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The effects of power-line telecommunications on broadcast reception: brief trial in Crieff

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Abstract

A brief site visit to Crieff is reported; it took place, at the invitation of Scottish and Southern Electricity, to examine some Power Line Telecommunications (PLT) installations (used to connect domestic and commercial premises to the internet). Two competing systems are described, examples of which were seen, and the scope for interference to HF broadcasting assessed. The circumstances of the trial limited the scale of scientific experimentation, nevertheless some clear conclusions are drawn. Both systems caused interference to HF reception, although one system appeared to have made some attempts to limit this. Some suggestions are made how co-existence between PLT and home radio reception might be investigated; such investigation would be essential before any wide-scale implementation of PLT. Audio recordings demonstrating the interference are available on the BBC R&D web site.

Key words: EMC PLC

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Authorisation of the Chief Scientist is required for publication.

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The effects of power-line telecommunications on broadcast reception: brief trial in Crieff

Jonathan Stott and John Salter

1 Introduction

Data communications using mains wiring (often called Power Line (Tele)communications, PLT or PLC) can be used for *access* (connecting the home to the outside), or for *home networking*, or indeed both. The capacity is described as 'broadband'. This means of the order of 10 Mbit/s for in-home networking, and 1 to 10 Mbit/s for access. (Dramatically higher rates than these have occasionally been claimed but are not believed to have been verified). These communication systems have the potential to be very useful, but there is a potential snag: sending data over wiring not specifically designed to convey RF signals means there is a likelihood of emission from the wiring occurring with the potential to cause interference to radio systems.

Despite being involved for some considerable time in discussions of how to regulate such emissions from PLT systems (together with related *x*DSL systems using telephone wiring), BBC R&D had never been granted an opportunity to examine a PLT system at close quarters. An invitation kindly made by Scottish & Southern Electricity (S&SE) for us to visit some of their access-PLT pilot installations in Crieff was therefore keenly accepted.

The opportunity offered to us was to visit a total of four PLT-equipped premises in Crieff over a two-day period. One was the S&SE shop; the other three were private households. Although both S&SE and the householders were very co-operative, the range and extent of tests was somewhat limited by time, the weather and the fact that the PLT system was in service to paying customers and therefore could not be turned off to provide a datum. The visits took place on 12 & 13 November 2002.

Excerpts from audio recordings made during the visits are available to accompany this White Paper [1].

2 The PLT systems encountered

2.1 Systems deployed in Crieff

The access-PLT installations in Crieff were to some degree for S&SE to gain experience themselves. They were not therefore all of one type. Two very different systems were therefore in use, made by Main.Net and Ascom. The nature of access PLT is that all electricity customers connected to one power sub-station[1] are, in principle, potentially in communication with a central modem which has connection to an Internet backbone. Commonly this central modem would be situated at the sub-station (as it is somewhere under the control of the electricity supplier and is also likely to be 'in the middle' of the area it serves). It follows that all installations connected to one sub-station must be of the same compatible type, so that each of the sub-station areas in Crieff

[1] For the benefit of international readers, it must be explained that a sub-station contains a transformer that delivers the 'Low Voltage' electricity supply to a number of premises. When these are domestic premises, the number served by one sub-station in the UK is of the order of one hundred homes (more in towns, fewer in rural areas). The distribution from the sub-station is three-phase but individual homes are served with only one phase at nominally 230 V, 50 Hz.

which had been equipped for PLT either used Main.Net throughout or Ascom throughout. Premises A and B used Main.Net while premises C and D used Ascom. It is understood that premises D was the sole customer served with PLT from its sub-station.

2.2 Main.Net system

The description that follows is our best understanding based on discussions with S&SE and our observations. Definitive data is elusive — at the time of writing, the Main.Net web site [2] contained no description of the working of their system. A presentation given to the authors by a Main.Net representative at the S&SE Headquarters in April 2002 was very similarly unenlightening.

The system was nevertheless described as "spread spectrum". It therefore communicates using a wide, if unspecified, chunk of HF spectrum, which is used by all terminals. It appears that the "access" signal itself is expected to travel through the electricity meter to modems connected to the indoor wiring, without frequency translation (in contrast to the Ascom system, see below).

The Main.Net system does make use of repeaters to extend range (while allegedly thereby reducing necessary power levels and consequent emissions). A repeater was installed at nearby premises to premises A. Since all terminals use the same spectrum they must in principle be separated using either time- or code-division multiplexing. Whichever may be the case, it is clear that the use of repeaters that hand on information in the same frequency band must reduce the total system capacity.

We now understand that the system uses frequency-hopping spread spectrum. This has been made particularly clear by measurements published by the Austrian Radio Amateurs [3].

2.3 Ascom system

The description that follows is our best understanding based on discussions with S&SE, our observations and a paper found on Ascom's website [4].

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 19.8, 22.4 and 24.6 MHz (according to e.g. Fig. 5 of the Ascom paper [4], apparently dated 15 August 2001) but described by S&SE as 19.8, 22.8 and 25.2 MHz. The Ascom paper also includes 22.8 MHz amongst the frequencies for which attenuation is plotted in its Fig. 11.

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 it 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[2]. So it appears that the designers have made a commendable effort in their choice (whether to protect broadcast reception from emissions or to avoid broadcast-signal ingress may be speculated). However, it appears that each band carries data using a simple single-

[2] 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 S&SE 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.

There is another potential snag of such an avoidance strategy: spectrum allocations under the ITU-R Radio Regulations evolve over time, for example the 7 MHz amateur and broadcasting bands are in the process of being realigned.

carrier modulation scheme, so that the intrinsic roll-off is shallow and is supplemented (if at all) by relatively gentle filtering. So, sadly, some 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 C & D, 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. 1, which depicts the outdoor meter cupboard at premises C. 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 (as is acknowledged on p 12 of [4]).

Fig. 1. The Ascom Outdoor Access Point, installed in an outdoor meter cupboard at Premises C. 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 Premises D there was an electrically similar arrangement, but in this case the meter and OAP were housed indoors.

The system uses time-division multiplexing on each carrier (see §3.4.3). The frame repetition rate is about 100 Hz.

3 The experiments

3.1 General procedure

The main items of equipment we took with us were (see details in the Appendix §9.1):

- calibrated loop antenna
- current clamp and preamplifier
- measuring receiver
- spectrum analyser
- consumer portable radio
- cassette recorder

The portable radio served as the ultimate demonstration of whether disturbance was caused to domestic reception of broadcasting. In conjunction with the cassette recorder, recordings were taken of various reception conditions, both radio and recorder being battery powered to minimise the risk of unintended disturbance by mains-borne interference[3]. The entire contents of the recorded tape was subsequently transferred into a computer-based editing package and saved. The separate items were then identified, extracted and saved as separate .wav files. Finally a set of excerpts of more convenient length (each roughly 10 seconds in length) was produced. These excerpts are available from the BBC R&D web site [1]. The recordings (items 1 to 31) are all listed in the Appendix §9.4.

The loop antenna served three purposes:

- In conjunction with the measuring receiver, to measure the field strength of wanted broadcast signals. The measured field strength could then be compared with the ITU-R minimum protected median field strength, which is 40 dBμV/m in the HF band [5]. Signals whose median strength is at least equal to this value are entitled to be protected (within their service area) from interference from other radio services. It appears reasonable to use this also as a criterion in relation to interference from systems such as PLT.
- In conjunction with the measuring receiver, to measure the field strength of any PLT emissions. Note that the magnetic field is measured, but for convenience the results are expressed as the *equivalent* electric field strength $E_{equiv} = Z_0 H$, where Z_0 is the so-called impedance of free space, having the value $120/\pi \approx 377\Omega$. The true electric field of the emissions (which determines the impact on a receiver with a whip antenna) may not have the same value[4] when close to the source.
- In conjunction with the spectrum analyser[5], to examine the spectrum (or, exceptionally, the variation with time) of any emissions.

The current clamp enabled the common-mode current on accessible mains wiring to be examined. It may be expected that it is these common-mode currents that give rise to the emissions detected by a radio receiver. The advantage of the current clamp is that the proportion of the detected signal that corresponds to the PLT system is increased compared with the general background of radio signals. The PLT-signal characteristics are thereby more readily determined.

[3] Of course, many listeners use mains-powered radios, and it may be conjectured that these will be more prone to PLT interference. This should perhaps be investigated.

[4] In contrast, the measurements of E_{equiv} of the wanted broadcast signals may be assumed to correlate well with the true electric field, as in this case the reception takes place in the far field.

[5] Note that a spectrum analyser does not perform complex modulation analysis.

3.2 Premises A (Main.Net system)

3.2.1 General

Premises A took the form of an end-terrace house, separated by a narrow driveway from another terrace — where it is understood a repeater was installed. Measurements were made both outdoors, in a yard overlooking the drive (and the other terrace), and indoors, in the downstairs room which was located at the front, on the end-terrace side of the house. Recordings were made of reception: indoors, in the hallway of premises A; indoors, in the hallway of the house adjoining premises A in the same terrace; and outdoors on the pavement along the street leading to the electricity sub-station. It was not possible to turn off the PLT system, but the indoor modem could be turned off or, by operation of the computer connected to the indoor modem, this modem could be made to be either busy (transferring large files) or relatively quiescent.

3.2.2 Outdoor experiments, in the yard

Fig. 2. First experiments in the yard of premises A. The spectrum analyser and pre-amp for the current clamp can be seen, together with the domestic portable radio (only being used as a pointer here!).

At the far end of the yard was an outhouse that was being converted/refurbished. We made measurements on a mains extension lead that was being used by the householder to supply power for the work (there being no fixed mains power circuit). The equipment was set-up in one corner of the yard, Fig. 2, and a current clamp eagerly applied to the extension lead to get our first assessment of the power line spectrum with the house modem quiescent. The output from the current clamp was amplified (26 dB) before being applied to the spectrum analyser. A 'busy' spectrum was observed and the first problem was to try and identify 'what was what' from the wealth of signals present. Some continuous signals could be identified as broadcast station ingress, and confirmation was achieved with the portable receiver. Other signals appeared to be noise-like (continuous), whilst others appeared to have significant time and frequency dependencies. The spectrum centred on 5955 kHz (a broadcast station) was examined whilst the house modem was made busy. A significant increase in current (roughly 25 dB average) was observed with the modem powered, both 'before' and 'after' conditions being shown in Fig. 3.

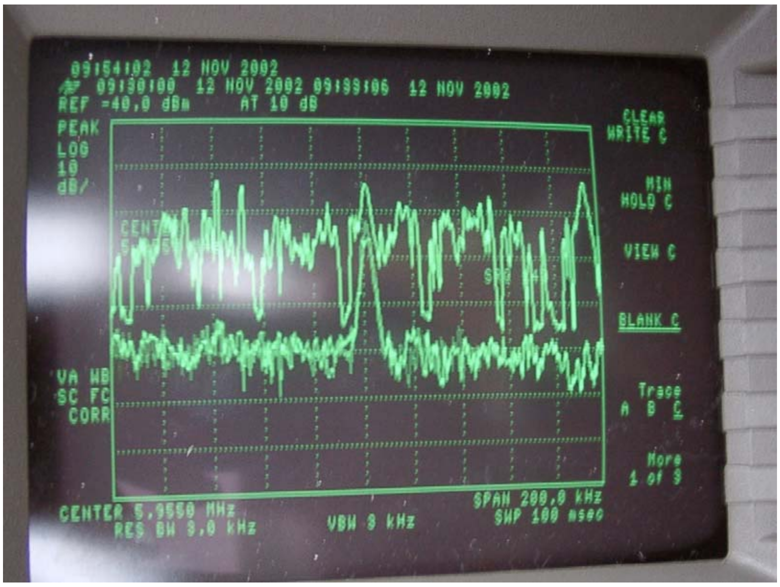


Fig. 3. Spectrum observed using the current clamp around the extension lead in the yard of Premises A. The two traces correspond to the PLT modem in Premises A being switched on and off, showing a difference of 20 to 30 dB.

The question now was — does this current, and presumably current in other nearby mains conductors, produce an interfering field?

The Wellbrook loop was used to measure field strength. First the loop was positioned for optimal coupling to the mains cable that was previously clamped, see Fig. 4. The difference in field strength, for the modem quiescent/busy, was measured as roughly 10 dB, see Fig. 5. It was concluded that some other interference source was lifting the measurement noise floor, since a difference of roughly 25 dB had been observed using the current clamp, and the apparent floor with the loop was higher than the known noise floor of the loop itself.

Fig 4. Adjusting the loop position for maximum coupling to the extension cable (on the ground), in the yard of Premises A.

Fig. 5. Spectra obtaining using loop antenna, for comparison with the current-clamp measurement of Fig. 3. The noise floor was higher than expected, but there is still a clear distinction between modem on and off conditions.

(We apologise for the poor quality of this picture, which was taken with a hand-held camera. This was our back-up recording system, see footnote 9 on page 12).

There now followed a secondary investigation in order to track down the source of this additional interference. With different loop orientations (for direction finding) it was concluded that the lamp-post outside the house next door (not adjoining, and the other side of the driveway) was the probable source of this additional interference — maybe because of a fault. However, before getting too distracted from our PLT measurements we measured the field strength of this interference, with the loop positioned 3.2 m from the lamp-post and 2 m from the wall of the next door house, see Table 1 and Fig. 6.

Frequency	5820	kHz
Bandwidth[6]	10	kHz
Average	33.7	dBμV/m
Peak	48.2	dBμV/m
CISPR	37.7	dBμV/m

Table 1. Measured field strength of unidentified emissions near the lamp-post at Premises A. (“Average”, “Peak” and “CISPR[7]” refer to the detector selected on the measurement receiver)

Of course, although this interference is not related to PLT, it serves to highlight some of the measurement difficulties encountered when venturing out into the real world. This was only the first of many spurious sources of confusion!

[6] The bandwidth of standard receivers used for CISPR noise measurements is variously described as 9 or 10 kHz. Since the specified passband shape is far from ‘brick-wall’, it follows that the –3 dB bandwidth and the noise bandwidth of the receiver filter cannot be the same, which may explain this apparent discrepancy. Certainly, inspection of the manual of the measurement receiver that we used shows that the filter selected at the “10 kHz” position of the manual control, and the filter used in “CISPR” (i.e. quasi-peak) mode are one and the same!

[7] The “CISPR” detector has a quasi-peak characteristic defined by CISPR, the international body that sets standards for interference measurement.

Fig. 6. The loop positioned on its tripod in order to measure emissions from the lamp-post (which is not itself visible in this view). The view is from the yard of premises A, with the house itself on the right. The house on the left is the start of the adjoining terrace on the other side of the access drive.

3.2.3 Indoor experiments

The equipment was moved into the house to do indoor measurements. The current clamp was used as before on the extension lead supplying our equipment. Significant interference was observed as a regular 46 kHz 'comb' over the range 1.5 to 2.75 MHz and a regular 120 kHz 'comb' over the range 3.5 to 9.5 MHz. The latter 'comb' was some 20 dB greater in strength, with a maximum value of 6 dBμA at 5.15 MHz. Again, spurious sources of interference were suspected and by de-powering various items within the house the 120 kHz 'comb' was traced to a Sky set-top box and the 46 kHz 'comb' was traced to a switch-mode power supply unit used upstairs by the householder.

With these indoor spurious interference sources removed, the current clamp was used to observe changes in mains wiring current for different modem states. Peak modem current was measured at 16 dBμA (10 kHz bandwidth) which was about 20 dB greater than the peak currents with the modem off. Again, the real question is whether these currents produce an interfering field. Field-strength measurements of ambient noise were made at 5820 kHz with the loop and measuring receiver in the downstairs bedroom (on the driveway side of the house), see Table 2. There was still some concern about the external noise from the lamp-post so the loop was orientated to minimise this.

Modem state	**Peak FS dBμV/m**	**Ave. FS dBμV/m**	**CISPR dBμV/m**
Busy	64 ± 2	29.7	56 (steady)
Quiescent	64 ± 2	25.2	31 (46 pk)

Table 2. Measured field strength (in a 10 kHz bandwidth) of PLT emissions indoors at Premises A.

These results need some explanation. The Main.Net modem is frequency-hopping, so it occupies each frequency slot that it affects on an intermittent basis. When the modem is busy, each slot is occupied for a high proportion of the time; when the moment is quiescent, each slot is occupied only occasionally. Thus the peak field strength is the same, whether the modem is busy or quiescent. The 'CISPR' detector is 'quasi-peak' in operation: it almost registers peaks, but with attack and decay time constants. Thus with very short pulses it underestimates the true peak, and when the pulses are spaced out (as when the modem is quiescent) the meter kicks up as each pulse appears and decays between them, so the 'low' reading can depend on the pulse spacing. Note that the usual rules of thumb relating average, CISPR and peak readings for broadband noise sources do not apply to the signal from this PLT modem.

The output from the loop antenna was fed to the spectrum analyser (100 kHz bandwidth) in order to identify broadcast signals and the effect of the modem peak interference. Fig. 7 shows the averaged signal (lower trace) and the peak-hold signal (upper trace) over the frequency span 3.5 to 13.5 MHz. This analyser trace records the analyser input in dBm; to convert to field strength in dBμV/m roughly 113 should be added to the values in dBm (see Appendix §9.2). Note the broadcast signals in the 9 and 12 MHz bands and the peak-hold trace at a substantially higher level. It seems clear that the PLT signal occupies most of this band, as is revealed by the peak trace which gradually built up a template of all the spectrum over which the PLT signal hops.

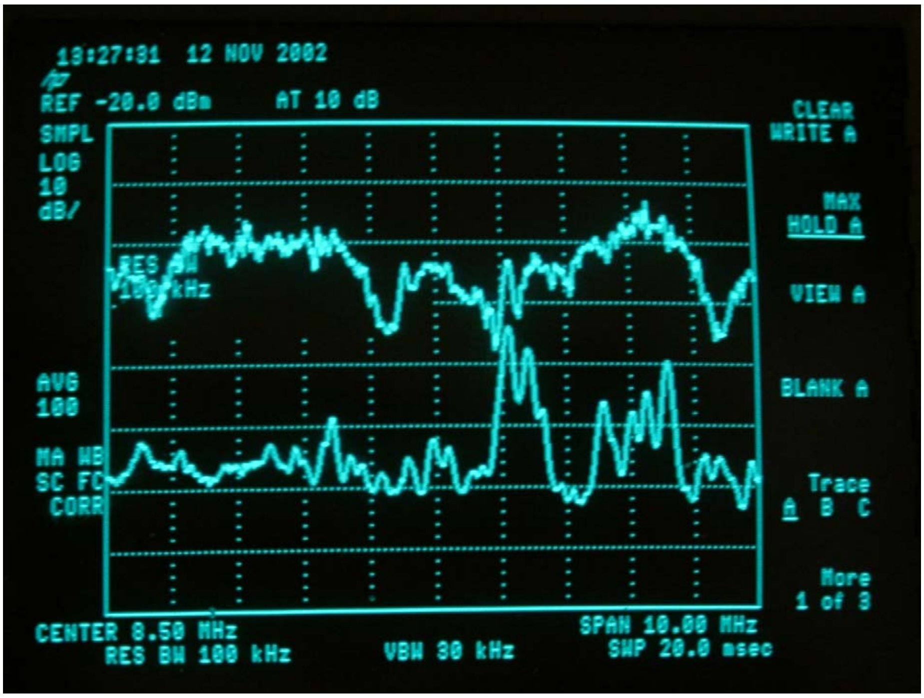


Fig. 7. Spectrum recorded using the loop antenna indoors at Premises A. The upper trace is peak-hold, while the lower is averaged. The upper trace shows the PLT signal occupying most of the spectrum (span 3.5 to 13.5 MHz), while signals in the 9 and 12 MHz broadcasting bands can be discerned in the lower trace.

Recordings were then made of a selection of broadcasts (items 1-10, tabulated in Appendix 9.4), using the portable receiver (with its whip antenna) and the cassette recorder. Broadcasts were found whose field strength (as determined using the measurement receiver and loop) ranged from extremely strong down to one representative of the ITU-R minimum protected field strength. A broadcast in the 6 MHz band gave at best hissy reception despite being measured as of reasonable strength – this was probably another manifestation of the noise source associated with the nearby lamp-post. Reception in the 9 and 12 MHz bands did not suffer this problem, but was indeed affected by the PLT modem. PLT interference was audible even on the very strong broadcast signal (67 dBμV/m, i.e. 27 dB stronger than the ITU-R minimum protected field strength); compare items 1 and 2. Other broadcasts were more badly affected (items 3 & 6) while the signal representative of the ITU-R minimum protected field strength (item 10) was seriously impaired. What can also be gleaned from the recordings is the regular occurrence of very short clicks when the modem was quiescent. This is brought out in Fig. 8 which shows the recorded audio waveform.

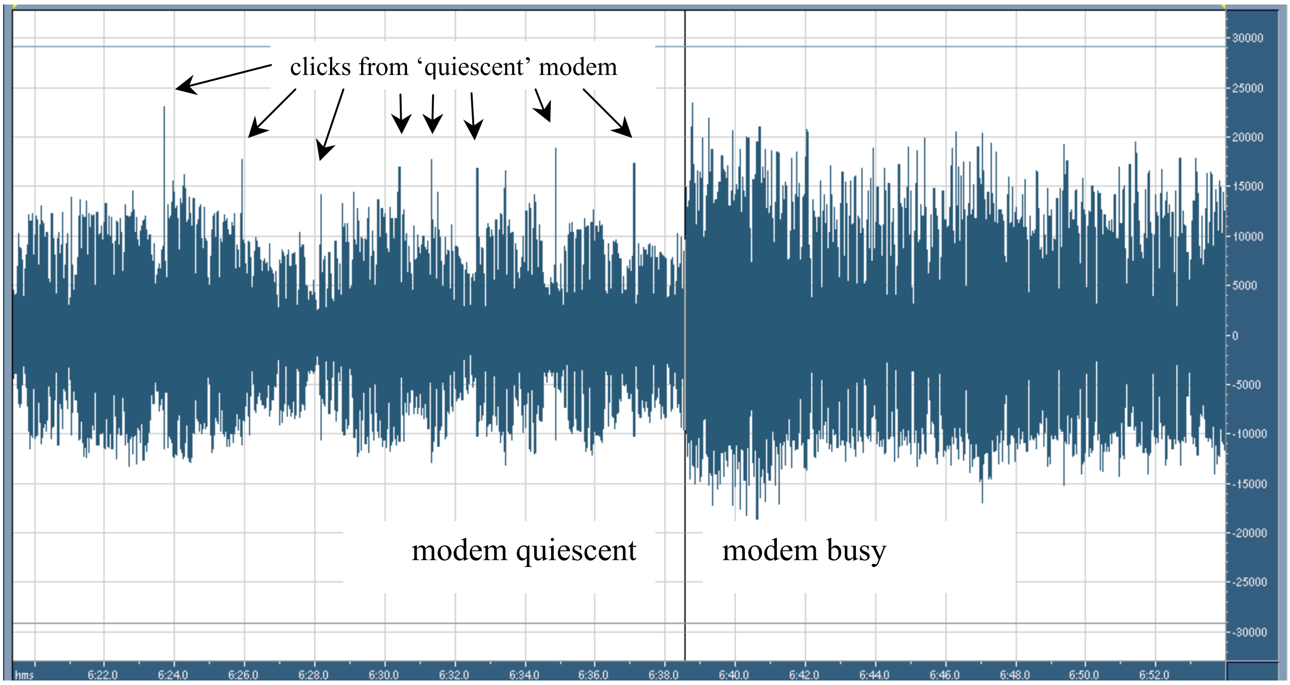


Fig 8. The recorded audio waveform at the boundary between items 9 and 10. This shows how the audio is 'submerged' under PLT interference as the modem becomes busy, and also shows that the 'quiescent' Main.Net modem introduces visible (and audible) regular clicks.

3.2.4 Reception in neighbour's house

The householder of premises A introduced us to his neighbour in the adjoining house (in the same terrace); this neighbour kindly permitted us to make recordings (items 11 to 13) in the hallway of his house, using the portable receiver and cassette recorder. Items 12 and 13 are of a station whose field strength (measured within premises A using the loop antenna and measurement receiver) slightly exceeded the ITU-R minimum protected field strength. The modem in premises A was first busy, item 12, then quiescent, item 13. Reception was significantly impaired when the modem was busy.

3.2.5 Reception in the street

Recordings of the same broadcast station (items 14 to 19) were then made at various locations in the street between premises A and the sub-station serving it, where the PLT modem giving access to the internet for the whole area was situated. See Fig. 9.

The degree of interference to reception varied somewhat with location, between "annoying" and a level sufficient to make the broadcast completely unintelligible. The latter was certainly the case just beyond the nearby premises where a repeater was known to be situated (item 15) but some other locations were almost as bad, although the reason why these were worse than others was not always immediately apparent. Some correlation was noted with the underground run of the main distributor cable. Curiously, the location near to the sub-station was not the worst, although badly affected.

Fig. 9. Making recordings of HF broadcast reception in the street between Premises A and the sub-station serving it. The portable receiver is held in the experimenter's left hand, with its whip antenna extended vertically, while the recorder is operated with the right hand.

3.3 Premises B (Main.Net system)

Premises B were in fact a retail shop operated by S&SE as "Scottish Hydro". As it was of modest size, and quite naturally maximising its use of this for retail purposes, there was no real physical scope for any 'scientific' experiments. We came there in the mid-afternoon, so time was limited as well.

We took some recordings using the portable SW broadcast receiver and cassette recorder, both outside the shop (item 20) and inside it (items 21-23). We found that the extensive use of low-voltage halogen lights for shop lighting caused significant interference to radio reception, but we were able to turn off some lighting for brief periods during which our recordings were made.

Items 22 and 23 show clearly that reception of an apparently strong[8] broadcast signal was badly impaired when the PLT modem was busy. The receiver was situated in the middle of the shop when this recording was made.

As it happened, our hotel was more or less opposite the shop, on the other side of a narrow road. Somewhat after leaving the shop we were able to record radio reception in a hotel bedroom (item 24), of the same station and frequency as items 22 & 23. In this case no interference from PLT or anything else was apparent, despite no special precautions being taken, but the signal propagation was by now subject to more fading. We do not know whether the modem and lighting in the shop had been switched off by then.

[8] The field strength of the wanted broadcast signal is unknown in this case, since it was not feasible to deploy the loop and measurement receiver, but reception of the signal when the modem was quiescent was of a quality suggesting a strong signal.

3.4 Premises C (Ascom system)

3.4.1 General

The outdoor access point for these premises (a detached house) was installed in the exterior meter cupboard (see Fig. 1) on one corner of the house which was also the point of entry for the electricity supply. The room where the indoor modem and computer were installed was nearby. Our measurements were made at the *opposite* corner of the house, either indoors in the dining room or immediately outdoors.

3.4.2 Outdoor experiments

Fig. 10. Setting up the loop antenna to measure emissions outside Premises C. It soon started to rain!

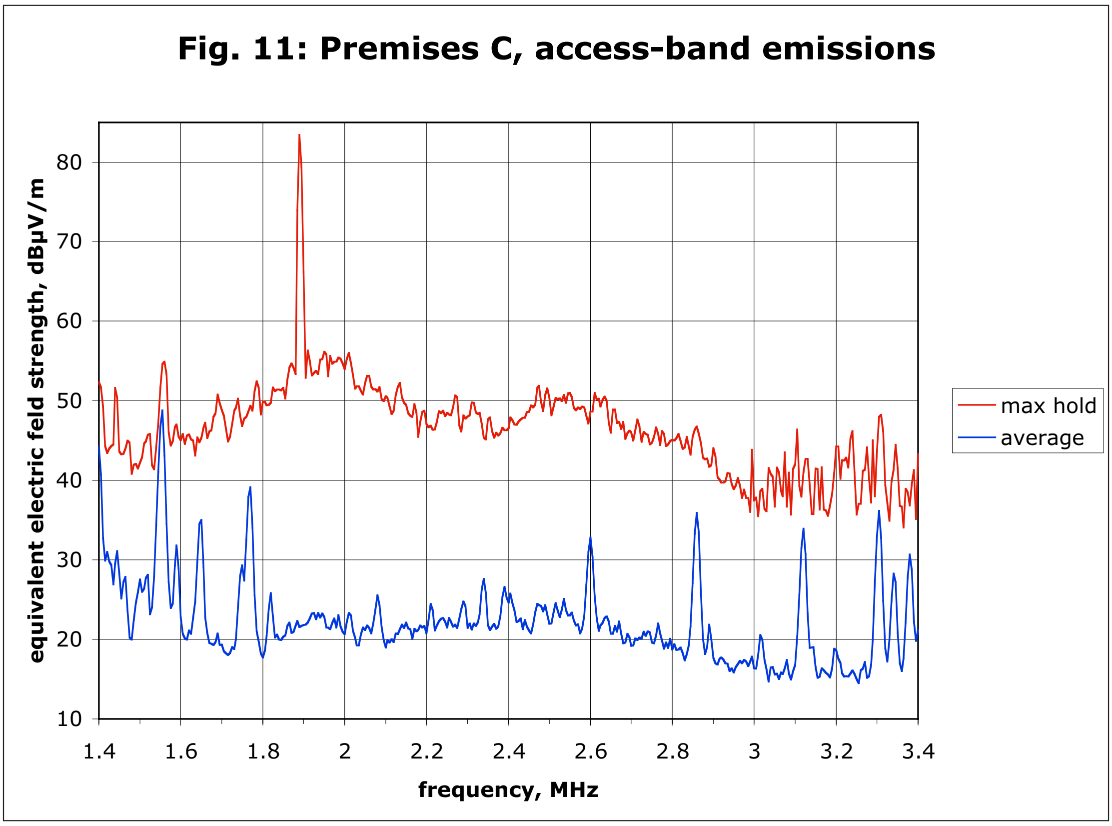
The loop antenna was set up outdoors on a tripod approx 3.2 m from the front corner of the house (the opposite corner from the meter cupboard), see Fig. 10. 'Average' and 'Max-hold' traces were taken of the spectrum about 2.4 MHz using 10 kHz resolution bandwidth. We knew that this was one of the frequencies used by the *access* part of the system and thus would be expected to be present on the incoming mains wiring to the house, and on the indoor wiring in a more-attenuated form. Fig. 11 shows the results, corrected for antenna calibration[9]. A broad spectrum, apparently centred just *above* 2.4 MHz, can be seen. The reason for a second peak at about 2 MHz is not obvious, unless perhaps resonances in the mains wiring happen to have placed a partial notch in the vicinity of 2.3 MHz, thus giving a single band the appearance of two.

Rain prevented any further outdoor experiments. It would of course have been interesting to compare the emissions received here at 'access' and 'in-house' frequencies.

3.4.3 Indoor experiments

Moving indoors, the loop antenna was set up at a convenient location in the dining room (towards the windows at the front) and connected to the spectrum analyser. Spectrum traces were obtained (using 100 kHz resolution bandwidth) from 1.5 to 11.5 MHz, covering the 'access' bands, see Fig. 12, and from 10 to 30 MHz, covering the 'indoor' bands, see Fig. 13.

[9] By extracting stored tabulated data from the spectrum analyser, the calibration factor can be simply added using a spreadsheet and the resulting corrected trace plotted. Unfortunately this was not possible with the traces taken at Premises A, as a result of equipment difficulties. This technique was also applied to all subsequent plots in this report.



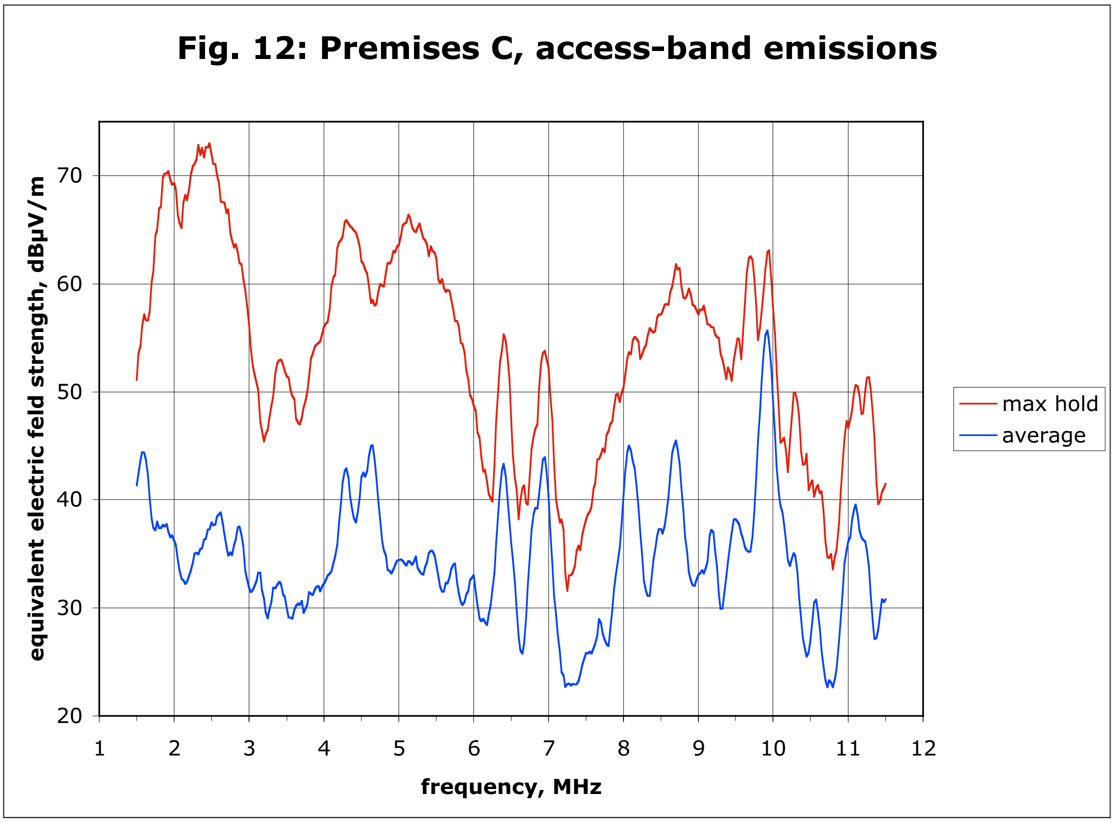


Fig. 12 confirms the existence of bands in about the expected places, with some minor dips and peaks — perhaps the dips are resonance effects in the wiring, as suggested above in §3.4.2. Some odd peaks are unexplained, as they do not appear to correspond to expected PLT operation or to broadcast frequencies.

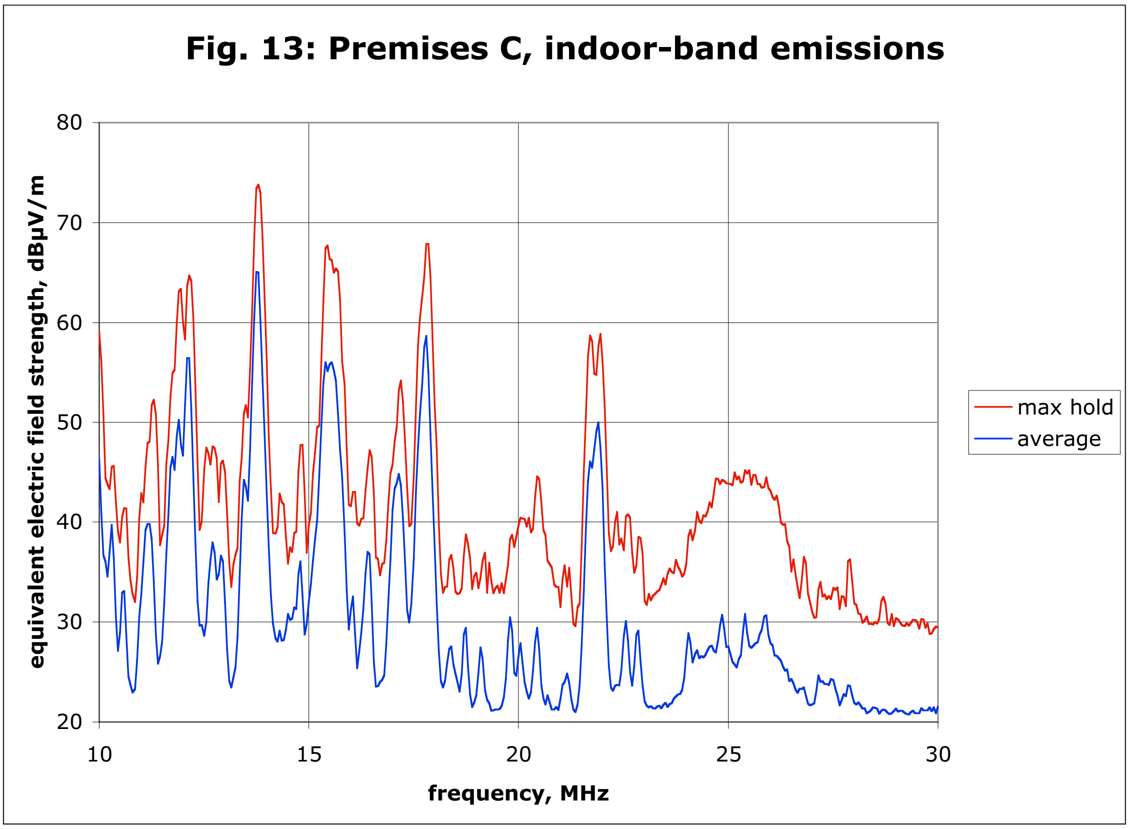
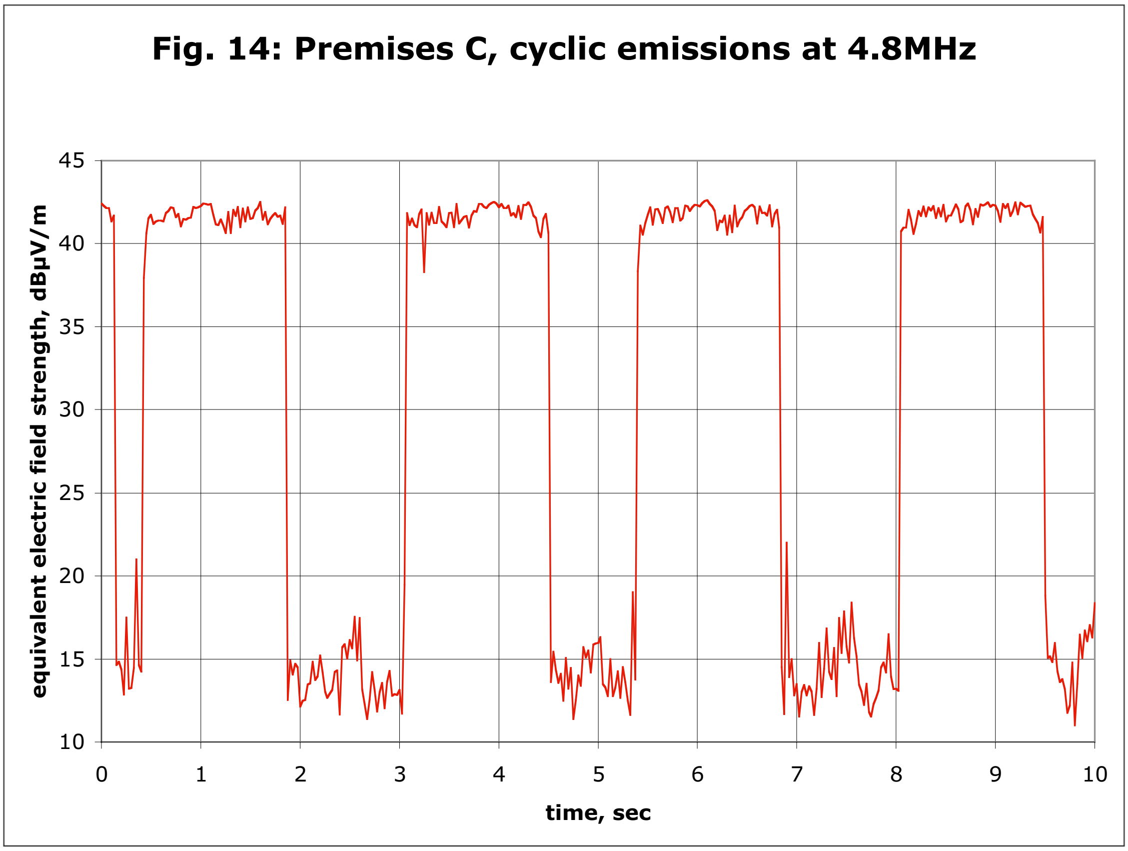


Fig. 13 (above) shows that many broadcast signals were present at this time of day in the 12, 13, 15, 17 & 21 MHz broadcasting bands. The broader 'humps' corresponding to the 'indoor-band' PLT emissions at 19.8, 22.8 and 25.2 MHz are visible, the last being the most prominent.



The consumer radio was tuned to the centre of the 2.4 MHz ‘access’ band and a recording was made (item 25). Note that in this case we were deliberately tuning in to the PLT signal in the absence of any broadcast signal, simply to obtain the aural signature. This took the form of regular rhythmic bursts with a slight ‘chirrup’ separated by silence, and with a period of repetition of roughly 2.5 seconds.

This behaviour was checked by tuning the spectrum analyser to the ‘access’ bands while set to ‘zero span’ and 1 kHz resolution bandwidth, so that it functioned similarly in effect to a tuned receiver connected to an oscilloscope. A trace when tuned to 4.8 MHz is shown in Fig. 14. This plot clearly confirms the periodic behaviour already noted ‘by ear’. There is a hint of something happening in the ‘gaps’ — perhaps the high level results from the local modem, while the detail in the ‘gap’ reflects the action of one or more distant PLT modems?

The loop antenna was then connected to the measuring receiver and field-strength measurements made at frequencies approximating to the centres of the bands known to be used by the Ascom PLT system. The bursty time-division nature of the emissions was apparent: the average-detector levels varied over a wide range. The results, after due conversion to equivalent electric field strength, are tabulated in the Appendix §9.5. Care was taken, using the gaps between bursts, to try to find frequencies that were clear of legitimate radio-service signals. The average-detector levels noted in the gaps may overestimate the true level, as there was scarcely time for the meter needle to fall back between bursts. Two sets of measurements were taken, with the loop rotated by 90º between them.

It is clear from the results that the emissions were at levels that would cause severe interference to short-wave broadcast reception — if the emissions measured had occurred within a broadcasting band. However, as noted in §2.3, the Ascom system uses nominal frequencies that are not in broadcasting bands. An attempt was therefore made to check a broadcasting band (which would then suffer only the attenuated ‘skirts’ of the PLT signals). A signal from R Nederlands on 5955 kHz was located and its field strength noted as approximately 42 dBµV/m, broadly representative of a signal having sufficient strength to justify protection. Interference from PLT (presumably from ‘skirts’ of its 4.8 MHz band) was clearly audible. It appeared to be worse when using the portable receiver with its whip antenna than when using the loop antenna with the measuring receiver. This suggests that the interference *E* field (as received by the whip) was greater than the equivalent-*E* of the *H* field (as received by the loop). Unfortunately, we were unable to make a satisfactory recording of this owing to problems with the tape recorder, compounded by running out of time. However, we were subsequently able to make similar recordings in premises D.

3.5 Premises D (Ascom system)

Only indoor measurements were undertaken at Premises D, another large house. Measurements took place on the ground floor. Test equipment and the portable receiver were deployed in the dining room, while the loop was set on its tripod in the adjacent spacious hallway — the only place it could safely be deployed. The computer and indoor PLT modem were in a basement room roughly beneath the dining room.

3.5.1 Current-clamp measurements

The current clamp was used as before on the extension lead supplying our equipment. Spectrum traces were taken on the three bands centred on 2.4, 4.8 and 25 MHz and are reproduced in Figs. 15, 16 and 17 respectively. All three traces were made with a 10 kHz resolution bandwidth. Both the 2.4 and 4.8 MHz traces appear to suffer from resonance effects, as also seen in Premises C. The narrow-band signals visible in the ‘average’ trace (where trace time-averaging was used) are not obviously identifiable and are probably not radio-service ingress; indeed the one at 25.6 MHz is in a Radio Astronomy band where radio-service transmissions are forbidden!

Fig. 15: Premises D, conducted current

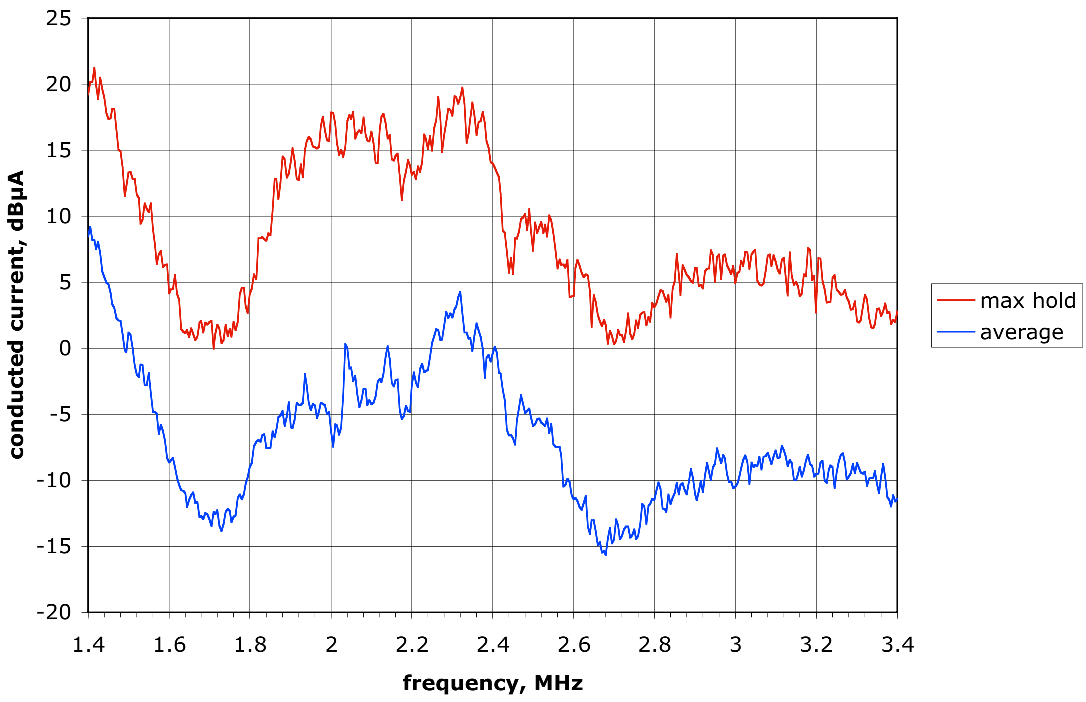
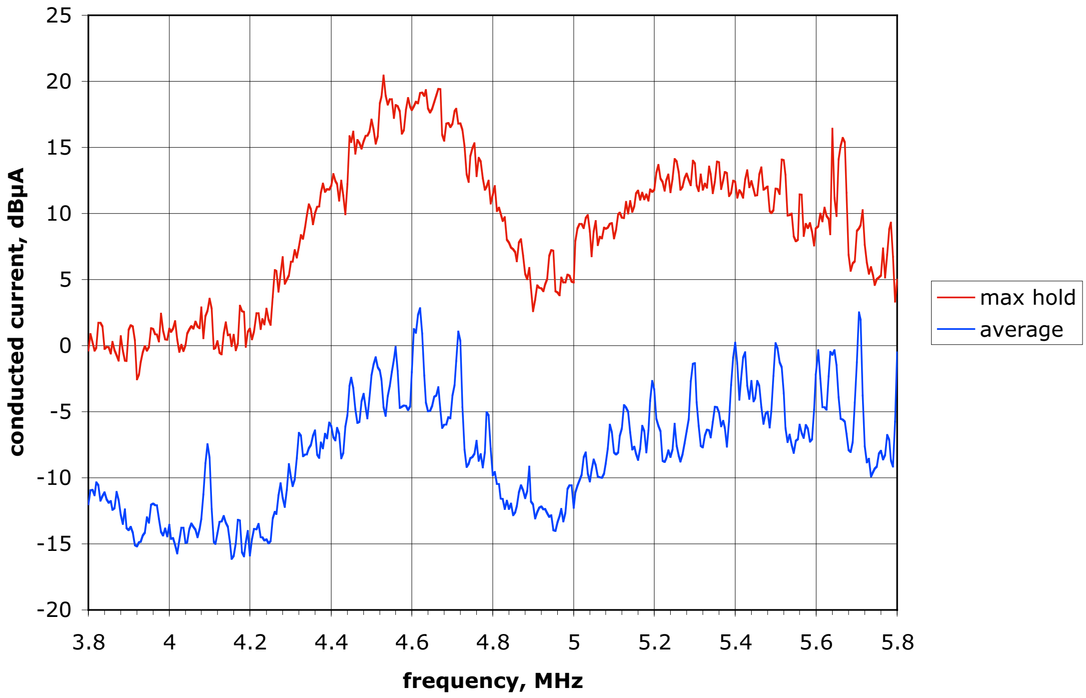
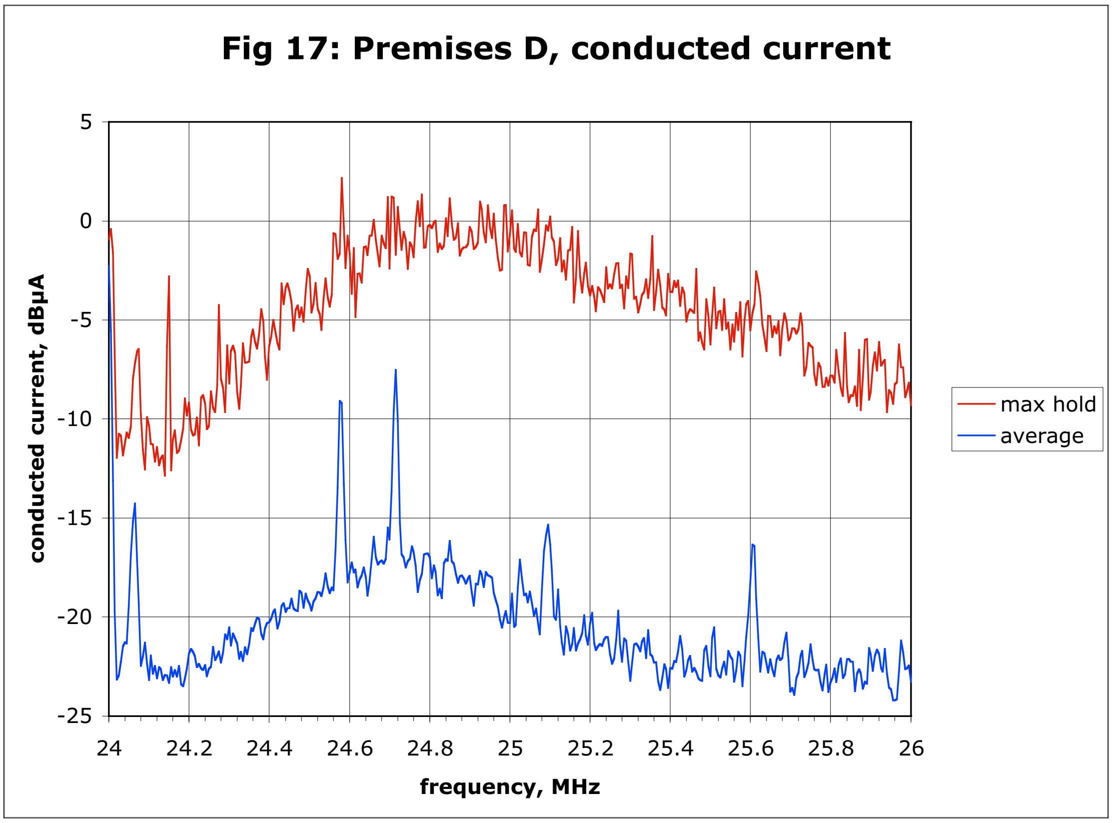


Fig. 16: Premises D, conducted current



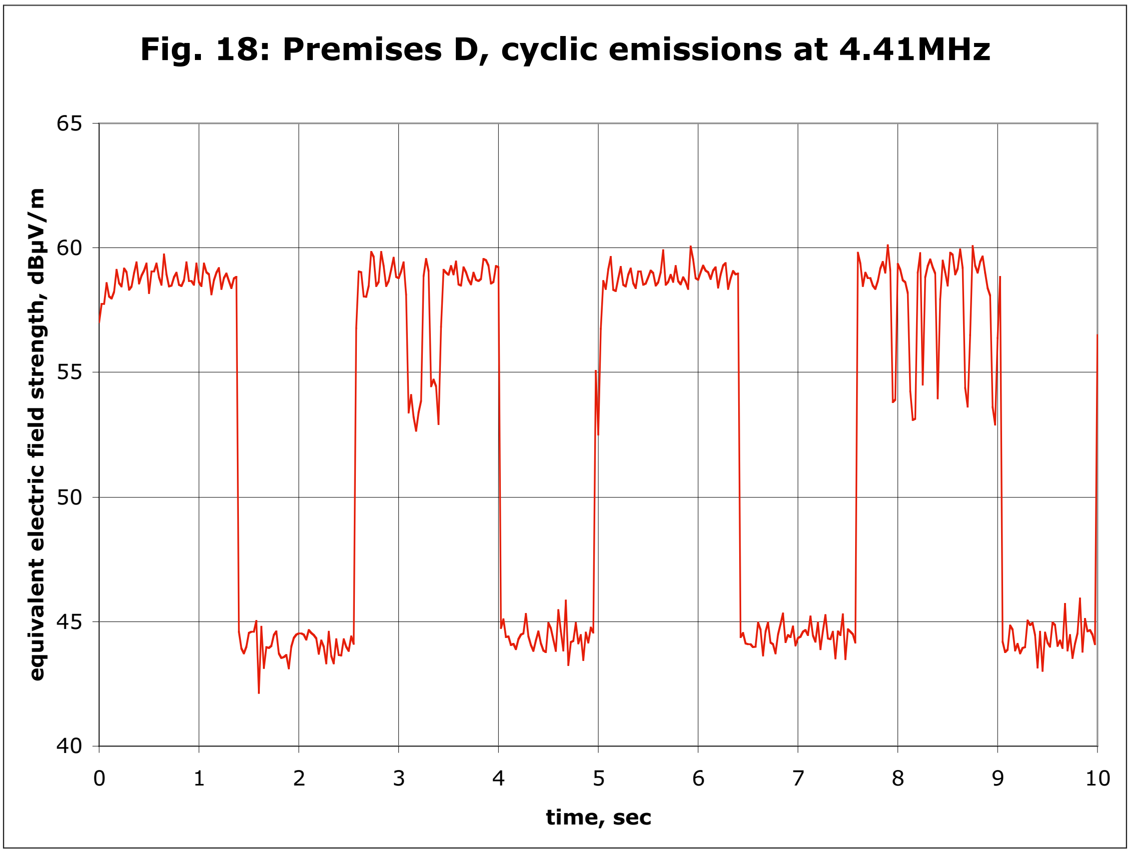


3.5.2 Emissions field-stength measurements

Indoor field-strength measurements were made using the loop and measuring receiver, tabulated in the Appendix §9.6. They followed a generally similar procedure to Premises C. There did not appear to be PLT activity at 8.4 MHz.

At one point a reduction of 6 dB in the injection-level of the indoor master was instigated by remote tele-command, as a demonstration of this mitigation measure. 'Before' and 'after' field-strength measurements are tabulated at the end of Appendix §9.6; they roughly confirm a 6 dB drop in emissions. Conducted-current measurements at the same time showed a drop in the 'peak' reading of 6 dB as expected.

As in premises C, the periodic behaviour of the PLT signal was explored by using the spectrum analyser on 'zero span' in conjunction with the loop antenna. Fig. 18 shows the results of a measurement at 4.41 MHz (a convenient frequency apparently clear of other radio signals). The periodic pulsing is similar to that seen in premises C, with the addition of some detail to the tops of the bursts. It appears that the level during the burst sometimes drops by 6 dB — perhaps this is the result of some automatic power-control process that is 'hunting'? The corresponding sound character was slightly altered, as might be expected.



3.5.3 Effects on broadcast reception

An attempt was made to find representative broadcast signals that might be adversely affected by the PLT operation. As in Premises C, the LF end of the 6 MHz band appeared the most likely to contain a suitable wanted signal at the time of day, while also being close enough in frequency to one of the spectral blocks nominally used by the PLT system (in this case, the one nominally centred on 4.8 MHz). Some recordings were made which showed that PLT pulsing was audible on a strong signal at 5915 kHz (wanted field-strength 46 to 56 dBµV/m, item 29) and more annoyingly so on a signal at 5925 kHz (40 to 50 dBµV/m, item 30, plus item 31[10] as a control with the PLT modem disabled) which was more nearly representative of the ITU-R minimum protected field strength. Stations at higher frequencies in the broadcasting band (and hence further separated from the 4.8 MHz PLT band) were, as expected, less affected e.g. item 28 (6140 kHz) which was seemingly unaffected despite being slightly weaker than item 30.

As an aside, we note that the basement room at these premises was equipped with halogen lights, which caused interference to reception and were turned off in order to perform the recordings.

[10] Item 31 shows that this particular broadcast (presumably not targeted at the UK) was affected by adjacent-channel interference (ACI) from another broadcaster. However, this does not alter the fact that it was of representative field strength and PLT interference was nevertheless audible. It follows that if a different broadcast was targeted to the UK in the same frequency range (and therefore planned so as not to suffer ACI) it would have been affected by PLT operation where, in the absence of PLT, it would have been of adequate, usable quality.

4 Discussion

4.1 Limitations of the work

While this opportunity to have a first close-up look at a PLT system was indeed very welcome, there were inevitable limitations on what we could achieve, in terms of both science and indeed demonstration of the effects.

Going into people's homes sets a limit to what you can do in terms of the time and duration of the visit and of the disruption that can reasonably be caused. While saying this, we stress that all householders involved were extremely hospitable!

So, for example, in erecting the tripod and measuring antenna we felt obliged to choose locations indoors that did not involve moving furniture or running the risk of accidental damage. To this end, in one property the measurements were only made in the hallway in view of vulnerable, possibly priceless objets d'art in the other rooms. So the location was not really chosen for any specific distance from mains wiring. Of course, this distance is a moot point anyway — some cables may be seen, but others in the walls, floor or ceiling are hidden and the visitor has no simple way to know where they are. Nevertheless, the measuring-antenna locations used were, if anything, probably further away from mains wiring than likely locations that would be used in practice to place receivers for domestic listening. When we recorded actual reception using a representative portable broadcast receiver this was *not* necessarily in the same place as the measurement antenna, but rather somewhere convenient, for example on a table.

In making current-clamp measurements, convenient rather than especially relevant mains cables were used.

Outdoor measurements were much limited by the changeable weather.

The recordings we made of broadcast reception are in some ways difficult to use for subsequent demonstrations. We had difficulty in choosing representative material, for good reason. International broadcasting is different from the local or national broadcasting to which most readers will be more accustomed. International broadcasts are commonly directed to a particular target area for only limited periods in each day, partly for reasons of economics and sometimes as a consequence of the possible propagation options. Usually a broadcaster would choose a time of day when the audience is most likely to want to listen. Often this will be breakfast-time or early evening in the target area. Having chosen a time, a suitable frequency or frequencies would be sought that could reach the target at that time using the available transmitter locations and facilities (transmitter frequencies and antenna-beam directions). If none were available then perhaps the time would be changed until it was possible, but always noting whether it is relevant to the intended audience.

Our visits were thus at times when overseas broadcasters were least likely to be targeting the UK audience. So if trying to assess the potential interference to a particular broadcasting band, we simply had to find any broadcast signals in that band that we could receive, and hope that we could pick one having a representative field strength. Now this signal would be unlikely to be directed to the UK, would most likely be in a language other than English, and most importantly would be suffering unrepresentative propagation conditions: although the field strength might have been in the right range, it is possible that it would be fading in a more unpleasant manner than would normally be tolerated or planned for[11]; furthermore it might be suffering co- or adjacent-channel interference from other broadcasting stations. Our recordings therefore run the risk of being interpreted as showing that short-wave reception is worse than it is, even before any effects of PLT are added.

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[11] For example, the frequency and transmitting-antenna vertical radiation pattern would normally be chosen to minimise the excitation of multiple propagation modes to the target.

One of our biggest difficulties came from the fact that the systems were effectively ‘in service’ to paying customers and thus could not be fully turned off on request in order to establish an interference baseline. It was thus difficult to determine unambiguously all the effects uniquely caused by the PLT system. This was a particular problem at Premises A, where we did not have a clear picture beforehand of the characteristics of the Main.Net system. As well as effects that we can be certain were caused by it (since they varied in character with the data load on the system), there was a separate noise-like interferer that we could not positively identify. As we could not turn off the system, it was not possible to say for certain that this interferer was nothing to do with the system or its repeaters, although that is what we eventually came to believe to be likely — after wasting some time.

4.2 Deductions from experiments

Whatever limitations there may have been on our ability to perform ‘proper science’ in this brief field trip, one thing was very clear, and may readily be confirmed from our audio recordings: these PLT systems do cause interference to the normal indoor reception of HF radio broadcasts.

Of the two systems, the Main.Net system presented the greater intrusion because it made use of a wide portion of the radio spectrum, encompassing a great number of the broadcasting bands. In contrast, the Ascom system appeared to have been designed to try to avoid broadcasting bands, but was insufficiently well filtered to avoid disturbing them altogether. For example, the ‘skirts’ of the ‘4.8 MHz’ emissions had noticeable and undesirable impact on broadcasts in the lower-frequency part of the 6 MHz broadcasting band. However, the impact on other broadcasts higher up the band was not so serious, so this opens the possibility that this spectrum-partitioning approach might be made to work with more careful (and inevitably more expensive) engineering of the PLT system.

A question, which follows naturally from the observation that interference occurred, is “How do the emissions from these systems compare with various proposals intended to restrict the degree of interference?”

The German NB30 limit is often taken as a yardstick in this. It was designed to be a ‘compromise’ between the very different requirements of radio-service users and telecommunications providers — and probably satisfies neither camp! Certainly, it is easy to show that it is inadequate to protect broadcasting [6]. NB30 is specified as a limit to be measured at 3 m distance, using a loop connected to a receiver having 10 kHz bandwidth and a peak detector.

Fig. 19 shows the various spot-frequency indoor emissions measurements we made using the receiver’s peak detector with various limit curves superimposed. These limits comprise:

- the NB30 limit (which, as just noted, is intended to be applied at 3 m)
- the EBU/BBC proposal developed in [7] (which is intended to be applied at 1 m)
- another curve representing what might be expected[12] at 1 m, under the assumption that the NB30 limit was satisfied at 3 m

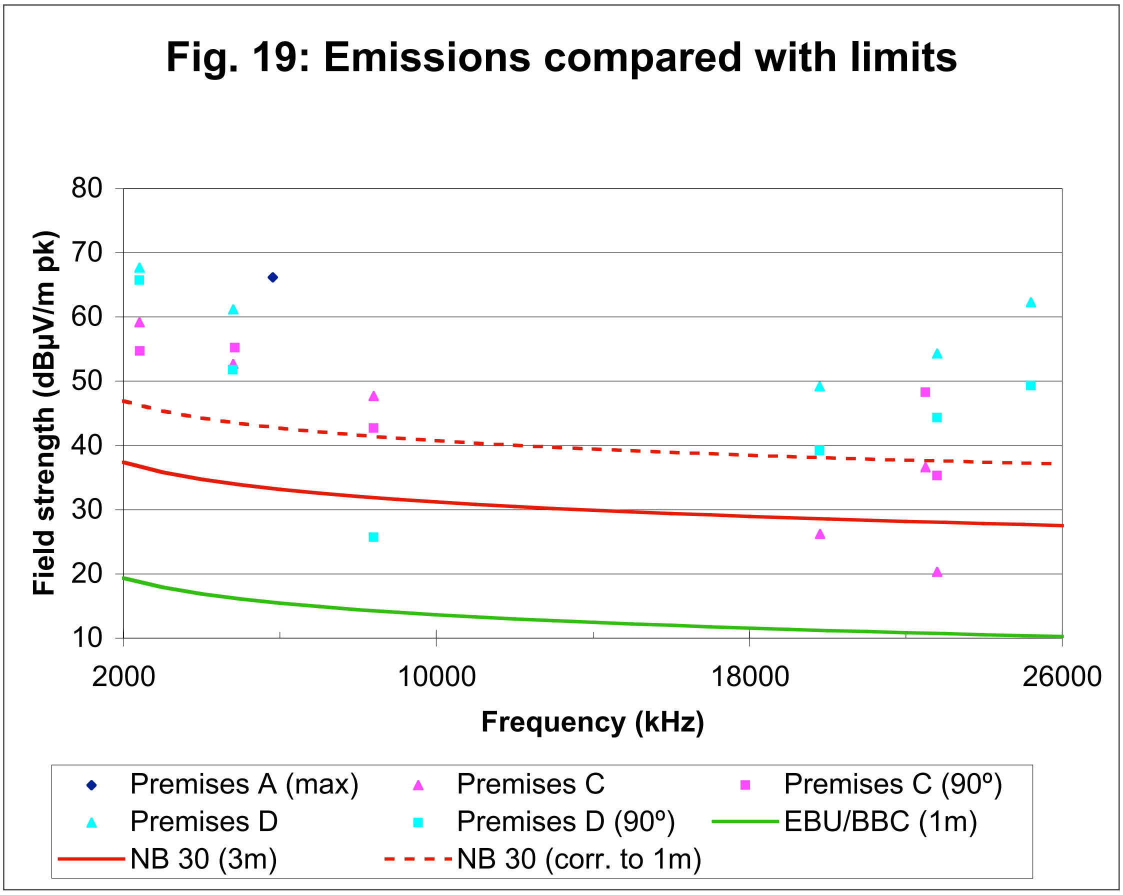
Of course, we do not know at what distance each of our indoor measurements was taken. Indeed it is difficult to see how this could ever be known in a typical house, where one is surrounded by wiring, both built into the structure and in the form of flying leads to appliances. We can be fairly confident that the nearest mains wiring was *no more than* 3 m away from the measuring antenna, simply because of the size of the rooms — even the more-generously proportioned rooms of Premises D. Probably the distance was somewhere between 1 and 3 m, without being able to exclude completely the possibility that it was *less* than 1 m in some cases.

[12] Assuming that the *H*-field decays with distance at 20 dB/decade.

The first thing to note is this. In Premises C & D, where readings were taken with two orthogonal orientations of the receiving loop[13], the direction giving greater pick-up at one frequency did not necessarily also give greater pick-up at another. This could perhaps suggest that indeed more than one section of mains cable is coming into play, with different sections assuming greater importance at different frequencies as a result of resonance effects. If we consider the mains wiring to contain a mixture of stubs of different lengths, facing in different directions this idea is easy to accept.

The next thing to note is that all measurements are above the EBU/BBC 1 m proposal, mostly very substantially so, and we should not therefore be surprised that our recordings showed severe interference occurring.

At each location there were several frequencies where the NB30 limit value was substantially exceeded, as was the NB30 value converted to 1 m distance. In other words, whether our measurements might be considered to have been taken at 1 m or 3 m or somewhere in between, none of the installations would have complied with the requirements of NB30 at all frequencies.



Another comparison is with the various proposals being considered at the time of writing by the ETSI/Cenelec Joint Working Group which has been charged by the EC under Mandate M313 with developing a harmonised standard to control emissions from *x*DSL, PLT and related systems.

One JWG proposal is for an *emissions limit*, measured at 3 m, but which is measured using a CISPR *quasi-peak* detector with 9 kHz bandwidth. The proposal under discussion sets a value of 55.5 dBµV/m equivalent *E*-field strength. Leaving aside the fact that a quasi-peak detector does not appear appropriate for obtaining consistent measurements of PLT signals, we note from the tabulated values in §9.5 and §9.6 that this value was never exceeded by the Ascom systems at Premises C & D. Noting that our measurements were almost certainly at a closer distance than 3 m

[13] Recall that only one orientation was used at Premises A in order to be able to null-out the unidentified but unrelated noise-like interferer from outside.

(and thus over-estimate what would have been measured at 3 m) we may tentatively conclude that these Ascom installations would pass this JWG proposal. However, note that our spot-frequency measurements were taken at the nominal centres of the PLT 'bands', while the spectrum traces reveal that owing to resonance effects, these particular spot frequencies do not necessarily correspond to the greatest emissions.

We have less to go on for the Main.Net system — the single set of values in Table 2 shows a 0.5 dB transgression of the JWG emissions proposal, so maybe this is marginal.

Another JWG proposal is for a *common-mode conducted-current limit*, measured using a suitable current clamp. In the HF frequency range, the proposed limit is 30 dBμA (quasi-peak)[14] or 20 dBμA (average detector)[15], either measured in the usual CISPR measurement bandwidth of 9 kHz. How does this compare with our measurements?

Referring back to Figs. 15 to 17, we have measurements at Premises D in the appropriate bandwidth, although they were taken using a spectrum analyser rather than the measuring receiver. If we interpret the 'max-hold' trace as equivalent to a peak detector we see that the greatest value in the 2.4 or 4.8 MHz bands is about 20 dBμA, suggesting that the proposal would be complied with here. The current at the higher frequency 25 MHz band was far less.

A rough comparison of conducted current and emissions may be made from the observations in the yard of premises A, in this case with the relevant cable being laid out in a longer straight line than may often apply indoors. Reading the corresponding peak levels from the traces in Figs. 3 & 5, with due application of the respective calibration factors, application of the Biot-Savart formula leads to the result that the measurement distance for the loop is calculated as 1.4 m — a surprisingly good correlation, see Fig. 4. Unfortunately we do not appear to have collected a body of comparable indoor data in the limited time available.

Another point to note from the measurements is that there is no simple, consistent relationship between readings taken with average, quasi-peak and peak-reading detectors — far from it! In contrast, with a Gaussian-noise-like signal we expect simply 5 to 6 dB difference between them (i.e. quasi-peak reads roughly 5 dB more than average, and peak roughly 5 dB more than quasi-peak), and this rule of thumb was borne out in past measurements of ADSL and VDSL systems. This calls into question whether we can simply convert from one type of limit to another for PLT signals.

5 Suggested further work

This brief trial was not able to do very much more than simply to observe that the two systems in use in Crieff did cause significant disturbance to the reception of HF broadcasting in the homes visited, including one home which was not equipped with the PLT service. Measurements taken helped to confirm this observation, in that the measured levels of interference were such that disturbance of reception should be expected.

However, many questions remain unanswered following this trial. Some are considered below, with suggested ways to try to answer them.

Any regulator considering licensing of commercial (as opposed to experimental) PLT systems should ensure that these questions are answered.

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[14] It is simple to show that this corresponds to the radiated-emissions proposal, under the assumption that the simple Biot-Savart law $H = I/(2\pi R)$ is valid. Strictly it applies to an infinite wire carrying DC. See also [9]

[15] As for the emissions limit, it is to be questioned whether either average or quasi-peak detectors are suitable for PLT signals.

Are all access-PLT systems similarly disturbing?

There are several competing access-PLT technologies. One apparently having significant market presence is a multi-carrier system using chip technology from the Spanish company DS2. As it has both market presence and significant technical differences from the Ascom and Main.Net systems it would be very helpful to examine it.

Are there any ways to make PLT and in-home reception of radio compatible?

The two PLT systems examined make use of spectrum on mains wiring to communicate. The consequent emissions are demonstrably not compatible with normal reception in the home of radio services such as broadcasting, where the spectrum used by PLT overlaps the broadcasting spectrum. If there was no spectral overlap between the PLT emissions and the radio service there would be no problem, and so one obvious proposal is to require that PLT does not use spectrum that is used by radio services for which reception in or around the home is the essence of their use (i.e. broadcasting and a few other services such as amateur radio). In effect some form of *spectral partitioning* would be involved.

The Ascom system examined makes a gesture in this direction by its choice of carrier frequencies, but the poor roll-off outside its nominally-used spectral chunks means some interference to broadcasting still occurs. Could this be improved at acceptable expense?

In principle a frequency-hopping system like the Main.Net system could be arranged to hop only between frequencies in parts of the spectrum that did not impact on home reception[16]. Of course, the question of roll-off would arise in a similar way as for the Ascom system. Furthermore, since one terminal of a frequency-hopping system normally only uses one frequency at a time, then the data capacity available to any one terminal is determined by the instantaneous bandwidth that is occupied during the time that it dwells on each frequency. It follows that a system offering appreciable capacity to each consumer must use a relatively small number of relatively wide blocks of spectrum, restricting the frequency discrimination that is possible. Finer granularity (with the same capacity per terminal) would require each terminal to use more than one frequency at a time.

Multi-carrier systems like the DS2 system are said to allow spectral partitioning as they can be arranged not to transmit those carriers that overlap specified services. In this case there should be less of a problem with granularity. However, our experience with COFDM broadcasting systems suggests that the depth of the 'notch' achieved by omitting carriers, without any additional filtering, may not be sufficiently deep. This gives another reason to seek to examine a practical implementation of the DS2 system.

Would such a 'spectral-partitioning' strategy work in practice?

Even if a PLT modem does not generate certain frequencies, that does not mean they will not be present. We know that intermodulation takes place when a multi-carrier signal passes through a transmitter, generating both in-band and out-of-band intermodulation products. Indeed one way to test the level of in-band intermodulation products when transmitting COFDM is to create a notch in the middle of the spectrum of the input signal[17], and observe the extent to which it fills up when the output spectrum is observed. Since this happens when passing through a transmitter amplifier — a functionally linear device with practical imperfections — it seems likely that the effect of more-fundamentally non-linear loads (rectifiers, switched-mode power supplies…) present on mains circuits will be to cause intermodulation on at least a similar scale, and perhaps worse.

[16] Since we know so little about the Main.Net system itself, we cannot say whether a facility like this forms any part of it.

[17] This requires the omission of several adjacent carriers at the COFDM-generation stage, followed by supplementary filtering.

So the extent to which a spectral-partitioning strategy would be thwarted by such intermodulation effects should be examined in a practical system. It is possible that a multi-carrier system will fare worse in this regard than a frequency-hopping one, since in the former case multiple carriers will be present simultaneously in the output from a single terminal. In the latter case, any given terminal will normally (we presume) use one frequency at a time, and so intermodulation products will be reduced to the extent that PLT signals are dominated by those from one terminal — intermodulation products can only be generated when signals from multiple terminals are present simultaneously.

Would such a 'spectral-partitioning' strategy be satisfactory for other radio services?

The idea of a spectral-partitioning strategy to protect broadcasting rests on the idea that in-home broadcast reception is an especially critical case because the receiving antenna is so close to the PLT interference source. The non-broadcast spectrum, which PLT would then be expected to use, is of course still used by other radio services that are just as entitled to expect protection from interference. It would have to be established that the greater distance between PLT systems and the receiving locations of those non-broadcast services was sufficient to protect them. Note that in this case the cumulative effect of many interference sources must be considered [8] and that particular rigour is needed in this assessment as some of the services potentially affected concern safety of life.

Can we predict what E- and H-field emissions should be caused by a PLT modem?

This would require measurements in more controlled environment, plus further verification in the field that the laboratory model matches reality. The total problem is quite involved: for a given injected signal level (Presumably more-or-less differential mode at source? Measured as forward power or as available power or…?) what *E*- and *H*-field strength arises at likely receiver locations? Note that *H* fields are caused essentially by the common-mode current flowing on any wiring — however, the presence of stubs in mains wiring means that a clear mechanism for significant local differential-to-common-mode conversion exists [9]. Furthermore, knowledge of *E* fields is desirable since most HF receivers currently use whip antennas, although *H* fields are easier to measure.

We can make some suggestions for the conduct of future experiments, based on the experience of these limited trials. When first encountering a new PLT system, it is essential to determine as much as possible about the principles of its operation before making measurements. A good first step would then be to apply a current clamp in the vicinity of a modem so as to be as sure as possible that observations are indeed of the system, and not some irrelevant distraction. Ideally this would then be confirmed by switching the PLT system off completely. Following this, time should be taken to observe the salient features of the system's behaviour and to determine the best way to illustrate this by appropriate choice of control settings when using e.g. a spectrum analyser.

Finally, our experiences in this trial lead us to suggest that there are some other sources of interference to radio reception that do not appear to be adequately controlled, e.g. the power supplies of certain halogen lamps and other appliances.

6 Conclusions

Data communications using mains wiring (often called Power Line (Tele)communications, PLT or PLC) is a promising technique. It can be used for access (connecting the home to the outside), or for home networking, or indeed both. The capacity is described as ‘broadband’. This means of the order of 10 Mbit/s for in-home networking, and 1 to 10 Mbit/s for access. (Dramatically higher rates than these have occasionally been claimed but are not believed to have been verified).

Two competing systems for providing Internet access to the home through the incoming mains wiring have been briefly examined in service in Crieff, by courtesy of the operator, Scottish & Southern Electricity.

The forms of Access PLT that were tested in Crieff were found to have demonstrable potential to cause interference to indoor reception of broadcasting in relevant bands.

As examined, the Main.Net system caused more interference — it affected a wide block of spectrum encompassing several short-wave broadcasting bands, at a level which disturbed reception, not just in the home which was equipped but also in the neighbouring property.

The Ascom system has the advantage of reduced emission levels in many of the broadcasting bands, as it nominally ‘uses’ a range of 1 MHz segments of spectrum which appear to have been well chosen. However, the roll-off outside these nominally-used segments is relatively shallow, so the improvement is not as substantial as might be desired. Nevertheless, this segmentation of spectrum might be a useful principle to develop, as noted further below.

The opportunity to make these observations of operational PLT installations is very much appreciated. However it also became clear that there is distinctly limited scope for scientific, quantitative investigation in domestic environments while the system is in (paid-for) service. This suggests a possible strand of further work, where measurements are made in a more controlled environment. Some clearly-demonstrative recordings of domestic reception of SW broadcasting were made, using broadcast signals of representative field strength. However, the limitation to normal working hours meant that the broadcasts recorded were not specifically targeted at a UK audience (who would more commonly be addressed at breakfast and evening times). This unfortunately undermines their value for demonstration, as they are open to a challenge of the form “no-one in the UK would routinely listen to that, so who cares if it is interfered with?” despite being technically representative. Brief excerpts from the recordings are nevertheless available together with this report.

Areas where further study is needed before licensing commercial applications of PLT include:

- examining other candidate PLT systems (beyond the two examined in this trial)
- relating measurements of current and field strength
- comparing spectra as injected (into a linear load) with those which arise on a mains circuit containing representative non-linear loads
- investigating and developing any possible techniques to promote compatibility between PLT and indoor reception of broadcasting. This could involve compatibility studies for other services for which reception in or near the home is not required, to explore whether enough (if any) spectrum could be identified wherein operation of PLT did not cause unacceptable interference to the existing radio users.

7 Acknowledgements

We very gratefully acknowledge the assistance of Scottish & Southern Electricity in inviting us to Crieff, setting up the house visits, helping with the conduct of the experiments and for taking digital-camera records, several of which are included in this report. We also warmly thank the householders for welcoming us into their homes, despite the inconvenience to which we must have put them, and similarly the staff of the Scottish Hydro shop.

8 References

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† BBC R&D White Papers may be downloaded from the BBC R&D web site: http://www.bbc.co.uk/rd/pubs/whp/index.html

9 Appendix

9.1 List of main items of test equipment

1. Active loop antenna, Wellbrook ALA1530. This is not supplied as a measurement antenna, but was calibrated by a test house (Mectronics Marine) so that we could use it for this purpose. It has a substantially lower noise floor than the conventional CISPR loop.
2. Current clamp, Ailtech 91550.
3. Preamplifier, HP 8447D.
4. HF Measurement receiver, Rohde & Schwarz ESH 2.
5. Spectrum Analyser, Hewlett-Packard 8494E.
6. Consumer portable radio, Sony ICF 7600 (battery operated, envelope detector selected).
7. Cassette recorder, Superscope CD-330 (battery operated).

9.2 Loop antenna calibration

The test house previously calibrated the 'Wellbrook' loop antenna used for measurements of the *H* field. The results are shown in Fig. 20 as a plot of the calibration factor required to convert its terminated output voltage, measured in dBμV, to equivalent *E* field in dBμV/m. The spots denote the values measured by the test house; these have then been interpolated for intermediate frequencies.

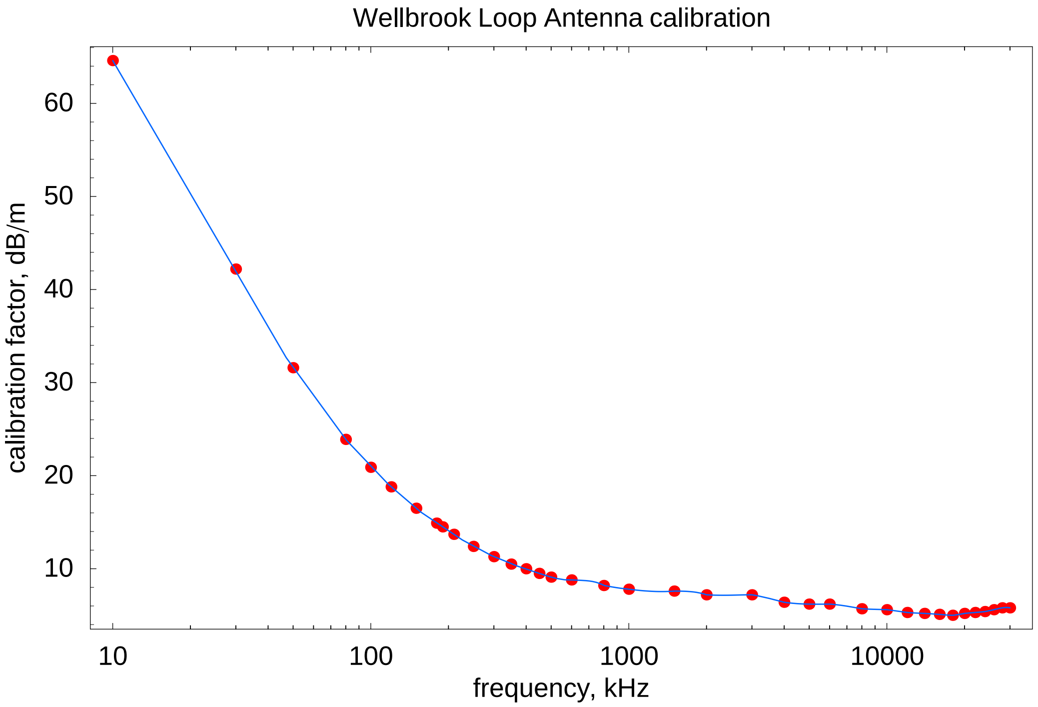

Fig. 20. Individual calibration curve for the loop antenna

The above calibration factor is added to measurements of voltage in dBμV in order to convert to dBμV/m.

If we make measurements using a spectrum analyser, the readings are in dBm and need a further conversion. An additional factor of 107 must be added in order to convert from dBm (measured in a 50Ω system) to dBμV. Thus to convert from dBm to dBμV/m we must add a combined correction factor which, in the HF range, for example, has a value of roughly 113.

9.3 Current loop calibration

This was calibrated in-house in our laboratory by measuring the current flowing in a matched 50Ω circuit. The results are shown in Fig. 21 as a plot of the calibration factor required to convert its output, measured in dBm, to the current in dBμA. The spots denote the measured values; these have then been interpolated for intermediate frequencies.

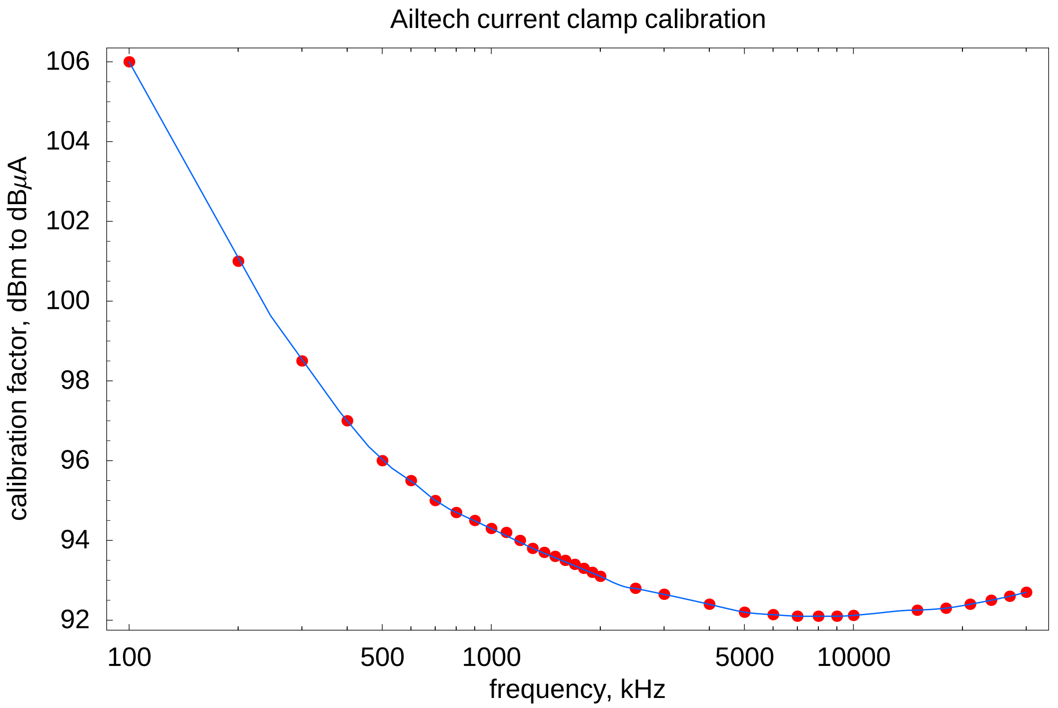

Fig. 21. Calibration curve for the current clamp

Note that this calibration curve applies to the clamp itself and does not include the 26 dB gain of the preamplifier which was used with the spectrum analyser.

9.4 List of audio recordings

'Start' and 'Stop' times refer to the CoolEditPro file containing a copy of the entire recorded tape.

In the Tables following, 'BC' means 'broadcast', 'FS' means 'field strength' and 'OOB' means 'out-of-band'.

				Full version			*Excerpt version*			
Item	*Frequency*	*FS, dBµV/m*	*Description*	*Start*	*Stop*	*Filename*	*Start*	*Stop*	*Filename*	*Further comment*
Premises A										
1	9590 kHz	66.6	Modem quiescent	0:04.7	0:31.7	track1.wav	0:08.8	0:18.0	x1.wav	Very strong BC signal, no obvious effects
2			Modem busy	0:31.7	1:17.0	track2.wav	0:50.5	1:01.3	x2.wav	Relatively minor effects, strong BC signal
3	12070 kHz	50.3 to 59.3	Modem busy	1:19.3	2:21.3	track3.wav	2:02.7	2:13.1	x3.wav	Strong BC signal but noticeably affected
4			Modem quiescent	2:21.3	3:00.1	track4.wav	2:21.3	2:34.6	x4.wav	
5	9895 kHz	50.6 to 59.6	Modem quiescent	3:01.0	3:25.4	track5.wav	3:05.1	3:15.7	x5.wav	Another strong BC signal, occasional clicks
				3:01.0	3:21.0	track5S.wav	N/A			(5S is shorter, avoids an irrelevant burble)
6			Modem busy	3:25.1	4:14.7	track6.wav	4:01.1	4:12.0	x6.wav	Noticeable effects on this strong BC signal
				3:52.8	4:12.3	track6S.wav	N/A			(6S is shorter, avoids irrelevant burble)
7	5955 kHz	41.2 to 46.2	Modem quiescent	4:16.5		track7.wav	no excerpt taken			Other impairments of signal reception dominate, not useful for comparison
8			Modem busy	5:03.1	5:50.0	track8.wav				
9	11885 kHz	35.3 to 45	Modem quiescent	5:50.7	6:38.1	track9.wav	5:54.9	6:06.3	x9.wav	BC representative of minimum ITU protected FS, clicks from quiescent modem
10			Modem busy	6:38.5	7:26.5	track10.wav	7:03.6	7:13.3	x10.wav	Badly impaired by active PLT modem
In neighbouring house to premises A										
11	11885 kHz	35.3 to 40.3	Modem quiescent	7:27.8	8:14.6	track11.wav	8:01.7	8:12.8	x11.wav	Previous broadcast continued, but ended before could make modem busy
12	11530 kHz	40.4 to 45.4	Modem busy	8:15.5	8:34.1	track12.wav	8:15.4	8:26.9	x12.wav	BC above ITU minimum FS, yet still impaired in neighbour's home, whereas usable while modem quiescent
13			Modem quiescent	8:36.1	9:00.3	track13.wav	8:42.1	8:53.7	x13.wav	

In street between premises A and its sub-station										
14	11530 kHz	40.4 to 45.4	Modem busy, variety of locations walking along pavement, receiver hand-held at chest height	9:01.3	9:23.3	track14.wav	9:05.8	9:16.5	x14.wav	1 to 2 houses away (opposite direction from items 11-13). Bad.
15				9:24.2	9:41.3	track15.wav	9:26.0	9:36.0	x15.wav	One house further away, worse.
16				9:42.0	10:10.9	track16.wav	10:01.4	10:10.9	x16.wav	Further in direction of sub-station. Less bad.
17				10:11.0	10:57.9	track17.wav	10:15.6	10:25.4	x17.wav	By sub-station.
18				10:58.6	11:18.9	track18.wav	11:08.6	11:19.1	x18.wav	Starting to return on other side of road
19				11:22.1	12:03.6	track19.wav	11:22.1	11:31.9	x19a.wav	:
							11:45.7	11:54.5	x19b.wav	Roughly opposite premises B again
In and around premises B										
20	6140 kHz	unknown	Outside shop	12:05.1	12:15.7	track20.wav	12:08.2	12:15.8	x20.wav	Right outside shop window, on pavement
21			Modem quiescent	12:16.9	13:47.9	track21.wav	12:23.8	12:35.1	x21a.wav	Inside shop, excerpt during modem quiescence
			Modem busy				13:23.1	13:32.7	x21b.wav	… then with modem busy, badly impaired
22	5955 kHz	unknown	Modem quiescent	13:48.5	14:52.3	track22.wav	14:39.9	14:49.0	x22.wav	Inside shop, modem mostly quiescent, stronger clear BC signal
23			Modem busy	14:54.2	15:15.5	track23.wav	14:45.1	15:35.8	x23.wav	Inside shop, modem busy, badly impaired
24			In hotel room	15:15.5	15:55.2	track24.wav	15:41.1	15:49.6	x24.wav	Same BC later in hotel room for comparison
Premises C										
25	2400 kHz	N/A (no BC)	Modem busy	15:59.2	16:42.7	track25.wav	15:59.3	16:10.7	x25.wav	Receiver tuned to modem band to capture characteristic sound signature
26	5955 kHz	42.2	Modem busy	16:43.1	17:25.2	track26.wav	no excerpt taken			Apparatus problems so excerpt not taken
Premises D										
27	6155 kHz	Unknown	Modem busy	17:33.6	19:46.1	track27.wav	no excerpt taken			Looking for OOB effects from 4.8MHz PLT …
28	6140 kHz	39.2 to 49.2	Modem busy	19:48.4	21:28.5	track28.wav	20:57.3	21:06.6	x28.wav	Fairly strong BC, far enough away in frequency, negligible impairment
29	5915 kHz	46.2 to 56.2	Modem busy	21:29.2	25:14.5	track29.wav	24:38.0	24:49.4	x29.wav	Stronger BC, but nearer in frequency, rhythmic effects audible
30	5925 kHz	40.2 to 52.2	Modem busy	25:23.6	27:22.4	track30.wav	27:07.9	27:18.9	x30.wav	BC badly affected by rhythmic PLT
31			Local modem OFF	27:33.8	30:05.4	track31.wav	29:56.4	30:06.3	x31.wav	BC FS exceeds ITU min protected FS, albeit affected by BC adjacent-channel interference

9.5 Emissions measurements in premises C

These spot-frequency emission measurements were made using the R&S measurement receiver, together with the Wellbrook loop deployed in two orientations. The *H* field was measured, but is expressed as equivalent *E* field strength HZ_0.

Location: Premises C, indoors, loop in front dining room
Orientation: loop axis parallel to drive and side of house

Frequency	**2400 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
43.2 to 48.2	Average	Active	during bursts
14.2	Average	In gaps	limited by meter dynamics
49.2 to 51.2	CISPR quasi-pk	Active	
58.2 to 59.2	Peak	Active	
Frequency	**4800 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
41.2	Average	Active	
16.2	Average	In gaps	
46.2 to 47.2	CISPR quasi-pk	Active	
51.2 to 52.7	Peak	Active	
Frequency	**8400 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
34.7 to 35.7	Average	Active	
12.7	Average	In gaps	
42.2	CISPR quasi-pk	Active	
46.7 to 47.7	Peak	Active	
Frequency	**19804 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
2.2 to 7.2	Average	Active	'Indoor' band. Portable with whip affected much worse than these loop measurements. Frequency chosen to avoid utility station on 19800 kHz
16.2 to 18.2	CISPR quasi-pk	Active	
24.2 to 26.2	Peak	Active	
Frequency	**22500 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
7.3 to 20.3	Average	Intermittent	reflecting duty cycle of interference
26.8 to 27.8	CISPR quasi-pk	Intermittent	steady!
34.3 to 36.3	Peak	Intermittent	
Frequency	**22800 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
2.3 to 6.3	Average	Active	
8.3 to 10.3	CISPR quasi-pk	Active	
18.3 to 20.3	Peak	Active	

Location: Premises C, indoors, loop in front dining room
Orientation: at 90º to previous table, loop axis parallel to front of house, some frequencies changed to avoid revealed signals

Frequency	**2420 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
17.2 to 37.2	Average	Intermittent	
25.2 to 47.2	CISPR quasi-pk	Intermittent	Seemed to have 3 different levels
40.2 to 54.7	Peak	Intermittent	
Frequency	**4845 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
10.7 to 41.2	Average	Intermittent	
18.2 to 51.2	CISPR quasi-pk	Intermittent	
25.2 to 55.2	Peak	Intermittent	
Frequency	**8400 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
6.7 to 27.7	Average	Intermittent	
10.7 to 37.7	CISPR quasi-pk	Intermittent	
17.7 to 42.7	Peak	Intermittent	
Frequency	**22500 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
16.3 to 30.8	Average	Intermittent	
38.3 to 40.3	CISPR quasi-pk	Intermittent	
45.3 to 48.3	Peak	Intermittent	
Frequency	**22800 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
7.3 to 19.3	Average	Intermittent	Some evidence of three levels
26.3 to 27.3	CISPR quasi-pk	Intermittent	
33.3 to 35.3	Peak	Intermittent	

9.6 Emissions measurements in premises D

As for premises C, these spot-frequency emission measurements were made using the R&S measurement receiver, together with the Wellbrook loop deployed in two orientations. The *H* field was measured, but is expressed as equivalent *E* field strength HZ_0.

Location: Premises D, indoors, loop in hallway
Orientation: loop axis in line with hall

Frequency	**2400 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
34.7 to 58.7	Average	Active	Clear pulsing audible
39.2 to 62.7	CISPR quasi-pk	Active	
45.2 to 67.7	Peak	Active	
Frequency	**4800 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
31.2 to 50.2	Average	Active	
37.2 to 55.2	CISPR quasi-pk	Active	
44.2 to 61.2	Peak	Active	
Frequency	**8400 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
15.2	Average	Active	Seemed not to be audibly pulsing. Some utility traffic, no totally clear 10kHz slot could be found
Frequency	**19800 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
8.2 to 27.2	Average	Active	This frequency noticeably pulsing
34.2 to 38.2	CISPR quasi-pk	Active	
44.2 to 49.2	Peak	Active	
Frequency	**22800 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
26.3	Average	Active	Present, but not pulsing. Large difference between Average and CISPR is very curious but was consistent on re-checking.
46.3	CISPR quasi-pk	Active	
54.3	Peak	Active	
Frequency	**25200 kHz**		
Eq. FS, dBμV/m	*Detector*	*Modem status*	*Comments*
29.3 to 47.3	Average	Active	
53.8	CISPR quasi-pk	Active	
62.3	Peak	Active	

Location: Premises D, indoors, loop in hallway
Orientation: at 90º to to previous table, loop axis parallel to front of house, one frequency changed to avoid revealed signals

Frequency	**2400 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
33.2 to 59.2	Average	Active	
37.2 to 61.7	CISPR quasi-pk	Active	
44.2 to 65.7	Peak	Active	
Frequency	**4790 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
25.3 to 34.3	Average	Active	
29.3 to 46.3	CISPR quasi-pk	Active	
37.3 to 51.8	Peak	Active	'Low' value probably overestimate, limited by meter dynamics
Frequency	**8400 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
12.7	Average	Active	As before, appeared not to be pulsing
18.7	CISPR quasi-pk	Active	
25.7	Peak	Active	Some higher transients ignored, did not appear to be PLT
Frequency	**19800 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
17.2 to 27.2	Average	Active	
29.7 to 33.2	CISPR quasi-pk	Active	
37.2 to 39.2	Peak	Active	
Frequency	**22800 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
21.8	Average	Active	
35.8	CISPR quasi-pk	Active	
44.3	Peak	Active	
Frequency	**25200 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
20.3 to 35.3	Average	Active	
36.8 to 41.3	CISPR quasi-pk	Active	
44.3 to 49.3	Peak	Active	

Test of power control

On request, the indoor master could be tele-commanded to reduce power by 6 dB.
Location: Premises D, indoors, loop in hallway
Orientation: loop axis in line with hall

Frequency	**25200 kHz**		
Eq. FS, dBµV/m	*Detector*	*Modem status*	*Comments*
47.3	Average	Normal	These agree well with earlier test of same situation, see above.
54.3	CISPR quasi-pk	Normal	
60.3 to 62.3	Peak	Normal	
39.3 to 43.3	Average	–6dB	
48.3	CISPR quasi-pk	–6dB	
55.3 to 58.3	Peak	–6dB	