Research White Paper

WHP 195

March 2011

VHF emissions from PLT devices

First investigation of potential interference to broadcast reception

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BRITISH BROADCASTING CORPORATION

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Abstract

Power-Line Transmission (PLT) of data using HF signals injected on to mains wiring has previously been demonstrated to cause interference to reception of HF broadcasting. PowerLine Adaptors (PLAs) have recently been introduced that use VHF spectrum for home networking. This paper describes experiments on a pair of such PLAs, conducted in the laboratory and in two homes, to study their potential to cause interference to reception of FM and DAB radio broadcasts, which occupy part of the same spectral range.

It was confirmed that the PLAs examined use spectrum from 50 to 300 MHz to achieve greater throughput than is possible at HF, although it was also found that in the real-home environment the PLAs did not always achieve VHF networking anyway, several factors being found that appeared to disturb their operation.

Operation of the PLAs caused interference to indoor-portable reception of both FM and DAB broadcasts, in varying degrees from no effect to total disruption. The 'digital cliff' of DAB reception means that when interference occurs the impact is extreme. The PLAs were also found to disturb reception of FM using an external antenna at one of the homes.

It is difficult to extrapolate with precision from these results in just the two homes visited. Since interference was shown to occur in conditions that were *not* equivalent to edge of coverage (they had a substantial margin above that), the number of homes whose reception of FM and DAB broadcasts would be affected if such PLAs were widely used would clearly be appreciable. However, conditions were also found in which no significant interference was noted, so we can also say that not all homes would be so affected.

A possible prediction exercise to try to refine this estimate is proposed, together with other possible future experiments.

Other Keywords

home networking, interference measurement, emissions, EMC

Acknowledgements

The authors wish to record their thanks to their colleagues in BBC Distribution for their kind assistance with field-strength predictions and measurements.

White Papers are distributed freely on request.

Authorisation of the Head of Broadcast/FM Research is required for publication.

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1. Introduction

Power Line Transmission (PLT)[1] and its potential for causing interference to reception of radio services has been under study for over a decade. PLT means sending data signals along electrical power wiring. It can be used for two different purposes:

- **access** — connecting homes to the outside world (e.g. the internet) using their electric power supply ('mains') connection
- **home networking** — interconnecting devices within the home, possibly in turn connecting them to the internet, whether this is provided by access PLT or some other means, e.g. *x*DSL.

Initially frequencies in the HF range were used, with corresponding first concerns over interference to HF radio services relating to HF *access* PLT systems. *Home networking* PLT currently appears[2] to have overtaken access PLT in its likely scale of deployment (certainly so in the UK). Both types of HF PLT have led to serious concerns amongst radio users about interference, and arguments about whether, how and to what extent this might be regulated have continued for over a decade without resolution. In the UK, responsibility for spectrum regulation lies with Ofcom, whilst BIS[3] holds responsibility for EMC issues. At present, PLT interference has been considered an EMC issue, and given the limited resources at BIS, little progress is being made in dealing with the problem.

Home networking PLT products typically take the form of small 'wall-wart' adaptors (sometimes called PLAs — Power Line Adaptors) which plug into a mains wall socket and provide an Ethernet interface to a home computer network. A pair of devices is typically used to link IT equipment in the home, e.g. for connecting an IP-enabled TV to an internet router. The PLT circuitry to provide this functionality can also be built-in to some other type of device for which connectivity is useful (for example smart connected domestic appliances, such as future fridges, or connected TVs), but currently this is less common.

Competition in the marketplace for home networking products has led to the desire to offer devices claiming ever higher data capacity. This has led to PLT networking devices making use of spectrum above the HF range to improve throughput. Devices are now available which make use of VHF spectrum that overlaps with the Band II and Band III frequencies used for FM and DAB broadcasting. Reception of this form of radio broadcasting is a popular activity, so any interference threat to it is one potentially affecting a large number of people.

This White Paper presents the first results of an investigation into the interference potential of one specific PLA device.

[1] Sometimes, arguably erroneously, written Power Line Telecommunication. Other terms are PLC (Power Line Communications) and Broadband Power Line (BPL) although the latter usually refers to *access* rather than *in-home* use.

[2] However, PLT techniques are also under discussion for so-called *SmartGrid* applications, which may mean a resurgence of interest in a form of *access* PLT.

[3] UK Department for Business, Innovation and Skills.

2. Further background

2.1. Other early evidence

When anecdotal reports first appeared suggesting interference to VHF radio-broadcasting services it became clear that broadcasters ought to pay attention. A formal report [1] was made to the ITU-R describing measurements performed by IRT[4] Munich on behalf of NDR/ZDF[5]. It includes results from some PLA devices that only operate at HF, but the part of interest for our present purposes relates to an initial investigation of the same model of PLA devices as had been mentioned in the anecdotal reports. It showed that these PLAs use the spectrum from 50 to 305 MHz, in addition to the HF spectrum from 2 to 30 MHz. It also showed that use of the VHF spectrum depends on the distance between PLT terminals — if the distance is too great, then so too is the attenuation at VHF, and a point is eventually reached where only HF spectrum is used, with a lower data rate then being supported. This limiting distance in these experiments was reported as approximately 10 metres.

2.2. A proposed plan for experiments

The IRT measurements served a very useful purpose in that a reputable laboratory had confirmed that appreciable emissions were observed in the VHF range. What they did not give directly was a clear indication of the extent to which listeners to FM or DAB radio broadcasts would be disturbed in practice. This will clearly depend on both the level of unwanted emissions caused by operation of the PLAs and the field strength of the wanted broadcast signal which is being listened to.

Discussion in an EBU group led to one of the present authors being charged with producing a draft plan for further experiments by broadcasters through which it was hoped it would be possible to scope the extent of the interference threat. This plan, with some additional explanation, is available as a public document in the form of a paper to the EMC UK 2010 Conference [2].

The work reported in this White Paper represents a first step in putting this plan into practice. In order to permit comparisons to be made with the other evidence mentioned above, the experiments reported here also used the same model of PLA devices.

3. Overview of experiments conducted

Experiments were conducted in three convenient locations:

- in a screened room in the BBC R&D laboratory
- in two homes — for convenience, those of the authors

3.1. Experiments in screened room

The BBC R&D Screened Room is equipped with a means of generating known levels of RF field, using two transmission lines near its ceiling and floor. Conventional battery-powered receivers with built-in whip antennas can be placed in a zone where the field is well known. Using an FM signal generator, wanted signals with defined but variable field strengths can be generated to explore the receiver performance.

A small PLT network can also be established in the Screened Room. Its RF emissions can be measured using a calibrated antenna, and the impact on reception determined for a range of wanted-signal strengths.

[4] Institut für Rundfunktechnik GmbH

[5] Norddeutscher Rundfunk, Zweites Deutsches Fernsehen respectively

3.2. Experiments in home A

Home A is a semi-detached house in a suburban residential area well served with FM and DAB signals. It has two mains power rings, one serving only the kitchen, with all other rooms sharing a second ring. Using the pair of PLAs, together with laptop computers, PLT networks were established between a selection of pairs of mains sockets on the 'common' ring and the impact on indoor reception of FM and DAB services determined. Using a calibrated antenna, the field strengths of both the wanted signals and the unwanted PLT emissions could be determined at a range of locations.

3.3. Experiments in home B

Home B is a detached bungalow in a semi-rural residential area. It is well served with FM and DAB signals, but in general more distant from broadcast transmitters than Home A. Its mains wiring is a little more complicated, having three separate power rings, in addition to two lighting circuits and two spurs serving cooking appliances in the kitchen. Note however that all the supply in Home B, as in Home A, is on one single mains phase, as is normal practice in the UK.

Similar experiments were performed in Home B as in Home A, but with the addition of examining the impact on FM reception using the external-antenna installation. Home B also revealed performance shortcomings of the PLAs.

4. The screened room experiment

4.1. The screened room

The screened room at BBC R&D is illustrated in Fig. 1. It is equipped with upper and lower transmission lines, which, when fed via a 180° splitter, generate a defined field at the location of the whip antenna of the portable receiver, which is situated on the wooden table. The arrangement is referred to as a pseudo TEM cell or P-TEM and has been carefully calibrated over a number of years [3].

The measurement antenna is also shown, although for the purposes of measurement of the wanted field it would be situated in place of the portable receiver, at the same location. In this way the calibration of the generation of the wanted field can be

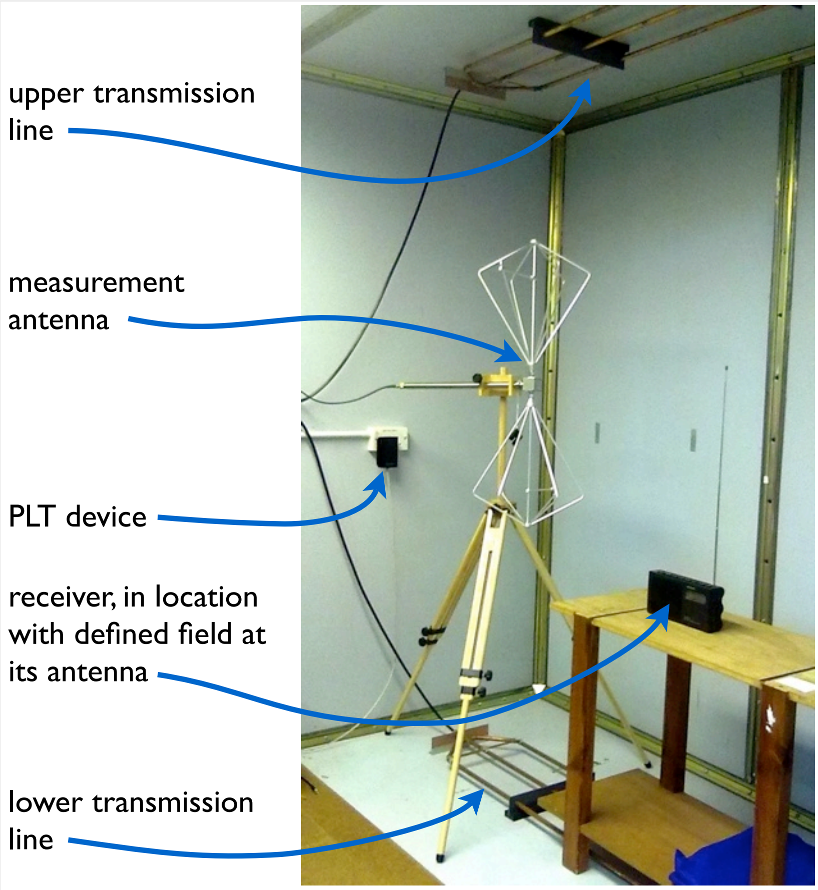

Figure 1: the BBC R&D screened room

determined [6]. Equally the measurement antenna can be used to measure unwanted emissions from the PLT network established in the room, using two PLT devices, one of which is shown plugged in to the room's mains supply. Note that the mains wiring in the room is carried in plastic conduit, close to the metallic wall of the room.

Unfortunately, due to cavity resonance effects, this P-TEM is only suitable for generation of known fields at frequencies up to and including the lower part of the FM band II. For this reason no calibrated work could be performed using DAB receivers — which would require the generation of defined signal fields in Band III.

4.2. Radiated emissions from the PLT network

Field-strength measurements were made in the screened room with no 'wanted-broadcast' test signals being generated in the P-TEM, and with and without the PLT adaptors in use. They were made using the calibrated biconical antenna connected to a spectrum analyser. The results are illustrated in Fig. 2, in the form of spectrum-analyser screen captures. Note that these specific measurements of PLT-emission field strengths were made with the measurement-antenna in the position indicated in Fig. 1, i.e. in a position separate from that occupied by the broadcast receiver. They cannot therefore be used to infer directly the precise RF signal-to-interference ratio (SIR) encountered by the broadcast receiver.

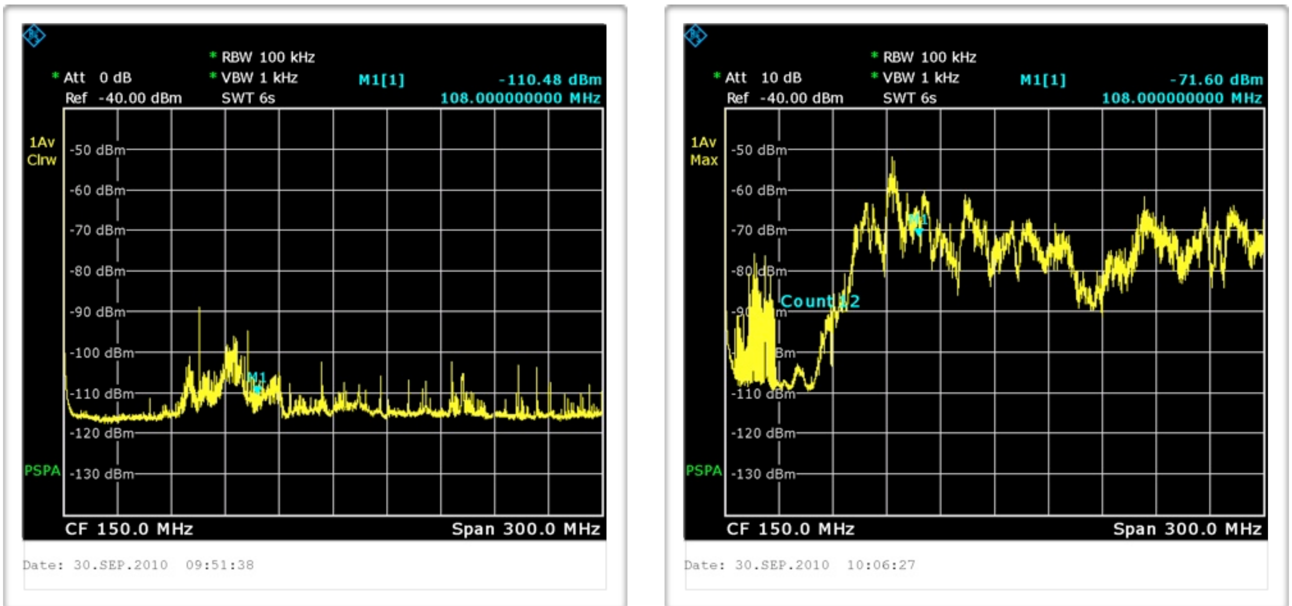

Figure 2: emissions in the screened room from 0 to 300 MHz, without (left) and with (right) the PLT network established and carrying data. To convert the measurements in dBm into field strength the appropriate frequency-dependent conversion factor has to be applied (see Appendix §12.1, Fig. A1).

The trace on the left of Fig. 2 shows the spectrum of the antenna signal with the PLT devices disabled, and the trace on the right shows the effect of enabling the PLT network and passing data traffic over the network. Note that the noise floor *without* the PLT network powered was not completely flat, with some emissions visible, particularly in the range 60 to 120 MHz; these signals are believed

[6] Furthermore, the measurement antenna would normally be removed except when actually in use, in order to avoid disturbing the wanted or unwanted fields presented to the receiver.

to be radiated from the spectrum analyser itself[7] as all other equipment in the screened room was switched off for this measurement. However, the trace on the right shows that the PLT emissions were sufficiently greater in level that no confusion results. Indeed the emissions from the PLT network are some 30-40 dB higher than the noise floor of the left trace, and it was necessary to add 10 dB of attenuation at the spectrum analyser for the trace on the right to avoid overloading; as a result it is just possible to see that the analyser noise floor has risen correspondingly, e.g. at around 45 MHz.

The striking feature is the strong emissions in the VHF range, from 50 to 300 MHz, which result from the network carrying data, in this case performing an FTP file transfer at about 12 Mbit/s. By way of example, once the correction factor for antenna calibration is applied, the level of emissions at 90 MHz is about 47 dBμV/m in a 100 kHz bandwidth. In the absence of PLT, we see an analyser noise floor of –115 dBm in the 100 kHz resolution bandwidth of the analyser filter; this corresponds to a noise density of –165 dBm/Hz which would correspond to an analyser noise figure of 9 dB. With the PLT network enabled and carrying traffic, the noise density increases by some 35 dB.

Although the PLT network is using VHF for the data transfer, emissions can also be seen in the HF range, below 30 MHz[8].

4.3. Impact of the emissions on an FM receiver

Clearly, with interfering field strengths of the order indicated in Fig. 2 (comparable with wanted-signal strengths) significant effects on reception were to be expected. These could be assessed subjectively or objectively.

For *objective* comparison, the wanted signal was generated using an FM signal generator, with audio tone modulation at 1 kHz set to 24.2 kHz deviation, with a range of levels simulating different wanted-signal field strengths. The audio output of the receiver was coupled to an audio test set, using a ferrite-loaded cable[9], and the weighted audio signal-to-noise ratio (SNR) according to ITU-R Rec. 468 determined, for each of the wanted-signal field strengths in turn, for each of three conditions:

- no PLT
- PLT idling
- PLT undertaking an FTP file transfer

The results obtained using one particular broadcast receiver are shown in Fig. 3.

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[7] Normally the measurement signal would be routed out of the screened room, with measurement apparatus like the spectrum analyser situated outside so that any emissions from it would not reach the measurement antenna. However, on this occasion it was more convenient to make progress with the equipment and its single operator within the room.

[8] Beware of drawing too many conclusions about relative levels at HF and VHF since the measurement antenna used is not designed for HF and the calibration factor (see Appendix) alters markedly with frequency. Note also that 'max-hold' mode has been used in an attempt to capture the spectrum regardless of PLT duty cycle. It appears that the PLT devices under examination will use either VHF or HF for the actual carriage of data, depending on whether the connection is adequate to provide useful capacity at VHF, but, whichever band is in use, the other band remains in an 'idle mode' so that the channel behaviour can still be assessed in readiness. Thus emissions are always present to some degree in both bands.

[9] This is needed in order to try to keep the portable receiver working as it would on its own. The extra cable will tend to function as an added part of the antenna, which we try to suppress with the ferrite loading.

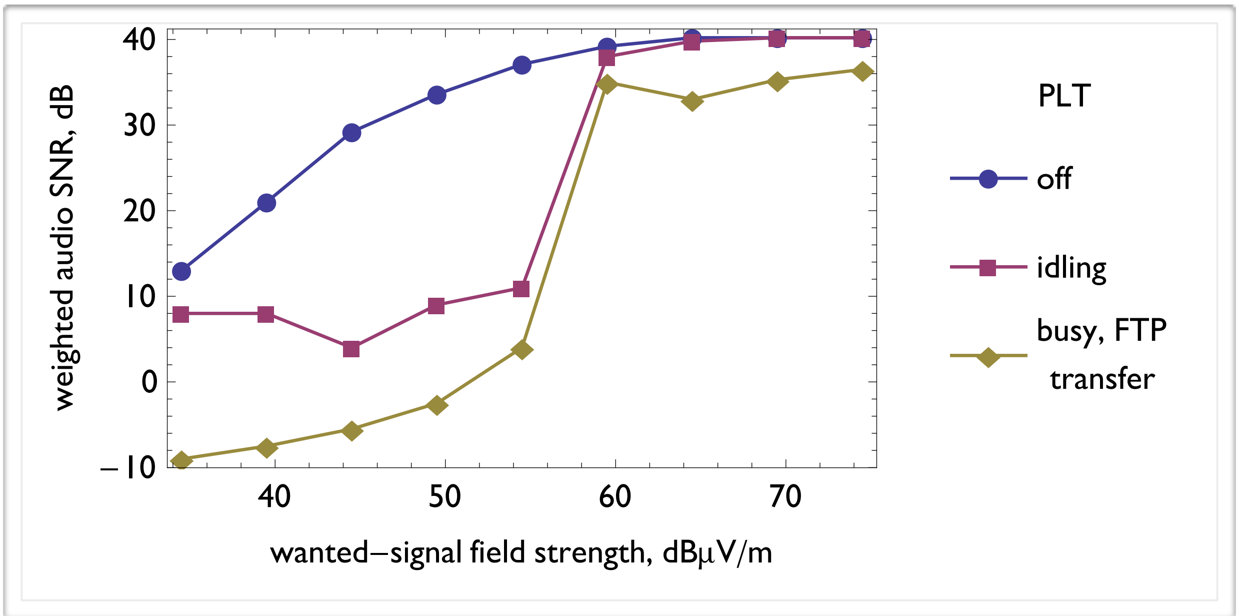


Figure 3: variation of audio SNR with wanted-signal field strength, for portable receiver in screened room with different PLT-network conditions.

Fig. 3 clearly shows the significant impairment caused by PLT operation unless the wanted-signal field strength is very high. There is a range of field strengths (roughly 35 to 50 dBμV/m) where, as expected, the audio SNR more or less tracks field strength in the absence of PLT; in this range an increase of wanted-signal field strength of roughly 20 dB is needed to restore the SNR when PLT is busy.

This experience was also borne out *subjectively*; whatever wanted-signal field strength was chosen (below that which achieved the limiting SNR of which the receiver was capable), it needed to be increased by about 20 dB to restore the same perceived reception quality when PLT is busy.

The character of the audible interference depended on whether the PLT was idling or busy. A distinctive popping or ticking could be heard when the PLT was idling. Once it was busy, there was a continuous 'tearing' sound which was at best annoying and at worst made comprehension impossible, if programme material was substituted for the test tone.

The subjective experiment was repeated with two other different portable receivers, with similar conclusions.

Now, it has to be remembered that the screened room is a rather special situation, with the sole advantage that it is easy to explore a range of wanted field strengths, and to make objective measurements of SNR because test signals can be used, rather than being limited to off-air signals. Furthermore, because of the special construction, both in terms of the mains-wiring style and by having conducting walls, we cannot assume that the PLT emissions were at a level representative of those occurring in normal homes. For that reason the next phase of the tests, in real homes, was crucial.

5. Experiments in home A

5.1. Introduction and first observations

Home A is a semi-detached house, well served with FM and DAB signals. All rooms except the kitchen are served by a common mains power ring.

Some inconsistencies occurred when trying to establish a PLT network operating at VHF between two laptop-and-PLA combinations. A first relatively short run between the conservatory and the nearest socket in the adjacent sitting room worked well, but attempts then to make a connection from one end of the sitting room to the other (a few metres) would not at first operate at VHF. Later this was revisited and the same route did work without difficulty[10]. Similarly inconsistent experiences occurred when trying to connect rooms on different floors. The first 'long' VHF run that worked well was established from one end to another of a long mains-extension lead simply run out in the middle of the sitting room. This also appeared to radiate somewhat less than later connections (more representative of real use) established between wall sockets.

Inconsistencies also appeared in trying to assess the total data-transfer capacity achieved by the PLT network. Neither FTP file transfers nor UDP transmissions appeared able by themselves to exploit the full capacity of the network. Only when both were performed simultaneously, and the bit rates apparently achieved for both added together, was an apparent maximum capacity achieved, in the order of 120 to 140 Mbit/s in the best cases found, but reducing for many of the routes established.

Figure 4: one reception/interference scenario in Home A.

The PLT network is established between PLAs 1 and 2 in the conservatory and sitting room respectively — a separation of barely 2 m while the signal has to travel roughly 4 m along the mains wiring.

The FM receiver is placed on a mantelshelf, about 2.6 m horizontally and 0.8 m vertically from the nearer PLA 2. The measurement antenna is also included in the pictures to show the wanted and interfering fields were measured as nearly as possible in the same location as the receiver antenna.

[10] We were not able to explain this at the time. Later experience in home B (see §6) suggests it may possibly have been related to where the spectrum analyser was plugged in to receive its mains power, but this cannot now be determined.

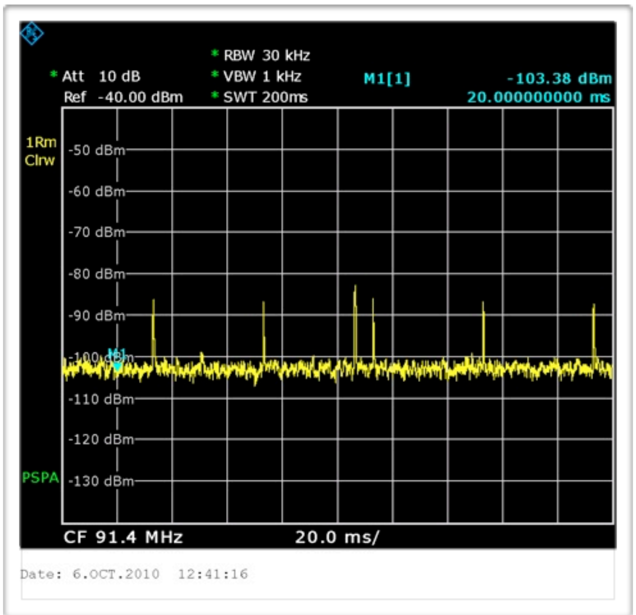
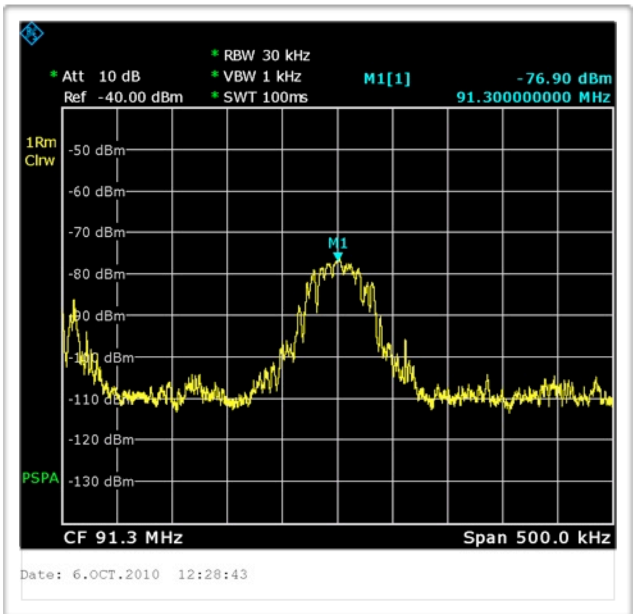


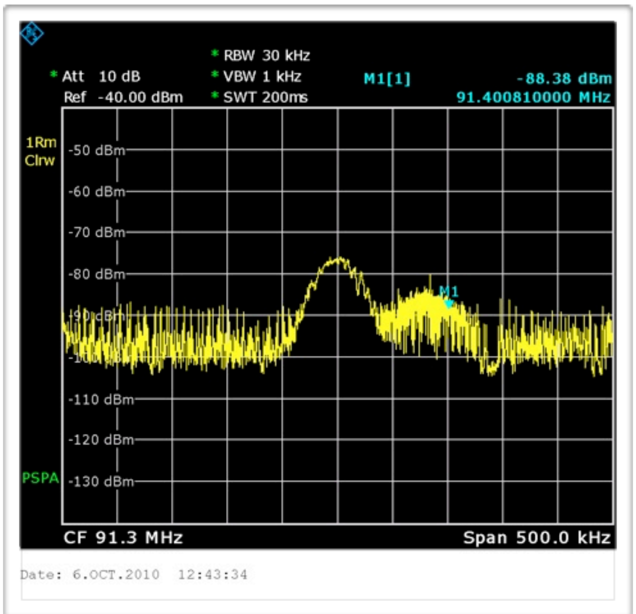
Figure 5: measurements of the scenario of Fig. 4.

Left is a zero-span time-domain plot showing the pulse-like nature of the interference when the PLT network is idling.

Below left shows the wanted BBC Radio 3 FM signal from the Wrotham transmitter in the absence of PLT interference. The field strength corresponds to about 40 dBμV/m.

Below right shows the spectrum when the PLT network is executing a transfer. It is clear that the (noise+interference) floor is very appreciably raised.





E.g. 80 Mbit/s was achieved between the opposite ends of the sitting room, and 70 Mbit/s from the sitting room to the bedroom above it.

5.2. Indoor reception of FM

Home A is served with national-network FM signals from a choice of two transmitters. The original one is at Wrotham, and would normally be regarded as a main station adequately serving this location. However, an additional relay transmitter was later installed at Crystal Palace (primarily to improve portable and mobile reception in the London area) which by view of its nearness to Home A gives an alternative offering greater signal strength. Home A thus gives the opportunity to compare two scenarios of national-network FM reception at the one location. Without any PLT network, either readily provided satisfactory portable reception indoors.

When the PLT network was established, interference was readily audible when receiving national-network FM transmissions from the Wrotham transmitter. The photographs of Fig. 4 show one such scenario, with the network established over the rather short distance from the conservatory to the nearest mains socket in the adjacent sitting room, with the (battery-powered) FM receiver at the other end of the sitting room.

Video recordings were made[11] of reception without PLT, and with PLT idling and then transferring data. These were subsequently used in the presentation made in connection with [2].

Measurements of field strengths at the receiver location showed that the wanted-signal level in this case was about 40 dBμV/m. With PLT idling, the interference took an audible pulsing character, loosely similar to interference from an idling unsuppressed petrol engine. This was confirmed by taking a zero-span measurement that showed the interfering signal to take the form of narrow 'spikes'. This, and conventional spectra with and without PLT carrying data is shown in Fig. 5. With PLT carrying data, reception was essentially unintelligible.

When different PLT-network scenarios were later established, from end-to-end of the sitting room, or from the sitting room to the bedroom above, the PLT emissions were greater than shown in the plots of Fig. 5, the peaks of the interference being indicated at –82 dBm compared with the –88 dBm shown in Fig. 5.

The corresponding national-network wanted-signal field strength from the Crystal Palace transmitter was measured at the same indoor location as about 53 dBμV/m, so that the impact of PLT interference on its reception was greatly reduced[12] compared with reception from Wrotham.

5.3. Indoor reception of DAB

No real impact on indoor DAB reception from the operation of the PLT network was observed at this location. Since home A is situated fairly close to (and within line of sight of) Crystal Palace, one of the transmitter sites forming the national DAB single-frequency network (SFN), it was assumed that it is served with a sufficiently high wanted-signal strength that no impact on indoor DAB reception should be expected, and no further investigation was made. In light of later discoveries (see §6.3 and §7.3) this proved unfortunate, as indicative measurements of RF SIR in the DAB band would have been useful and informative.

6. Experiments in home B

6.1. Introduction and first observations

Home B is a detached bungalow in a semi-rural residential area, well served with FM and DAB signals. It is equipped with external antennas for FM radio and UHF TV, each with separate distribution amplifiers in the loft so that several rooms can be fed with off-air signals. There is also an active-loop antenna for HF reception which is situated at some distance from the bungalow, towards the end of the garden.

The mains wiring installation of Home B is more complicated than that of Home A, and this proved to be more of a challenge for the PLT devices! There are three separate power rings, two separate power circuits for cooking apparatus[13] in the kitchen, two lighting circuits and separate circuits for

[11] Using a hand-held device with built-in microphone to avoid disturbing the reception and interference scenario. Attempts made to connect to the receiver directly for a higher-quality audio recording were abandoned when they were observed to change things (a common difficulty with portable receivers).

[12] Confusingly, when attempts were made several hours later in the afternoon to reproduce some of the scenarios examined that morning, the indoor field strength from the Wrotham transmitter was found to have increased, while that from Crystal Palace was unchanged. This is not totally unexpected, given that the path from Crystal Palace was essentially line-of-sight, while that from Wrotham would have involved some diffraction over hills.

[13] One for a hob, the other for an oven, each circuit additionally having a single associated 13 A socket.

an immersion heater and the garage[14]. All are fed on a single phase from the consumer unit in the attached garage; this consumer unit is to contemporary standards, being only recently installed.

When trying to establish PLT networks in home B, it was found to be rather difficult to ensure that PLT operation took place at VHF (there was no difficulty establishing networks at HF). Either of the following conditions were found to *prevent VHF PLT operation completely:*

- powering the spectrum analyser from a socket on the same ring
- trying to communicate between sockets on different rings, except for one specific combination of a particular pair of sockets which were close together physically (adjoining rooms) and where each was at the point on its ring nearest to the consumer unit

Furthermore, switching on a particular[15] compact fluorescent lamp (in a fitting pendant from a ceiling rose, powered by the lighting circuit in the normal way) greatly reduced the achievable capacity.

The issue with the spectrum analyser was resolved by powering it, via an extension lead, from a socket in the kitchen associated with one of the special circuits for a cooker — whereupon communication was possible within any one of the three main power rings.

Tests of indoor portable radio reception focused mainly on the kitchen/dining area, as representative of where portable reception was most likely to take place in this particular home (since the study and sitting room both have fixed radio installations of better quality). Some measurements were nevertheless made in the sitting room to represent conditions in other homes not so equipped.

6.2. Indoor FM reception

Home B is well served with national-network FM services from the Wrotham transmitter, at a field strength intermediate between the levels received at Home A from the Wrotham and Crystal Palace transmitters. Reception was assessed using a portable receiver situated on a counter top dividing the kitchen from the dining area, while the PLT network was established between the dining area and the sitting room (the only working VHF 'cross-ring' scenario as described in §6.1, and not the worst case for interference to reception at this location). The location can be seen in Fig. 6.

Figure 6: the counter top, dining area and doorway through to the sitting room in home B, showing typical receiver location (in this case the battery DAB receiver used in §6.3). One PLA is just visible in the centre of the picture, partly obscured by the dresser.

The corresponding spectra, with and without the PLT network carrying data traffic, can be seen in Fig. 7. By comparison with the home A scenario shown in Fig. 5, the wanted-signal strength is about 11 dB greater while the interference is only a few dB higher, so the SIR is improved. The audible disturbance was therefore less marked, but still quite objectionable.

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[14] This plurality of circuits, while a consequence at this particular property of extensions and modifications to it, is not uncommon now that modern installations are expected to have RCDs. Each circuit has its own circuit breaker. By spreading both the power and lighting circuits across 2 RCDs it is possible to avoid plunging the entire home into darkness when a trip occurs, and to minimise the nuisance it causes.

[15] This was, logically enough, only discovered as darkness began to fall and there was not time for an exhaustive assessment of all the many CFLs in the property. Some at least did not cause any problems… The late discovery also meant that it did not prevent measurements being made of the circuits tried during daylight hours!

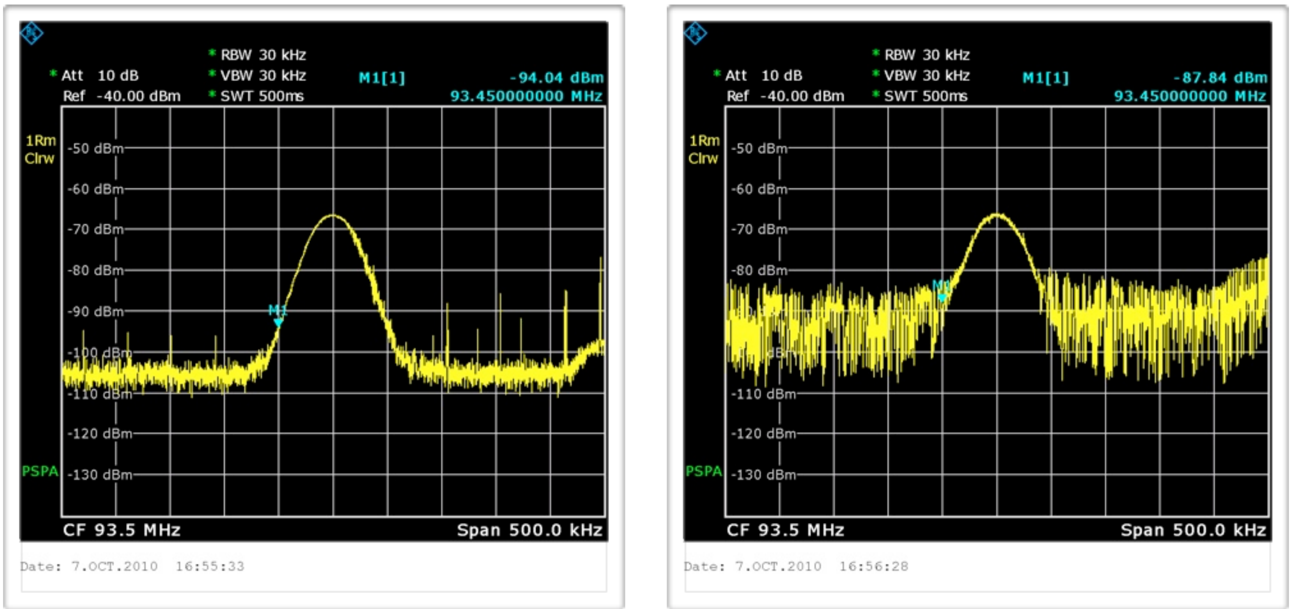

Figure 7: spectra of BBC Radio 4 FM, measured at the receiver location in home B depicted in Fig. 6, without (left) and with (right) PLT in operation.

Reception of BBC London 94.9 MHz at the same location was more drastically disrupted, since its the indoor field strength measured some 3 dB lower[16].

6.3. Indoor DAB reception

Home B is well-served with national-network DAB and variously served with ‘local’ multiplexes. The national networks give solidly reliable DAB reception with a battery-powered portable receiver throughout the property. This is not just a subjective assertion, since DAB receivers are able to give an objective measure by monitoring the operation of the internal error-correction/ detection processes (see Fig. 8). Muxes London 1 and 3 are in practice perfectly usable, while London 2 is unreliable.

Fig. 8: DAB reception under conditions of severe interference — note the indication “Signal error 86” which would read 0 under undisturbed conditions.

Once PLT is operated the effects agree closely with what measured spectra at the receiver location would suggest; as the interference level increases (in relation to the wanted signal) DAB reception becomes first garbled and unreliable and then mutes altogether. The objective error indication on the receiver agrees well with the perceived performance result.

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[16] It is very surprising that the indoor BBC London FM signal was not much weaker still. Its field strength at 10 m outdoors is predicted to be some 18dB weaker than the main national networks from Wrotham. Measuring the signal delivered by the rooftop antenna (see §6.4), BBC London was measured as about 20dB weaker than the main national networks — reasonable, as the BBC London signal is somewhat off the main beam of the antenna. The anomalous indoor result can only serve as a reminder of indoor location variation, and the fact that penetration loss varies with direction. In this example the signal from Wrotham would have had to pass through two solid walls without windows, while that from the BBC London transmitter at Crystal Palace would have entered the bungalow through large glass patio doors.

Fig. 9 shows examples of spectra recorded with a few combinations of PLT network configuration and DAB receiver location. (Many more were collected). Note that as both PLT and DAB are broadband in comparison with the analyser bandwidth in use it is possible to estimate SIR directly by visual inspection.

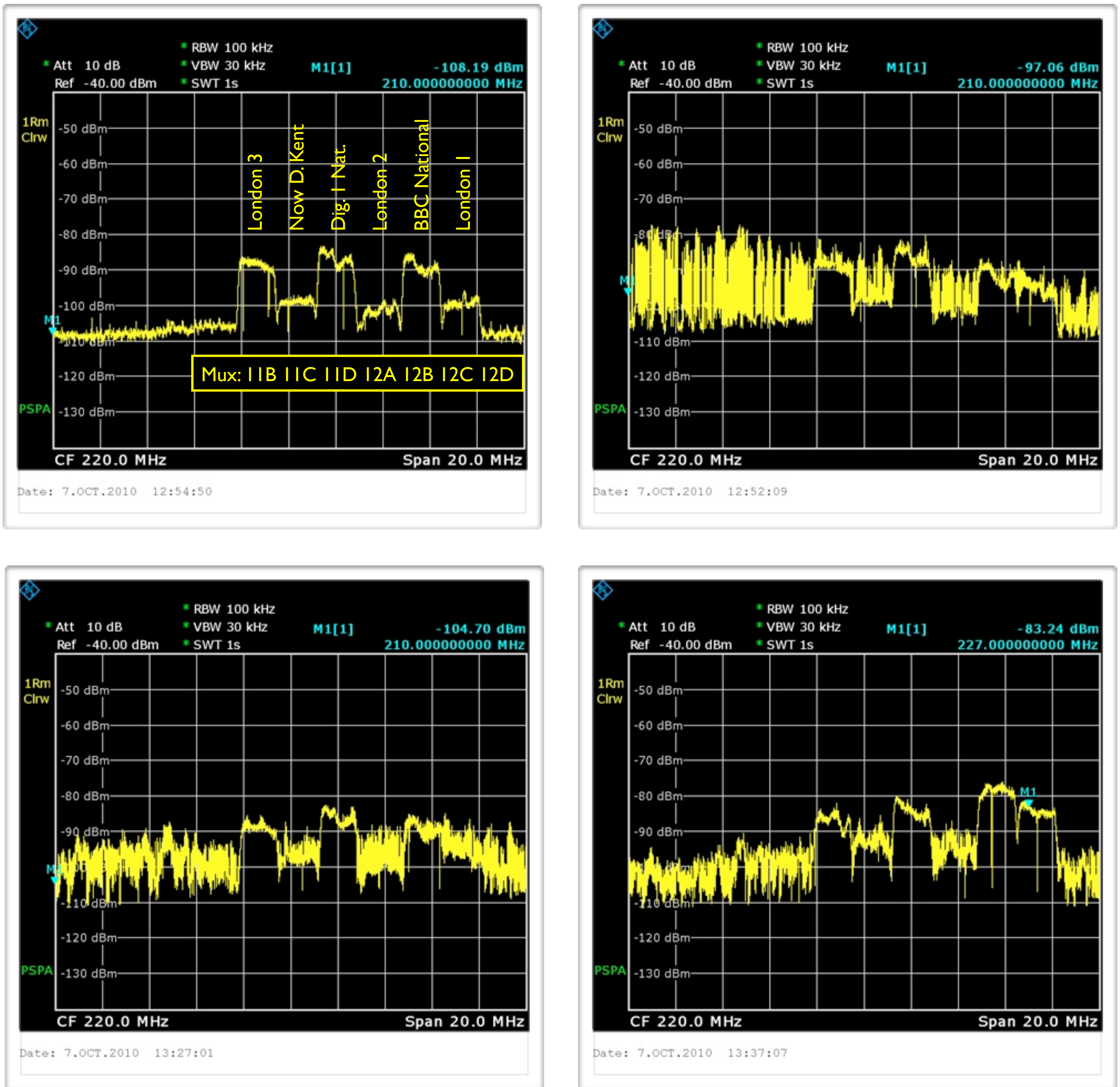

Figure 9: DAB-band spectra. Bottom right is measured in the sitting room, while the other three are all measured at the kitchen countertop location shown in Figs. 6 and 8. Top left is with PLT switched off, the others all show VHF PLT data transfer in progress. Top right is for a network from the dining area to the kitchen, while the two at the bottom are for a network from the sitting room to the adjacent master bedroom.

Fig. 9 shows that at the kitchen location the signals of the Greater London 3 and both national multiplexes are clearly distinguished, while the other local muxes are rather weaker. There is appreciable variation with indoor location of course, and the bottom-right plot measured in the sitting room

does show increased levels for all muxes, slightly favouring the higher-frequency ones and also showing that the London local muxes have gained slightly relative to the national ones[17].

Comparing top left and top right plots (with and without PLT interference) it is clear that the interference in this case exceeds the level of even the strongest muxes (e.g. the national ones) and it is no surprise that in this scenario their reception was not possible.

Bottom left shows the same kitchen reception location, but with a different PLT-network route; the SIR was slightly improved but reception of even the national networks was still significantly impaired. Bottom right shows reception in the sitting room with the same PLT network route; the SIR is slightly further improved and some reception was now possible for the stronger muxes.

6.4. External-antenna FM reception

Home B is equipped with external antennas for FM radio and UHF TV, each with separate distribution amplifiers in the loft so that several rooms can be fed with off-air signals. Experiments were performed using the FM-radio outlet in the study, while the PLT network was configured between the dining area and the adjacent corner of the sitting room (the only cross-ring PLT configuration that worked at VHF). The PLT network was by turns switched off or set to idle or carry traffic.

Stereo reception of broadcasts from national-network stations and also a local-radio station (BBC London 94.9 MHz) was auditioned and recorded using the high-quality equipment in regular use in this home. With PLT switched off the householder would classify the reception of national networks as “Excellent” and of BBC London as “Very good” [18].

A check was made whether switching on the CFL in the study (that greatly disturbed PLT operation at VHF, see §6.1) had any effect on reception; none was heard nor observed on recorded spectra. A further quick check turned on every CFL in the property (nearly all the lamps present), again without effect.

With the strongest signals from the BBC national networks, interference when PLT carried data traffic at VHF manifested as a clearly audible, slightly burbly background hiss; idling PLT had little effect. With the weaker signal from BBC London, idling PLT added a disturbing sound similar to ignition interference; once data traffic was carried the audible disturbance then comprised a combination of hiss, rasps and buzzes that rendered the programme virtually unintelligible.

Spectra are shown in Fig. 10 for reception of the national-network BBC Radio 4; traces for BBC London (not shown) were similar except that the wanted-signal lobe was about 20 dB weaker. The noise-floor degradation from the PLT interference is clear. Take care in inferring SNR and SIR from the Figure. The spectrum analyser used a bandwidth of 30 kHz, whereas the FM-receiver bandwidth will be appreciably greater, so the receiver’s RF SIR in the presence of PLT traffic will be worse than the right trace suggests. Interpretation of receiver SNR from the left trace is doubly affected by the bandwidth issue and the fact that the spectrum analyser has an attenuator in circuit[19]. However, ears and analyser are in agreement that PLT operation causes a degradation here!

[17] The London local multiplexes use a different set of transmitter locations from the national networks; the nearest from each (Crystal Palace and Reigate respectively) is loosely north of Home B (the direction in which the sitting-room patio doors face) but not with exactly the same bearing.

[18] The antenna installation is optimised for reception of national networks, the 3-element Yagi being aimed at the Wrotham transmitter. BBC London has a lower field strength and its transmitter is slightly off the main beam of the antenna, which together made its signal voltage delivered to the receiver input 20 dB lower than for the national networks.

[19] Nevertheless the transmissions from more remote transmitters are clearly visible, all on a 100 kHz grid.

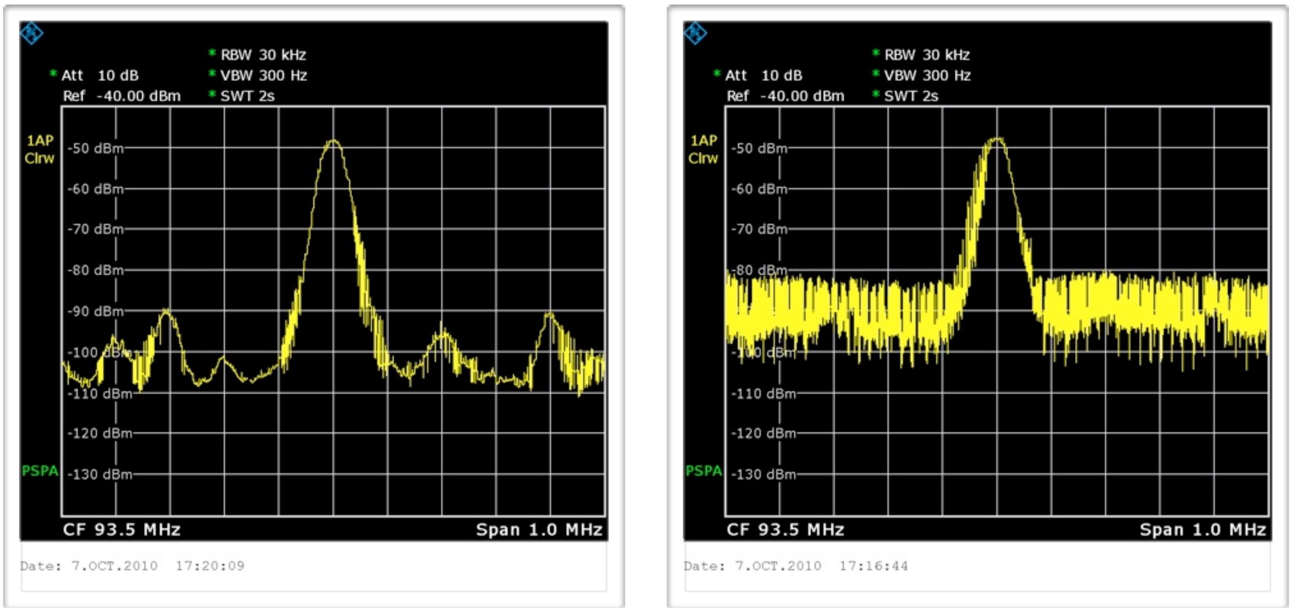

Figure 10: spectra of FM signal (BBC Radio 4 93.5MHz, Wrotham transmitter) received using the external antenna installation at home B, with PLT off (left) and carrying data traffic (right).

There was not time to determine the mechanism whereby the PLT contributed the interference to this installation. Any or all of the following are possible and would require more work to resolve:

- radiated PLT emissions (from the mains wiring it uses) are received by the external antenna
- conducted PLT emissions reaching the mains supply of the distribution amplifier are insufficiently rejected
- coupling between mains wiring and coaxial cable, before or after the distribution amplifier

Nevertheless, to the extent that home B is representative of homes with an external-antenna installation this would suggest that advice that any PLT interference problems can be solved by using an external antenna is misguided.

6.5. HF reception

No calibrated antennas for HF were available on this occasion, and VHF emissions were in any case the key subject of study; nevertheless a few brief observations were possible.

Using a portable ‘all-bands’ HF receiver it was clearly audible that the PLT network, when conveying data at VHF, still operated in an ‘idling mode’ at HF. As expected, the HF emissions became much stronger if data was actually being conveyed at HF because a PLT-network configuration was chosen which did not support VHF operation. Manually tuning through the spectrum, it appeared that the emission levels were reduced in the radio-amateur bands, consistent with the devices applying fixed notching similar to that previously encountered in HF PLT using the *HomePlug* standard.

Home B is equipped with an active LF/MF/HF loop antenna located in the garden, some 15 m from the building. The opportunity was therefore briefly taken to see if emissions from the PLT network affected this. Fig. 11 shows a sweep of the full range from 0 to 30 MHz; the rightmost end of the trace, corresponding to the highest frequencies, is of particular interest since propagation conditions make it unlikely that many true radio-service signals would be present in this particular range at this time. Additional ‘spikes’ became clearly visible when the PLT network was operating, showing that the noise floor of the antenna was indeed raised. Note that the spiky nature of the indicated PLT spectrum could well represent burstiness in time rather than true spectral lines; these two cases are indistinguishable without further investigation, e.g. by using ‘max-hold’ and ‘zero-span’ in turn.

Note also that no additional contribution is visible above 28 MHz, which is consistent with the hypothesis that these PLAs apply notching for radio-amateur bands such as 28-29.7 MHz.

There was no time for any more detailed observations at HF.

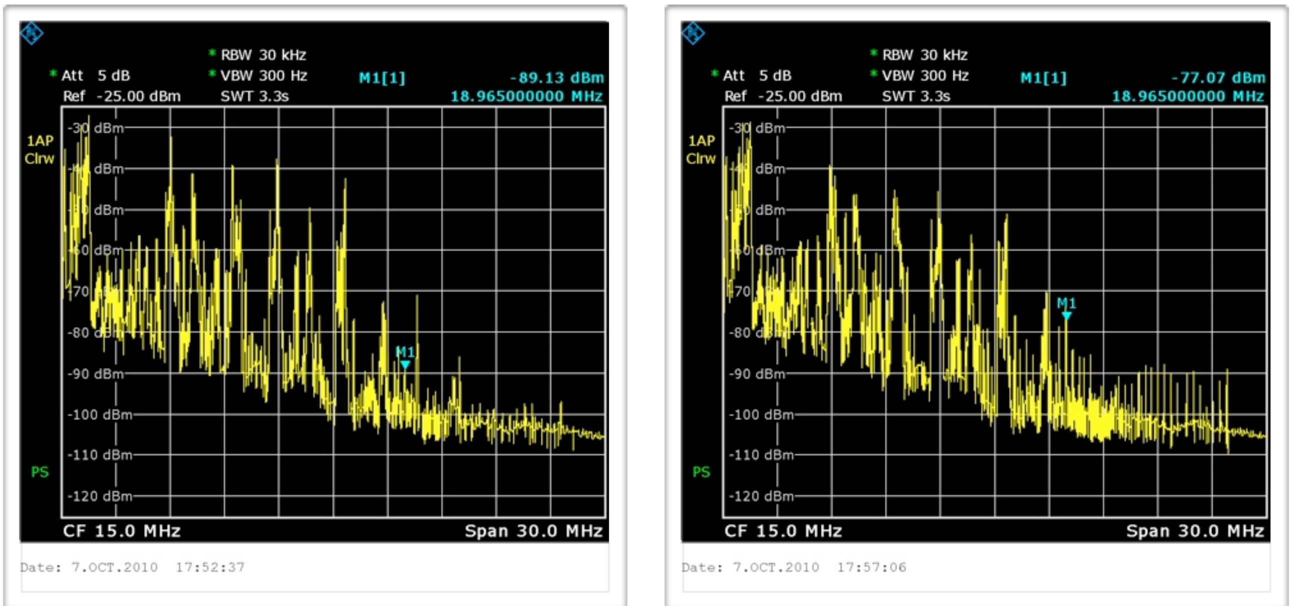

Figure 11: spectra from active LF/MF/HF antenna installed in the garden of Home B, with PLT off (left) and carrying data (right).

7. Associated prediction work

7.1. Motivation

To put the experiments into context we need some idea of how representative the reception conditions of Homes A & B are of the general listenership.

As a first step we asked BBC Distribution to provide, for various FM and DAB broadcast services and at both sites:

- *predictions* of the field strengths, as would normally be used in predicting whether an area is covered
- *measurements* of the field strengths outdoors, for comparison with the predictions and with the field strengths encountered indoors in the experiments

Unfortunately operational constraints meant this could only be undertaken *after* the experiments in Homes A and B were performed.

A further desirable step would be to be able to provide an analysis along the lines of “what percentage of homes, of those which are deemed to be covered, receive a field strength no greater than that enjoyed by Home X for a particular service?”. It could then be argued that (if they had a similar PLT system installed) at least that x % homes would suffer a disruption to reception similar to or worse than that encountered at Home X in the experiments. The converse also applies, so for those circumstances where the disruption encountered in the experiments was negligible, we might deduce that $(100 - x)\%$ of homes would similarly be free of disruption.

7.2. Results — FM

The results shown in Table 1 below relate to reception outdoors at a height of 10 m above ground level. The predictions are made for a 100 m by 100 m square in which the location falls, and give the predicted *median* field strength, it being usually supposed that the field strength within the square follows a log-normal distribution[20] with a standard deviation of 5.5 dB.

		Home A		Home B	
	Transmitter	Predicted	Measured	Predicted	Measured
BBC Radio 2	Crystal Palace	81	74.8	-	-
	Wrotham	61	66.2	72	64.3
BBC Radio 3	Crystal Palace	81	75.1	-	-
	Wrotham	61	66.1	72	67.2
BBC Radio 4	Crystal Palace	81	75.1	-	-
	Wrotham	61	65.6	72	68.6
BBC London	Crystal Palace	79	74.4	54	-

Table 1: field-strengths in dBμV/m of BBC FM Radio services, at 10 m above ground level at the locations of Homes A and B, according to predictions and outdoor measurements by BBC Distribution.

To relate these values to the indoor scenarios of the experiments we need to consider the effects of *height* (for ground-floor measurements at least) and *penetration loss*. A correction commonly applied, to convert a field strength at 10 m to 1.5 m, is 12 dB. So we should expect ground-floor indoor field strengths to be reduced by the order of 12 dB *plus* the penetration loss as the signal passes through walls or windows. We should also expect appreciable location variation within the room.

We can also compare the measured and predicted values to each other, and to those deemed to be necessary for coverage.

We see that the measured and predicted values outdoors typically differ by the order of the expected standard deviation within a prediction square (5.5 dB), with some smaller differences and one rather larger (7.7 dB, about 1.4 standard deviations). Considering the acknowledged difficulties in field-strength prediction, these results are entirely reasonable.

All the national services measured, at both locations, delivered field strengths comfortably sufficient for service to be deemed to be provided (see Appendix, §12.2). At Home B, the local service BBC London was predicted to be at the limiting value for stereophonic reception, 54 dBμV/m[21].

[20] The field strength (μV/m) is supposed to follow a log-normal distribution, so that the field strength when expressed in logarithmic measure (dBμV/m) follows a normal distribution. Therefore the standard deviation can be expressed in dB.

[21] Strictly this is the value applicable in 'Rural' areas according to the ITU-R, see §12.2. However, given that the need to provide stronger signals to city centres is already taken into account when choosing and planning the transmitter locations, it is not uncommon that the edge-of coverage falls in a rural area. In any event, home B is in an essentially rural location, while home A is in a low-density suburban area bordering some open space and so more nearly matches the 'Rural' case than it does the 'Urban' one, the ITU-R Rec. having no category in between these two.

7.3. Results — DAB

Predictions for the two national DAB multiplexes are shown in Table 2, where in this case the field strength is given for a height of 1.5 m outdoors.

Block	Multiplex	**Home A**	**Home B**
11D	Digital One (national)	74.6	75.8
12B	BBC National	72.3	73.6

Table 2: field-strengths in dBμV/m of national DAB Radio services, at 1.5 m above ground level outdoors at the locations of Homes A and B, according to predictions by BBC Distribution.

Since DAB uses SFNs, the coverage prediction software operates in a more complicated way than the simple numbers in the Table might suggest. The field strengths of all relevant transmitters in the network are first predicted individually; then the time of arrival of each signal is also considered so that allowance can be made for any self-interference that may be caused within the network by the contributions from the more distant transmitters. The values in the Table are simply the sum of wanted signal components; what really determines reception reliability is the effective signal-to-(noise-plus-interference) ratio. Both locations are predicted to have a substantial margin in these terms as well, and therefore are considered to be covered for 100% locations outdoors.

Concerning indoor reception, UK practice is to consider a location served for indoor DAB reception if the predicted field strength from a dominant single transmitter without interference is 69 dBμV/m at 10 m outdoors. A correction of 10 dB for the loss of field strength with height makes this equivalent to 59 dBμV/m at 1.5 m outdoors. On that basis, both homes A and B may be considered to be covered for indoor portable reception, with a good margin. This agrees well with the householders' experience, in the absence of PLT.

7.4. Simple prediction exercises for FM and DAB

It is desirable to infer from the results of the experiments of §6 what impact the widespread deployment of these PLAs would have on reception by the wider public. One simple exercise was tried following the observation that the PLT emissions could be considered to increase the 'noise floor' indoors, by 20 dB. The prediction model used by BBC Distribution incorporates a noise-floor value, so prediction runs were made in which (a) the noise floor was assigned its customary value for planning and (b) this noise-floor parameter was increased by 20 dB. The results are shown in Table 3.

	Normal assumptions	**Noise floor raised by 20 dB**
FM	97.8%	34.6%
DAB	93%	58%

Table 3: predicted national-network[22] coverage expressed as % homes for FM and DAB, with conventional assumptions, and with the noise floor raised by 20 dB above the conventionally assumed level.

It would be perhaps unwise to read any precision into these results, but they appear to suggest that if PLA devices like those tested were widely deployed the impact on broadcast-radio coverage would be appreciable.

[22] Specifically, for FM this result is for BBC Radio 2; closely similar results would be expected for Radios 3 and 4.

8. Discussion

8.1. The PLT devices

The experiments were performed using a single specific type of PLA obtained on the open market beforehand (and chosen to be of the same type that others had reported testing [1]).

First we may note that the performance of these PLAs in delivering their intended connectivity was quite variable. Indeed, in home B they singularly failed to deliver consistently any bit-rate advantage, as promised by their VHF operation[23], throughout the (relatively small) property, since in many situations they failed to communicate using VHF. This is in contrast to the complete coverage afforded there by WiFi. Other factors (plugging in the spectrum analyser, switching on a CFL) were also found to compromise their operation in Home B, and may also explain inconsistent PLT-network performance in Home A.

From the networking performance obtained, it would appear that VHF transmission between PLA devices over a mains circuit is likely to be quite unreliable. Other mains-powered devices, which may include EMC filters, are likely to decouple the VHF signals, greatly increasing the attenuation between the PLAs forming the network. To be fair, the devices we tested might also work perfectly acceptably in other locations; we merely report the difficulties we encountered at the two locations (in the UK, with UK wiring practice) that we were able to study.

We only had the pair of PLAs available, so we could not investigate networks having more than two nodes, nor could we investigate any possible mutual interference between PLT networks established in neighbouring properties.

Concerning the observed interference to radio reception, the key factor is the RF power injected into the mains, and its spectral range. The devices tested used a spectral range that overlapped both FM and DAB broadcasting bands and were observed to affect reception of both. It would be reasonable to suppose that other PLT devices also using these frequency ranges, and injecting similar-level signals onto the mains could also cause similar interference to radio reception. Of course, if other designs injected at different levels from the ones tested, then different degrees of interference should be expected.

8.2. Impact on FM reception in the experiments

The experiments in the screened room showed that the signal-to-interference ratio encountered by the FM receiver determined the impact that interference has on reception quality. When interfering emissions were present, the FM-radio reception quality could be restored by increasing the wanted-signal level in order to improve the SIR. Different wanted-signal levels would give different quality in the absence of PLT interference (i.e. RF SNR affects the audio SNR, as expected). However, once PLT emissions were present (presumably at similar levels throughout the experiment), the necessary dB increase in the wanted-signal level to restore similar quality of reception was roughly the same, whatever the initial wanted-signal level. In other words, the noise-plus-interference floor has been elevated.

With this in mind, the experimental results in homes A and B are not very surprising. Whether and how much particular PLT emissions affected reception depended on the strength of the wanted signal; those services with weaker field strengths were more markedly disturbed. Similarly, scenarios where the PLT emissions were greater caused a greater disturbance.

[23] They did however still offer connectivity at lower bit rates using HF. Users of these devices in other locations might well be using HF without realising it, since only close scrutiny of the transfer bit rates, or observation of the RF emissions, reveals whether HF or VHF is in use.

FM broadcasting was originally established before the existence of portable FM radios. The agreed planning standards therefore all concern fixed receivers with external rooftop antennas. Whether a home falls into a nominal coverage area of a particular FM service therefore relates to the outdoor field strength at 10 m above ground level. However, the everyday reality is that a large proportion of FM radio reception actually takes place using portable receivers indoors (or mobile in cars). This thesis is readily confirmed by examining how many homes have external FM antennas visibly installed — it is a very small proportion, much smaller than those having external UHF TV antennas.

There is therefore no *official* concept of coverage for portable FM receivers indoors, but they are nevertheless clearly very much in use. As previously noted, the wanted-FM-signal strength indoors will be reduced by two factors: one for the loss of reception height, the other for the penetration loss in passing through windows or exterior walls. The reason indoor portable reception remains possible despite this is a function of several things, largely related to the analogue nature of the signal:

- if the portable only has mono operation (or defaults to it with weak signals) then the necessary field strength is reduced substantially
- the direct relationship between RF and audio SNR means that a further drop in wanted signal strength may be acceptable: the audio SNR a listener will accept from a portable receiver in a relatively casual listening environment is somewhat less than would be demanded when listening intently to a fixed 'hi-fi' installation

These two factors mean that at least some form of portable indoor FM reception is normally possible in homes that are 'served' according to the 'official' external-antenna definition. There will also be appreciable field-strength variation with position within rooms, but those using portable receivers indoors will have sought and chosen the suitable locations[24] to use their receivers.

The experiments at homes A and B gave many examples where portable receivers, in indoor locations where they adequately received services in the absence of PLT operation, then suffered interference when the PLT network was set working. The degraded reception quality was clearly audible, while the PLT emissions and associated resulting RF SIR could be observed on the spectrum analyser fed by the measurement antenna placed close to the point of reception.

At home A, indoor reception of the Wrotham BBC national services was badly affected. These signals had an outdoor field strength at 10 m of 61 dBμV/m predicted, and about 66 dBμV/m measured (7 and 12 dB respectively above the nominal edge-of-coverage value of 54 dBμV/m), while the indoor field strength when the measurements with the PLT device were made was about 40 dBμV/m. (Note that this cannot be directly compared with the outdoor measurement, since it was performed on a different day, while the indoor field strength was itself seen to rise later in the day.) Indoor reception of Crystal Palace BBC national services was not badly affected

At home B, indoor reception of the Wrotham BBC national services was affected, less badly but still to a very disturbing extent. In this case these signals had an outdoor field strength at 10 m of 72 dBμV/m predicted, and about 64 to 69 dBμV/m measured (18 and 10 to 15 dB respectively above the nominal edge-of-coverage value of 54 dBμV/m), while the indoor field strength was about 50 dBμV/m (see Fig. 7). Meanwhile reception at home B of a different service, BBC London, is particularly interesting since this was predicted to have the outdoor edge-of-coverage field-strength value of 54 dBμV/m. Its reception indoors was, as expected, more greatly disrupted by PLT interference, although its indoor field strength at the point of reception measured only some 3 dB lower than the national networks[25].

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[24] Note that %locations within rooms is often discussed. However, there are practical features to remember. Excluding those receivers small enough to wear, a portable receiver has to be placed somewhere, on a shelf, mantelpiece, or some other item of furniture. The choice is thus restricted in practice, and in many cases to locations close to walls.

[25] See the earlier discussion at the end of §6.2 as to why this signal was as strong as this indoors.

Disturbance of indoor FM reception was thus encountered not only for services which could be deemed to be edge-of-coverage, but also for those with an appreciable margin from it outdoors (18 dB predicted, 15 dB measured). Only the Crystal Palace signals at home A (with outdoor margins of 27 dB predicted, 21 dB measured) were relatively unaffected.

A surprise in the tests was the impact on *external-antenna* reception at home B. Reception of the just-edge-of-coverage BBC London using it was essentially destroyed (i.e. as bad as the indoor reception!), while despite their predicted 18 dB margin even the national networks suffered an audible degradation, although this was less dramatic than the effect on their indoor reception.

8.3. Impact on DAB reception in the experiments

DAB, as a digital system, has a much more 'cliff-edge' behaviour than FM in response to both RF signal strength and RF SIR. Thus negligible PLT-interference effects on indoor DAB reception were observed at home A compared with very serious ones at home B.

The problems at home B are entirely explicable given spectra like those shown in Fig. 9: the RF SIR is visibly of the order of 0 dB — slightly better for some combinations of mux and location, and slightly worse for others. The reception varied correspondingly from mildly impaired to completely disrupted (i.e. the receiver lost lock altogether and muted).

Conditions at home A must have been better, since no obvious disturbance of DAB reception occurred. Unfortunately no further technical investigation into DAB was performed there, since (at the time) there did not appear to be any problem to investigate. Surprisingly the national DAB networks are predicted to be just over a dB weaker outdoors at home A than home B; however the expected variations in penetration loss (as well as in the prediction) could easily turn this the other way indoors in practice. The other possibility is that PLT emissions might have been slightly greater in home B; Figs. 5 & 7 could be read as suggesting that emissions *in the FM band* at least were perhaps a dB or two higher in home B. However, similar variation could also be expected with location in the room.

In any case, with DAB it all happens over a very small change in RF SIR, from no effect to complete loss of lock. Without PLT operating, home B appeared to have a comfortable margin for indoor reception (the national networks were reliable throughout the property, and in most locations this remained the case even if the antenna was not extended properly). With PLT operating, DAB reception was badly impaired almost everywhere.

Incidentally, it should be noted that the DAB receiver was operated using battery power to avoid prejudicing reception with a direct connection to the mains that was also carrying PLT. A brief experiment using its mains adaptor demonstrated greater vulnerability to PLT interference then occurred. This does raise the question of what proportion of portable DAB receivers are normally operated from the mains when used indoors.

8.4. Wider implications for reception

The reader (whether listener, broadcaster, regulator or PLT manufacturer) is no doubt looking for simple statements like "PLT will affect reception of FM/DAB in x% of homes" or "PLT will prevent reception of FM/DAB in y% of homes" or "there will be z million official complaints" — hoping for x, y and z to be very small, but fearing they might be large.

Unfortunately, it is far from easy to infer such precise statements from the results available. Effects on both FM and DAB reception were observed under conditions which were not edge-of-coverage. It follows that *if PLA devices like those measured were to be widely installed* then x and y would not be negligibly small, since you clearly don't have to be at the edge of the coverage area to be affected. That much is easy to deduce; so some appreciable number of those listeners who install PLAs will be affected.

To go further requires a planning exercise that may be difficult to perform, since it is not in the form of the usual questions asked of planning software. One attempt has already been reported in §7.4, in which the noise floor normally assumed in coverage predictions was increased by 20 dB, an amount that appeared to be representative from scrutiny of the various measurements in homes A and B. In effect this approach considers that the edge-of-coverage field strength has to be increased to compensate for the worsening of the noise-plus-interference floor. Of course, it is not possible to increase the transmitter power of existing networks, so the physical edge-of-coverage boundary must move to achieve the same result: how many homes are thereby excluded?

Perhaps as another approach we can try to determine something like "what % of homes are predicted to receive less than v dBμV/m, as a function of v?", for both FM and DAB[26]. We then have to decide what value of v to use as a criterion. It is made all the more uncertain by the fact that it is the *indoor* wanted-signal field strength that affects the receiver, and it is related to the outdoor value by the height and penetration loss factors, themselves subject to appreciable statistical variation.

This is particularly a problem for DAB, where the 'digital cliff' is perhaps only a very few dB wide between unaffected and loss of lock, a range considerably smaller than the uncertainty in (height plus penetration) loss. Nevertheless, a first suggestion of using v of about 74 dBμV/m at 1.5 m for DAB seems a good start; services at both homes A & B were predicted to lie just either side of this, yet their reception was affected at B and not at A. Provided the % of homes receiving less than v does not vary too dramatically as v varies then this might yield a useful rough estimate for y.

A similar exercise for FM could perhaps use v in the range around 70 dBμV/m outdoors at 10 m, but would require some interpretation, on the basis that:

- services predicted to be 81 dBμV/m outdoors at home A were essentially unaffected indoors
- services predicted to be 61 dBμV/m outdoors at home A were very badly affected indoors
- services predicted to be 72 dBμV/m outdoors at home B were significantly affected indoors[27]

8.5. Suggestions for further work

The discussion above suggests a further planning exercise to help to interpret the results already obtained. However, further experiments could be considered as well.

The experiments we report only looked at interference occurring within the home in which the PLT network was established: in effect, a self-inflicted wound[28]. Ideally the situation arising when receiving radio in premises neighbouring those having the PLT installation should be studied as well. It might be expected that adjacent flats or semi-detached or terraced homes present the case most likely to be problematic, but other cases should ideally be studied too since any coupling between adjacent properties could be by either radiation or conduction. It would also be interesting in these scenarios to install PLT networks in both premises and see if *they* suffer mutual interference!

The reported experiments used a network only having a *pair* of PLAs whereas a network could use *multiple* PLAs — would this scenario cause any worse effects?

The impact on reception in homes in city areas should perhaps also be studied directly, rather than relying on extrapolation from the suburban and rural homes A and B.

In view of the effect that the spectrum analyser had on the operation of the PLT network, it would be good to use a battery-powered spectrum analyser (and similarly for any other test equipment of a

[26] Note that field strength v refers to heights outdoors of 10 m and 1.5 m respectively for FM and DAB, as usual.

[27] And also with an external antenna, see §6.4.

[28] Albeit one that the typical consumer will not know they are risking, unless the information at the point of sale of PLAs is drastically changed.

non-domestic nature). If at all possible, outdoor field-strength measurements should be undertaken at the same time as the measurements indoors so they can more reasonably be compared.

9. Conclusions

Home-networking PLT devices called Power Line Adaptors (PLAs) communicate by injecting data signals onto the mains wiring. Previous studies on PLAs that use HF for communication have shown that the resulting unwanted emissions can disturb the reception of HF broadcasts. More recently PLAs have become available that promise greater data-carrying capacity by exploiting the VHF range. This raises the concern that they might interfere with reception of broadcast FM and DAB radio services.

This paper describes experiments on a particular pair of PLAs, in the laboratory and in two homes to try to establish their interference-causing potential. It was confirmed that they used frequencies in the VHF range, roughly from 50 to 300 MHz. They could also default to operation at HF, with a lower data rate, if the mains-path conditions at VHF were too 'difficult', although some VHF transmissions would nevertheless continue. Indeed, whichever of HF or VHF was used for data transmission, intermittent transmissions continued in the other, presumably for channel-sounding purposes. Intermittent transmissions also took place in both bands when no data was being actively transmitted, i.e. when the network was 'idling'.

Although PLT networking using VHF was shown to be possible in the two homes, it was not always readily established, especially in home B where many factors were found which could prevent it. The presence of other mains-powered devices as well as the communicating PLAs, particularly equipment with EMC filtering, was found to disrupt PLT operation at VHF. As a result, there were many combinations of rooms in home B which could not be interconnected using VHF PLT — in contrast to the universal coverage of the property already established using WiFi.

When VHF PLT networking was established and carrying data, the resulting emissions were found to increase the reception noise floor by some 20 dB. In many cases this was found to disturb FM or DAB reception indoors. Some disturbance to reception was also caused when the PLT network was idling, even if only using HF because VHF PLT data transmission did not work over a particular path. The precise impact on reception was found to depend on the RF signal-to-PLT-interference ratio.

Spectrum analyser plots of the received signals in homes A and B show that the operation of the PLAs elevated the apparent noise floor in VHF Band II by between 15 and 25 dB. A similar degradation was also apparent in VHF Band III where DAB broadcast networks are deployed. The impact on reception was found to depend on the reception margin of the victim radio service.

Home A suffered significant interference to portable indoor reception of national-network FM services from Wrotham, but not to reception of those from Crystal Palace which had greater signal strength (and hence greater margin). Note that home A would nevertheless be regarded as within the coverage area of both.

Home B also suffered interference to portable indoor reception of national FM networks from Wrotham (in this case the intended transmitter) — and very severe interference to reception of BBC London, for which home B is predicted to be just at the edge of the coverage area.

Rooftop reception of FM services in home B was also disrupted, particularly when the PLA devices were carrying significant traffic. The audible degradation was clearly noticeable on a ‘hi-fi’ receiver. Reception of the service predicted to be just at edge of coverage was greatly disturbed, while interference could also still be clearly heard when receiving the appreciably stronger national network service.

The tentative conclusion is that the number of homes which could suffer interference to indoor FM reception from VHF PLA devices could be quite significant, since interference was observed in both homes even though the received signal levels exceeded the minimum field strength expected at the edge of the coverage area. Homes enjoying signal levels that match or exceed that of the national networks from Crystal Palace at home A would probably not be affected. Having said that, the reception of weaker signals from distant transmitters would almost certainly be compromised by the operation of PLAs, and for indoor portable reception, the percentage of locations where satisfactory performance can be obtained will be reduced.

To quantify further the proportion of households that could be affected requires a detailed planning study, perhaps using prediction techniques in novel ways. Additional variability will be introduced by height loss, building penetration loss and location variation indoors. A preliminary estimate, based on a 20 dB increase in man-made noise levels, suggests a substantial reduction of the coverage area could result from widespread use of VHF PLA devices.

Similar reception problems were observed in the DAB band, with elevated noise floors clearly observed. Home A, which receives very strong DAB signals, suffered no obvious effects from PLT operation on indoor DAB reception, but the impact in home B (which normally has reliable DAB reception) was quite severe. The ‘digital cliff’ effect of DAB means that only a very small change in RF SIR is needed to go from unaffected reception to no reception at all. This could be directly confirmed in Home B, since different DAB multiplexes were received with a range of signal strengths and their performance in the presence of PLT emissions could be seen to range correspondingly. Homes A and B are predicted to receive similar national-network DAB field strengths; since the reception outcomes were so different it follows that variability in prediction, and in (height loss plus penetration loss) is greater than the few-dB width of the ‘digital cliff’.

A similar conclusion must be drawn for indoor DAB reception: if they had similar PLAs in operation, a non-negligible proportion of homes would be affected, but not all homes. Refinement of this crude result looks to be more difficult than for FM, since prediction software only tells us about outdoor field strength, and in this case the variability in (height loss plus penetration loss) has a more drastic impact, being more than enough to go from no PLT-interference effects to total loss of reception.

Nevertheless some pointers have been given how prediction tools could perhaps be used to try to refine the estimate of the percentage of homes potentially affected, assuming a widespread deployment of PLAs like those tested. Guidance has also been given regarding extra precautions to be taken in any future experimental work.

It must be noted that any conclusions drawn here specifically relate to PLAs like those tested; other PLAs also using VHF for data communication might well behave differently, although if they use similar injection levels in the FM and DAB bands their impact on reception might be expected to be generally similar.

10. References

1. NORDDEUTSCHER RUNDFUNK (NDR), ZWEITES DEUTSCHES FERNSEHEN (ZDF), 2010. Spectrum measurements on various types of power line adapters. Paper input to International Telecommunication Union (ITU-R) WP6A, 12 April 2010.

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3. Poole, R H M, 2006. Digital Radio Mondiale: a 'pseudo TEM-cell' for receiver testing. BBC Research White Paper WHP 140.

   Available from http://www.bbc.co.uk/rd/pubs/whp/whp140.shtml.

4. International Telecommunication Union, 1998. Planning standards for terrestrial FM sound broadcasting at VHF. Recommendation ITU-R BS.412-9.

Readers interested in past work by BBC R&D on this topic are also directed to the series of White Papers on the subject available at http://www.bbc.co.uk/rd/pubs/whp/index.shtml. Relevant White Papers include nos. 004, 012, 013, 055, 063, 067, 099, 114, 116 and 151.

11. Glossary

BER	Bit-Error Ratio
CFL	Compact Fluorescent Lamp
COFDM	Coded Orthogonal Frequency-Division Multiplex
DAB	Digital Audio Broadcasting
DFT	Discrete Fourier Transform
DRM	Digital Radio Mondiale
*x*DSL	generic Digital Subscriber Line (embracing ADSL, SDSL, VDSL etc)
EBU	European Broadcasting Union
EMC	ElectroMagnetic Compatibility
FFT	Fast Fourier Transform
FM	Frequency Modulation (used for radio broadcasting in VHF Band II (87.5-108 MHz)
FTP	File Transfer Protocol
ITU-R	Radiocommunication sector of the International Telecommunication Union
OFDM	Orthogonal Frequency-Division Multiplex
PLA	Power Line Adaptor
PLT	Power Line Transmission
RCD	Residual Current Device
SFN	Single Frequency Network
SIR	Signal-to-Interference Ratio
SNR	Signal-to-Noise Ratio
UDP	User Datagram Protocol

12. Appendix: further details

12.1. Measurement antenna calibration

The measurement antenna comprised a bicone element mounted in a balun. The necessary calibration curve (derived from that provided by the manufacturer) for converting measurements in dBm to field strength in dBμV/m is shown in Fig. A1.

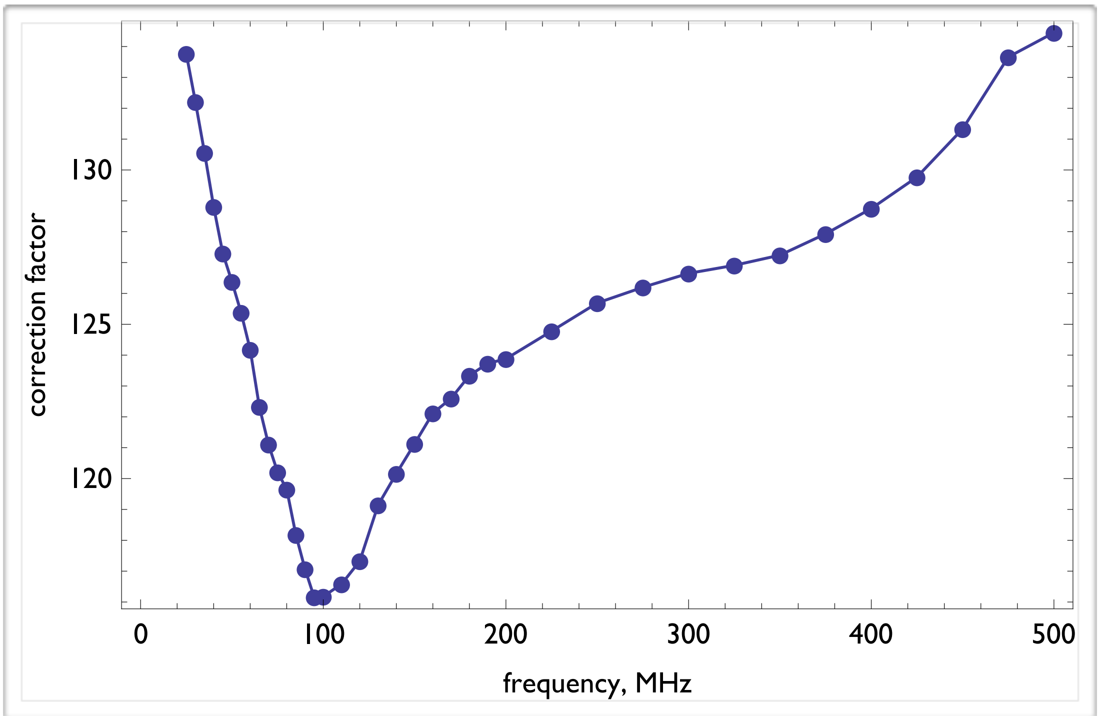

Figure A1: calibration curve for the measurement antenna. The 'correction factor' shown should be added to measurements in dBm to get the field strength in dBμV/m

Representative example values of the correction factor for FM and DAB respectively are +117.07 at 90 MHz and +124.78 at 225 MHz. Note that for measurements of DAB a further correction for bandwidth is needed if (as is usual) measurements are made using a spectrum-analyser bandwidth which is less than the 1.5 MHz bandwidth of the DAB signal. E.g. if the measurement bandwidth is 100 kHz, the additional bandwidth-correction factor is +11.76 dB.

12.2. Coverage criteria for FM radio broadcasting

The following values are taken from ITU-R Recommendation BS.412-9 [4]. It says "In the presence of interference from industrial and domestic equipment […] a satisfactory service requires a median field strength (measured at 10 m above ground level) not lower than those shown in" Table A 1 below.

	Services	
Areas	Monophonic, dBμV/m	Stereophonic, dBμV/m
Rural	48	54
Urban	60	70
Large cities	70	74

Table A 1: recommended field strengths taken from Table 1 of Ref. [4]

The Recommendation goes on to add "In the absence of interference from industrial and domestic equipment, the field strength values (measured at 10 m above ground level) given in" Table A 2 below "can be considered to give an acceptable monophonic or stereophonic service respectively. These field strength values apply when an outdoor antenna is used for monophonic reception, or a directional antenna with appreciable gain for stereophonic reception […]".

Services	
Monophonic, dBμV/m	Stereophonic, dBμV/m
34	48

Table A 2: recommended field strengths taken from Table 2 of Ref. [4], applicable in the absence of interference from industrial and domestic equipment