly embrace the home-networking function as well, since connecting your *home* to the Internet is of little value unless your computer itself is connected.

Re-using the existing mains infrastructure has obvious economic advantages. Telecommunications regulators view access-PLT favourably because it is a way to have competition in the market for providing "Broadband to the Home". They hope this will make domestic broadband access both cheaper and more readily available, which is indeed a worthy aim, and one that the BBC (with a major web presence at **www.bbc.co.uk**) strongly supports.

1. PLT is also sometimes written as Power-Line Telecommunication. Other names for it include: Power-Line Communication (PLC); Digital Power Line (DPL) or Broadband Power Line (BPL). There are probably others!

But the advantages come at a price: mains wiring was never designed to carry the RF signals that PLT transmits. This presents challenges in making the PLT system itself operate with the desired throughput and reliability. However, there is also a serious problem for radio services: some of the transmitted PLT-signal energy escapes and can cause interference to them.

Interference and its regulation

When interference (of whatever origin) spoils a radio listener's enjoyment of their favourite radio programme, they do not care about what caused the problem — they just wish it had not occurred, and maybe start looking for someone to blame. They may even think the receiver is faulty. Indeed, with a digital receiver, the listener could not be expected to recognize interference, since its only symptom may well be, simply, no reception.

The regulatory process is different; it makes a distinction between sources of interference. Interference between (legitimate) radio services is handled within the radio community; interference from non-radio systems to radio services is treated quite differently.

Interference between radio services

Mutual interference between radio systems and services became an issue as soon as the second radio transmitter had been made, and so this topic is well studied and regulated. The ITU-R Radio Regulations [1] control which services can use which radio frequencies (the "Frequency Table" [2]), and set out procedures for planning which ensure that transmitters operating on the same or nearby frequencies are sufficiently separated that the degree of mutual interference remains at acceptable levels, with high probability.

The procedure is based on knowing the appropriate protection ratios to apply for every circumstance. The protection ratio (PR) is the ratio S/I of wanted-signal power [3] to the interfering signal which must be met or exceeded for satisfactory reception to be assured. It is usually expressed in dB. The value of PR will depend on the particular combination of wanted and interfering signal *types*. It will also depend on the extent of overlap between the spectra of the wanted and interfering signals. When a band is solely or primarily used by one radio service on a channelised basis, as is the case for many of the broadcast bands, spectrum planning simply requires the appropriate PRs for those frequency offsets corresponding to co-, adjacent-, and 2nd-adjacent-channel operation. These PRs are documented in the ITU-R and are applied together with propagation predictions for both wanted and interfering signals as part of the planning procedure. Addition of a new transmission is subject to restrictions on the (predicted) interference that it may cause to existing services within their agreed service area. A simple test is applied: does the field strength of the wanted signal, at a given location, exceed a certain minimum value, known as the *minimum protected field strength*? If it does, then its reception should be protected, and the interfering-signal field strength may not exceed that of the wanted signal divided [4] by the PR.

Alternatively, in some cases a different procedure is mandated: the introduction of a new transmission is not allowed to increase the total interference power affecting a given wanted signal by more than some specified amount. The maximum permitted increase is usually small, e.g. 0.25 dB.

2. Sect. 4 of Article S5 of the ITU-R Radio Regulations.
3. The definition of "power" for this purpose depends on the customary way of specifying and measuring signal strengths for the signal types in question. This is a pragmatic and convenient approach; it is simply important to ensure consistency between definitions used to specify the PR and those used in its application.
4. When, as usual, values are expressed in dB then this division simplifies to a *subtraction* of the PR in dB.

Interference between radio service transmissions is thus quite tightly regulated and planned. But what about interference from non-radio-service signals?

Interference from non-radio-service sources

> "S15.12 § 8 Administrations shall take all practicable and necessary steps to ensure that ***the operation of electrical apparatus or installations of any kind, including power and telecommunication distribution networks***, but excluding equipment used for industrial, scientific and medical applications, ***does not cause harmful interference to a radiocommunication service*** and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations."
>
> *(Quotation from the ITU-R Radio Regulations)*

In principle, interference from other man-made sources is also covered in the ITU-R Radio Regulations *(see the quote from Article S15.12 in the text box to the left)*. However, the responsibility is placed on Administrations.

Man-made interference comes about as an unwanted by-product of the operation of electrical apparatus.

Emission limits for many types of apparatus have been set by CISPR. They inevitably take a rather broader approach than the "apply-relevant-PRs" one taken in planning radio services. A simple spectral template is applied to radiated or conducted emissions. The level of protection given does not guarantee unimpaired reception, on the basis that, at least with "historical" interferers (see later below), emissions would typically be limited in place, frequency and time, thus reducing the probability and impact of impairment occurring.

In the European Union an EMC Directive [2] applies, whose underlying principle is intended to ensure that apparatus can be placed freely on the market with causing or suffering interference *(see the quote in the text box below)*.

> "The apparatus … shall be so constructed that: (a) the electromagnetic disturbance it generates does not exceed a level allowing ***radio … equipment … to operate as intended….*** "
>
> *(Quotation from Art.4 of Directive EMC 89/336/EEC.*
> *This Directive will be superseded by another in which similar wording is present.)*

Normally, presumption of compliance is achieved by following product standards that in many cases are derived from CISPR work.

Some CISPR standards are beginning to show their origins, in that they were derived from the need to protect analogue radio systems from appliances with switches, thermostats or motors, or simple harmonics of local oscillators. These examples are clearly isolated in time or frequency respectively, and appliances generally may have been less widespread physically in less affluent times.

In the context of today, some of the old assumptions may no longer be valid, and the standards may even be counter-productive. For example, something containing a microprocessor might generate a clock harmonic that exceeds the spectral template laid down in a standard. One way for the manufacturer to bring this into compliance would be to add some jitter to the clock so that its spectral lines are spread out – broader than the specified bandwidth of the measuring receiver – and thus it *appears* that its potential to cause interference has been reduced.

However, suppose the radio service potentially affected uses a modern digital modulation system: COFDM [5]. This distributes coded data over many regularly spaced carriers. A narrow-band interferer, even of relatively high level, causes little problem – it prevents reception of one carrier, but the error corrector in the receiver can cope with the resulting erasures. However, the same interfering

5. COFDM is used in digital broadcasting systems for terrestrial radio and television broadcasting: DAB, DVB-T, DRM and DVB-H.

Abbreviations

AM	Amplitude Modulation
CISPR	*Comité International Spécial des Perturbations Radioélectrique*
COFDM	Coded Orthogonal Frequency Division Multiplex
DAB	Digital Audio Broadcasting (Eureka-147) http://www.worlddab.org/
DRM	Digital Radio Mondiale http://www.drm.org/
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting http://www.dvb.org/
DVB-H	DVB - Handheld
DVB-T	DVB - Terrestrial
FM	Frequency Modulation
HF	High-Frequency
ITU	International Telecommunication Union
ITU-R	ITU - Radiocommunication Sector
ITU-T	ITU - Telecommunication Sector
LAN	Local Area Network
LF	Low-Frequency
MF	Medium-Frequency
NVIS	Near-Vertical Incidence Sky-wave
PLT	Power-Line Transmission/Telecommunication, also written PLC, BPL ...
PR	Protection Ratio
RF	Radio-Frequency

power spread over several carriers (an outcome encouraged by the present standard) will cause reception to fail.

The emissions from digital broadband communication systems such as DSL or PLT represent a more extreme example since they may occur continually, and affect many MHz of spectrum. The rest of this article will refer explicitly to PLT, since PLT emissions have so far proved in practice to be more problematic to radio services than present DSL installations. This is a natural consequence of the topology of mains wiring compared with phone wiring. However, the principles discussed could be applied to any interfering system, PLT or otherwise.

PLT-system emissions

Bands and radio services affected, and why we care

PLT systems at present are proprietary in nature, and in most cases the manufacturers are very secretive about technical details – even down to general details concerning the spectrum they use [6]. Most of the PLT systems currently in use appear to be restricted to the HF range.

The LF/MF bands are heavily used for broadcasting, including some on an international scale. Several bands in the HF range are also used heavily by broadcasters, mostly for international broadcasting. However, some broadcasters, especially in the less developed parts of the world, rely on HF broadcasting to provide their own national services, exploiting NVIS propagation. Certain parts of the HF spectrum (“Tropical Bands”) are reserved for this use by these countries.

The LF/MF/HF bands have historically used AM, the original analogue modulation method used since the very start of broadcasting. However, a digital replacement, Digital Radio Mondiale, DRM [3][4], has been developed, standardized and launched. It can be used in all three bands, and is expected to start a transformation of their use since it offers a significant improvement in quality.

These bands below 30 MHz are of special value since the long-distance propagation from which they benefit is unique to this frequency range. They enable tropical countries to provide national broadcast coverage without the need for infrastructure, and international broadcasters to target countries which would otherwise be closed to them. Other radio users benefit from the long range too: radio amateurs, ships, aircraft and military amongst others.

There are signs that in the quest for increased capacity, PLT vendors are turning their attention further up the spectrum, above 30 MHz. This means that the 87.5 - 108 MHz band used for FM broadcasting could be affected.

6. An exception is the HomePlug 1.0.1 specification to which many manufacturers adhere.

Mains wiring: a recipe for radiation

Consider sending a signal along a 2-conductor balanced transmission-line. If properly matched, the signal will be little impaired by its journey apart from the gradual attenuation caused by the cable losses. If properly balanced, the two conductors will carry equal and opposite currents, and the external electric and magnetic fields (the "emissions") will be small unless measured sufficiently close to the cable that the separation between the conductors no longer appears negligibly small. Such an arrangement therefore works as a means of data transmission yet would not interfere with radio reception.

To a reasonable degree, this remains the case when a telephone line is used to carry ADSL: the line is nominally balanced and goes directly from one place (the telephone exchange) to another (the ADSL modem in the home). The use of micro-filters stops telephone apparatus acting as stubs. Experience suggests that emissions are not in practice a major issue unless, rarely, there is a wiring fault – which can be fixed. Lesser emissions can arise from differential-to-common-mode conversion in the cable (it is of balanced construction, but isn't perfect) but, in this case too, there is a simple fix, if necessary: the insertion of a common-mode choke.

In contrast, mains wiring is made unbalanced by its very topology, even if the cable itself were perfect. Apparatus or extension leads plugged into a wall socket whose single-pole switch is "off" will add a one-legged stub to the neutral, while switched lighting circuits can add the same to the live. *Fig. 1* illustrates, somewhat tongue-in-cheek, how a combination of live and neutral stubs could even look well-balanced at the point where a PLT signal is injected, while causing currents in the stubs, giving rise to radiation there. Hence measuring the balance at the feed point does not necessarily give a good indication of the level of resulting emissions.

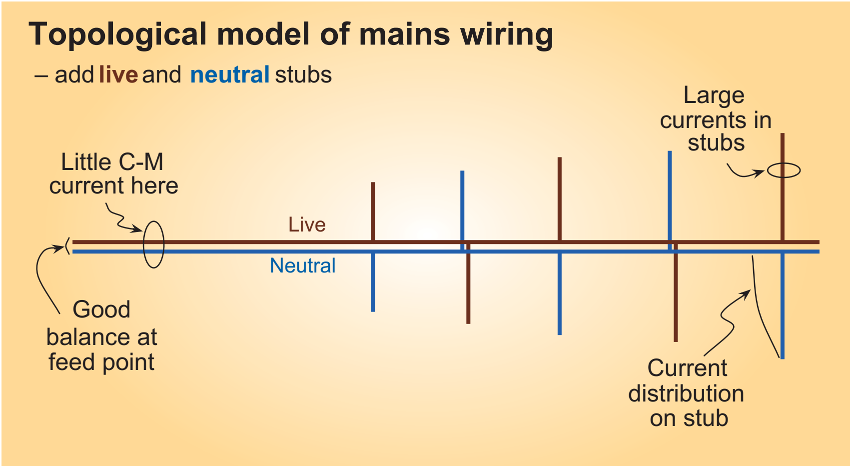

Figure 1
How stubs on mains wiring support currents and therefore radiate, without necessarily causing imbalance at the point where a PLT signal is inserted

This also means that placing limits on common-mode current at the point of injection is unlikely to control interference levels.

Unlike the case of telephone wiring, common-mode chokes are not a feasible solution: in principle they would be needed for every apparatus lead or mains extension lead, and for each lighting circuit, while being expensive to make in view of the current rating and safety requirements.

Experimental evidence

Access PLT in Crieff

BBC engineers, with thanks to Scottish & Southern Energy, had the opportunity of seeing three different types of access-PLT systems serving some of S&SE's electricity customers in Crieff, Scotland. The equipment was made by Main.Net, Ascom and DS2.

The first two of these were seen in 2002. Measurements and audio recordings of their impact on reception of HF broadcasting were made in the homes of PLT customers and, in one instance, recordings were made in the house of a non-equipped neighbour. These are reported in [5]; note that you may download audio samples and assess the impact on AM reception for yourself.

The DS2 system was assessed during a second visit in 2004. Unfortunately on this occasion we were unable to make measurements and recordings in a directly comparable way, as the DS2 representative would not permit measurements within homes using their system [6]. *Fig. 2* shows measurements being made outside one of the homes.

Figure 2
Measurements being made outside one of the houses

HomePlug

We have also examined some examples of home-networking PLT products. Co-operation between PLT vendors in this part of the market seems to be further advanced in that there exists at least one standard (HomePlug [7] 1.0.1) to which many vendors adhere, so that inter-working between equipment from different vendors is possible.

Figure 3
A selection of HomePlug products available in Europe

We purchased HomePlug products from Devolo and Corinex, see *Fig. 3*, but there are many others. They behaved essentially identically and were interoperable without problems, confirming the expected benefit of the existence of a common specification. Measurements of the spectrum of the signal they inject are shown in a later section. We also made a video, downloadable from [7], demonstrating that in normal use they caused interference to broadcast reception. The emissions causing this interference are illustrated in *Fig. 4*.

The video [7] also documents a further experiment – reproducing the reported work of Dr Markus Wehr, of RBT in Germany – which undeniably confirmed the existence of PLT emissions in the very practical way of using them to transmit data in what is, in effect, a Wireless LAN!

We established a HomePlug network whose first 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

7. See the HomePlug website: **http://www.homeplug.com**. This site contains a link to an article on another website which gives a useful system description: **http://www.commsdesign.com/main/2000/12/0012feat5.htm**.

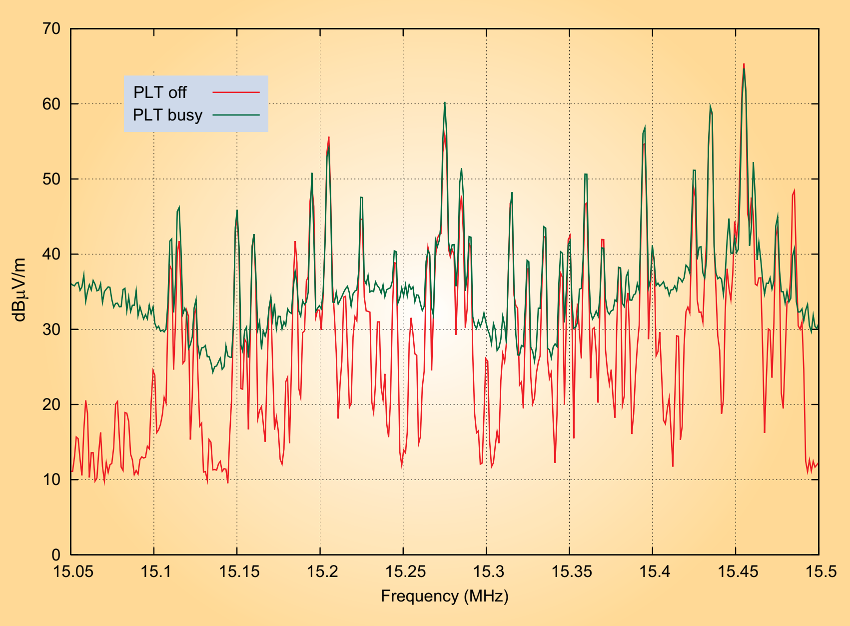

Figure 4
Spectrum of the 15 MHz broadcast band, measured using a loop antenna and spectrum analyser with 1 kHz resolution bandwidth and "max hold". The red trace shows that many broadcast signals can be discerned when the HomePlug PLT system is off, but when it is active (green trace) the "noise floor" is raised significantly, to a level such that broadcast signals exceeding 40 dBμV/m would be badly impaired. The "noise floor" varies cyclically, corresponding to the HomePlug OFDM carriers.

lead, see *Fig. 5*. The second terminal was another laptop, in this case using an Ethernet-to-mains-PLT HomePlug device. The PLT network functioned as expected.

When the mains extension lead was then unplugged from the wall, so that the first laptop PC's HomePlug device was no longer physically connected to the mains, the HomePlug network nevertheless continued to function [8]. It was now functioning in effect as a Wireless LAN, using HF frequency spectrum. The lights acted as an antenna for the first terminal, while 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" Home-Plug device. The broadcast receiver suffered interference whenever the PLT system was operating, whether in "wired" or "wireless" mode.

8. This is possible since the particular USB-to-mains-PLT device draws its power supply from the USB connection, not from the mains, and thus can still inject PLT signals.

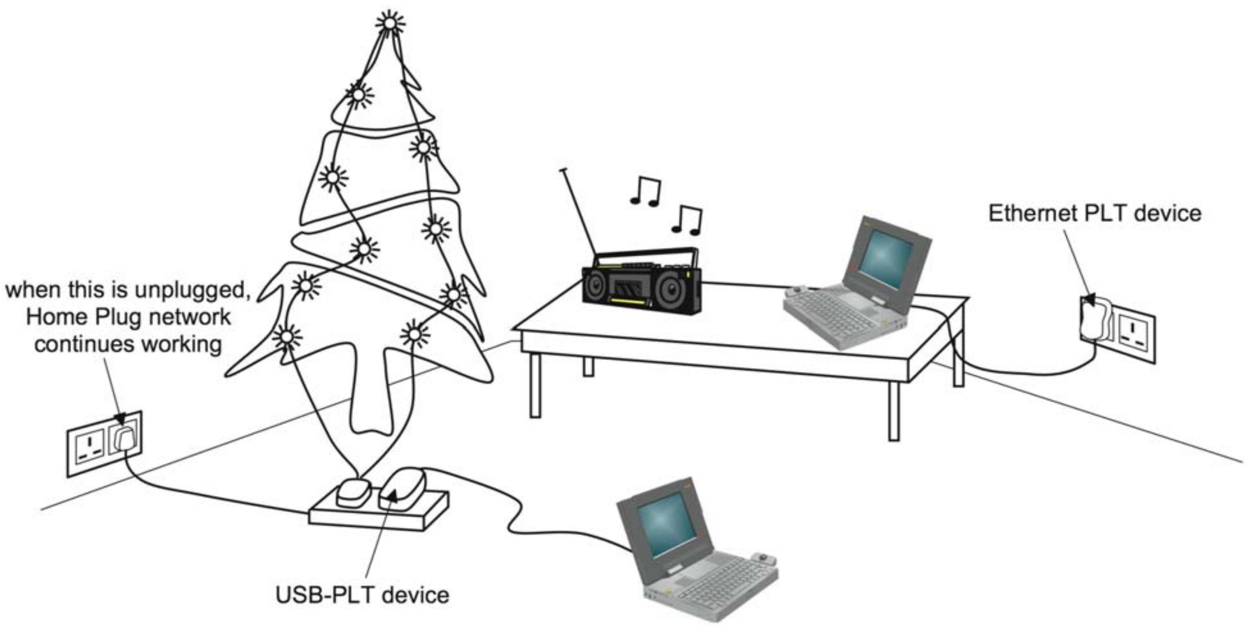

Figure 5
Arrangement by which a home-networking PLT system can be shown to operate as a wireless network. When the mains extension cable is unplugged from the wall the PLT network continues to operate, despite there being no (wired) connection any more.

Some emissions-limit proposals

Many proposals have been debated for setting emissions limits for PLT equipment. A selection of limits on *radiated* emissions is shown in *Fig. 6*.

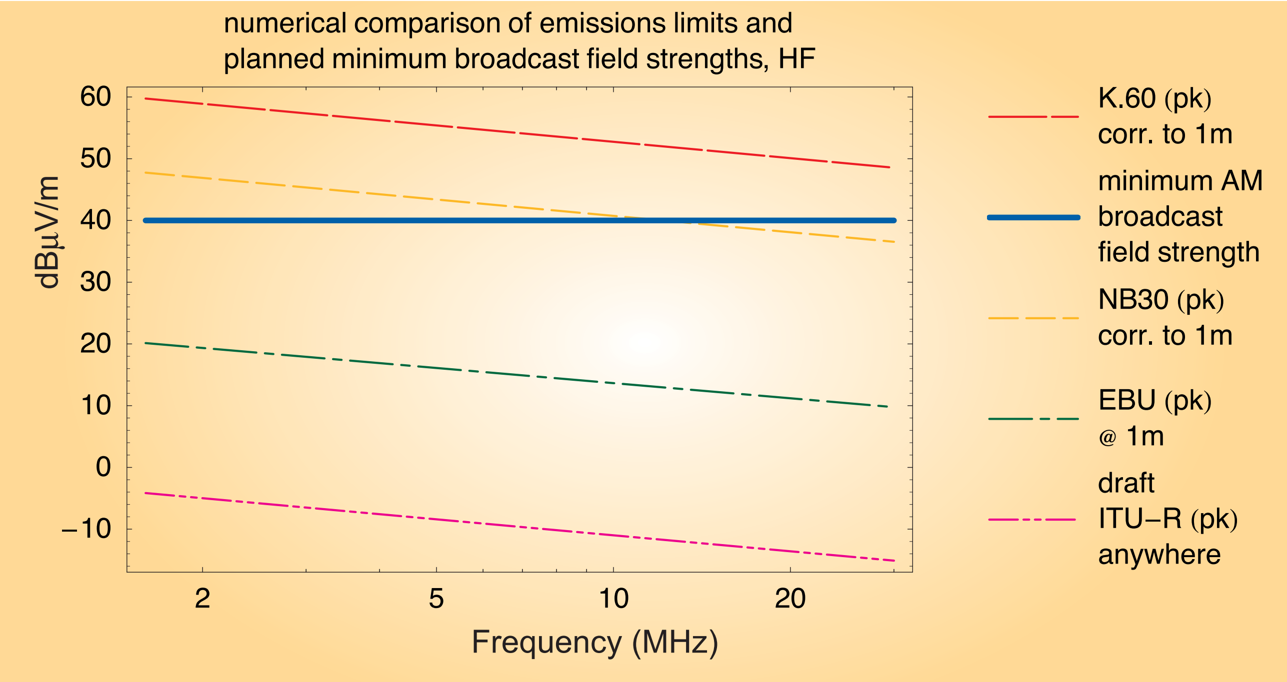

Figure 6
Various proposals for radiated-emissions limits compared with the minimum protected field strength in the HF broadcasting bands. The limits all apply to measurements made within the standard CISPR bandwidth of 9 kHz using a peak detector. The K.60 and NB30 values have been scaled to a distance of 1 m, to match both the EBU proposal and the reasonable requirement for the location of a receiver.

To enable comparison they have, where necessary, been converted to indicate the permitted field value at a common reference distance of 1 m from the interference source. (Some proposed regulations specify the field strength at 3 m distance. Note that in typical homes it is very unlikely that a receiver can be used in a position so that it is 3 m away from all mains wiring.)

The bold solid blue line indicates the minimum protected field strengths for broadcasting in the HF broadcasting bands. Wanted broadcast signals of this strength would be entitled to protection from interference from other radio services. Applying the necessary protection ratios would show that interfering signals would have to be substantially weaker in strength. The "EBU" proposal for limiting emissions from PLT and other line-transmission systems requires just this *(chain-dotted green line)*. See [8] for details of its derivation [9], which actually followed the "permit a modest increase in equivalent noise floor" approach, but with the addition of accepting a degree of compromise in indoor reception. Note that it is specified at 1 m distance from the cable bearing a PLT signal. Interference at a higher level than this proposal would cause audible interference to reception of AM and disrupt reception of the digital DRM system. A further curve lies below the EBU proposal *(magenta, chain-double-dotted line)* to show a proposal recently prepared within the ITU-R as a draft new Recommendation; this curve is intended to show the value strictly necessary to protect reception in all locations.

The "K.60" curve is from ITU-T (the Telecommunication Sector of the ITU) and is perhaps typical of proposals reflecting the needs and wishes of the PLT industry. As can be seen, it would permit emissions to be greater than the wanted broadcasting signals – obviously unsatisfactory for the listener.

9. Ref. 8 considers the LF/MF bands as well as HF, although it appears less likely that PLT systems will generate substantial emissions at LF/MF.

The “NB30” curve is from the regulatory authorities in Germany, and was developed as a compromise – it lies between the extremes (albeit perhaps rather nearer to the needs of the PLT operators than of broadcast listeners). However, it allows little satisfaction to either camp: the permitted emissions are still too high for broadcast listening to be usable, but too low to permit operation of most PLT systems at any worthwhile capacity. So nobody wins.

To help you to put these limits into perspective, there is an interactive demonstration of the effects of simulated DSL and PLT emissions on reception of AM broadcasts available at [9], prepared by members of EBU Project Group B/EIC.

Note that other proposals have been couched as limits on *conducted emissions* in the LF-HF range. Of course, it is the *radiated emissions* that actually affect the radio receiver. So any conducted-emissions limits have to be interpreted [10] to judge what effect on a receiver they permit – but none of this alters the fact that emissions affect receivers.

An unwelcome conclusion

The uncomfortable but inescapable conclusion is that there is no satisfactory outcome based on the setting of blanket limits. This is perhaps supported by the long period of debate on this subject without any resolution in sight.

Quite simply, it appears that radio reception and PLT operation cannot try to use the same frequency in the same place at the same time. Mains wiring is ubiquitous throughout the home. PLT normally operates as an “always-on” resource. So if PLT uses the same spectrum as radio services that are received in or near the home (broadcasting, amateur radio…) then ***interference and conflict is inevitable***.

Is there any way to avoid the conflict?

Notches – a possible way forward?

Principle

PLT and radio services received in the home cannot use the same spectrum without conflict.

But conflict can be avoided if PLT does not use any frequency that a home listener wishes to receive. This could be achieved by modifying the PLT spectrum to introduce one or more notches – parts of the spectrum in which there is a substantial reduction in emissions.

HomePlug example

As mentioned before, HomePlug 1.0.1 is a PLT system for home networking. It is OFDM-based, and its specification calls for notches 30 dB deep in each of the HF bands allocated to radio amateurs in the USA. The need to afford some protection from interference to one class of radio users is thus acknowledged.

The notches appear to do what the specification says. *Fig 7* shows example spectra of the signal injected onto the mains by HomePlug devices, measured using a differential transformer. The many notches corresponding to the radio-amateur bands can be seen in the left trace, while the right trace confirms that the required depth is achieved, and that the performance of the two examples from different manufacturers is similar.

The notches do not help broadcast-band reception (with the exception of a small part of the 7 MHz band).

10. With some difficulty. Note the point made in the earlier section “*Mains wiring: a recipe for radiation*” on page 5 that substantial currents can be made to flow on stubs without any correspondingly-substantial common-mode current at the point of PLT signal injection.

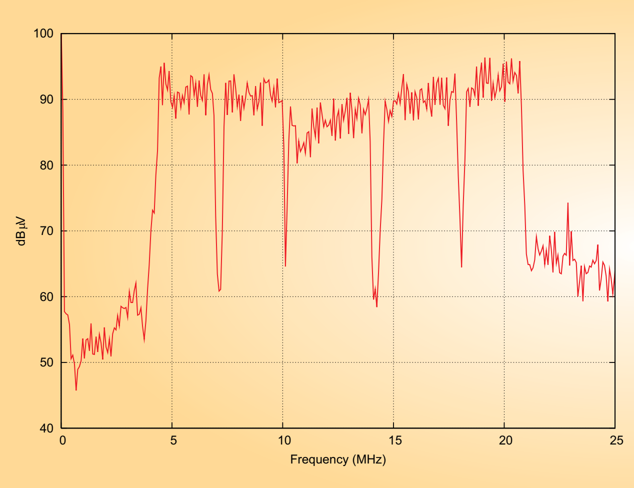

Figure 7a
HomePlug spectrum measured using a differential transformer connected to the mains. The notches corresponding to numerous radio-amateur bands are clearly visible (but note the resolution bandwidth is too great to show their precise shape clearly).

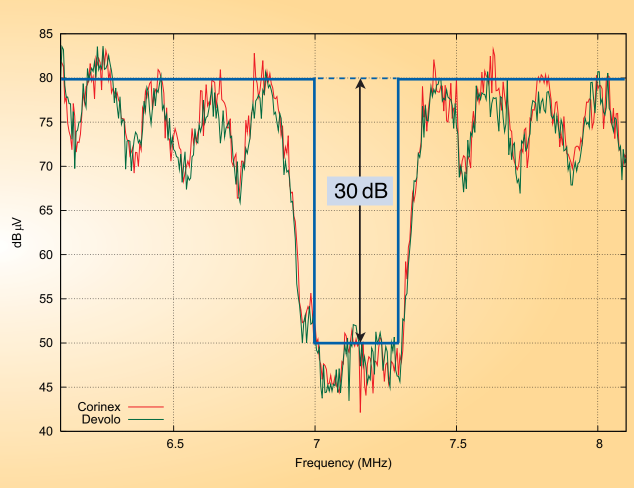

Figure 7b
Details of the HomePlug spectral notch for the 7.0 - 7.3 MHz (US) amateur band. The notch depth and width are as required by the specification

Problems of fixed notches

The problem with the use of fixed notches is precisely that: they are *fixed*.

They cause *loss of flexibility*. The Frequency Allocation Table of the Radio Regulations is revised from time to time at World Radio Conferences to reflect changing needs for spectrum, as old services perhaps decline and others become more important. For example, the spectrum available to broadcasting in the HF range was increased by the Conference of 1992, and further revisions in the HF range are under consideration at present. Widespread deployment of devices with notches fixed in place for their lifetime would thus disempower World Radio Conferences.

They also cause *loss of capacity* for the PLT systems, since the bandwidth in which they can operate is permanently reduced. This in turn means that it is less likely that notches will be provided wherever listeners need them.

Programmable notching

If fixed notches are too inflexible, is there a more flexible alternative?

PLT manufacturers increasingly speak of providing *programmable* notches, as a means of mitigating interference problems. While being welcome, in that it acknowledges interference concerns, this does raise further questions, such as:

- Who does the programming?
- Is a bureaucratic procedure involved? Would it require an interference complaint to the national regulator for each instance? How long would it take to respond?
- Who decides whether a notch should be implemented to protect a particular transmission? They would be in the position of potential *censor* [11].
- How many notches are available simultaneously?

11. This could set a difficult precedent. Certain countries are known to jam incoming international broadcasts, in contravention of the Radio Regulations. However, it would be difficult to make a formal complaint about this if *their* broadcasts were inaccessible in Europe and elsewhere because of local PLT interference.

If a manual process is involved, then for access-PLT systems it is likely that the system operator would seek to maintain control. There will be an obvious desire to maximize system capacity by minimizing the number of notches. An in-home-only system could in principle be under the control of the user, but with potential problems in the ease of use by the uninitiated.

Radio services in the HF band tend not to use the same frequency all the time, since the nature of ionospheric propagation means that different frequencies must be used at different times to support a particular path. This includes a strong element of daily variation. So to protect reception of a particular broadcaster would require different notches at different times of day. It is easy to conclude that it would be unwieldy to cater for this with a manual system (perhaps from a call centre) when there are perhaps many different listeners with different tastes in broadcasts, and schedules that are themselves changing.

Dynamic notching

This leads to a further idea: notches should be provided *automatically* whenever and wherever in the spectrum they are needed to protect local reception.

By making it automatic we should avoid:

- bureaucratic delays;
- the cost overhead for access-PLT operators in supporting frequent requests;
- potential accusations of censorship by bureaucracy or operators;
- bewilderment of the public who might otherwise have to administer home-PLT systems.

The method would cope with the frequently varying schedule at HF. Furthermore, by only applying protection where it is needed, the capacity of a non-interfering PLT system would be greater than if blanket fixed notches were used.

So much for the principle, how could it work?

One obvious method would be for all receivers in the vicinity of the PLT system to communicate to it what spectrum they were tuned to. However, this is impractical, given the large number of receivers in service, none of which is equipped with this facility, and, considering *portable* receivers might be in use, would require some kind of wireless network to implement it [12]. It would have the advantage, for PLT-system capacity, of limiting notches to the services actually being received.

What we actually propose is that any PLT system should regularly cease transmission for brief periods, during which it observes the occupancy of the spectrum. A notch is inserted wherever radio signals of sufficient strength to be receivable in the home environment are found. Thus, in principle, radio reception in the home would be protected. The proportion of the spectrum that would be notched is greater than with the “ideal” system of the previous paragraph but the remaining PLT capacity would still be much greater than if blanket notches were applied.

Now, the idea of requiring short periods of “radio silence” from the PLT system is not itself onerous. Indeed, something like it is probably happening anyway. The PLT network has to resolve contention: each terminal has to be sure no other is transmitting before transmitting itself. Furthermore, those PLT systems which use OFDM, or related methods, adapt by adjusting how much data they send on each carrier according to how well that carrier is working. The presence of radio-signal ingress is one of the factors which would reduce the capacity of a particular PLT carrier. So the basis for “radio silence” and “spectrum-occupancy analysis” may well exist in some existing PLT designs.

At first it would appear that the PLT system would need to be equipped with an antenna. This would be undesirable for a home-PLT network, but perhaps acceptable for an access-PLT network. The

12. If you have to implement a wireless network anyway, the point of the PLT system becomes questionable.

latter would only need one antenna per substation network, since the use of frequencies could be controlled by the master modem.

However, it would obviously be preferable to avoid the need for an antenna. Could *the mains wiring itself* be used, on the basis that if it can radiate interference it must also function as a receiving antenna? That is the question we set out to resolve with a simple experiment.

A first experiment: is the principle feasible?

We conducted a brief experiment to determine how readily the occupancy of spectrum in broadcasting bands could be assessed by measurement of signals present on mains wiring.

We fed a spectrum analyser with signals derived from the mains by one of two methods, either (i) sampling the differential voltage appearing on the mains using a differential transformer [13] or (ii) sampling the common-mode current on the mains using a current clamp. To put the results into context, we also installed a calibrated loop antenna outside the building at some 11 m distance from the building. This meant that we would know the field strength of any broadcasts we identified on the mains. For the proposed method to be suitable, we would need to show that all broadcasts whose field strength was sufficient to justify protection could also be detected by sampling the mains.

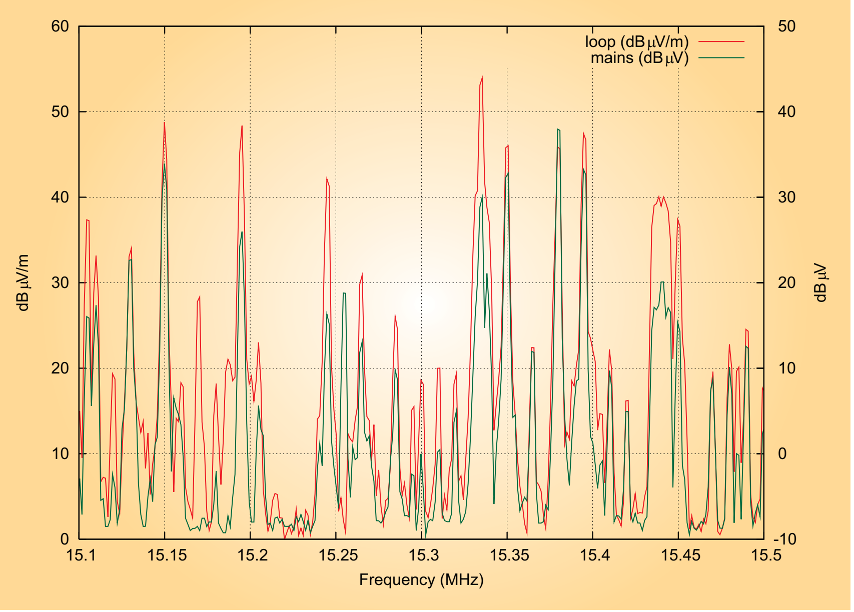

Figure 8
Spectrum of part of the 15 MHz broadcasting band, comparing the signal received using the calibrated loop antenna (red curve, left-hand scale in dBµV/m) with that measured as a differential voltage across the mains supply at a wall socket (green curve, right-hand scale in dBµV)

A sample result can be seen in *Fig. 8*, which shows the spectrum of part of the 15 MHz broadcasting band.

It is immediately striking how close a correlation there is, and how even broadcast signals much weaker than the minimum protected field strength of 40 dBµV/m (for AM signals in the HF band) can still be clearly discerned in the mains-wiring curve.

Note that the vertical alignment of the two traces is arbitrary, but chosen to make visual correlation easy. The correlation is not exact, for which two reasons may be surmised:

- signals at HF are subject to fading, and the two traces were made sequentially, not simultaneously (the spectrum analyser was a single-channel instrument);
- the loop antenna is directional, just as the mains (acting as an antenna) may also be supposed to have some directivity, and these directivity patterns are unlikely to be the same.

In examining the figure, you may find it helpful to be aware that HF broadcasting frequencies are multiples of 5 kHz, but with a nominal channel bandwidth of 10 kHz.

13. With appropriate measures for safety and to block 50 Hz. **DO NOT** try this experiment without due care!

Dynamic notching: conclusions

The results of this simple experiment are encouraging and suggest the proposed dynamic-notching technique merits further examination. It would require further work to bring it to fruition, and this is clearly a job for PLT-system developers, not a broadcaster [14].

However, the idea is not a perfect panacea for all problems for all radio services. Radio amateurs receive very weak signals that are only present for relatively short periods. The system proposed here would clearly provide a notch when a radio amateur was transmitting in the vicinity – but when the amateur is transmitting, they are not listening and do not need the notch. When they are listening, they are not transmitting and the notch would be removed again, leaving any weak signals they would wish to receive masked in interference. So there is probably a case for amateur bands to be notched permanently, as in HomePlug, but preferably with scope for (very occasional) revision of the details of the notch frequencies in the event of changes in the Frequency Allocation Table.

As already noted, other non-broadcast services also use the HF band, and some of them use weak signals. Most of these services do not need to operate in the immediate vicinity of homes, and so have not been expressly targeted in this suggestion. It may be argued whether their frequency bands should be included in the dynamic notching process. Unfortunately, just because their receivers are further away does not mean that they are not affected. The interference generated at a distance by a single PLT system may indeed be truly negligible, but when a large number of PLT installations is in service, the cumulative effect of them all could still be significant *(see* [10]*)*. This requires further investigation by those responsible for these services. It would appear that HF reception on board aircraft is likely to be the most critical case.

Perhaps the greatest difficulty with dynamic notching is its regulation. Completely new ground would be broken in drafting an emissions standard around its use. Testing, verification and enforcement would pose many challenges. But the prize of PLT capacity, without the consequent destruction of radio as we know it, might make it worthwhile.

Discussion and further work

The examples presented in this article should make it clear that PLT systems, if used, present a very real threat to broadcast reception, especially in the HF band, affecting AM and DRM alike.

How great is this threat? Will PLT systems achieve sufficient penetration in the marketplace to cause real difficulty? PLT manufacturers presumably hope to achieve sales on a sufficient scale to make a return on their investment, so we have to consider that this is a real possibility.

The scale of likely *access*-PLT operations varies country-by-country. There does not seem to be an appreciable place in the market for access PLT in those countries where DSL broadband access has already rolled out on a substantial scale, e.g. the UK. On the other hand, access PLT might appear attractive to those countries where the installed base of telephone lines to homes is smaller.

The greatest threat to reception of broadcasting in the home may therefore come from *home-networking* PLT products. Perhaps this is where we should concentrate our efforts.

Conclusions

PLT systems exploit existing mains wiring to provide a data channel that can be used to provide Internet access to the home, or home networking, or both. However, they give rise to emissions that can interfere with the reception of broadcasting and other services. Interference with reception of

14. The author regrets that he has already been misquoted in print to the effect that “the BBC has developed a dynamic-notching PLT system”; the true extent of our work is the simple experiment reported here.

HF broadcasting has been clearly demonstrated and may be verified by downloading the audio examples from [5], while the levels which could be tolerated can be explored in an interactive simulation [9]. It is clear that satisfactory reception in the home is not possible when a PLT system is in use in the vicinity and is operating in the same part of the spectrum.

The ITU-R Radio Regulations require "all practicable steps" to be taken to prevent "harmful interference" to radio services – which include broadcasting.

"Notching" has been proposed as a solution. However, there are snags. If bands are notched permanently (as in HomePlug's notching of the US radio-amateur bands) then the right of World Radio Conferences to revise frequency allocations is diminished, and the capacity associated with those parts of the spectrum is permanently lost by the PLT system. If they are manually notched only in response to complaints, there arise both cost and delay-in-processing complaints, and the process is open to accusations of censorship.

A system of dynamic notching may be the answer. A simple experiment reported here shows that measurements of voltages on the mains, as could be performed by PLT equipment in regular brief "quiet periods", can distinguish the parts of the spectrum that are occupied and which should not be used by the PLT system for the time being. In this way, coexistence of PLT systems and broadcast reception in the home may perhaps be possible – a constructive alternative to the inevitable stalemate of the standards process.

The idea requires further work to bring it to fruition. It has to be done before there is mass roll-out of PLT systems, and be done with the active involvement of the PLT industry. It is unlikely to happen without strong pressure from the regulators, whose responsibility it is to assure that radio apparatus can "function as intended" – as well as to promote competition between network providers.

Note that notches must be deep enough to reduce interference to an acceptable degree, and that dynamic notching may not be appropriate for the bands used by radio amateurs — the other radio service that, along with broadcasting, is intended for reception by the public in their homes.

The possibility of cumulative interference to other services such as aviation should also be investigated carefully.

Extension upwards in frequency of PLT systems could threaten reception of other broadcast band including the "FM" band, 87.5 - 108 MHz.

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References

[1] International Telecommunication Union. Radio Regulations. Geneva, 2004.
ITU website: **http://www.itu.int**.

[2] European Commission: **Directive EMC 89/336/EEC on the approximation of the laws of the Member States relating to electromagnetic compatibility**
Available from EU website:
http://europa.eu.int/comm/enterprise/electr_equipment/emc/directiv/text.htm.
Note that a successor Directive, containing similar wording to that quoted, will supersede it from 20 July 2007:
http://europa.eu.int/comm/enterprise/electr_equipment/emc/directiv/dir2004_108.htm.

Jonathan Stott studied Engineering and Electrical Sciences at Churchill College, Cambridge University, graduating with Distinction in 1972. He has performed research for the BBC ever since, almost exclusively on the application of digital techniques to broadcasting. He was deeply involved with the development of the DVB-T standard for digital terrestrial television, and moved on from this to the BBC team that worked with the DRM Consortium to develop a standard for broadcasting in the bands below 30 MHz.

While working on DRM, Mr Stott also become aware of the potential threats to this part of the spectrum from various new types of interference, such as PLT and xDSL, so "protection of the spectrum" became a parallel task. He continues to work on future developments in digital broadcasting.

[3] DRM Consortium website: **http://www.drm.org**

[4] J.H. Stott: **DRM — key technical features**
EBU Technical Review, No. 286, March 2001.
Available from EBU website: **http://www.ebu.ch/trev_286-stott.pdf**

[5] J.H. Stott and J.E. Salter: **The effects of power-line telecommunications on broadcast reception: Brief trial in Crieff**
BBC R&D White Paper WHP 067, BBC Research and Development, September 2003.
Available, including audio recordings, from BBC website:
http://www.bbc.co.uk/rd/pubs/whp/whp067.shtml.

[6] S. Fleming, J.H. Stott and J.E. Salter: **The effects of power-line telecommunications on broadcast reception: second trial in Crieff**
BBC R&D White Paper WHP 116, BBC Research and Development, June 2005.
Available from BBC website: **http://www.bbc.co.uk/rd/pubs/whp/whp116.shtml**.

[7] J.H. Stott: **PLT and broadcasting — can they co-exist?**
BBC R&D White Paper WHP 099, BBC Research and Development, November 2004.
Available, including video recording, from BBC website:
http://www.bbc.co.uk/rd/pubs/whp/whp099.shtml.

[8] J.H. Stott: **Emission limits. A new proposal based on a limited increase in the noise floor**
BBC R&D White Paper WHP 013, BBC Research and Development, November 2001.
Available from BBC website: **http://www.bbc.co.uk/rd/pubs/whp/whp013.shtml**.

[9] Interactive simulation on EBU web site: **http://www.ebu.ch/en/technical/projects/b_eic.php**

[10] J.H. Stott: **Cumulative effects of distributed interferers**
BBC R&D White Paper WHP 004, BBC Research and Development, August 2001.
Available from BBC website: **http://www.bbc.co.uk/rd/pubs/whp/whp004.shtml**.