PLT and broadcasting — can they co-exist?

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INTRODUCTION

PLT, Power-Line Transmission (or Telecommunication) is a means of transmitting data using existing mains-electricity cables. This is clearly an attractive proposition since there is no need to install new cabling, and in principle it can therefore be literally ‘plug and play’ for the consumer. It can be used for two purposes:

- *access* to the home, that is, to connect the home to the Internet
- *in-home networking*, e.g. to network home computer(s) and peripherals, or to interconnect home-entertainment devices

In practice an access-PLT system may combine both functions, since an external Internet connection is only useful if it reaches the customer’s home computer(s).

Note that various names are used for this technology: it is also known as PLC, Power-Line Communications; DPL, Digital Power Line; and BPL, Broadband over Power Line.

So far, so good. PLT constitutes another way to provide communication. In particular, 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.

But there is a snag. The mains-electricity wiring infrastructure was never designed to carry high-speed data. On the one hand, this means that it is technically challenging for PLT designers to achieve the capacity and reliability they wish. On the other hand there is the difficulty for radio-system users that the signals PLT injects do not simply travel from point to point along the wiring, they also escape as *radiated emissions*, and these undesired emissions can interfere with radio services.

This interference question has given rise to much heated debate, and to attempts to put regulations in place to favour the cause of PLT, or radio, or, in effect, neither. At the time of writing no satisfactory outcome appears in prospect.

This paper outlines the nature of the problem, presents evidence of actual interference, and postulates a possible way forward.

RADIO SERVICES’ ENTITLEMENT TO PROTECTION

Importance of radio spectrum

The radio spectrum is important because it provides a way to communicate in almost every conceivable scenario — on the move, by land, sea or air; over distances large and small — and is in many cases the *only* possible means for communication. This was recognised very early on and has led to the organisation and protection of radio services by legal sanction.

Internationally recognised principle

The key instrument at the international level is the Radio Regulations (RR), produced by the Radiocommunication Sector of the International Telecommunication Union (ITU-R). This has the status of a Treaty between States. It both establishes general principles and sets out detailed procedures for planning and operating radio services. Article S15 of the RR deals with every aspect of “Interferences” and in particular Article S15.12 covers interference to radio services from non-radio systems (emphasis added by present author):

“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.”

So it is clear that Administrations are required by the RR to ensure that PLT — a telecommunication service using the power network — does not interfere with radio services.

Similarly, the European EMC Directive (89/336/EEC and subsequent amendments) sets out its over-riding principle in its Article 4 (emphasis added by present author):

“The apparatus referred to in Article 2 shall be so constructed that:

(a) the *electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment* and other apparatus ***to operate as intended***; …”

How radio services protect each other

Now, as soon as two radio systems operate in the same part of the frequency spectrum, there is potential for mutual interference. If each part of the spectrum were used only once, there would be no interference but the use of spectrum would be very severely curtailed indeed. So radio services have for a long time had to deal with this by agreeing how much interference can be tolerated and then planning the radio systems and networks so that it is sufficiently improbable that this level will be exceeded. In this way frequencies can be re-used.

Often the potential interference is of the same type as the wanted signal (e.g. in those bands allocated exclusively to one type of radio service). Some bands are allocated by the RR to be shared between different types of services, in which case more combinations of wanted and interfering signals have to be considered. For each combination a *protection ratio* (PR) is established; it is the minimum ratio of wanted and interfering signals that ensures satisfactory reception of the wanted signal. Radio services are then planned so that the necessary PR will be achieved with an agreed high probability. In this way it is possible to invest in substantial communication or broadcasting networks with confidence.

Note that protection is normally only given to receiving locations where the wanted signal is received at or above a certain minimum field strength. E.g. for AM broadcasts in the HF band this minimum protected field strength is taken as 40 dBμV/m for the purposes of this paper. This is derived from ITU-R Rec. BS.703 [1].

Glossary

AAC	Advanced Audio Coding
ADSL	Asymmetric Digital Subscriber Line/Loop
AM	Amplitude Modulation
BPL	Broadband Power Line
CELP	Code Excited Linear Prediction
Cenelec	European Committee for Electrotechnical Standardization
COFDM	Coded Orthogonal Frequency-Division Multiplex
DRM	Digital Radio Mondiale
DVB-T	Digital Video Broadcasting (Terrestrial)
ETSI	European Telecommunications Standards Institute
HF High	Frequency
HFCC	High Frequency Coordination Committee
HVXC	Harmonic Vector Excitation Coding
ITU	International Telecommunication Union
JWG	Joint Working Group
LAN	Local Area Network
LF	Low Frequency
MF	Medium Frequency
MLC	Multi-level Coding
NVIS	Near-Vertical-Incidence Sky-wave
PLC	Power Line Communication
PLT	Power Line Transmission/ Telecommunication
PR	Protection Ratio

BROADCASTING AND THE RADIO SPECTRUM

An important radio service

Broadcasting is one of the radio services recognised by the ITU-R and will be well known to all! It has allocations in many parts of the frequency spectrum ranging from the low frequencies of Long Wave to the microwave frequencies used for satellite broadcasting. Particular allocations can be used for radio or for television, and will suit applications from small-scale local broadcasting to international broadcasting.

At the time of writing, most PLT systems of which the author is aware use spectrum in the range below 30 MHz, which, amongst other radio services, contains the LF/MF/HF broadcasting allocations (also known as Long- Medium- and Short-wave bands). Furthermore, most PLT systems also seem to avoid the LF/MF bands, so the potential threat at the moment is chiefly to reception of HF broadcasting. HF is therefore the focus of this paper, but with a clear note that other frequency bands used for broadcasting also require careful consideration.

Broadcasting below 30 MHz

Radio (i.e. sound) broadcasting began in this part of the spectrum in the early part of the 20th century, and is still going strong. It is used for all types of broadcasting from local to international. Amplitude Modulation (AM) was used from the beginning, but see below for a description of a digital replacement.

The spectrum below 30 MHz is unique in that it has propagation mechanisms that can support long-distance communication and as such it is important to broadcasters and other radio users alike.

Medium wave (and Long wave in Europe) can cover a large area by ground-wave propagation (especially so at the lower frequencies). Thus a single LF transmitter is often sufficient to cover a whole country; perhaps a network of a few is needed to do the same at MF. At night-time, sky-wave propagation occurs, bringing an increase in range (and an increase in mutual interference which has to be planned for). Some international broadcasting takes place to neighbouring countries in these bands. At the other extreme, low-power MF transmitters are also used to provide local services, the reduced range of low-power transmissions enabling frequency re-use even within a country.

Short-wave broadcasting normally makes use of sky-wave propagation, which enables an *international* broadcaster to reach a target country without needing any transmitter within the target area. It is in many cases the *only* practicable means to serve a target country, since the few technically-feasible alternatives[1] require the cooperation of third parties — which may not be forthcoming.

Short wave is also used for *national* broadcasting, especially for countries that are large, are in the Tropics or have a scattered population in difficult terrain. All of these factors make short-wave broadcasting advantageous. A single transmitter of modest power can cover a large area using Near-Vertical-Incidence Sky-wave (NVIS) propagation. This is of sufficient importance that the RR reserve certain broadcasting bands for use in the Tropical Zone defined by ITU-R.

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[1] E.g. local relays, satellite broadcasting, Internet. (Local relays are also unlikely to cover a large area).

Digital Radio Mondiale (DRM™)

As explained, spectrum below 30 MHz is uniquely valuable for broadcasting, to both international and certain national broadcasters, because of its long-range possibilities. There is a snag, which is that using the analogue AM technique in conjunction with 9 or 10 kHz RF channelling means that the audio bandwidth is low. Taken together with the multipath nature of sky-wave propagation, this means that the audio quality of AM reception is not up to modern expectations — not unreasonable for a technology that is more than 80 years old.

But there is a way to eat our cake and have it. The DRM Consortium [2] (of broadcasters, manufacturers and research institutes) has developed a digital system [3] (also called DRM) which can be used in this frequency range instead of AM, and which delivers much-improved audio quality. This involves two processes. First it uses modern audio-coding techniques so that a low bit-rate is sufficient to describe the audio signal adequately. Depending on the application and bit rate available, the broadcaster can choose between a waveform coder (AACplus or AAC) and a speech-only coder (CELP or HVXC). This low bit-rate information is then sent using a modulation and channel-coding system that combines COFDM (Coded Orthogonal Frequency-Division Multiplex) and MLC (Multi-level Coding). The result is that good-quality audio can be received, even over a short-wave channel that would sound very poor using analogue AM.

Note that DRM is designed to meet the needs of all kinds of broadcasters, small and large, from local to international, long wave to short wave, to which end it has a number of options that broadcasters can set to match it to their situation. Receivers recognise the appropriate mode in which to work without any intervention from the user. Indeed the system contains other features intended to make the receivers much easier to use, so that, for example, having to pick frequencies from a daily schedule list becomes a thing of the past.

The DRM system was officially launched in June 2003 (coincident with a World Radio Conference) and is expected to be widely taken up in the next few years. Many DRM transmissions are made every day by a number of broadcasters.

The Protection Broadcasting Needs

Simply put, broadcasting needs the level of interference at the listener's antenna to be 'small enough' in relation to the strength of the wanted broadcast signal. More scientifically, we require that the signal-to-interference ratio, S/I, exceeds the relevant *protection ratio*, PR. The necessary PR has to be determined for every relevant combination of wanted and interfering signal types. Thus, for example, the necessary PRs have been established for broadcast signals receiving interference from other broadcasts on the same and on adjacent channels, as a necessary prelude to planning the use of broadcast bands.

When it comes to considering a PLT system as an interferer, the necessary PRs have not yet all been determined. Indeed, in the absence of definitive accessible specifications for many PLT systems, this would be difficult to achieve. It is easy to make some estimates. If the PLT signal were reasonably noise-like (as appears to be the case for ADSL systems[2], at least in the part of the spectrum that is actually carrying traffic) then the PR could be deduced from the known behaviour of the broadcast signal in the presence of thermal noise. Real PLT systems vary in character but generally appear to be slightly more annoying, at the same level, than white noise when they interfere with an AM signal, so we can deduce that the necessary PR is as least as great as that for white noise/ADSL, and perhaps somewhat greater. When the wanted signal is digital it is perhaps unwise to speculate, and the PR really should be determined by laboratory experiments.

Whatever the fine details, one generalisation is safe: the PR for interference to either AM or DRM from broadband interferers will always be substantially positive when expressed in dB, where the interfering power is measured in the same bandwidth as the AM/DRM channel width. In other words the interfering power in the channel must be significantly less than that of the wanted broadcast signal.

REGULATION OF INTERFERENCE

Approaches

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. The regulatory process is different; it makes a distinction between sources of interference.

Interference between (legitimate) radio services is handled within the radio community. Generally there is some form of planning based on propagation models and the application of appropriate PRs. This can take the form of very rigid and long-lived plans established by a major World Radio Conference (common in most broadcasting bands except HF) or a more informal seasonal approach as is taken for HF broadcasting through the HF Coordination Committee, HFCC.

Interference from non-radio systems to radio services is treated quite differently. As we have seen, there are instruments (internationally, the RR, and in Europe, the EMC Directive) that set out the general principle that radio services should be protected from interference. But the way to turn this into practice is where difficulty can start.

Interference from appliances and apparatus is dealt with under EMC regulations. In principle these should do a similar job to the way that radio services protect each other: determine the protection strictly necessary, and then apply whatever relaxation is reasonable considering the likelihood that the item in question will cause problems. E.g. an item only used in large factories will always be much farther away from a domestic radio than items commonly used in the home. It makes a difference whether interference occurs sporadically and briefly, or is continuous in nature. Emissions templates drawn up to set a limit on say clock-frequency leakage will have taken into account that only a few spectral components will be present. They do not imply that broadband interference will also be acceptable if it just does not exceed this template. A simple example will make this clear. The COFDM system used in several types of broadcasting is very tolerant to isolated narrow-band interferers

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[2] Asymmetric Digital Subscriber Line, a popular means of connecting homes to the Internet using *phone* wiring.

that in effect knock out just one, or very few, of the OFDM carriers it uses [4]. In this way, DVB-T digital television can accept surprisingly high amounts of co-channel interference from analogue TV signals (where a high proportion of the signal power is concentrated at the vision and sound carriers). In contrast, co-channel interference from another DVB-T transmission would have to be at a significantly lower level to be acceptable. This is recognised in the different PRs applied in planning for these two cases. Interference from any other type of broadband interferer would have to be treated in the same way.

Interference from PLT is a bit of a special case that does not fit comfortably within existing procedures. The interfering emissions actually come from mains wiring (a passive item). They occur because signals are injected on to the wiring by PLT modems, and unlike other apparatus potentially causing incidental interference (e.g. electric drills, fluorescent lamps) the signals are injected deliberately, even if the radiation is unintended. The interference from access-PLT systems at least will occur more-or-less continually and will potentially affect all households receiving mains supply from a sub-station in an equipped area, whether they subscribe to the service or not.

Some previous proposals

The author has witnessed the evolution of proposals to regulate PLT emissions for many years. Right from the start there was debate whether to apply a ‘flat’ limit or to have ‘chimneys’. (The ‘flat’ limit would not necessarily be literally flat; it might have a slope across the band to a degree matching the trend of the noise floor. ‘Chimneys’ were parts of the spectrum where greater emissions would be permitted; they would be the complement to notches). There was resistance to ‘chimneys’ on various grounds:

- radio users felt they would give a degree of legitimacy to interference, supplanting the RR
- the prerogative of World Radio Conferences to allocate and re-allocate frequencies would be diluted or bypassed
- the radio user(s) in whose spectrum allocation any chimney would fall would be justifiably aggrieved

So a general preference for a ‘flat or slowly varying’ limit was established quite early. Initially Administrations took the lead (exercising their responsibility under the RR).

NB 30

A typical and often-quoted example is the German ‘NB 30’ proposal. This was described as a compromise between radio users and PLT operators. Unfortunately the gulf between what the two wanted was large (many 10s of dB) so establishing a compromise in the middle satisfied no one. PLT systems either could not meet the limit or would have to reduce performance substantially to do so. Meanwhile this limit demonstrably [5, 6] fails to protect broadcast reception in the home. NB 30 is specified over a wide frequency range; in the MF/HF range, 1 to 30 MHz, measurements are to be made at a distance of 3 m using a loop antenna. The equivalent *E*-field limit, measured in a 10 kHz bandwidth with a peak detector, is given by the following formula:

$$E \leq 40 - 20\,\mathrm{Log}_{10}\left[f_{MHz}\right],\ \mathrm{dB\mu V/m}$$

BBC/EBU

Many types of radio services use the HF band. You might therefore think that an attempt to protect them all from first principles, using their individual wanted-signal levels and different protection ratios, would lead to a limit that was far from flat or smoothly varying with frequency. However, this neglects the fact that the different wanted-signal levels have all evolved driven by the same thing — the general noise floor.

The present author therefore derived [7] a limit proposal that was, as required, ‘flat or smoothly varying’ and which sought to provide appropriate protection for all LF/MF/HF services in their different situations. It was based on accepting a limited degradation of the existing noise floor for outdoor reception, and if anything, it made the greatest compromise in its level of protection for indoor reception of broadcasting[3]. The measurement in this case would be made with a loop antenna at a distance of 1 m, and applies to the frequency range 150 kHz to 30 MHz. The equivalent *E*-field limit, measured in a 10 kHz bandwidth with a peak detector, is given by the following formula:

$$E \leq 21.8 - 8.15\,\mathrm{Log}_{10}\left[f_{MHz}\right],\ \mathrm{dB\mu V/m}$$

We immediately face a difficulty that this proposal is not directly comparable with NB 30 as the measurement distance is different. The author chose 1 m for good reasons:

- it increases the level of the unwanted emissions, making them easier to measure
- it is not possible in most homes to find anywhere that is 3 m from all mains cables
- 1 m is representative of the likely distance that a battery-powered receiver will be from mains cables in the home, so the limit can be mapped onto the real problem

This limit was taken up by the European Broadcasting Union and also received wide support from other radio users; unfortunately it found little support amongst Administrations.

‘Joint Working Group’ proposals

The European Commission issued a mandate (M313) to a Joint Working Group of ETSI/Cenelec to produce a harmonised standard for emissions from networks (including PLT). After protracted debate it became clear that agreement within this group was unlikely, and instead three proposals were prepared and put out to National Standards Organisations for voting. The three proposals were:

- conducted-emissions limit derived from product standards
- radiated-emissions limit, equivalent-*E* 55.5 dBμV/m quasi-pk in 9 kHz at 3 m

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[3] A limit based strictly on the concept of (minimum protected FS less PR) for AM broadcast reception would give a limit that is tighter still, for all the international broadcasting bands at 6 MHz and above.

- radiated-emissions limit, essentially NB 30

NB 30 is the tightest of these, but even that is quite inadequate to protect broadcast reception. Unfortunately the slacker second option seems to be currently favoured. The author considers that setting an emissions limit that, like this proposal, permits emissions that are very substantially *stronger* at the point of reception than the wanted signals (when the converse is clearly necessary for reception) simply brings EMC activity into disrepute.

The conducted-emissions limit has the benefit of being linked to other product standards, but also raises questions. There is no allowance for the broadband and continual nature of the interference. The currently-favoured, second-option radiated-emissions limit is essentially derived from it. The tests for conducted emissions assume that common-mode current is worst at the injection point under specified test conditions (a test-fixture provides the load). This neglects the fact that the structure of mains wiring, with its many one-legged stubs (for light-switches, extension cables plugged into wall sockets which are switched off, etc) will convert a differential input into a common-mode current *elsewhere* [8].

EXAMPLES OF EXISTING PLT SYSTEMS

In this section we discuss some example PLT systems of which BBC R&D has had some experience, albeit in some cases limited. We have paid two visits to Crieff in Scotland, where Scottish and Southern Electricity (SSE) have deployed access PLT from three manufacturers. On the first visit in 2002 (reported in detail in [9]) we saw systems by Main.Net and Ascom, and on a second visit in 2004 we saw a system by DS2. We have also acquired on the open market some home-networking PLT devices to the HomePlug specification, from two manufacturers, that we have studied in the laboratory.

Main.net access PLT

System

Available information about the Main.Net system is very scarce. Their web site [10] gives no insight into how the system works (in terms of what signal is fed onto the mains). It does explain that it makes use of repeaters, and that the concept includes home-networking as well as access.

We were informed that it uses direct-sequence spread-spectrum, although the observable characteristics rather support the notion that it is frequency-hopping spread-spectrum. We noted that the in-home terminals communicate directly with the outside world, whether that is the modem at the sub-station or a repeater located somewhere on the way.

Observed behaviour

The system observed in Crieff affected the spectral range from roughly 4.5 to 13 MHz. We were not able to turn the PLT system fully off, but we could specially contrive a 'quiescent' state in which there was no deliberate traffic. In this condition reception of any broadcast channel in the frequency range was affected by brief regular clicks. Once the traffic was restored continual interference could then be heard. This is best appreciated by listening to it (all the audio samples from the 2002 Crieff visit, identified as items 1 to 31, are available from the BBC web site [11]). Nevertheless, Fig. 1 conveys it graphically with a display of the audio waveform, recorded using a normal portable radio tuned to an HF broadcast in the 12 MHz band which was chosen to be representative of a signal at the minimum protected field strength of 40 dBµV/m. At the left of the Figure the modem is quiescent and the programme audio can be seen, with small clicks from the PLT, and then once the modem is busy (right of Figure) the programme audio is submerged below the interference.

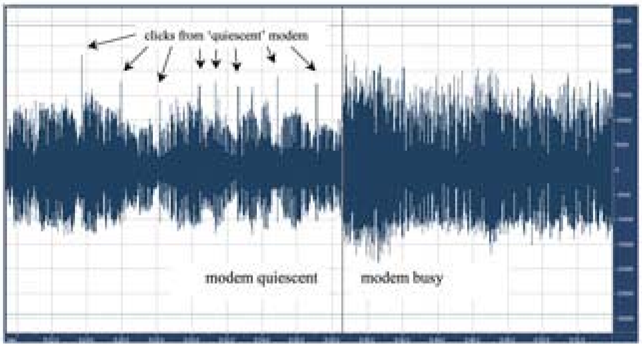

Fig. 1. The recorded audio waveform at the boundary between items 9 and 10. This shows how the audio is 'submerged' under PLT interference as the modem becomes busy, and also shows that the 'quiescent' Main.Net modem introduces visible (and audible) regular clicks.

The interfering field strength was measured indoors using a calibrated loop antenna and measuring receiver. For example, at 5820 kHz (chosen as a clear frequency near to a broadcasting band) the equivalent *E*-field strength in a 10 kHz bandwidth was 64 dBµV/m (with a small fluctuation above and below) using a peak detector, whether the modem was busy or quiescent. The distance of the loop from the wiring carrying the emissions cannot be stated precisely; the loop was simply erected on its tripod where it could be in the close confines of the room where the measurement was made. Assuming the relevant wiring was in the walls or ceiling, the distance was of the rough order of 1 m. This reinforces a point: rooms in most people's homes are not large enough to give them the option of moving a radio very far away from mains cables (even supposing that the radio is battery-powered, as ours was for the recordings). If we walked about with the portable radio, the impairment remained similar.

We were fortunate to have the opportunity to make a brief visit to the neighbour's house. This was the adjoining house in the same terrace, and thus is representative of the situation where houses are in terraces or are semi-detached. This neighbour did not have the PLT service — but he still suffered the interference[4]! Once again we recorded a broadcast of representative field strength, which was significantly impaired (listen to items 12 and 13 from the web site [11]).

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[4] The brevity of the visit meant that we merely established that interference indeed occurred in this situation, and might reasonably be expected to happen to other neighbours of PLT subscribers. What could not be conclusively determined without a more prolonged experiment is whether the interference was received by radiation from the PLT-equipped house, or by radiation within the victim's house of the conducted PLT signal. However, interference was also found to be widespread in the street, tending to suggest that more than the immediate neighbour might also be affected.

Ascom access PLT

System

The Ascom system is more fully described in public sources, e.g. Ascom's website [12], than Main.Net.

The Ascom system uses different parts of the spectrum for *access* and *internal networking*, conforming to the common convention of using lower HF for access and higher HF indoors.

The frequencies used for *access* are four bands, centred on 2.4, 4.8, 8.4 and 10.8 MHz. We believe that any particular installation only uses three out of these four. Ascom claims a capacity of 2.25 to 4.5 Mbit/s for each system. The frequencies used for *indoor networking* are bands centred on roughly 19.8, 22.4 and 24.6 MHz (there are minor inconsistencies about the precise details).

We were told that the system nominally uses 1 MHz blocks of spectrum centred on the above frequencies. If these were tightly constrained to this width they would represent a good choice as far as broadcasters are concerned, since there would be no overlap with any HF bands currently used for international broadcasting[5]. So it appears that the designers have made a commendable effort in their choice. However, it also appears that each band carries data using a simple single-carrier modulation scheme; the intrinsic roll-off is shallow and is supplemented (if at all) by relatively gentle filtering. So, sadly, significant interaction with broadcasting can still occur.

The bridge between these internal and external systems is provided by the *outdoor access point* (OAP). This was connected to the supply side of the electricity meter in both premises we visited, so that the higher-frequency indoor-band signals had to pass through the meter to reach the indoor modem, which was situated adjacent to the computer. This can be seen in Fig. 2, which depicts the outdoor meter cupboard at one of the premises. As the indoor frequencies are injected/received by the OAP on the supply side of the meter it is clear that interference could occur between households if OAPs are too close together.

The system uses time-division multiplexing on each carrier.

Fig. 2. The Ascom Outdoor Access Point, installed in an outdoor meter cupboard. The OAP is the unit in the lower right of the picture, and, as can be seen, was connected to the supply side of the electricity meter. (At the other Ascom-equipped premises visited there was an electrically similar arrangement, but in that case the meter and OAP were housed indoors.)

Observed behaviour

The time-division-multiplex nature of this system was audibly apparent, and can be seen in Fig. 3, which is derived from a zero-span spectrum analyser plot, with a resolution bandwidth of 10 kHz.

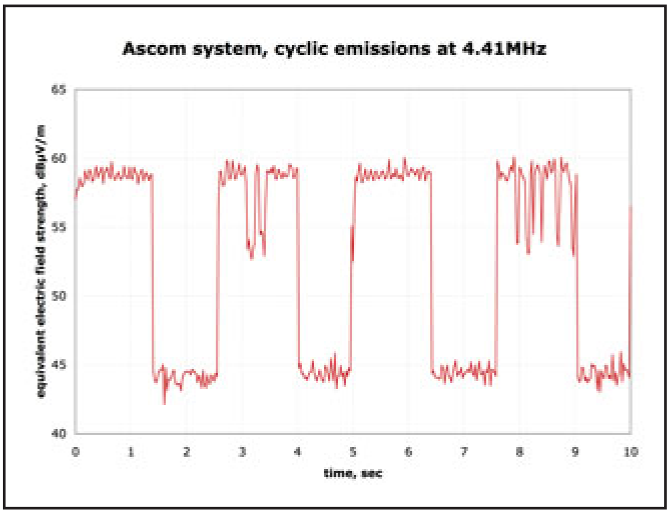

Fig. 3. The cyclic nature of Ascom-system emissions at 4.41 MHz.

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[5] The bands centred on 2.4 and 4.8 MHz clash with the so-called Tropical Bands used for national broadcasting in the Tropical Zone defined by the ITU-R. If SSE are right in asserting that the highest indoor band is centred on 25.2 MHz (instead of 24.6), then that would overlap the lower part of the 26 MHz band.

Despite the designers' apparently careful choice of frequency bands, the impact on broadcast reception was still enough to be disturbing at certain broadcast frequencies, e.g. listen to recorded items 30 and 31 from the website [11].

Further details of emissions measurements can be read in [9].

DS2 access PLT

System

The publicly-available technical information about the DS2 system is limited [13]. It is based on OFDM technology. It uses different bands for upstream and downstream, and for indoors and access, and all can be programmed — there is no single defined range. There is some facility for introducing notches to reduce emissions in specific bands.

Observed behaviour

Our second field trip to Crieff, in June 2004 was intended to enable us to compare the DS2 system directly with the Ascom and Main.Net systems we had already seen and measured. DS2 gives the impression that its later-generation system has somehow solved many interference issues of those earlier systems. Unfortunately, however, DS2 representatives would not allow us to make measurements inside subscriber's homes and so we cannot make any valid comparisons between DS2 and the other systems, nor can we describe reliably what the experience of a DS2 user trying to receive radio indoors would be like. All our measurements on this visit were made either *outside* two houses served by the system, or outside the sub-station, or on the road.

We were able to confirm the multi-carrier nature of the system by observing its spectrum. The spectrum has regular narrow peaks spaced at roughly 1.1 kHz, although every 4th appears to be missing, giving another periodicity at 4.4 kHz. Without further information it cannot be deduced whether the OFDM carrier spacing is actually 1.1 kHz, or 4.4 kHz with sideband artefacts, perhaps from pilot information. However, the regularity means that an AM radio receiver reproduces a 1.1 kHz tone, wherever it is tuned in the relevant frequency range.

A report detailing our measurement results is in course of preparation at the time of writing this present paper. We can however note that measurements *outside* an equipped house gave interference field strengths[6] in the range 40 to 50 dBµV/m (i.e. at or above the minimum broadcast field strength). So it seems very likely that significant interference to broadcasting would have been experienced indoors. It was certainly obvious on a recording made outdoors at some 3 m from the house. This may also be indicative of what a neighbour in an attached house might suffer.

HomePlug home-networking PLT

System

This system was developed by a consortium, the HomePlug Powerline Alliance, and there is an agreed specification to which many vendors make apparatus.

It is intended to provide networking in the home similar to Ethernet or WiFi, but through the medium of the mains wiring. It is OFDM-based and uses the spectral range from 4 to 21 MHz. It appears to have been designed with some radio users in mind, in that its spectral mask is specified with fixed notches to a depth 30 dB below the maximum level. These notch frequency ranges correspond to the bands allocated in the USA to Radio Amateurs[7], the so-called 160, 80, 40, 30, 20, 17, 15, 12 and 10 metre bands. Each device uses the full frequency range (less notches) to transmit Ethernet packets.

Observed behaviour

We have examined devices from two suppliers, Corinex and Devolo. They appear to be interoperable without problems, confirming the expected benefit of the existence of a common specification.

We were able to confirm that the notches were implemented as required by the specification. This was checked using a wide-band transformer arrangement[8] to examine the differential RF voltage between Live and Neutral, see resulting plot, Fig. 4. All devices checked had very similar results. The specification indicates that relevant OFDM carriers in the notches are never transmitted; however, it is easy to calculate the spectrum of the specified OFDM waveform, accounting for its pulse shape and the omitted carriers, and note that this is wholly insufficient to produce the required notch depth. We therefore deduce that further digital filtering must be used.

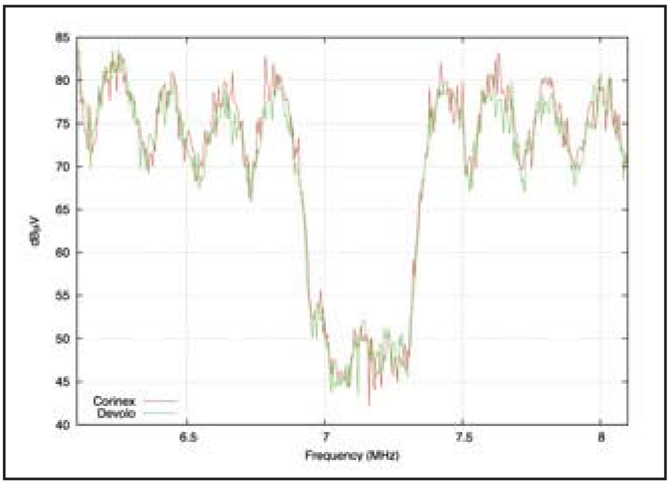

Fig. 4. Spectrum of HomePlug PLT, showing the 7-7.3 MHz notch and the ripples in the rest of the spectrum, which correspond to the HomePlug OFDM carriers. These ripples are pronounced because the cyclic prefix is relatively long. (Measured using differential transformer and spectrum analyser with 3 kHz resolution bandwidth and 'max hold').

Unfortunately for broadcasters, the notches do not protect most of the parts of the spectrum they use. It was easy to show that operation of a Homeplug network caused disruption of reception of both AM and DRM HF signals, see Fig 5.

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[6] Equivalent-*E*-field measured with loop and spectrum analyser using max-hold and 10 kHz bandwidth, an essentially comparable technique to the 2002 results, which used a measuring receiver.

[7] Since the USA allocations are in some cases broader than those in the rest of the world, radio amateurs everywhere take benefit from this.

[8] With appropriately rated safety arrangements, including isolating capacitors!

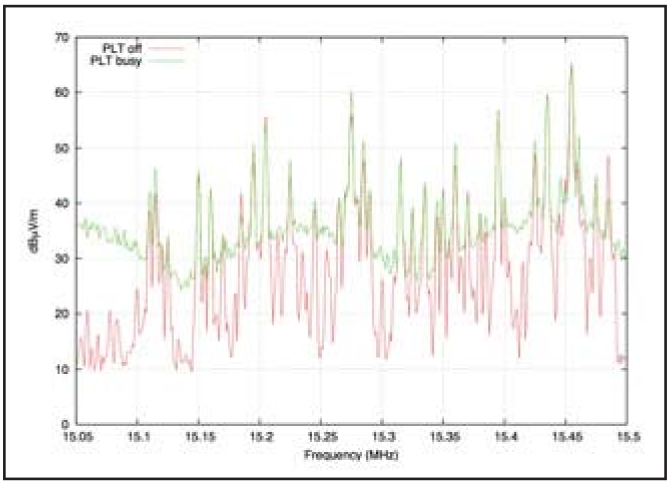

Fig. 5. Spectrum of the 15 MHz broadcast band, measured using a loop antenna and spectrum analyser with 1 kHz resolution bandwidth and 'max hold'. The red trace shows that many broadcast signals can be discerned when the HomePlug PLT system is off, but when it is active (green trace) the 'noise floor' 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.

A further experiment graphically demonstrated that PLT signals are radiated. 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[9], see Fig. 6. 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.

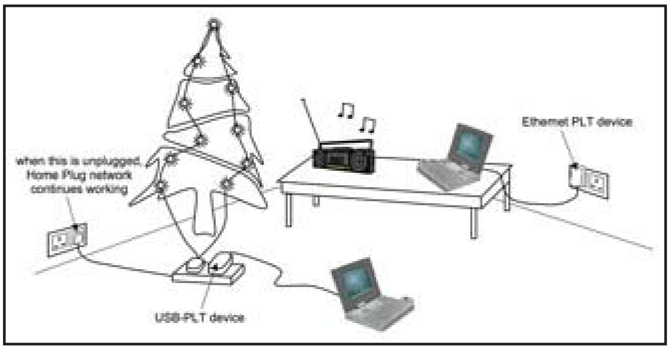

Fig. 6. Arrangement by which a home-networking PLT system can be shown to operate as a wireless network. When the mains extension cable is unplugged from the wall the PLT network continues to operate, despite there being no (wired) connection any more. The broadcast receiver suffers interference when the PLT system is operating, whether 'wired' or 'wireless'.

POSSIBLE APPROACHES TO CO-EXISTENCE

Simple limits will fail

Emissions from all PLT systems discussed here are at a level that will disturb broadcast radio reception in the immediate vicinity, if the wanted signal is in the same part of the spectrum as is being used for (or occupied by) PLT. It seems likely that this will continue to be true, for all PLT systems having a worthwhile capacity. Hence attempts to set a simple emissions limit will never be a solution. A level high enough to permit PLT operation offers no protection to reception of broadcasting. A level low enough to protect reception of broadcasting will prevent PLT operation.

So the key to possible co-existence has to be more complicated. We can say that it is possible, but broadcasting and PLT must not try to use the same spectrum at the same time at the same place.

In effect this has been partly recognised already. The Ascom system appears to have bands chosen trying to avoid most broadcasting and amateur bands (even though the implementation does not deliver the desired result). The DS2 system has some notching ability and the HomePlug system has fixed notches corresponding to the radio-amateur bands.

Notches may be the answer, but…

The European Commission and others make much of the idea that PLT operators can notch out interference on a specific frequency after interference has arisen and been reported. Unfortunately "the devil is in the detail". In principle, if the interfering signal is removed from the part of the spectrum in which a listener's chosen programme is located, the problem is solved. But much more has to be done before this can be quoted as the simple answer:

1. The technology to notch the interference adequately has to be demonstrated (We cannot confirm at present that the DS2 notches are adequate. However, we have been demonstrated an early prototype of a home-networking PLT system by another company which did implement very flexible notch facilities that appeared to be of adequate depth, although there was no time to confirm this by detailed measurement).

2. There have to be guarantees that notches would be operated to protect listeners whenever the latter need it. Since providing the notch reduces the PLT operators' capacity, it is unlikely that this will happen unless there is regulatory pressure to do so.

3. How would this be operated in respect of broadcasting? Listeners to international broadcasting have a wide range of possible stations to choose from, on a constantly varying transmission schedule. They fill many broadcasting bands to bursting point — albeit not all at once, since the ionospheric propagation varies, favouring different frequencies on a diurnal, seasonal and 11-yearly cycle. Who would decide which channels or bands would be protected and when? We presume PLT operators have no intention of protecting the entirety of

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[9] The author is deeply indebted to Dr. Markus Wehr of RBT in Germany who first proposed this scenario and reported its behaviour.

all the broadcast bands, all the time[10] — nor do they need to. There is a risk that the PLT operators are perhaps to assume the mantle of *censor* — you can listen to stations they choose to protect, but not to others.

This is very dangerous, and would be an absolute gift to the regimes of the many countries in the world where freedom of expression and uncensored access to the Internet is non-existent. At present international broadcasters from Europe, such as the BBC World Service, can broadcast to these countries, and their citizens can listen, even if this is disapproved of. Such countries (say country X) may choose to jam the broadcasts, with varying success, and in contravention of the ITU Radio Regulations. At present, European countries are in a position to complain to X about this, and sometimes these complaints have effect. However, once radio reception in Europe becomes ‘censored’, albeit in an unofficial way by PLT providers, then there are no longer valid grounds for complaint. Note that this ‘reciprocal’ argument obliges us to protect even a radio programme broadcast to Europe by country X to which maybe no one actually cares to listen in Europe, and thus there is no listener who will complain about its loss.

The only obvious way to avoid this argument (and a lot of bureaucracy and resulting costs) is for PLT equipment to be operated in a way that it senses the use of the radio spectrum by radio services (during intentionally inserted ‘silent’ periods in the PLT network’s transmissions) and avoids all parts of the spectrum[11] in which it finds radio services currently operating. This would ensure that no censorship was deemed to take place — and would maximise the PLT capacity, under the constraint that interference from PLT to indoor radio reception was minimised.

Some statements by the European Commission clearly recognise the possibility of this method[12], although they might be misinterpreted as implying that systems like this are already available. To the best of our knowledge this is not the case, and indeed seems very unlikely to be unless there is some regulatory pressure to encourage their development. We have made a brief experiment to see if it might be feasible.

Experiment in using mains as sensing antenna

What we need is for the PLT modem to be able to detect whether there is a receivable signal in each part of the spectrum. Wherever one is found the PLT system must not operate, i.e. it places a notch. It may not be practicable to provide the PLT modem with a separate antenna for this purpose, so we tried using the mains itself. We tried two ways. In one we used the previously mentioned transformer that sensed the differential voltage between Live and Neutral; in the other we placed a current clamp around a convenient mains cable (actually that feeding our spectrum analyser).

We also placed a (calibrated) loop antenna outside and at a distance of 11 m from the building in which we were experimenting. This was used as a reference, so we knew what RF signals were potentially available for reception, and their signal strengths. The challenge was to see if by examining the signal from the mains we could identify all the receivable transmissions. Fig. 7 shows part of the spectrum, with traces for the signal received outside and that obtained from the mains, in this case using the wideband transformer. Results with the current clamp are similar. ‘Eye-balling’ these traces suggests that it should indeed be possible to devise an algorithm that would identify the channels occupied by receivable signals. Some simple algorithms were tried, with good results. Further work along these lines is strongly recommended.

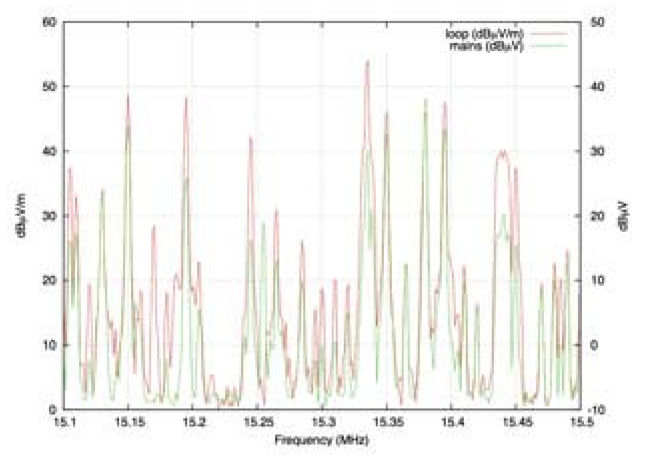

Fig. 7. Spectrum traces (1 kHz resolution bandwidth) of the 15 MHz broadcast band, comparing the broadcast-signal field strength received by an outdoor antenna (red trace, dBµV/m scale on left), with the differential voltage sensed across the mains (green trace, dBµV scale on right). The peaks correspond well — although not always dB-for-dB. This could suggest that the loop and the mains wiring have different directional characteristics; however, it could also be a consequence of the traces being recorded sequentially when signals were subject to fading.

CONCLUSIONS

Radio services are entitled to protection from interference under the terms of the International Radio Regulations and the European EMC Directive.

The radio spectrum below 30 MHz is a unique resource of special value to radio users because of its long-distance propagation properties which, in the case of broadcasting, are essential to international broadcasters and are also of very great value for national broadcasting where countries are large, poor, have scattered populations or are in the Tropics.

Broadcasting below 30 MHz is in the process of being transformed by the introduction of DRM to replace AM, bringing greater audio quality and ease of use — an all-round improvement of the listening experience.

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[10] And even doing this requires programmability of the notches. Spectrum allocations under the ITU-R Radio Regulations evolve over time, for example realignment of the amateur and broadcasting bands around 7 MHz is currently under discussion. Thus fixed notches, as implemented by HomePlug, are not a solution.

[11] The protection could perhaps be limited to internationally allocated broadcasting and radio-amateur bands, i.e. those for which home reception is intended. It would have to be verified in this case that other radio users’ services (with receiving antennas situated away from home environments) did not suffer undue interference either. The author has registered concern that *cumulative interference* from a very large deployment might have a significant impact on aeronautical radio services in particular, which should be assessed further [14].

[12] E.g. the statement “Advanced mitigation techniques such as the ability to put spectral notches in real time will facilitate interference resolution”, from [15].

Mains wiring acts as an antenna at HF and therefore has the potential to radiate and receive electromagnetic fields.

Power-Line Transmission has the potential to cause substantial interference to reception of broadcasting in listener's homes. This potential has been confirmed by the recording and measurement of actual interference from all the PLT systems examined.

Proposals by Administrations or the European Commission for the regulation of emissions do not adequately protect broadcasting. In one case the gulf is of the order of 60 dB. Proposals like this just bring EMC regulation into disrepute.

A limit that did protect broadcasting and other radio services would have the effect of outlawing PLT and other similar broadband services. This is probably politically untenable, however, it may not be necessary.

What is needed is for interference to be prevented. It appears that this can only be achieved if PLT does not operate at the same time, at the same frequency and in the same place as broadcast reception is taking place. 'Notching' of the PLT system is proposed as the way to achieve this.

Notching alone is not enough. It has to be verified that sufficiently deep notches can be achieved. They have to be flexibly allocated whenever and wherever needed. A human system for doing this would be costly, slow to respond to need and would raise difficult ethical questions over censorship.

A possible method has been suggested whereby the PLT system might itself determine automatically which parts of the spectrum are occupied by radio signals and avoid them. An experiment suggests that this should be feasible.

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REFERENCES

1. ITU-R Recommendation BS 703. Characteristics of AM sound broadcasting reference receivers for planning purposes.
2. DRM web site: http://www.drm.org/
3. STOTT, J.H., 2002. Digital Radio Mondiale: key technical features. *Elect. and Comm. Eng. Journ.*, **14**, (1), pp 4-14.
4. STOTT, J.H., 1998. The how and why of COFDM. *EBU Tech. Rev.*, Winter 1998, pp 43-50.
   Also available at: http://www.bbc.co.uk/rd/pubs/papers/pdffiles/ptrev_278-stott.pdf
5. STOTT, J.H., 2001. AM broadcasting and emissions from xDSL/PLT etc. BBC R&D White Paper† WHP 012.
6. EBU. Demonstration prepared by Project Group B/EIC of the EBU, and available via link from: http://www.ebu.ch/en/technical/projects/b_eic.php
7. STOTT, J.H., 2001. Emission limits. BBC R&D White Paper† WHP 013.
8. STOTT, J.H., 2003. How best to protect radio services as intended? BBC R&D White Paper† WHP 063.
9. STOTT, J.H., *and* SALTER, J.E., 2003. The effects of power-line telecommunications on broadcast reception: brief trial in Crieff. BBC R&D White Paper† WHP 067.
10. Main.Net website: http://www.mainnet-plc.com/index.htm
11. Files available via BBC R&D web site at: http://www.bbc.co.uk/rd/pubs/whp/whp067.html
12. Ascom website: http://www.ascom.com/powerline
13. DS 2 website: http://www.ds2.es/
14. STOTT, J.H., 2001. Cumulative effects of distributed interferers. BBC R&D White Paper† WHP 004.
15. European Commission. Papers COCOM04-50 and COCOM04-50Annex, available as:
    http://forum.europa.eu.int/Public/irc/infso/cocom1/library?l=/publicsdocuments2004/cocom04-50_coverpdf/_EN_1.0_&a=d
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